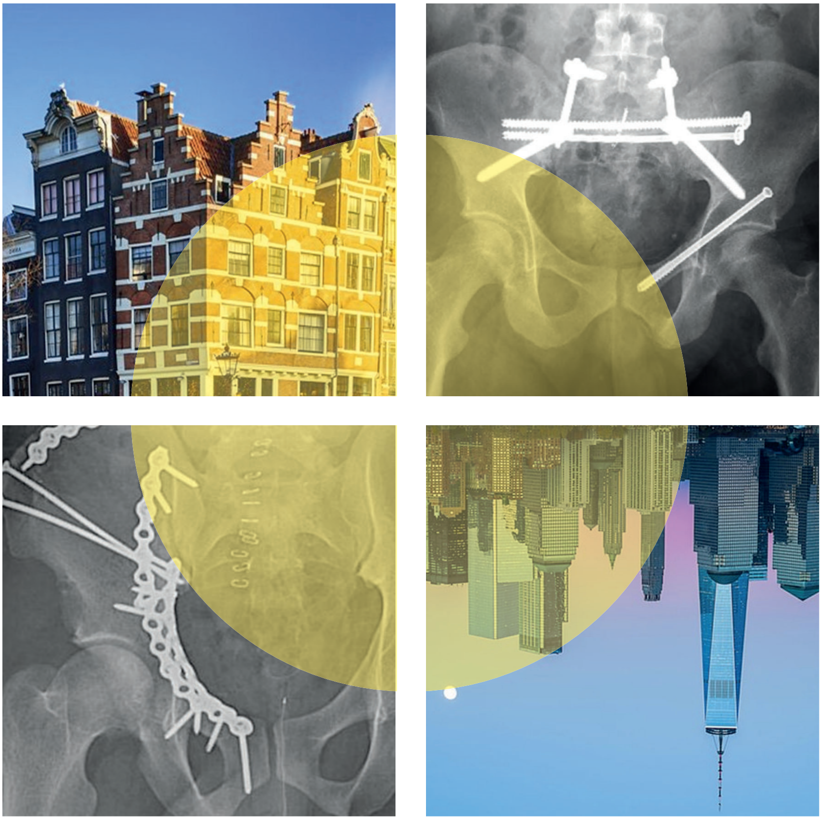
Diederik Verbeek 2019

PELVIC AND ACETABULAR FRACTURES

EARLY MANAGEMENT AND LATE OUTCOME



2019

DV

PELVIC AND ACETABULAR FRACTURES

PELVIC AND ACETABULAR FRACTURES: Early management and late outcome

Thesis Universiteit van Amsterdam, Amsterdam, the Netherlands

Printing of this thesis was financially supported by:
Nederlandse Vereniging voor Traumachirurgie, Afdeling Heelkunde Amsterdam UMC, TraumaNet AMC, Traumacentrum Zuid-west Nederland, Chipsoft, Smith and Nephew, Stryker, Biomet, DePuy Synthes, J&J Medical Devices, Imove Medical

ISBN/EAN: 978-94-6323-902-8
Author: Diederik Verbeek
Cover/design: Diederik Verbeek
Lay Out and Printed by: Gildeprint

PELVIC AND ACETABULAR FRACTURES

Early management and late outcome

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. dr. ir. K.I.J. Maex
ten overstaan van een door het College voor Promoties ingestelde
commissie, in het openbaar te verdedigen in de Agnietenkapel
op woensdag 4 december 2019, te 12.00 uur
door

Diederik Otto Ferdinand Verbeek

geboren te Nijmegen

Promotiecommissie:

Promotores:	Prof. dr. J.C. Goslings	AMC-UvA
	Prof. dr. O.M. van Delden	AMC-UvA
Copromotores:	Dr. K.J. Ponsen	Noordwest Ziekenhuisgroep
	Prof. dr. M.H.J. Verhofstad	Erasmus Universiteit Rotterdam
Overige leden:	Prof. dr. P. Kloen	AMC-UvA
	Prof. dr. M. Maas	AMC-UvA
	Dr. S. van Dieren	AMC-UvA
	Prof. dr. V.A. de Ridder	Universiteit Utrecht
	Dr. J. Biert	Radboudumc
	Prof. dr. D.L. Helfet	Cornell University

Faculteit der Geneeskunde

TABLE OF CONTENTS

PART I

EARLY MANAGEMENT OF MAJOR PELVIC TRAUMA PATIENTS

PELVIC & ACETABULAR FRACTURES

EARLY MANAGEMENT & LATE OUTCOME

TABLE OF CONTENTS

PART II

LATE OUTCOME AFTER ACETABULAR FRACTURE FIXATION

PELVIC & ACETABULAR FRACTURES
EARLY MANAGEMENT & LATE OUTCOME

TABLE OF CONTENTS

E

01

CHAPTER

GENERAL INTRODUCTION

2019

GENERAL INTRODUCTION

Pelvic fractures represent a broad injury spectrum. Minor pelvic ring (and isolated acetabular) fractures are typically sustained by elderly patients following low-impact falls [1-3]. By contrast, major high-energy pelvic ring disruptions may be life threatening and are largely found in young multiple-injured patients [4,5].

The pelvic ring is comprised of the sacrum and two innominate bones, which contain the bilateral acetabula. The three bones meet anteriorly in the symphysis pubis and posteriorly in two sacroiliac joints. As the pelvic ring itself possesses no inherent mechanical stability it relies heavily on its strong ligamentous structures to resist deforming forces and maintain its shape.

Minor pelvic ring injuries are minimally displaced and typically considered to be mechanically stable. Major pelvic injuries however are associated with significant osteo-ligamentous disruption resulting in mechanical instability. These more severe pelvic injuries present as a combined (anterior and posterior) fracture, fracture-dislocation and/or pure ligamentous injury of the pelvic ring. Ultimately, the specific pelvic injury pattern and degree of stability is determined by the direction and amount of energy on impact, which forms the basis for classification systems [6,7].

Pelvic ring and acetabular fractures occur infrequently but reliable data on nationwide epidemiology is limited [1,8,9]. Importantly, details on minor pelvic fractures in the elderly are often lacking while the size of this fragile patient cohort is expected to continue to grow at an alarming rate [8,10].

Treating patients with pelvic injuries can be particularly difficult. From acute management to definitive fixation, surgeons may be faced with any number of critical challenges. In recent years, several developments and evolving technologies have had a significant impact on early and late care for both pelvic ring and acetabular fractures.

Pelvic ring fractures

Urgent treatment of high-energy major pelvic fracture patients is exceedingly demanding particularly in the presence of hemorrhagic shock. Exsanguination is a substantial contributor to the substantial mortality found in these severely injured patients [11]. In haemodynamically unstable patients, multiple pelvic as well as extra-pelvic (e.g. abdominal) injuries can cause protracted bleeding. In order to improve outcome, it is critical to rapidly identify the principal source of bleeding to allow immediate hemorrhage control [12,13].

Computed Tomography (CT) for initial trauma assessment may play an important role in these complicated instances. Early CT scanning has presented a major evolution in trauma care and has been shown to hold much promise [14,15]. Many trauma centers have now installed multi-detector CT scanners in their emergency department or trauma resuscitation room, as is the situation in the Academic Medical Center (Amsterdam University Medical Centers) [16]. With more strategic placement of CT scanners and advances in technology, this modality has become a useful tool for timely triage of trauma patients.
At the same time, angiographic embolization to control arterial bleeding has gained considerable popularity. This endovascular treatment method has proven to be highly effective for treating abdominal as well as pelvic sources of bleeding [17-19]. The decision to proceed for surgical or endovascular intervention in pelvic trauma patients is increasingly made based upon CT results. However, specific early CT indications for immediate hemorrhage control such as the presence of intraperitoneal free fluid and pelvic arterial bleeding (or CT "blush") need to be further refined.

Early CT scanning has undoubtedly influenced and potentially improved initial assessment of trauma patients [15,20]. Its current popularity has grown to such an extent that essentially all "stable" major trauma patients admitted to Level I trauma centers undergo CT scanning. Subsequently, many institutions have abandoned routine for more selective use of plain radiography (prior to CT scanning).

In concurrence with acute management of major pelvic ring fracture patients, there may also be an additional role for (CT) imaging in surgical treatment of acetabular fracture patients. Radiographic (as well as clinical) outcome assessment following operative intervention for these complex fractures is a rapidly developing area of interest.

Acetabular fractures

Until as recently as the 1970's open reduction and internal fixation for (pelvic and) acetabular fractures was rarely performed. Patients were rather treated conservatively or in traction and remained non-weightbearing for prolonged periods of time [21]. However, increasingly, adverse outcomes of this nonoperative treatment strategy were recognized. In 1963 Emile Letournel and Robert Judet published their seminal work on the operative treatment of acetabular fractures [22]. In extensive detail these French pioneers of pelvic surgery described their results following surgical treatment of over 1000 acetabular fracture patients. This marked an important turning point for acetabular fracture care and successively internal fixation gained considerable attraction across the globe.

Acetabular fracture surgery is widely regarded as a highly specialized endeavor. The complicated nature of acetabular fractures and demanding surgical approach renders definitive fixation particularly problematic. In-depth knowledge of the acetabular fracture configuration and local anatomy is therefore an absolute prerequisite for successful surgical treatment.

A fundamental aspect in the operative treatment strategy of acetabular fractures is the selection of the appropriate surgical exposure. In this regard, the introduction of the (modified) Stoppa approach in the early nighties has altered surgical treatment of these fractures drastically [23]. At present, this intra-pelvic anterior approach has largely replaced the more traditional ilio-inguinal exposure for acetabular fractures in a growing number of institutions such as the Academic Medical Center in Amsterdam [24]. It should be noted however that outcome data to support this latest trend is scarce. Particularly, (contemporary) patient reported outcome measures and hip survivorship at longer durations of follow-up are lacking.

Quality of reduction is a key determinant of outcome following acetabular fracture fixation [25-27]. Indeed, an adequate postoperative reduction is commonly used as an early proxy for effective surgical treatment. But prior investigations on this subject have had important limitations. While it is likely that accuracy of reduction is best determined on CT imaging, acetabular fracture studies have mostly used postoperative plain pelvic radiography for this purpose [28,29]. Moreover, previous reports have generally neglected to provide a detailed description of the radiographic technique used to measure residual acetabular displacement despite a clear need to standardize assessment methods [30].

Acetabular fracture patients have an increased risk for osteoarthritis of the affected joint, which may ultimately result in conversion to total hip arthroplasty. Acetabular fracture surgery primarily aims to reduce the amount of residual (gap and step) displacement within the joint, which is thought to increase the likelihood of native hip survivorship [25-27].
Along with fracture reduction quality, a variety of other “non-surgeon dependent” factors (e.g. age and fracture specifics), can have an influence on clinical outcome [26,27,31]. The independent association of various risk factors (both within and outside the surgeon’s control) and conversion to total hip arthroplasty (THA) requires additional research, especially in larger patient cohorts with long-term follow-up.

Overall, it is apparent that through the years major advancements have been made in the treatment of pelvic ring and acetabular fracture patients. The rapid evolution of imaging technology appears to have paid a positive contribution to areas ranging from initial assessment and treatment to definitive fixation and outcome prediction. Yet, treating these complex injuries continues to be demanding and various recent developments in early and late care warrant further investigation.

THESIS OUTLINE

This thesis seeks to address the evolving aspects and current challenges mentioned previously and is divided into two sections pertaining to early and late aspects of pelvic ring and acetabular fracture treatment.
Difficulties in the treatment of pelvic injuries are first put into perspective in **Chapter 2**, which describes the comprehensive epidemiology of (major and minor) pelvic fractures in the Netherlands based on a large cohort of roughly 12.000 patients from the Dutch National Trauma Registry. Furthermore, characteristics and risk factors for in-hospital mortality in older and younger patients are examined.

Part I Early management of major pelvic trauma patients

In **Chapter 3**, acute management of haemodynamically unstable pelvic trauma patients is assessed in 11 Level I trauma centers across Australia and New Zealand. In this multicenter review, key aspects of initial assessment and treatment strategies for hemorrhage control are evaluated. The following two chapters examine early CT indications for immediate (abdominal and pelvic) hemorrhage control in a cohort of major pelvic fracture patients admitted to a Level I trauma center in Amsterdam. The correlation between (the amount of) intraperitoneal free fluid as assessed on CT and need for abdominal hemorrhage control is determined in **Chapter 4**. Whether pelvic hemorrhage control is required in the presence of pelvic arterial bleeding on early CT (or CT "blush") is evaluated in **Chapter 5**. Next, in **Chapter 6**, the effect of an imaging strategy with selective use of plain pelvic radiography prior to CT scanning is assessed in a group of pelvic fracture patients admitted to a large Level I trauma center in Houston. In particular, the time to diagnosis of major pelvic ring disruptions and prioritization of key interventions is determined. Finally, a review of recent literature with respect to acute management of haemodynamically unstable pelvic fracture patients is presented in **Chapter 7**. Specific emphasis is placed on optimal imaging assessment and the current role of interventional radiology for pelvic hemorrhage control.

Part II Late outcome following acetabular fracture fixation

Chapter 8 describes 10- year experience with the (Modified) Stoppa approach for acetabular fracture fixation in a Level I trauma center in Amsterdam and investigates mid-term follow-up results. Subsequently, a reliable standardized digital CT-based method for measuring displacement following acetabular fracture fixation (Addendum I) is used in two studies based on a large cohort of acetabular fracture patients with long-term follow-up from a New York tertiary referral hospital. In **Chapter 9**, postoperative CT imaging is compared to plain pelvic radiography in terms of its ability to detect residual acetabular displacement. Also, risk factors for conversion to total hip arthroplasty at long-term follow-up are identified. **Chapter 10** specifically focusses on the type of articular displacement found on postoperative CT. It examines, the independent correlation between residual gap and step displacement and long-term hip survivorship as well as their separate impact on conversion to total hip arthroplasty following acetabular fracture surgery.

REFERENCES

1. Balogh Z, King KL, Mackay P, McDougall D, Mackenzie S, Evans JA, et al. The epidemiology of pelvic ring fractures: a population-based study. J Trauma 2007;63:1066-73; discussion 72-3.
2. van Dijk WA, Poeze M, van Helden SH, Brink PR, Verbruggen JP. Ten-year mortality among hospitalised patients with fractures of the pubic rami. Injury 2010;41:411-4.
3. Herath SC, Pott H, Rollmann MFR, Braun BJ, Holstein JH, Hoch A, et al. Geriatric Acetabular Surgery: Letournel's Contraindications Then and Now-Data From the German Pelvic Registry. J Orthop Trauma 2019;33 Suppl 2:S8-S13.
4. Pohlemann T, Stengel D, Tosounidis G, Reilmann H, Stuby F, Stockle U, et al. Survival trends and predictors of mortality in severe pelvic trauma: estimates from the German Pelvic Trauma Registry Initiative. Injury 2011;42:997-1002.
5. Yoshihara H, Yoneoka D. Demographic epidemiology of unstable pelvic fracture in the United States from 2000 to 2009: Trends and in-hospital mortality. J Trauma Acute Care Surg 2014;76:380-5.
6. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS, Jr., Poka A, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30:848-56.
7. Pennal GF, Tile M, Waddell JP, Garside H. Pelvic disruption: assessment and classification. Clin Orthop Relat Res 1980:12-21.
8. Nanninga GL, de Leur K, Panneman MJ, van der Elst M, Hartholt KA. Increasing rates of pelvic fractures among older adults: The Netherlands, 1986-2011. Age Ageing 2014;43:648-53.
9. Best MJ, Buller LT, Quinnan SM. Analysis of Incidence and Outcome Predictors for Patients Admitted to US Hospitals with Acetabular Fractures from 1990 to 2010. Am J Orthop (Belle Mead NJ) 2018;47.
10. Boufous S, Finch C, Lord S, Close J. The increasing burden of pelvic fractures in older people, New South Wales, Australia. Injury 2005;36:1323-9.
11. Costantini TW, Coimbra R, Holcomb JB, Podbielski JM, Catalano R, Blackburn A, et al. Current management of hemorrhage from severe pelvic fractures: Results of an American Association for the Surgery of Trauma multi-institutional trial. J Trauma Acute Care Surg 2016;80:717-23; discussion 23-5.
12. Tran TL, Brasel KJ, Karmy-Jones R, Rowell S, Schreiber MA, Shatz DV, et al. Western Trauma Association Critical Decisions in Trauma: Management of pelvic fracture with hemodynamic instability-2016 updates. J Trauma Acute Care Surg 2016;81:1171-4.
13. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.
14. Huber-Wagner S, Lefering R, Qvick LM, Korner M, Kay MV, Pfeifer KJ, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet 2009;373:1455-61.
15. Chidambaram S, Goh EL, Khan MA. A meta-analysis of the efficacy of whole-body computed tomography imaging in the management of trauma and injury. Injury 2017;48:1784-93.
16. Fung Kon Jin PH, Goslings JC, Ponsen KJ, van Kuijk C, Hoogerwerf N, Luitse JS. Assessment of a new trauma workflow concept implementing a sliding CT scanner in the trauma room: the effect on workup times. J Trauma 2008;64:1320-6.
17. Crichton JCI, Naidoo K, Yet B, Brundage SI, Perkins Z. The role of splenic angioembolization as an adjunct to nonoperative management of blunt splenic injuries: A systematic review and meta-analysis. J Trauma Acute Care Surg 2017;83:934-43.
18. Green CS, Bulger EM, Kwan SW. Outcomes and complications of angioembolization for hepatic trauma: A systematic review of the literature. J Trauma Acute Care Surg 2016;80:529-37.

19. Tesoriero RB, Bruns BR, Narayan M, Dubose J, Guliani SS, Brenner ML, et al. Angiographic embolization for hemorrhage following pelvic fracture: Is it “time” for a paradigm shift? J Trauma Acute Care Surg 2017;82:18-26.

20. Huber-Wagner S, Kanz KG, Hanschen M, van Griensven M, Biberthaler P, Lefering R. Whole-body computed tomography in severely injured patients. Curr Opin Crit Care 2018;24:55-61.

21. Prevezas N. Evolution of pelvic and acetabular surgery from ancient to modern times. Injury 2007;38:397-409.

22. Letournel E JR. Fractures of the acetabulum. 2nd ed. Elson RA, translator, editor. New York: Springer; 1993 Translation of Les fractures du cotyle.

23. Cole JD, Bolhofner BR. Acetabular fracture fixation via a modified Stoppa limited intrapelvic approach. Description of operative technique and preliminary treatment results. Clin Orthop Relat Res 1994:112-23.

24. Ponsen KJ, Joosse P, Schigt A, Goslings JC, Luitse JS. Internal fracture fixation using the Stoppa approach in pelvic ring and acetabular fractures: technical aspects and operative results. J Trauma 2006;61:662-7.

25. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 1996;78:1632-45.

26. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am 2012;94:1559-67.

27. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years’ follow-up. J Bone Joint Surg Br 2011;93:229-36.

28. Moed BR, Carr SE, Gruson KI, Watson JT, Craig JG. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J Bone Joint Surg Am 2003;85-A:512-22.

29. Borrelli J, Jr., Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma 2005;19:299-304.

30. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Radiographic Measurement of Displacement in Acetabular Fractures: A Systematic Review of the Literature. J Orthop Trauma 2016;30:285-93.

31. Giannoudis PV, Grotz MR, Papakostidis C, Dinopoulos H. Operative treatment of displaced fractures of the acetabulum. A meta-analysis. J Bone Joint Surg Br 2005;87:2-9.

02
CHAPTER

PELVIC FRACTURES IN THE NETHERLANDS

Epidemiology, characteristics and risk factors for in-hospital mortality in the older and younger population

AMSTERDAM, THE NETHERLANDS

D.O. Verbeek,
K.J. Ponsen,
M. Fiocco,
S. Amodio,
L.P.H. Leenen,
J.C. Goslings

Academic Medical Center
University of Amsterdam
Amsterdam
the Netherlands

Eur J Orthop Surg
Traumatol 2018;
28:197-205

2018

ABSTRACT

Purpose: To examine nationwide epidemiology of pelvic fractures in the Netherlands and to compare characteristics and outcome of older versus younger patients as well as predictors for in-hospital mortality.

Methods: Retrospective review of pelvic fracture patients admitted to all Dutch hospitals (2008-2012) utilizing National Trauma Registry. Average annual incidence of (minor and major) pelvic fractures was calculated for the population. Older (≥65 years) and younger (<65 years) patients were compared. Multivariate regression analysis was performed to identify independent predictors for in-hospital mortality.

Results: Of 11 879 pelvic fracture patients (61.8%, ≥65 years). Annual incidence of pelvic fractures in older versus younger population was 57.9 *vs* 6.4 per 100 000 persons. Older patients had lower ISS (7.1 (SD 6.9) *vs* 15.4 (SD 13.4)) and less frequently had severe associated injuries (15.6% *vs* 43.5%), an admission systolic blood pressure (SBP) ≤90 mmHg (1.6% *vs* 4.1%) or Glasgow Coma Score (GCS) ≤12 (2.0% *vs* 13.3%) (all, p<0.01). In-hospital mortality was equal in older and younger patients (5.3% *vs* 4.8%: p=0.28). In both subgroups, greatest independent predictors for in-hospital mortality were GCS ≤12, ISS ≥16, and SBP ≤90 mmHg and in all patients age ≥65 (OR 6.59 (5.12-8.48): p<0.01).

Conclusion: The annual incidence of (both minor and major) pelvic fractures in the older population was substantially higher than in the younger population. Elderly patients had a disproportionately high in-hospital mortality rate considering they were less severely injured. Among other factors, age was the greatest independent predictor for in-hospital mortality in all pelvic fracture patients.

INTRODUCTION

Pelvic fractures range from major disruptions to minor breaks of the pelvic ring. Major pelvic fractures are typically a result from high-energy trauma and have been the focus of extensive research [1-3]. Minor or isolated breaks of the pelvic ring are typically found in the elderly population after a low impact fall and have previously received much less attention [4]. In recent years, however, it is increasingly recognized that these low-energy (osteoporotic) pelvic fractures may be associated with poor clinical outcome in elderly patients [5-7]. Furthermore, several studies have suggested that the incidence of pelvic fractures in the elderly is increasing at an alarming rate [8-10].
Reliable epidemiological data on (particularly minor) pelvic fractures is scarce and often limited to particular regions within a country or based on administrative (non-scientific) databases [4,8,11,12]. Likewise, in the Netherlands the comprehensive epidemiology of pelvic fractures is largely unknown. As a result, the full extent of this urgent health care concern in the older as well as the younger population remains to be further defined.
The Dutch National Trauma Registry records all acute admissions due to traumatic injury in the Netherlands including those resulting from less severe fractures. Every hospital providing trauma care provides data for this comprehensive database.

The primary objective of this study was to examine the nationwide epidemiology of older and younger patients with a (minor or major) pelvic fracture in the Netherlands. Our secondary objective was to compare the characteristics and outcome (hospital and intensive care unit (ICU) length of stay and in-hospital mortality) in both age groups and to determine independent predictors for in-hospital mortality.

METHODS

Dutch National Trauma Registry

The Netherlands is a densely populated country which recently reached a population of 17 million[13]. Hospitals in the Netherlands are designated Level I, II or III trauma centers based on criteria similar to those formulated by the American College of Surgeons[14]. The Dutch National Trauma Registry (Landelijke Traumaregistratie) was instituted by the National Network of Acute Care (Landelijk Netwerk Acute Zorg) in 2007 to monitor the quality of trauma care in the Netherlands. Through the years, hospital participation increased and currently all trauma patients who present at a Dutch Emergency Department (ED) within 48 hours from injury and are admitted to hospital or expired in the ED are captured in the National Trauma Registry. In addition to multiple injured patients, patients with isolated

injuries and/or a short hospital stay are included in this nationwide registry. Data entry is performed by trained data managers in each individual hospital and is collected by the coordinating hospitals of the 11 trauma regions. These coordinating (Level I) major trauma hospitals are joined in the National Network of Acute Care.
During the 5-year study period the rate of participating hospitals increased from 74% to 94%. All 11 Dutch Level I major trauma centers participated during the complete study period.

Patients

A retrospective review of the Dutch National Trauma Registry was performed from January 1, 2008 to December 31, 2012. All patients with an abbreviated injury score (AIS) of the pelvic bones were included in this study [15]. The following AIS pelvis codes were used for patient identification: 852600.2, 852602.2, 852604.3, 852606.4, 852608.4, 852610.5, 852800.3 and 853000.3 (AIS version 1998). Collected data included; age, gender, admitting hospital (Level I *vs* II/III), injury severity score (ISS), associated injuries ((AIS) per body region), admission systolic blood pressure (SBP) and Glasgow Coma Score (GCS) on arrival [15,16]. In addition, the following outcome parameters were collected; hospital and ICU length of stay and in-hospital (or emergency department (ED)) mortality.

Definitions

Older patients were defined as aged ≥65 years, major pelvic fracture as AIS pelvis ≥3 (versus minor pelvic fractures AIS pelvis <3), major trauma center as Level I (versus Level II/III), severe associated injury as AIS ≥3, multiple injured patients as ISS ≥16, hypotension as SBP ≤90 mmHg and decreased level of consciousness as GCS≤12.

Statistical Analysis

The average annual incidence of patients hospitalized for a pelvic fracture in the Netherlands in the 5-year study period was calculated based on an average Dutch population between 2008 and 2012 of 16 655 799 with 2 538 328 older and 14 117 471 younger persons[13].
Contingency tables were constructed to compare the baseline characteristics and outcome of older and younger patients. Furthermore, ISS and in-hospital mortality were compared in a sub-analysis according to the presence of a minor or a major pelvic fracture.
Continuous variables are presented as mean values with standard deviations (SD) and compared with the independent t-test. Categorical values were calculated as percentage of frequency of occurrence and compared using Pearson Chi-square test. Univariate and multivariate analysis was performed to identify dependent and independent risk factors for in-hospital mortality in all patients as well as in the older and younger subgroups. The following variables were entered for analysis; age ≥65 years (in all patients), male gender, ISS ≥16, major pelvic fracture (AIS pelvis ≥3), presence of a severe associated injury

(AIS≥3), SBP ≤90 mmHg, GCS ≤12 and admission to a major trauma center. All listed variables were entered into the multivariate model considering the clinical significance of each factor and the large patient cohort. Results are presented as odds ratio (OR) along with the corresponding 95% confidence intervals (CI).

Statistical significance was declared at the 0.05 level. Multiple imputation was used to manage missing SBP and GCS values[17]. This statistical technique assigns multiple plausible alternative values for each missing values. Each imputed data set is subsequently analyzed separately and the results are averaged out. Standard errors are calculated by using Rubin's rules which takes into account the variability in the results between the imputed datasets,

Statistical analysis was performed by two of the investigators (M.F. and S.A.) using R 3.4.1 for Windows [18]

RESULTS

In the 5-year study period, 334,437 trauma patients were admitted to Dutch hospitals and 11,879 (3.6%) had a pelvic fracture. Pelvic fractures occurred predominantly in patients over the age of 65 (61.8%) and the majority of patients (75.2%) was diagnosed with a minor pelvic fracture **(Table 1).**

Epidemiology

The average annual incidence of all patients with a pelvic fracture in the Netherlands was 14.3 per 100,000 persons. The incidence was considerably higher in the older than in the younger population (respectively 57.9 and 6.4 per 100 000 persons). Minor pelvic fractures occurred in 10.7 per 100 000 persons and major pelvic fractures in 3.5 per 100 000 persons. For both the older and younger groups the average annual incidence was greater for minor pelvic fractures (respectively 48.3 and 4.0 per 100 000 persons) as opposed to major pelvic fractures (respectively 9.6 and 2.5 per 100 000 persons).

Older versus younger patients

Older pelvic fracture patients (mean age 82.2 years, SD 7.8) compared to younger pelvic fracture patients (mean age 40.9 years, SD 16.5) were more likely to be female (76.3% *vs* 37.3%: p <0.01) and were predominately admitted to Level II/III trauma centers (82.1% *vs* 50.9%: p <0.01) **(table 1**). Compared to younger patients, more older patients sustained a minor pelvic fracture (83.4% *vs* 61.7%: p <0.01).

Table 1. Baseline characteristics in older (≥65 years) and younger (<65 years) pelvic fracture patients

	All	Older	Younger	p-value
Patients; n (%)	11879 (100.0)	7346(61.8)	4533(38.2)	
Age; mean (SD)	66.4 (23.3)	82.2 (7.8)	40.9(16.5)	<0.01
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Gender; n (%)				
male	4578 (38.5)	1739 (23.7)	2839 (62.7)	<0.01
female	7292 (61.4)	5603 (76.3)	1689 (37.3)	
missing; n (%)	9 (0.1)	4 (0.1)	5 (0.1)	
Admitting hospital; n (%)				
major trauma center	3542 (29.8)	1317 (17.9)	2225 (49.1)	<0.01
non-major trauma center	8337 (70.2)	6029 (82.1)	2308 (50.9)	
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Abbreviated injury score (AIS) pelvis; n (%)				
2	8928 (75.2)	6130 (83.4)	2798 (61.7)	<0.01
3	2473 (20.8)	1116 (15.2)	1357 (30.0)	<0.01
4	361 (3.0)	66 (1.0)	295 (6.5)	<0.01
5	117 (1.0)	34 (0.5)	83 (1.8)	<0.01
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Injury severity score; mean (SD)	10.3 (10.7)	7.1 (6.9)	15.4 (13.4)	<0.01
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Injury severity score; n (%)				
1-3	0 (0.0)	0 (0.0)	0 (0.0)	
4-8	6765 (57)	5166 (70.3)	1599 (35.3)	<0.01
9-15	2968 (25)	1676 (22.8)	1292 (28.5)	<0.01
16-24	897 (7.6)	227 (3.1)	670 (14.8)	<0.01
25-49	1051 (8.9)	240 (3.3)	811 (17.9)	<0.01
50-66	185 (1.6)	35 (0.5)	150 (3.3)	<0.01
75	13 (0.1)	2 (0.03)	11 (0.2)	0.013
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Any severe associated injury[1]; n (%)	3124 (26.3)	1148 (15.6)	1973 (43.5)	<0.01
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Severe associated injuries; n (%)[2]				
head	842 (7.1)	262 (3.6)	580 (12.8)	<0.01
face	72 (0.6)	12 (0.2)	60 (1.3)	<0.01
neck	9 (0.1)	1 (0.0)	8 (0.2)	0.04
chest	1329 (11.2)	275 (3.7)	1054 (23.3)	<0.01
abdomen	501 (4.2)	91 (1.2)	410 (9.0)	<0.01
spine	348 (2.9)	63 (0.9)	285 (6.3)	<0.01
upper extremity	899 (7.6)	384 (5.2)	515 (11.4)	<0.01
lower extremity	1080 (9.1)	406 (5.5)	674 (14.9)	<0.01
external	14 (0.1)	2 (0.0)	12 (0.3)	0.01
missing; n (%)	0 (0.0)	0 (0.0)	0 (0.0)	
Systolic Blood Pressure (SBP)				
mean mmHg (SD)	136.6 (28.6)	142.1 (29.6)	128.3 (24.9)	<0.01
SBP ≤90 mmHg; n (%)	305 (2.6)	119 (1.6)	186 (4.1)	<0.01
missing; n (%)	1950 (16.5)	1370 (18.6)	580 (12.8)	
Glasgow Coma Score (GCS)				
mean (SD)	14.1 (2.9)	14.7 (1.6)	13.2 (4.0)	<0.01
GCS≤12; n (%)	745 (6.3)	146 (2.0)	599 (13.2)	<0.01
missing; n (%)	3148 (26.5)	2262 (30.8)	886 (19.5)	

[1] AIS ≥3, [2] patients can have more than one severe associated injury (AIS ≥3).

The ISS in older patients was lower (mean 7.1, SD 6.9 *vs* 15.4, SD 13.4: p <0.01) and a smaller number was multiple injured (ISS ≥16; 6.9% *vs* 36.2%: p <0.01).
Severe associated injuries occurred less frequently in older patients (15.6% vs 43.5%: p <0.01). In particular, severe head, chest and abdominal injuries were less common in older patients compared to their younger counterparts (respectively 3.6% vs 12.8%, 3.7% vs 23.3% and 1.2% vs 9.0%: p <0.01). Systolic blood pressure on arrival was higher in older patients (mean 142.1 mmHg, SD 29.6 *vs* 128.3 mmHg, SD 24.9: p <0.01) and an SBP ≤90 mmHg was uncommon, particularly in older patients (1.6% vs 4.1%: p<0.01). Lastly, a GCS ≤12 was also found less frequently in older patients (2.0% *vs* 13.2%: p<0.01).

Outcome
Older pelvic fracture patients had a shorter hospital stay (mean 11.3 days, SD 11.4 *vs* 14.4 days, SD 17.8: P<0.01) and were less frequently admitted to the ICU (4.0% *vs* 20.6%: p<0.01) **(Table 2)**. The ICU length of stay in the older group was also shorter compared to the younger group (mean 6.4 days, SD 3.8 *vs* 8.2 days, SD 16.1: p<0.01).

The overall in-hospital mortality rate in older pelvic fracture patients was equal to younger patients (5.3% *vs* 4.8%: p=0.28). Few patients in both the older and the younger groups died in the ED (0.5% *vs* 1.0%: p=0.23).
When only patients with a minor pelvic fracture were considered, the hospital mortality was equal between the older and younger groups (4.0% (247/6130) vs 3.2% (90/2798): p=0.07) despite older patients with a minor pelvic fracture having a lower ISS (5.8 (5.2) vs 11.7 (11.5): p<0.01). When only patients with a major pelvic fracture were considered, the hospital mortality in older patients was higher than in younger patients (11.3% (138/1216)

Table 2. Outcome in older (≥65 years) and younger (<65 years) pelvic fracture patients

	All	Older	Younger	p-value
Patients; n (%)	11879 (100)	7346(61.8)	4533(38.2)	
Length of hospital stay; mean (SD)	12.5 (14.3)	11.3 (11.4)	14.4 (17.8)	<0.01
missing; n (%)	313 (2.6)	173 (2.4)	140 (3.1)	
ICU stay; n (%)	1224 (10.3)	291(4.0)	933 (20.6)	<0.01
Length of ICU stay; mean (SD)	7.8 (14.8)	6.4 (3.8)	8.2 (16.1)	<0.01
missing; n (%)	59 (4.8)	25 (8.6)	34 (3.6)	
Mortality; n (%)				
Emergency department; n (%)	78 (0.7)	33 (0.5)	45 (1.0)	0.23
In-hospital; n (%)	601 (5.1)	385 (5.3)	216 (4.8)	0.28
missing; n (%)	42 (0.4)	22 (0.3)	20 (0.4)	

vs 7.2% (126/1735): p<0.01) despite the older group having a lower ISS (13.7 (9.9) vs 21.3 (14.1): p<0.01).

Predictors for in-hospital mortality
Dependent and independent predictors for in-hospital mortality in pelvic fracture patients are presented in **Table 3 and 4**. In all patients, age ≥65 was the greatest independent predictor for in-hospital mortality (OR 6.59 (5.12-8.48): p<0.01).
In the older as well as the younger patient groups, the 3 greatest predictors for in-hospital mortality were GCS ≤12, ISS ≥16 and SBP ≤90 mmHg. The presence of a major pelvic fracture was also an independent predictor for in-hospital mortality in all pelvic fracture patients (OR 1.26 (1.02-1.56): p=0.03) and in the older patient group (1.35 (1.02-1.77): p=0.03) but not in younger patients (OR 1.15 (0.83-1.60): p=0.40).
Lastly, admission to a major trauma center was associated with a trend towards higher in-hospital mortality in all patients (OR 1.28 (1.00-1.63): p=0.05) but was unrelated to this outcome in the older and younger subgroups (respectively, OR 1.20 (0.90-1.60): p=0.21 and OR 1.55 (0.94-2.53): p=0.08).

DISCUSSION

In concurrence with trends from other industrialized nations, the elderly population in the Netherlands is projected to grow from 2.7 million in 2012 to 4.7 million in 2041 (16% to 26% of the population)[19]. As a consequence, the overall admission rate of elderly pelvic fracture patients is expected to continue to rise [8-10]. Our current findings are clearly reflective of this growing health care concern given that the majority (61.8%) of pelvic fracture patients in this large cohort was over the age of 65.

Epidemiology

Over the 5 year study period we found an average annual incidence of all pelvic fractures in the Netherlands of 14.3 per 100 000 persons. Though literature on the subject is sparse and populations dissimilar, this overall incidence of pelvic fractures is markedly lower than has been reported earlier in pelvic fracture patients (20-37 per 100 000 persons)[4,11,12]. A possible explanation for this finding appears to be the lower occurrence of major pelvic fractures. In a 1 year prospective population-based study in a region in Australia, an occurrence of 20 high- and low-energy pelvic ring fractures (excluding isolated acetabular fractures) per 100 000 persons was found in a cohort of hospitalized patients[4].

Table 3. Univariate analysis for predictors for in-hospital mortality in older (≥65 years) and younger (<65 years) pelvic fracture patients (Odds Ratio (OR) 95% confidence interval (CI))

	All		**Older**		**Younger**	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Age ≥65 years	1.11 (0.93-1.31)	0.25	NA	NA	NA	NA
Male gender	1.72 (1.46-2.03)	<0.01	2.38 (1.93-2.94)	<0.01	1.37 (1.02-1.85)	0.04
ISS ≥16	8.77 (7.37-10.43)	<0.01	16.27 (12.92-20.49)	<0.01	26.10 (15.36-44.22)	<0.01
Major pelvic fracture[1]	2.49 (2.11-2.94)	<0.01	3.01 (2.43-3.75)	<0.01	2.38 (1.79-3.15)	<0.01
Severe associated injury	6.38 (5.35-7.61)	<0.01	6.90 (5.58-8.54)	<0.01	20.28 (11.76-34.97)	<0.01
SBP ≤90 mmHg	9.99 (7.99-12.49)	<0.01	11.35 (7.89-16.31)	<0.01	10.33 (7.44-14.34)	<0.01
GCS ≤12	12.70 (10.58-15.25)	<0.01	23.17 (17.32-31.00)	<0.01	21.97 (15.26-31.65)	<0.01
Trauma center admission	3.79 (3.20-4.49)	<0.01	4.00 (3.22-4.91)	<0.01	8.65 (5.64-13.29)	<0.01

[1] AIS ≥3. ISS: injury severity score, SBP: systolic blood pressure, GCS: Glasgow coma score, NA: Not applicable

Tabel 4. Multivariate analysis for independent predictors for in-hospital mortality in older (≥65 years) and younger (<65 years) pelvic fracture patients (Odds Ratio (OR) 95% confidence interval (CI))

	All		**Older**		**Younger**	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Age ≥65 years	6.59 (5.12-8.48)	<0.01	NA	NA	NA	NA
Male gender	1.25 (1.02-1.54)	0.03	1.48 (1.15-1.90)	<0.01	0.94 (0.67-1.30)	0.69
ISS ≥16	3.74 (2.61-5.36)	<0.01	3.45 (2.25-5.28)	<0.01	4.51 (2.12-9.64)	<0.01
Major pelvic fracture[1]	1.26 (1.02-1.56)	0.03	1.35 (1.02-1.77)	0.03	1.15 (0.83-1.60)	0.40
Severe associated injury	1.76 (1.29- 2.41)	<0.01	1.83 (1.30-2.58)	<0.01	1.70 (0.78-3.73)	0.18
SBP ≤90 mmHg	3.09 (2.33-4.09)	<0.01	3.58 (2.31-5.54)	<0.01	2.74 (1.88-3.99)	<0.01
GCS ≤12	5.19 (3.92-6.87)	<0.01	4.45 (3.00-6.59)	<0.01	5.94 (3.83-9.20)	<0.01
Trauma center admission	1.28 (1.00-1.63)	0.05	1.20 (0.90-1.60)	0.21	1.55 (0.94-2.53)	0.08

[1] AIS ≥3. ISS: injury severity score, SBP: systolic blood pressure, GCS: Glasgow coma score, NA: Not applicable

The incidence of low-energy pelvic fractures was similar to the rate of minor pelvic fractures found in our study (10 versus 11 per 100 000) but the incidence of high-energy pelvic fractures was considerably higher (10 versus 4 per 100 000). The incidence of all pelvic fractures found in the Australian study is equal to the rate of 20 per 100 000 found in a prior report from a Swedish County[12]. An American study from Rochester (MI) however found an even higher occurrence for pelvic fractures of 37 per 100 000 persons[11]. Of note is that a range of other studies have described large cohorts of pelvic fracture patients using a variety of (non-scientific) databases and inclusion criteria but these reports are neither all-inclusive nor do they indicate the specific incidence in the general population[1,2,20]. The discrepancy between the nationwide incidence of pelvic fractures found in our study and the regional occurrences reported previously can in part be explained by differences in demographics. Although there is no definitive data to support this claim, it could also be speculated that it may be a result of variances in vehicle and road safety (affecting speed and compartment intrusion) and modes of transportation (more bikes)[21]. The majority of pelvic fractures are a result from motor vehicle collisions and less frequently from bicycle (and motorbike) accidents [20]. Indeed, aspects that impact direction and amount of energy transfer on the human body may also have a direct influence on the proportion of major as opposed to minor pelvic fractures in the Dutch population[21]. Furthermore, the overall shorter road travel distances in densely populated countries such as the Netherlands may have played an important role.

Older versus younger patients

In older individuals, the overall incidence of pelvic fractures was 9 times higher than in younger individuals (57.9 versus 6.4 per 100 000 persons) mostly as a result of a much higher occurrence of minor pelvic fractures in this age group (48.3 versus 4.0 per 100 000 persons). More strikingly, we found that the incidence of major pelvic fractures in older individuals was roughly 3 fold of that in younger individuals (9.6 versus 2.5 per 100 000 persons) suggesting that older persons are at risk for more severe pelvic fractures despite generally sustaining lower energy trauma [22]. To our knowledge, no earlier population-based studies have reported epidemiology of pelvic fractures in older and younger subgroups separately.

Elderly pelvic fracture patients present a uniquely different patient cohort compared to their younger counterparts. In older patients, pelvic fractures are more likely a result from low-energy falls as opposed to high-energy road traffic accidents in younger patients [5,10,23,24]. This was reflected in our study by a greater proportion of minor pelvic fractures, less severe injuries and a higher rate of admission to a non-major trauma center in older patients. In contrast, younger patients generally sustained a major pelvic fracture as well as severe associated injuries and were more likely to be admitted to a major trauma center. These aspects most likely resulted in a shorter length of hospital and ICU stay for the older group although the absolute difference in days was discrete. Our findings are corroborated by another large study in which older and younger pelvic fracture patients were directly compared. In this National Trauma Data Bank study, the older subgroup also had a larger percentage of minor pelvic fractures, a lower proportion of severe injuries and a lower ICU length of stay [24].

The results of this study further show a similar in-hospital mortality rate for older and younger patients (5.3% vs 4.8%; p=0.28). However, given the aforementioned differences between groups we conclude that older patients with a minor or major pelvic fracture had a disproportionately high mortality rate. Indeed, in the cohort of major pelvic fractures, older patients had a significantly higher in-hospital mortality rate than younger patients despite having a significantly lower ISS.

In contrast to our findings, data from approximately 12 000 elderly pelvic fracture patients extracted from the American National Trauma Data Bank indicated that the mortality rate in this group was significantly higher than in the younger group (13.3% versus 8.8%)[24]. Furthermore, a number of markedly smaller previous studies from single level I trauma centers reported a 10%-21% mortality rate in elderly pelvic fracture patients[5,23,25-27]. It should be noted however that the patients admitted to these major trauma facilities as well as the patients described in the National Trauma Data Bank study were more severely injured (mean ISS 12- 21) than those reported in our more comprehensive nationwide review (mean ISS 7). The significantly higher mortality rate for elderly patients found in these prior studies does appear to support our similar finding in the subgroup of more severely injured major pelvic fracture patients.

Predictors for in- hospital mortality

The overall in-hospital mortality rate (5.1%) for all pelvic fracture patients found in our study is at the lower end of rates reported previously in large database studies [1,2,20,28]. These prior studies found a mortality rate that ranged from 3% to 14% depending on the specific characteristics of the pelvic fracture patients (and participating institutions) included for review.

Few studies with a large enough population have examined independent predictors for in-hospital mortality in pelvic fracture patients[2,20,28]. In the present large cohort of pelvic fracture patients the single greatest risk factor for in-hospital mortality was age over 65 years, followed by a decreased level of consciousness, the presence of multiple injuries and hypotension. The latter three factors were also highly predictive for in-hospital mortality in the older and younger subgroups.

Results in the current study are supported by a study from the United Kingdom that included over 11 000 patients[20]. Age, physiologic derangement with hypotension and the presence of associated injuries were factors that independently predicted mortality. A further study from the National Trauma Data Bank included more than 30 000 (initially stable) pelvic trauma patients[28]. In this subgroup of pelvic fracture patients advanced age, a higher severity of injury and a lower Glasgow Coma Score were among other factors most predictive for in-hospital mortality. Finally, in a study from the German Pelvic Trauma Registry with roughly 5000 patients, age and ISS were significant risk factors for mortality as well as a variety of variables that indicated signs of significant bleeding (the Glasgow Coma Score was not considered in this study)[2].

Although not a significant independent risk factor, an unexpected finding in our study was that there was a trend towards higher in-hospital mortality in (all) patients admitted to a major trauma center (OR 1.28 (1.00-1.63): p=0.05). Admission to a major trauma center was not independently associated with this outcome in the individual subgroups of older and younger patients. Earlier studies that have investigated this particular matter have found mixed results but most have indicated that predominantly patients with more severe pelvic fractures would likely benefit from specialized (Level I) trauma care[28].
To our knowledge, older pelvic fracture patients as a separate subgroup have not been addressed previously in this context. In the National Trauma Data Bank study it was found that transport of stable pelvic trauma patients to a Level I or II Trauma facility was independently associated with lower mortality[20,28]. Furthermore, pelvic fracture patients admitted or transferred to a hospital with pelvic reconstruction facilities in the United Kingdom had significantly lower mortality rates[20]. This was particularly evident for the higher AIS pelvic classifications but not so much for lower AIS classifications. A secondary analysis from data from the American National Study on Costs and Outcomes of Trauma found mixed results (at various time points) for a number of subgroups of pelvic and acetabular fracture patients[29]. In-hospital mortality was not independently associated with admission to a Level I trauma facility (versus a large non-trauma center) in all pelvic fracture patients. However, outcome (in terms of survival and physical function) at 1 year was superior in patients with unstable pelvic and severe acetabular fractures that were admitted to these more advanced trauma facilities. Ultimately, it could be speculated that perhaps differences between Level I and II trauma centers in the Netherlands are more discrete than in other countries and that a comparison between Dutch Level I /II versus Level III facilities would have yielded different results.

The present study underscores that elderly pelvic fracture patients present a growing patient cohort that demands urgent attention. In treating these challenging patients, it should be recognized early that the elderly are at increased risk for death even in the presence of less severe pelvic fractures. Aggressive management of comorbid conditions as well as treatment directed at immediate pain relief and early restoration of function are particularly crucial in this high risk patient group. Future studies will have to evaluate which fracture specific treatment strategies are most successful in decreasing morbidity and mortality. A more detailed (pelvic trauma) registry may be an important first step to advance such efforts. Also, further research is needed to identify effective fracture prevention strategies such as programs aimed at decreasing falls in the elderly and osteoporosis treatment.

Strengths and Limitations

This study represents the first scientific report based on data from the Dutch National Trauma Registry. While previous studies have generally reported selected pelvic fracture patients from certain regions within a country and/or have been based on non-scientific databases [4,8,11,12], we were able to describe a near all-inclusive nationwide cohort of almost 12 000 pelvic fracture patients admitted to Dutch hospitals. This included patients with less severe fractures and admissions to smaller (non-major trauma) hospitals. More than 7000 patients over the age of 65 years were included, one of the largest cohorts of elderly pelvic fracture patients reported to date [24].

This study has several limitations inherent to large database reviews such as potential issues related to the accuracy and quality of the data entered. Miscoding of pelvic ring injuries has been found to be a significant problem in the American National Trauma Data Bank[30]. It is unknown if the current Dutch National Trauma Registry suffers from the same shortcoming. Furthermore, a number of potentially important variables such as Revised Trauma Score, packed red blood cell requirement, (surgical) interventions and cause of death were not recorded. Also, similar to other studies, the Dutch registry only collects AIS pelvic codes to classify pelvic fractures these codes did not allow us to further classify the various pelvic fracture types other than in minor and major fractures. We encountered a considerable volume of missing values for some variables (particularly the GCS). To deal with this important issue we employed the method of multiple imputation[17]. This statistical technique represents a superior alternative to simple (stepwise) deletion of patients with missing values which risks introducing a selection bias and decreases the effective sample size (and power) of the analysis. Results in the current study may have been influenced by (unknown) confounders that were not entered (or missing) in the multiple regression analysis. Lastly, it should be noted that while hospital participation currently approaches 100%, during the 5-year study period an average of 84% of hospitals participated in the Dutch National Trauma Registry. It is unlikely however that this had a significant impact on our findings as all (Level I) major trauma centers and the majority of other large hospitals participated in the registry during the entirety of the study period.

CONCLUSION

In this review of a near all-inclusive nationwide cohort of trauma patients in the Netherlands, the annual incidence of (both minor and major) pelvic fractures in the older population was substantially higher than in the younger population. However, overall, the incidence of (particularly major) pelvic fractures appeared to be lower than estimates from other industrialized countries.

Compared to younger pelvic fracture patients, elderly patients presented a uniquely different patient cohort with overall less severe injuries but with a disproportionately high in-hospital mortality rate. Among other factors, age was the single largest independent predictor for in-hospital mortality. Admission to a Level I major trauma center was not predictive for lower in-hospital mortality.

REFERENCES

1. Yoshihara H, Yoneoka D. Demographic epidemiology of unstable pelvic fracture in the United States from 2000 to 2009: Trends and in-hospital mortality. J Trauma Acute Care Surg 2014;76:380-5.
2. Pohlemann T, Stengel D, Tosounidis G, Reilmann H, Stuby F, Stockle U, et al. Survival trends and predictors of mortality in severe pelvic trauma: estimates from the German Pelvic Trauma Registry Initiative. Injury 2011;42:997-1002.
3. Verbeek D, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
4. Balogh Z, King KL, Mackay P, McDougall D, Mackenzie S, Evans JA, et al. The epidemiology of pelvic ring fractures: a population-based study. J Trauma 2007;63:1066-73; discussion 72-3.
5. Henry SM, Pollak AN, Jones AL, Boswell S, Scalea TM. Pelvic fracture in geriatric patients: a distinct clinical entity. J Trauma 2002;53:15-20.
6. Ayoung-Chee P, McIntyre L, Ebel BE, Mack CD, McCormick W, Maier RV. Long-term outcomes of ground-level falls in the elderly. J Trauma Acute Care Surg 2014;76:498-503.
7. van Dijk WA, Poeze M, van Helden SH, Brink PR, Verbruggen JP. Ten-year mortality among hospitalised patients with fractures of the pubic rami. Injury 2010;41:411-4.
8. Nanninga GL, de Leur K, Panneman MJ, van der Elst M, Hartholt KA. Increasing rates of pelvic fractures among older adults: The Netherlands, 1986-2011. Age Ageing 2014;43:648-53.
9. Kannus P, Palvanen M, Niemi S, Parkkari J, Jarvinen M. Epidemiology of osteoporotic pelvic fractures in elderly people in Finland: sharp increase in 1970-1997 and alarming projections for the new millennium. Osteoporos Int 2000;11:443-8.
10. Boufous S, Finch C, Lord S, Close J. The increasing burden of pelvic fractures in older people, New South Wales, Australia. Injury 2005;36:1323-9.
11. Melton LJ, 3rd, Sampson JM, Morrey BF, Ilstrup DM. Epidemiologic features of pelvic fractures. Clin Orthop Relat Res 1981:43-7.
12. Ragnarsson B, Jacobsson B. Epidemiology of pelvic fractures in a Swedish county. Acta Orthop Scand 1992;63:297-300.
13. Bevolking; kerncijfers. at http://statline.cbs.nl.)
14. Aprahamian C, Wolferth CC, Jr., Darin JC, McMahon J, Weitzel-DeVeas C. Status of trauma center designation. J Trauma 1989;29:566-70.
15. Baker SP, O'Neill B, Haddon W, Jr., Long WB. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma 1974;14:187-96.
16. Teasdale G, Jennett B. Assessment of coma and impaired consciousness. A practical scale. Lancet 1974;2:81-4.
17. Rubin D. Multiple imputation for nonresponse in surveys: John Wiley & Sons; 2004.
18. R. Core Team (2013). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.
19. Giesbers H VA, Beer J de. Vergrijzing: Wat zijn de belangrijkste verwachtingen voor de toekomst? . Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid 2013.
20. Giannoudis PV, Grotz MR, Tzioupis C, Dinopoulos H, Wells GE, Bouamra O, et al. Prevalence of pelvic fractures, associated injuries, and mortality: the United Kingdom perspective. J Trauma 2007;63:875-83.
21. Richter M, Otte D, Gansslen A, Bartram H, Pohlemann T. Injuries of the pelvic ring in road traffic accidents: a medical and technical analysis. Injury 2001;32:123-8.

22. Sterling DA, O'Connor JA, Bonadies J. Geriatric falls: injury severity is high and disproportionate to mechanism. J Trauma 2001;50:116-9.
23. Alost T, Waldrop RD. Profile of geriatric pelvic fractures presenting to the emergency department. Am J Emerg Med 1997;15:576-8.
24. Matityahu A, Elson J, Morshed S, Marmor M. Survivorship and severe complications are worse for octogenarians and elderly patients with pelvis fractures as compared to adults: data from the national trauma data bank. J Osteoporos 2012;2012:475739.
25. Dechert TA, Duane TM, Frykberg BP, Aboutanos MB, Malhotra AK, Ivatury RR. Elderly patients with pelvic fracture: interventions and outcomes. Am Surg 2009;75:291-5.
26. Ojodu I, Pohlemann T, Hopp S, Rollmann MF, Holstein JH, Herath SC. Predictors of mortality for complex fractures of the pelvic ring in the elderly: a twelve-year review from a German level I trauma center. Injury 2015;46:1996-8.
27. O'Brien D P, Luchette FA, Pereira SJ, Lim E, Seeskin CS, James L, et al. Pelvic fracture in the elderly is associated with increased mortality. Surgery 2002;132:710-4; discussion 4-5.
28. Wang H, Phillips JL, Robinson RD, Duane TM, Buca S, Campbell-Furtick MB, et al. Predictors of mortality among initially stable adult pelvic trauma patients in the US: Data analysis from the National Trauma Data Bank. Injury 2015;46:2113-7.
29. Morshed S, Knops S, Jurkovich GJ, Wang J, MacKenzie E, Rivara FP. The impact of trauma-center care on mortality and function following pelvic ring and acetabular injuries. J Bone Joint Surg Am 2015;97:265-72.
30. Haws BE, Wuertzer S, Lenchik L, Miller AN. Misclassification of Pelvic Ring Injuries in the National Trauma Data Bank. J Orthop Trauma 2015;29:460-2.

PART I

EARLY MANAGEMENT OF MAJOR PELVIC TRAUMA PATIENTS

03
CHAPTER

ACUTE MANAGEMENT OF HEMODYNAMICALLY UNSTABLE PELVIC TRAUMA PATIENTS: TIME FOR A CHANGE?

Multicenter review of recent practice

SYDNEY, AUSTRALIA

D.O. Verbeek, M. Sugrue, Z. Balogh, D. Cass, I. Civil, I. Harris, T. Kossmann S. Leibman, V. Malka, A. Pohl, S. Rao, M. Richardson, M. Schuetz, C. Ursic, V. Wills

Liverpool Hospital, University of New South Wales and Western Sydney, Sydney, Australia

World J Surg 2008;32: 1874-82

2008

ABSTRACT

Background: Hemorrhage-related mortality (HRM) associated with pelvic fractures continues to challenge trauma care. This study describes the management and outcome of hemodynamically unstable patients with a pelvic fracture, with emphasis on primary intervention for hemorrhage control and HRM.

Methods: Blunt trauma patients (ISS ≥16) with a major pelvic fracture (AIS pelvis 3) and hemodynamic instability (admission systolic (SBP) ≤90 mmHg or receiving ≥6 units of blood (PRBC) /24 hours) were included into a 48-month (ending in December 2003) multi-center retrospective study of eleven Level-1 trauma centers. Data are presented as mean ± SD.

Results: A total of 217 patients (mean age 41 ± 19 years, 71% male, ISS 42 ± 16) were studied. The admission SBP was 96 ± 37 mmHg and the Glascow Coma Scale (GCS) 11 ± 5. Patients received 4 ± 2 liters of fluids including 4 ± 4 units of PRBCs in the emergency room (ER). In total, 69 (32%) patients died, among whom the HRM was 19%; 29% of the deaths were due to pelvic bleeding. Altogether, 120 of the 217 (55%) patients underwent focused abdominal sonography for trauma (FAST) or diagnostic peritoneal aspiration (DPA) and diagnostic peritoneal lavage (DPL); 60 of the 217 (28%) patients were found to have pelvic binding in the ER. In all, 53 of 109 (49%) patients had no bleeding noted at laparotomy, 26 of 106 (25%) had no abdominal findings, and 15 of 53 (28%) had had no prior abdominal investigation (FAST/DPL/ computed tomography). Angiography was positive in 48 of 58 (83%) patients. The HRM was highest in patients with laparotomy as the primary intervention (29%) followed by the angiography group (18%), the combined laparotomy/ pelvic fixation group (16%), and the pelvic fixation-only group (10%).

Conclusion: HRM associated with major pelvic trauma is unacceptably high especially in the laparotomy group. Hence, nontherapeutic laparotomy must be avoided, concentrating instead on arresting pelvic hemorrhage. Standards of care must be implemented and abided by.

INTRODUCTION

The early management of hemodynamically unstable patients with a pelvic fracture following blunt trauma poses a significant challenge owing to competing clinical priorities and a reported mortality between 10% to 42% [1-8.] Uncontrolled pelvic bleeding is a contributing factor to mortality in 42% of these cases [3]. To improve the survival of these patients the source of hemorrhage needs to be identified during the early phase of resuscitation to enable rapid control of bleeding [9,10].
Clinical practice guidelines in pelvic trauma have been developed but are not universally accepted or adopted [3-5,7,10-16]. The need for early hemorrhage control was highlighted by two recent articles which advocated pelvic
packing [17,18].

Management of serious pelvic trauma tends to be individualized for major trauma centers and no multicenter analysis of current management have been published. This study undertook an evaluation of individual practice patterns in the early management of hemodynamically unstable patients with a pelvic fracture in 11 major trauma centers in Australia and New Zealand. Specifically, key early management strategies were assessed including abdominal clearance, pelvic stabilization in the emergency department, pelvic angiography and orthopedic pelvic fixation.

MATERIALS AND METHODS

A multicenter retrospective study was undertaken to evaluate trends in the management of patients with hemodynamically unstable pelvic fractures. Patients admitted between January 1, 2000 and December 31, 2003 to 11 major trauma centers in Australia and New Zealand were included in the study. The hospitals in Australia were the Royal North Shore Hospital, Liverpool Hospital, St. George Hospital, and Westmead Hospital, all in Sydney; The Alfred Hospital and Royal Melbourne Hospital in Melbourne; John Hunter Hospital in Newcastle; Royal Perth Hospital in Perth; Royal Adelaide Hospital in Adelaide; and Princess Alexandria Hospital in Brisbane. In New Zealand, the Auckland Hospital in Auckland participated. These hospitals are the principal teaching hospitals of nine universities. At the time of the study none had undergone Royal Australian College of Surgeons (RACS) verification for “Level I” designation (currently three centers have).

Patients were identified from the individual hospital trauma registries. All major blunt trauma patients [Injury Severity Score (ISS) ≥16] with a major pelvic fracture [Abbreviated Injury Score (AIS), pelvis ≥3] and hemodynamic instability were included in the study [19]. Hemodynamic instability was defined as having a systolic blood pressure (SBP) of ≤90 mmHg on admission or receiving at least 6 units of blood within the first 24 hours following admission. Exclusion criteria included age <18 years, the presence of penetrating injuries or isolated acetabular or pubic ramus fractures, interhospital transfers, those deemed dead on arrival, and uncontrollable thoracic hemorrhage.

Data were assembled from the institutional trauma registries, and additional or missing patient data were retrieved by focused chart review. Two patients' records (1.0%) could not be located, and these patients were not included in the study. In one hospital no trauma registry was kept over a period of 18 months, this institution's overall number of blunt trauma admissions covered only a period of 30 months. All sites were visited, and the charts were reviewed by a single investigator (D.V.).

The following variables were collected: age, sex, ISS, Glasgow Coma Scale (GCS), hemodynamic parameters, fluid requirements, temperature on arrival, mechanism of injury, and the results and timing of diagnostic and therapeutic interventions. Hypothermia was defined as a temperature of 35°C or less. Specifically, key management issues relating to abdominal clearance, pelvic stabilization, pelvic angiography, and timing were analyzed.
In the presence of posterior involvement indicative of major ligamentous disruption, fractures were classified as biomechanically unstable pelvic fractures (Young-Burgess classification LCIII, APII, APIII, VS, CM) [6,20,21].
Outcome measures included total units of packed red blood cells (PRBCs) and fresh frozen plasma received in the emergency room (ER) and during the first 24 hours, length of stay in the intensive care unit (LOS ICU), total hospital length of stay (LOS), and in-hospital mortality. The project was approved by the Human Research Ethics Committee of each hospital.

Univariate statistical analysis was performed using the chi-squared test or Fisher's exact test for categorical data and Student's *t*-test for continuous data. A value of $p < 0.05$ was considered significant. Continuous data are presented as the mean ± SD unless otherwise specified. Categorical data are presented as numbers and percentages.

RESULTS

Between January 2000 and December 2003, a total of 11,109 major blunt trauma patients were admitted to 11 trauma centers (mortality 1632/11,109, or 14.7%). Major pelvic fractures occurred in 1050 patients with an associated mortality of 17.0% (179/1050). Of these 1050, 217 patients (20.7%) were hemodynamically unstable and thus eligible for enrolment in this study.

The mean age of the patients was 41 ± 19 years, and 153 of the 217 (70.5%) were male. The mechanism of injury was road trauma in 77.7%, falls in 10.7%, crush injuries in 8.8%, and "other" in 2.8%. Among the road trauma injuries, motor vehicle crashes accounted for 53.7%, pedestrian vehicle accidents 27.9%, and motor bike accidents 18.4%. The mean ISS was 42 ± 16 (range 16–75) with a mean admission GCS 11 ± 5. The mean arrival SBP was 96 ± 37 mmHg (range 0–190 mmHg). The mean arrival pulse rate was 108 ± 29/min (range 45–185/min). Patients received a mean of 4271.1 ± 2428.8 ml of fluids in the ER. The mean SBP on leaving the ER was 111 ± 33 mmHg (range 0–214 mmHg) with a pulse rate of 107 ± 26/min (range 40–193/min). During the first 24 hours, patients received a mean of 15.9 ± 13.2 units of PRBCs, with a mean of 4.1 ± 3.9 units given in the ER. Patients received a mean of 8.3 ± 8.6 units of fresh frozen plasma within 24 hours. The temperature on arrival was recorded in 152 of the 217 (70.0%) patients, and the mean was 35.4 ± 1.3°C. In all, 71 patients (71/152, or 46.7%) were hypothermic.

Biomechanically unstable pelvic fractures were found in 112 of the 217 (51.6%) patients, which includes 3 patients who had had no pelvic imaging reported before urgent laparotomy but who clinically had grossly unstable pelvic fractures.

The achievement of key early management strategies is shown in **Fig. 1**.

A total of 120 of the 217 (55.3%) patients underwent rapid abdominal investigation in the ER, which included focused abdominal sonography for trauma (FAST) in 93 of 120 (77.5%) and diagnostic peritoneal aspiration/diagnostic peritoneal lavage (DPA/DPL) in 27 of 120 (22.5%) patients. No abdominal investigation at any stage (FAST, DPA/DPL, CT) was done in 30 of 120 (25.0%) patients. Noninvasive pelvic stabilization was used in 60 of the 217 (27.6%) patients in the ER, including the use of bed sheets in 53 (24.4%) patients and a variety of pelvic binders in 7 (3.3%). Another 14 (6.5%) patients arrived at the hospital in medical antishock trousers (MAST), and 2 (0.9%) patients had an external fixator applied in the ER.Biomechanically unstable pelvic fractures were stabilized in the ER in 51 of 112 (45.5%) patients.

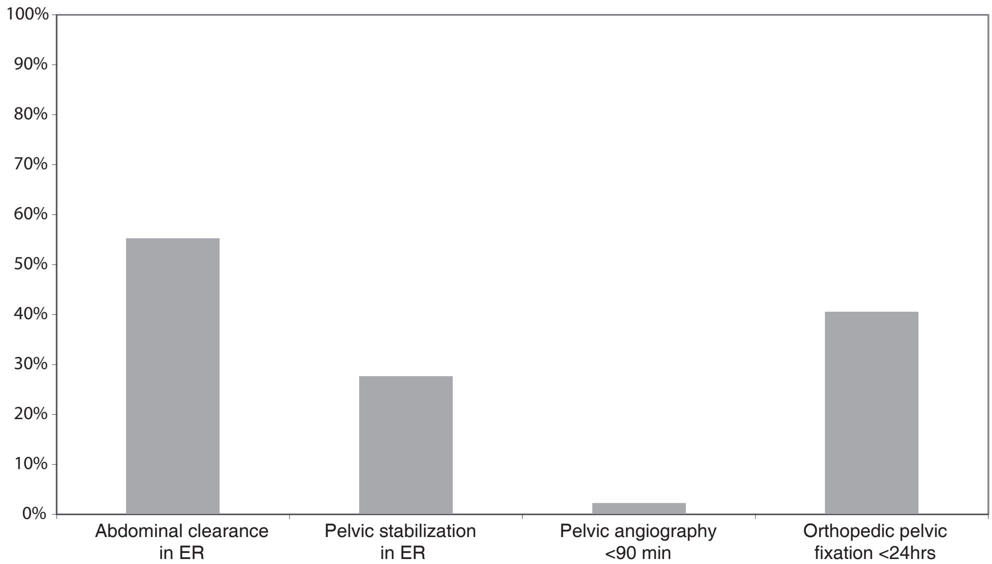


Figure 1. Achievement of key early management strategies (n=217).
ER: emergency room

An overview of the key steps in early management is illustrated in **Fig. 2**.

Pelvic angiography was performed in 58 of the 217 (26.7%) patients and was abnormal in 48 of the 58 (82.8%). Pelvic angiography showed active arterial bleeding in 43 of the 58 (74.1%) patients, and 5 (8.6%) had other signs of vascular damage (pseudoaneurysm, vasospasm). Angio- graphic embolization was successful in 46 of the 48 (95.8%) patients. In two patients embolization failed, with active bleeding on pelvic angiography (both patients died from pelvic hemorrhage). Of the 58 patients, 5 (8.6%) underwent repeat pelvic angiography; two of these five patients (40.0%)) had recurrent active pelvic bleeding, two (40.0%) had negative results, and one (20.0%) had active bleeding noted on previously negative angiography. As the primary treatment modality, 34 of the 217 (15.7%) patients underwent pelvic angiography, 5 (14.7%) within 90 minutes of arrival.

To evaluate the potential for ongoing pelvic hemorrhage following surgery, 24 of the 217 (11.1%) patients under- went pelvic angiography as a secondary treatment modality: 8 after laparotomy, 4 after orthopedic pelvic fixation, and 12 after combined laparotomy and orthopedic pelvic fixation. In all, 23 (95.8%) of these patients had abnormal pelvic angiography, and all underwent angiographic embolization. Orthopedic pelvic fixation within 24 hours of admission was performed in 88 of the 217 (40.6%) patients and in 68 of the 112 (60.7%) patients with biomechanically unstable pelvic fractures.

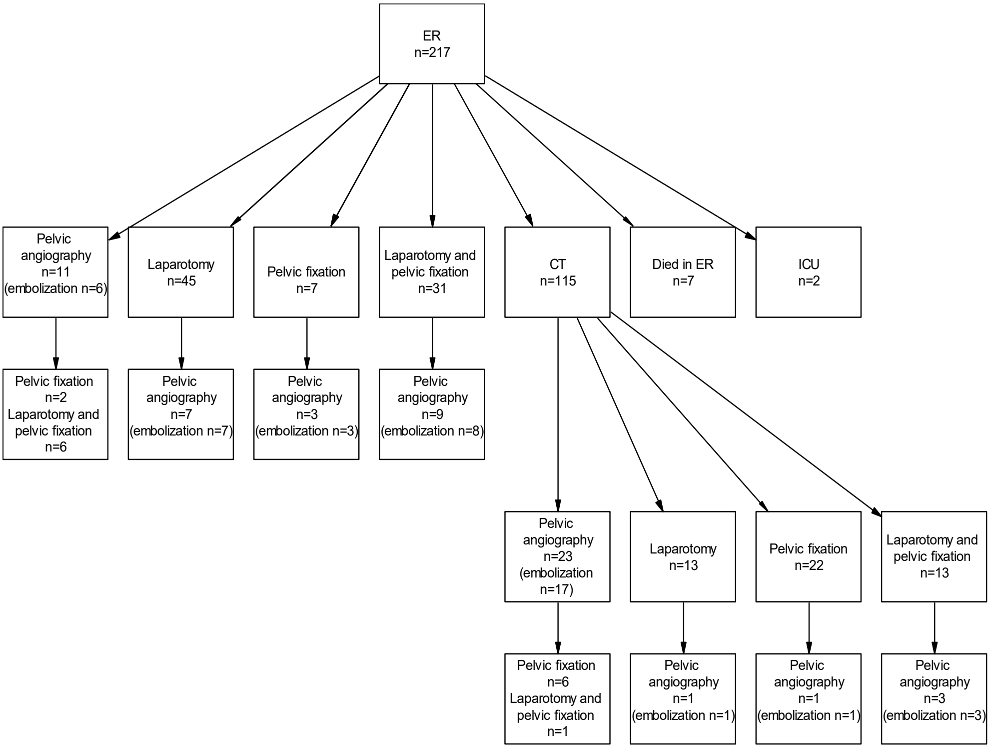


Figure 2. Management of hemodynamically unstable patients with a pelvic fracture. CT: computed tomography; ICU: intensive care unit

As the primary treatment modality, orthopedic pelvic fixation was done in 73 of the 217 (33.6%) patients; and in 44 of the 73 (60.3%) patients it was combined with laparotomy. Fixation techniques included external fixation (62/88, 70.5%), anterior plate (6/88, 6.8%), posterior screws (6/88, 6.8%), a combination of these methods (11/88, 12.5%), and C-clamp (3/87, 3.4%).

Orthopedic pelvic fixation was performed 24 hours after admission in 42 of the 217 (19.4%) patients within a median of 5.0 days (range 1–25 days). After earlier orthopedic fixation, 29 of 42 (69.0%) patients had definitive fixation. Treatment consisted of an anterior plate (13/42, 31.0%), posterior screws (9/42, 21.4%), external fixation (2/42, 4.8%), or a combination of these methods (22/ 42, 52.4%)

Laparotomy was performed on 109 of the 217 (50.2%) patients. Of all patients undergoing laparotomy, 26 of the 109 (23.9%) had no intraabdominal injury noted; abdominal injuries were found at surgery in the remaining patients, as shown in **Table 1**.

Table 1. Findings at abdominal surgery (n=109) (%)

Liver injury	72 (66.1)
Spleen injury	35 (32.1)
Bowel injury	21 (19.3)
Mesenteric injury	20 (18.3)
Urogenital injury	16 (14.7)
Diaphragmatic injury	12 (11.0)
No injury noted	26 (23.9)

In 53 of 109 (48.6%) patients there was no active intraabdominal bleeding at surgery, and 16 of 53 (30.2%) patients had undergone no prior abdominal investigation (FAST, DPA/ DPL, CT). Altogether, 11 of the 53 (20.8%) patients proceeded to pelvic angiography; active bleeding was noted in all 11 of these patients, and all of them underwent pelvic embolization. Among the 102 patients who had undergone laparotomy (with or without pelvic fixation) as the primary treatment modality, 33 (32.4%) had no apparent active intraabdominal bleeding. Abdominal investigations (FAST, DPA/ DPL, CT) were not performed in 16 of 33 (48.5%) of these patients. The median length of hospital stay was 25 days (range 1–630 days), with an ICU stay of 8 days (range 0–46 days). In total, 69 of the 217 patients (31.8%) died in hospital; and among them, 52 (75.4%) died within 24 hours of admission. The overall hemorrhage-related mortality (HRM) rate was 19.4% (42/217). The primary causes of death are listed in **Table 2**. The primary treatment modality and HRM rates are shown in **Table 3**. The HRM rate

Table 2. Primary cause of death (n=69) (%)

Diffuse hemorrhage	22 (31.9)
Pelvic hemorrhage	20 (29.0)
Traumatic Brain Injury	15 (21.7)
Respiratory	5 (7.2)
Multiple organ dysfunction syndrome	3 (4.3)
Sepsis	2 (2.9)
Cardiac arrest	2 (2.9)

Table 3. Primary therapeutic modality (n=217)

Primary intervention	N	ISS	Age	SBP (mmHg)	ER PRBC(U)	24hr PRBC(U)	HRM (%)
Angiography	34	42±16	49±23*	100±39	5±5	19±20	18
Laparotomy	58	45±15	40±20	89±38	4±4	18±12	29*
Pelvic fixation	29	33±11*	42±14	109±33*	3±3	14±9*	10
Laparotomy/ fixation	44	47±15*	36±14	92±35	5±4	22±12	16
No intervention	52	38±16	43±19	97±36	3±4	7±5*	10

ISS: Injury Severity Score; SBP: systolic blood pressure, ER PRBC: emergency room packed red blood cells, HRM: hemorrhage-related mortality. *$p<0.05$

after pelvic angiography was 17.6 (6/34), after laparotomy 29.3% (17/58), after orthopedic pelvic fixation 10.3% (3/29), and after combined laparotomy and orthopaedic fixation 15.9% (7/44).

DISCUSSION

This 4-year multicenter study reports one of the largest series of hemodynamically unstable pelvic fracture patients. It offers an insight in the variety of current practice methods in 11 major trauma centers in Australia and New Zealand. The study population consisted of mainly young male patients following road trauma. Many had extensive multi system injury and head trauma. Although the patient's demographics and mechanism of injury were similar to those in other reports, patients in this study were more severely injured as indicated by a significantly higher ISS (42 versus 27-30) [3,5,6,8,11,20].

The admission SBP and the 24-hour PRBC requirement were used to define hemodynamic instability. In some patient groups, using only the admission SBP to define hemodynamic instability is inadequate. Particularly older patients with hypertension and medicine use and patients who had large prehospitalization fluid transfusions and thereby had a blood pressure >90 mmHg on admission were taken into account by including the PRBC cell requirement. Furthermore, by including the 24-hour PRBC requirement as a criterion, patients who became unstable shortly after admission were also identified. Using both criteria, patients had similar to slightly higher 24-hour PRBC requirements than were seen in other reports (16 vs. 4–19) [3,5,8,11,20]. The role of hypothermia along with acidosis and coagulopathy in aggravating existing hemorrhage in trauma has been long since recognized [22]. Nearly half of the patients who had their temperature taken on arrival at the ER had hypothermia. Fracture patterns indicative of major ligamentous disruption were defined as bio mechanically unstable pelvic fractures. Similar to earlier studies using this definition 50% of patients had an unstable pelvic fracture [6,20].

Current early strategies for managing hemodynamically unstable pelvic fracture patients were suboptimal in this study. During the early stage of resuscitation, all potential sources of bleeding should be rapidly assessed through visual inspection (external and long bones), chest radiography, and rapid abdominal assessment (FAST, DPA/ DPL). The latter is a crucial early management step because a substantial number (31%) of pelvic fracture patients sustain associated intraabdominal injury [23]. A little more than half of the patients had a rapid abdominal investigation (FAST or DPA/DPL) in the ER, and a substantial number had a CT scan to guide further management. Other patients had had no abdominal investigation (FAST, DPA/DPL, CT) at any stage. In hemodynamically unstable patients, a positive test result from the rapid abdominal investigation warrants a decision for laparotomy. These patients should not be transported to the potentially hazardous environment of a CT scan.

Early pelvic stabilization may control bleeding from cancellous bone, venous vessels, and small arteries and may prevent clot dislodgement [13]. In most institutions, orthopedic pelvic fixation requires specialist intervention and transfer to the operating theater. In the ER setting, the fractured pelvis can be rapidly stabilized using a bed sheet wrapped around the pelvis to bridge the time to more definitive operative stabilization. Noninvasive pelvic stabilization was performed in only one-fourth of patients in the ER and for one-half of patients with biomechanically unstable fracture patterns.

Angiographic embolization has become the preferred method to control pelvic arterial hemorrhage [2,8,10,11,24,25]. It has been found to be a safe and effective means of hemorrhage control [24, 26]. In this study, pelvic angiography/embolization, as a primary treatment modality and as an adjunct following surgery, proved to be a valuable tool to control bleeding from pelvic arteries. However, pelvic angiography tended to be performed late, with only 14.7% being performed with 90 minutes of arrival. This suggests the lack of organization of trauma systems given the well-developed state of interventional radiology in Australia and New Zealand. Most (82.8%) of the patients undergoing angiography had abnormal findings indicative of vessel damage. The angiographic active bleeding rate (74.1%) and high success rate of embolization (95.8%) are similar to those in other recent series [11,27-31]. Of all the angiography patients, a small number (3/ 58, 5.2%) had repeat angiography/embolization to control bleeding. Earlier series reported higher rates, 42 of 556 (7.5%), 7 of 55 (12.7%), and 3 of 16 (18.8%), but the number of repeat angiographies were small, and the exact indications for embolization may have varied (e.g., in cases of indirect signs of or actual minor vessel damage) [28,32,33]. Any type of delay to the angiography suite because of prolonged resuscitation or unnecessary interventions may increase mortality [24]. In this study few patients had a pelvic angiography as primary therapeutic modality within 90 minutes of admission.

Although angiographic embolization is the preferred treatment modality for arterial bleeding, orthopedic pelvic fixation can successfully arrest venous and smaller arterial bleeding as well as bleeding from bony surfaces. As it may promote hemodynamic stability, it should be viewed as a resuscitative, not solely a reconstructive, procedure [13,16]. In fact, it should be considered as early as possible in the management of hemodynamically unstable patients with pelvic fracture patterns amenable to fixation. In this study, fewer than half of the patients (more so in those with biomechanically unstable pelvic fractures) underwent some form of orthopedic pelvic fixation within 24 hours of admission, mostly in conjunction with abdominal surgery. Several predictors of pelvic arterial bleeding have been identified in an attempt to differentiate patients who would benefit most from angiographic embolization in contrast to pelvic fixation [20,30,31]. They include age, sex, and initial hemodynamic parameters and fluid response. Furthermore, some recent studies found an association between biomechanically unstable pelvic fractures and pelvic arterial hemorrhage; but most agree that the fracture pattern cannot be used as a sole determinant to guide further management [6,8,20].

Some European studies have promoted early orthopedic fixation and subsequent pelvic packing in case of persistent hemorrhagic shock [7,14,15,34,35]. Pelvic fractures in these countries tend to be fixed at an early stage, sometimes in the ER using an external fixator or C clamp. These trauma surgeons also manage orthopedic trauma, whereas in the Anglo-American system orthopedic surgeons are consulting specialists. This can explain the emphasis on the orthopedic versus the angiographic approach. A single study in the United States of 28 patients evaluated the use of a modified preperitoneal packing technique in the clinical pathway [17].
Preperitoneal packing appeared to be a rapid, effective method for pelvic hemorrhage control, although the mortality rate (25%) remained substantial.
No studies comparing angiographic embolization and pelvic packing have been performed. It seems that both approaches can function well in their own hospital environment. Pelvic packing aimed at arresting venous and small arterial bleeding is an invasive technique that may lead to a lower nonoperative management rate. However, success of angiographic embolization aimed solely at arresting arterial bleeding depends on the rapid availability of experienced intervention radiologists (not available in all hospitals) [35]. Pelvic packing has the potential benefit of not requiring interventional radiology.

Laparotomy undertaken in 79 of 109 (72.4%) patients did not reveal significant bleeding. This may delay definitive control of hemorrhage and may add to com- plications, especially as 23.9% of the patients had no intraabdominal injury. Furthermore, no active intraabdominal bleeding was found in one-third of patients who underwent laparotomy (with or without pelvic fixation) as the primary treatment modality. One-half of these patients had had no prior abdominal investigation (FAST, DPL/ DPA, CT).
In a retrospective study, the decision-making process was difficult to determine, but errors in judgment were common [36]. An earlier study reports of similar rates of active intra-abdominal bleeding at laparotomy (39/86 (45%)) in hemodynamically unstable pelvic fracture patients [8]. A 50% negative laparotomy rate prior to pelvic angiography was found in a recent series of hemodynamically unstable pelvic fracture patients treated with early angiography and vasopressor administration [28]. These findings stress the importance of rapid abdominal investigation. They also highlight the limitation (i.e., false- positive rate), as 70% of patients with no active intraabdominal bleeding at surgery did undergo abdominal investigation. Possibly, some patients had a limited amount of intraabdominal blood at laparotomy but

the active bleeding had stopped spontaneously. Only rarely does profuse retroperitoneal bleeding reach the intraperitoneal cavity [35]. Other patients may have had a negative result but were subjected to laparotomy based on clinical grounds without a repeat investigation. Nevertheless, when rapid abdominal investigation is positive in the presence of continuing hemodynamic instability, immediate laparotomy remains warranted [10].

In the current study, patients were hospitalized for approximately a month, with 1 week in the ICU. The overall mortality was slightly higher than the average mortality reported in the literature (32% vs. 11–36%); but as discussed, the ISS in this study population was significantly higher than in other reports [3,5,6,8,11,20]. Even more striking was the high overall HRM (19% versus 7-11%) [3,11]. HRM was highest in the group with laparotomy as the primary treatment modality, followed (although statistically not significant) by those in whom angiography, combined laparotomy-pelvic fixation, or pelvic fixation was the primary treatment. The differences in HRM can be explained partly by the differences in ISS, age, and hemodynamic parameters. The primary laparotomy group includes exsanguinating patients who had minimal or no response to resuscitative measures and went straight to the operating theater without any diagnostic procedures. Furthermore, the high rate of patients without intraabdominal bleeding noted at surgery may have contributed to the unacceptably high HRM in the primary laparotomy group. Overall, hypothermia on admission may also have contributed to the high HRM, especially in the “diffuse hemorrhage” subgroup.

Clinical practice guidelines have been developed to aid in the management of multiple trauma conditions [37]. A variety of guidelines for the management of hemodynamically unstable pelvic fracture patients have been developed [3-5,7,10-16], and improved outcomes have been reported after the introduction of such clinical practice guidelines [9,11,14]. A large 22-year retrospective study of 1899 pelvic fracture patients reported a decreasing mortality rate over the years [14]. Although this trend might be largely attributed to overall advances in care of the critically injured, a significant factor may be the introduction of an aggressive treatment protocol based on early operative intervention to control bleeding. This algorithm promoted timely orthopedic pelvic stabilization (pelvic clamp) followed by surgical hemorrhage control (abdominal packing). Ongoing hemorrhage was addressed by pelvic angiography/ embolization as a secondary procedure.

The introduction of a clinical pathway with a more prominent position for pelvic angiography/ embolization to control arterial bleeding led to a significant decrease in mortality in a retrospective study of 216 patients with hemodynamically unstable pelvic fractures [11]. The 2002 Liverpool evidence-based guidelines on this issue recommend the use of early angiography in case of persistent pelvic bleeding after (non-invasive) stabilization of the pelvic ring [10]. The 24-hour transfusion requirement and the mortality rate were reduced significantly after introduction of the Liverpool guidelines, as reported in a 31- patient prospective study with a historical control group [9].

CONCLUSION

The HRM of major pelvic trauma in this study is unacceptably high, especially in the primary laparotomy group. Lack of guidelines led to a variable approach to management and a high negative laparotomy rate. Furthermore, the provision of care by different disciplines in the emergency department, operating theater, and ICU may have led to fragmented care and poorer outcome.

Although all trauma centers have intervention radiology available, the considerable variation in the management of this high-risk cohort may be due to differences in institutions' systems to provide timely angioembolization and access to orthopedic surgery. Therefore, it is crucial for guidelines to be tailored to each institution's resources.
After excluding all other potential sources of bleeding, the abdomen should be promptly assessed (FAST, DPA/ DPL). A positive abdominal assessment warrants laparotomy. The pelvis should be rapidly stabilized using a bed sheet or pelvic binder. In the case of persistent hemodynamic instability and a negative abdominal assessment, pelvic bleeding should be addressed. Systems should be in place to provide rapid hemorrhage control (within 90 minutes) with pelvic packing or pelvic angioembolization. For persistent bleeding, angioembolization is preferred. Orthopedic pelvic fixation should be done as soon as permissible, preferably within 24 hours.

Clinical practice guidelines for the management of hemodynamically unstable pelvic fracture patients need to be evaluated and implemented. The prime aim of treatment in this subgroup of pelvic trauma patients should be to arrest pelvic hemorrhage and avoid inappropriate procedures, particularly nontherapeutic laparotomy. The latter could have been averted by routine use of FAST and/or DPA. Practice guidelines could be used as a framework and be adapted by institutions to meet their individual circum- stances while providing optimal care.

ACKNOWLEDGEMENTS

We thank the data managers and nursing staff from the Trauma, Orthopedics, and Accident and Emergency departments of all participating hospitals.

REFERENCES

1. McMurtry R, Walton D, Dickinson D, et al. Pelvic disruption in the polytraumatized patient: a management protocol. Clin Orthop Relat Res. 1980;151:22-30.
2. Panetta T, Scalfani S, Goldstein AS, et al. Percutaneous transcatheter embolization for massive bleeding from pelvic fractures. J Trauma. 1985;25:1021-9.
3. Moreno C, Moore EE, Rosenberger A, et al. Hemorrhage associated with major pelvic fracture: a multispecialty challenge. J Trauma. 1986;26:987-94.
4. Flint L, Babikian G, Anders M, et al. Definitive control of mortality from severe pelvic fracture. Ann Surg. 1990;211:703-06.
5. Gruen GS, Leit ME, Gruen RJ, et al. The acute management of hemodynamically unstable multiple trauma patients with pelvic ring fractures. J Trauma. 1994;36:706-11.
6. Hamill J, Holden A, Paice R, et al. Pelvic fracture pattern predicts pelvic arterial haemorrhage. Aust N Z J Surg. 2000;70:338-43.
7. Ertel W, Keel M, Eid K, et al. Control of severe hemorrhage using C-clamp and pelvic packing in multiply injured patients with pelvic ring disruption. J Orthop Trauma. 2001;15:468-74.
8. Eastridge BJ, Starr A, Minei JP, et al. The importance of fracture pattern in guiding therapeutic decision-making in patients with hemorrhagic shock and pelvic ring disruptions. J Trauma. 2002;53:446-50, 450-1.
9. Balogh Z, Caldwell E, Heetveld M, et al. Institutional practice guidelines on management of pelvic fracture-related hemodynamic instability: do they make a difference? J Trauma. 2005;58:778-82.
10. Heetveld MJ, Harris I, Schlaphoff G, et al. Guidelines for the management of haemodynamically unstable pelvic fracture patients. Aust N Z J Surg. 2004;74:520-29.
11. Biffl WL, Smith WR, Moore EE, et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg. 2001;233:843-50.
12. Burgess AR, Eastridge BJ, Young JWR, et al. Pelvic ring disruption: Effective classification system and treatment protocols. J Trauma. 1990;30:848-56.
13. EAST Trauma Practice Guidelines. Available at: http://www.east.org/tpg.html Accessed October 10, 2006.
14. Pohlemann T, Bosch U, Gänsslen A, et al. The Hannover experience in management of pelvic fractures. Clin Orthop Relat Res. 1994;305:69-80.
15. Van Vugt AB, van Kampen A. An unstable pelvic ring: the killing fracture. J Bone Joint Surg (Br). 2006;88:427-433.
16. Riemer BL, Butterfield SL, Diamond DL, et al. Acute mortality associated with injuries to the pelvic ring: The role of early patient mobilization and external fixation. J Trauma. 1993;35:671-75.
17. Cothren CC, Osborn PM, Moore EE, et al. Preperitoneal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma. 2007; 62:834-842.
18. Tötterman A, Madsen JE, Skaga NO, et al. Extraperitoneal pelvic packing: a salvage procedure to control massive traumatic pelvic hemorrhage. J Trauma. 2007; 62:843-852.
19. Baker SP, O'Neill B, Haddon W Jr, et al. The injury severity score: a method for describing patients with multiple injuries and evaluating emergency care. J Trauma. 1974;14:187-96.
20. Sarin EL, Moore JB, Moore EE, et al. Pelvic fracture pattern does not always predict the need for urgent embolization. J Trauma. 2005;58:973-77.
21. Burgess AR, Tile M. Fractures of the pelvis. In: Rockwood C, Green D, eds. Fractures in Adults. Philadelphia, PA: JB Lippincott; 1991: 1399-442.
22. Patt A, McCroskey BL, Moore EE. Hypothermia induced coagulopathy. Surg Clin North Am. 1988; 68:775-85.

23. Demetriades D, Karaiskakis M, Toutouzas K, et al. Pelvic fractures : epidemiology and predictors of associated abdominal injuries and outcomes. J Am Coll Surg. 2002;195:1-10.
24. Agolini SF, Shah K, Jaffe J, et al. Arterial embolization is a rapid and effective technique for controlling pelvic fracture haemorrhage. J Trauma. 1997;43:395-99.
25. Velmahos GC, Chahwan S, Falabella A, et el. Angiographic embolization for intraperitoneal and retroperitoneal injuries. World J Surg. 2000;24:539-45.
26. Velmahos GC, Konstantinos GT, Vassiliu P, et al. A prospective study on the safety and efficacy of angiographic embolization for pelvic and visceral injuries. J Trauma. 2002;52:303-08.
27. Cook RE, Keating JF, Gillespie I. The role of angiography in the management of haemorrhage from major fractures of the pelvis. J Bone Joint Surg (Br). 2002;84: 178-82.
28. Fangio P, Asehnoune K, Edouard A, et el. Early embolization and vasopressor administration for management of life-threatening hemorrhage from pelvic fracture. J Trauma. 2005;58:978-84.
29. Hagiwara A, Minakawa K, Fukushima H, et al. Predictors of death in patients with life-threatening pelvic hemorrhage after successful transcatheter arterial embolization. J Trauma. 2003;55:696-703.
30. Kimbrell BJ, Velmahos GC, Chan LS, et al. Angiographic embolization for pelvic fractures in older patients. Arch Surg. 2004;139:728-33.
31. Miller PR, Moore PS, Mansell E, et al. External fixation or arteriogram in bleeding pelvic fracture: initial therapy guided by markers of arterial hemorrhage. J Trauma. 2003; 54:437-43.
32. Gourlay D, Hoffer E, Routt M, et al. Pelvic angiography for recurrent traumatic pelvic arterial hemorrhage. J Trauma. 2005;59:1168-74.
33. Shapiro M, McDonald A, Knight D, et al. The role of repeat angiography in the management of pelvic fractures. J Trauma. 2005;58:227-31.
34. Gänsslen A, Giannoudis P, Pape HS. Hemorrhage in pelvic fracture: who needs angiography? Curr Opin Crit Care. 2003;9:515-23.
35. Ruchholtz S, Waydhas C, Lewan U, et al. Free abdominal fluid on ultrasound in unstable pelvic ring fracture: is laparotomy always necessary? J Trauma. 2004; 57: 278-86.
36. Sugrue M, Caldwell E, D'Amours S, et al. Time for a change in injury and trauma care delivery; a trauma death review analysis. ANZ J Surg.in press.
35. Rhodes M. Practice management guidelines for trauma care: presidential address, seventh scientific assembly of the eastern association for the surgery of trauma. J Trauma. 1994;37:635-44.

04
CHAPTER

PREDICTING THE NEED FOR ABDOMINAL HEMORRHAGE ONTROL IN MAJOR PELVIC FRACTURE PATIENTS

The importance of quantifying the amount of free fluid

AMSTERDAM, THE NETHERLANDS

D.O. Verbeek,
IJ.A.J. Zijlstra,
C. van der Leij,
K.J. Ponsen,
O.M. van Delden,
J.C. Goslings

Academic Medical Center
University of Amsterdam
Amsterdam,
the Netherlands

J Trauma Acute
Care Surg 2014;
76:1259-63

2014

ABSTRACT

Background: In our institution the computed tomographic (CT) scan has largely replaced the ultrasound for the rapid detection of intra-peritoneal free fluid (FF) and abdominal injuries in severely injured patients.
We hypothesized that in major pelvic fracture patients quantifying the size of FF on CT improves the predictive value for the need for abdominal hemorrhage control (AHC).

Methods: The CT scans of major pelvic fracture (pelvic ring disruption) patients (January 1 2004 - June 31 2012) were reviewed for the presence of FF (small, moderate or large amount) and abdominal injuries. AHC was defined as requiring a surgical intervention for active abdominal bleeding or angiographic embolization for an abdominal arterial injury.
Positive and negative predictive values (PPV and NPV) (95%CI) were calculated for all patients and in a subgroup of patients with a high-risk for significant hemorrhage (BD ≥ 6 mEq/L).

Results: Overall, 160 patients were included in the study. Of 62 FF patients, 26 required AHC (PPV 42% (30-55)). Of 98 patients without FF, none required AHC (NPV 100% (95-100)). For a moderate-large amount of FF the PPV and NPV in all patients were 81% (60-93) and 96% (91-99).
In the subgroup of 49 high-risk patients (31%), 17 of 26 FF patients required AHC (PPV 65% (44-82)) and none of 23 patients without FF required AHC (NPV 100% (82-100)). For a moderate-large amount the PPV and NPV in high–risk patients were 93% (64-100) and 89% (72-96), respectively.

Conclusion: In major pelvic fracture patients, the predictive value of FF on CT for the need for abdominal hemorrhage control is closely related to the amount present. A moderate-large amount of FF is highly predictive for the presence of abdominal bleeding that requires hemorrhage control.

INTRODUCTION

The Computed Tomographic (CT) scan is increasingly used for the detection of traumatic injuries in the chest, abdomen and pelvis. As such it has become an essential diagnostic tool in the management of trauma
patients [1-3].
Traditionally, Focused Assessment with Sonography for Trauma (FAST) has been the preferred modality for initial abdominal screening of trauma patients. Similar to FAST, the CT scan can accurately detect intra-abdominal free fluid (FF) but it can also identify the potentially injured organ as well as the presence of active arterial bleeding (or contrast extravasation). In major pelvic fracture patients, accurate abdominal assessment is critical considering the high-risk (HR) for an abdominal injury (up to 40%) [4-6]. In pelvic fracture patients with major hemorrhage, abdominal as well as extra-abdominal (pelvic, thoracic and extremity) injuries are potential sources of significant bleeding. In these critically injured patients, rapid detection of the primary source of bleeding is crucial to allow timely hemorrhage control and improve patient outcome [7-9].

In 2004 a multi-detector CT scanner was placed in our institution's trauma resuscitation room [10]. In recent years, this modality has largely replaced FAST for the rapid detection of FF and abdominal injuries and for directing early management of severely injured patients. In this study, we examined the association between FF on CT and the presence of abdominal bleeding that requires hemorrhage control in patients with a major pelvic fracture.

We hypothesized that in major pelvic fracture patients quantifying the size of FF on CT improves the predictive value for the need for abdominal hemorrhage control.

PATIENTS AND METHODS

All adult patients with a major pelvic fracture admitted to the trauma resuscitation room of our Level 1 trauma center from January 1 2004 to June 31 2012 were identified from our prospective trauma registry and the hospital's DRG International Classification of Diseases - 9th Rev. database. Patients who had an intravenous contrast-enhanced abdominopelvic CT scan were considered for inclusion. A major pelvic fracture was defined as a disruption of the pelvic ring in (at least) two places. Patients with a single break of the pelvic ring (i.e. single acetabular, iliac wing or pubic rami fractures), transfer patients and patients declared dead on arrival were excluded from analysis. Medical records were reviewed for age, gender, mechanism of injury, injury severity score (ISS), systolic blood pressure and base deficit on arrival, packed red blood cell transfusion in 24 hours of arrival and (hospital and hemorrhage related) mortality. Pelvic fractures were classified using the Young and Burgess classification; major ligamentous disruption was defined as antero-posterior type II and III, lateral compression type III, vertical shear and combined mechanism[11-13]. Operative and radiology (angiography) reports were examined for the presence of abdominal (arterial) injuries and any surgical or radiological interventions performed for hemorrhage control.

For the purpose of the study, all CT scans were reviewed in consensus by two senior radiology residents who were blinded for the clinical course and findings at laparotomy. CT scans were examined for the presence of FF and abdominal (liver, spleen, kidney and/or bowel/mesentery) injuries.
FF was recorded as present or absent for the following abdominal regions; left and right upper quadrant (peri-splenic, peri-hepatic and peri-colic gutters) and pelvis or diffuse in the abdominal cavity. A small amount of FF was defined as present in one region, a moderate amount in two regions and a large amount in three abdominal regions or diffuse in the abdominal cavity.
Solid organ injuries were graded according to the American Association for the Surgery of Trauma organ injury scale (OIS) [14].

Patient management

Initial patient assessment followed our institutional protocol and Advanced Trauma Life Support (ATLS) principles. According to the local imaging protocol, all high-energy trauma patients receive a chest and pelvic radiography within 5-10 minutes of arrival. Major pelvic fracture patients also have an abdominopelvic intravenous contrast enhanced computed tomography (CT) scan. The location of the multi-slice CT scanner (SOMATOM Sensation 4 and 64 (from 2008); Siemens Medical Systems, Erlangen, Germany) in the trauma resuscitation room allows us to safely perform a rapid CT scan without moving the patient from the table or interrupting resuscitation, as described elsewhere [10]. Patients with refractory hemorrhagic shock despite adequate fluid resuscitation (ATLS "non-responders") did not have a CT scan but underwent a FAST. Diagnostic peritoneal lavage was not used for initial evaluation of trauma patients in our institution.

Further management was at the discretion of the attending trauma surgeon in conjunction with the (interventional) radiologist who is available on a 24-hour basis. In general, patients with abdominal (solid organ) injuries receive non-operative management in the absence of clinical signs of ongoing bleeding (stable vital signs without the need for continuing transfusion) regardless of the amount of FF present. Patients with clinical signs of ongoing bleeding (unstable vital signs and a continuing transfusion requirement) receive surgical and/or radiological hemorrhage control (in the presence of CT contrast extravasation). Patients with refractory hemorrhagic shock (ATLS "non-responders") have no CT scan but receive an immediate laparotomy if FF is detected on FAST or pelvic hemorrhage control in the absence of FF. Patients with a pelvic blush on CT and signs of ongoing bleeding generally receive pelvic angiographic embolization as primary intervention, rarely (primary) extra-abdominal pelvic packing is performed in our institution.

Definitions

The need for abdominal hemorrhage control was defined as requiring a surgical intervention for active abdominal bleeding or angiographic embolization for an abdominal arterial injury. The need for extra-abdominal (pelvic, thoracic or extremity) hemorrhage control was defined as requiring a surgical intervention for active extra-abdominal bleeding or angiographic embolization for an extra-abdominal arterial injury.
Patients with a high-risk (HR) for significant hemorrhage (high transfusion requirement) were defined as having a BD ≥ 6 mEq/L on arrival [15-17].

Statistical analysis

The association between FF on CT and the need for abdominal hemorrhage control in all patients as well as in the subgroup of HR patients was examined by constructing contingency tables. The positive and negative predictive values (PPV and NPV) with 95% confidence intervals (CI) were calculated for patients with any FF and in patients with a moderate-large amount of FF.

Continuous variables are presented as mean values with standard deviations (SD) and compared with the independent t-test or as median values with interquartile ranges (IQR) and compared using the Mann-Whitney U test, depending on data distribution. Categorical values were calculated as percentage of frequency of occurrence. Discrete variables were compared using Fisher's exact analyses. Statistical significance was declared at the 0.05 level. All management and statistical analysis were performed using SPSS version 20.0.0 software (IBM, Armonk, NY).

RESULTS

A total of 172 patients with a major pelvic fracture were identified. Of those 12 patients (7%) were excluded from analysis; 6 patients did not have a complete intravenous contrast enhanced abdominopelvic CT scan or were excluded due to the non-diagnostic quality of the images (none required hemorrhage control), 3 patients had an incomplete medical chart and 3 patients were unable to have a CT scan due to refractory hemorrhagic shock (all required hemorrhage control). The remaining 160 patients with a CT scan were included in the study.

Sixty-two patients had FF (39%) and 98 (61%) had no FF (**Table 1**).

Table 1. Patient characteristics

		FF		
	All patients n=160	**Present n=62**	**Absent n=98**	**P value**
Age, mean (SD) y	40 (19)	38 (19)	41 (18)	0.31
Gender, male, n (%)	122 (76)	44 (71)	78 (80)	0.35
Mechanism of injury, MVC,n (%)	36 (23)	20 (32)	16 (16)	*0.02*
Injury Severity Score, mean (SD)	27 (14)	32 (15)	24 (12)	*<0.001*
Type of fracture, MLD, n (%)	56 (35)	20 (32)	36 (37)	0.34
SBP*, mean (SD), mmHg	119 (34)	108 (34)	126 (30)	*<0.001*
Base deficit, median (IQR),mEq/L	4 (5)	4 (5)	3 (4)	*<0.001*
PRBC in 24 hrs, median (IQR), U	3 (11)	5 (17)	2 (8)	*<0.001*
Any PRBC, n (%)	111 (69)	49 (79)	62 (63)	*0.03*
Hemorrhage control, overall, n (%)	61 (38)	38 (61)	23 (24)	*<0.001*
Abdominal, n (%)	26 (16)	26 (42)	0 (0)	*<0.001*
Extra-abdominal**, n (%)	38 (24)	17 (27)	21 (21)	*0.18*
Hospital mortality, overall, n (%)	19 (12)	14 (23)	5 (5)	*<0.001*
Hemorrhage related, n (%)	9 (6)	7 (11)	2 (2)	*0.02*

MLD: major ligamentous disruption; MVC: motor vehicle collision; SBP: systolic blood pressure. PRBC: packed red blood cell. * in 153 patients. ** Thoracic, pelvic and extremity. Italics indicate statistical significance.

Between groups the age (p=0.31), gender (p=0.35) and type of fracture (p=0.34) were equally distributed. More patients with FF had a motor vehicle accident (p=0.02) and FF patients had a significantly higher ISS (p<0.001), lower systolic blood pressure on arrival (p<0.001), higher base deficit on arrival (p<0.001) as well as a larger 24-hour packed red blood cells requirement (p<0.001) and any packed red blood cell requirement (p=0.03). The need for hemorrhage control overall and for abdominal bleeding specifically was significantly higher in FF patients (p<0.001 and p<0.001) but the need for hemorrhage control for extra-abdominal bleeding was equal between groups (p=0.18). Furthermore, the hospital as well as the hemorrhage related mortality rate in FF patients was significantly higher (p<0.001 and 0.02).

Abdominal injuries

One or multiple abdominal injuries were found in 61 patients (38%). In total, 29 liver injuries (14 grade 1-3 and 15 grade 4-6), 24 splenic injuries (14 grade 1-3 and 10 grade 4-5), 22 renal injuries (18 grade 1-3 and 4 grade 4-5) and 6 bowel/mesenteric injuries were detected. Twenty-four of these injuries were associated with contrast extravasation on CT. Of 62 patients with FF, 44 had an abdominal injury (71%) and 18 patients (29% of FF patients or 11% of all patients) had FF without an abdominal injury.

Hemorrhage control

A total of 61 patients (38%) required (surgical or radiological) hemorrhage control for abdominal or extra-abdominal bleeding.
Hemorrhage control for abdominal bleeding (from one or multiple injuries) was required in 26 patients (16%). Surgical hemorrhage control was performed for 8 liver injuries (local hemostatic measures or packing), 8 splenic injuries (5 local hemostasic measures or packing and 3 splenectomies) and 8 bowel/mesenteric injuries (2 resection, 6 primary repair or suture ligation). Intra-abdominal pelvic packing was performed for 3 pelvic hematomas that had ruptured into the peritoneal cavity. Radiological hemorrhage control for abdominal bleeding was performed for 10 splenic injuries, 1 liver injury, 2 renal injuries and 1 injury of a branch of the mesenteric artery.

Hemorrhage control for extra-abdominal bleeding (from one or multiple injuries) was required in 38 patients (24%) (5 also had abdominal bleeding). Radiological hemorrhage control for pelvic bleeding was required for 32 pelvic arterial injuries and radiological or surgical hemorrhage control was required for 5 thoracic and 2 major extremity injuries (one of these patients also had a pelvic arterial injury).

FF and the need for abdominal hemorrhage control in all patients

The association between FF and the need for abdominal hemorrhage control is presented in **Table 2**.

Table 2. Association between FF on CT and the need for abdominal hemorrhage control in all patients (n=160)

		Abdominal hemorrhage control		
		Yes	**No**	
FF	Present	26	36	62
	Absent	0	98	98
		26	134	160

Of 62 patients with FF, abdominal hemorrhage control was required in 26 patients (16 large, 5 moderate, 5 small amount) (PPV, 42%; 95% CI, 30Y55%). Of the remaining 36 FF patients (3 large, 2 moderate, and 31 small amount), 23 patients had abdominal injuries that were treated non- operatively and 13 patients had no abdominal injuries. Of these 36 FF patients, 13 (36%) without abdominal hemorrhage control did have extra-abdominal hemorrhage control, 9 patients for pelvic bleeding, 3 patients for thoracic injuries, and 1 for a major extremity injury. Of 98 patients without FF, no patients required hemorrhage control (NPV, 100%; 95% CI, 95-100%). For a moderate-to-large amount of FF, the PPV and NPV for the need for abdominal hemorrhage control were 81% (95% CI, 60-93%) and 96% (95% CI, 91-99%), respectively.

FF and the need for abdominal hemorrhage control in high-risk patients

A total of 49 major pelvic fracture patients (31%) had an HR for significant hemorrhage. Compared with non-HR patients, HR patients had a similar mean (SD) age of 41 (17) years versus 40 (19) years ($p = 0.79$). Furthermore, HR patients had a significantly higher mean (SD) ISS of 37 (16) versus 23 (10) ($p < 0.001$), and they had a significantly worse hemodynamic status on arrival as expressed by a mean (SD) systolic blood pressure of 108 (42) mm Hg versus 124 (26) mm Hg ($p = 0.03$) and a median base deficit of 9 mEq/L (IQR, 5 mEq/L) versus 3 mEq/L (IQR, 3 mEq/L) ($p < 0.001$). HR patients also had a significantly higher median packed red blood cell requirement in 24 hours of 12 U (IQR, 21 U) versus 2 U (IQR, 4 U) ($p < 0.001$) as well as any packed red blood cell required in 45 (92%) versus 66 (60%) ($p <0.001$) non-HR patients. Lastly, the overall hospital mortality and the hemorrhage-related mortality were significantly higher in HR patients (15 [31%] vs. 4 [4%] [$p < 0.001$] and 8 [16%] vs. 1 [1%], respectively [$p < 0.001$]).

The association between FF and the need for abdominal hemorrhage control in patients with an HR for significant hemorrhage is presented in **Table 3**.

Table 3. Association between FF on CT and the need for abdominal hemorrhage control in patients with a HR for significant hemorrhage (n=49)

		Abdominal hemorrhage control		
		Yes	**No**	
FF	Present	17	9	26
	Absent	0	23	23
		17	32	49

Of 26 HR patients with FF, abdominal hemorrhage control was required in 17 patients (10 large, 3 moderate, and 4 small amount) (PPV, 65%; 95% CI, 44-82%). Of the remaining nine FF patients (one large, and eight small amount), seven patients had nonoperative management for solid organ injuries, and two had no abdominal injuries. Seven of these nine FF patients (78%) without abdominal hemorrhage control did have extra-abdominal hemorrhage control, four patients for pelvic bleeding, two patients for thoracic injuries, and one for a major extremity injury.

Of 23 patients without FF, no patients required abdominal hemorrhage control (NPV, 100%; 95% CI, 82-100%). For a moderate-to-large amount of FF, the PPV and NPV for the need for abdominal hemorrhage control were 93% (95% CI, 64-100%) and 89% (95% CI, 72-96%), respectively.

DISCUSSION

In this study, we found that in major pelvic fracture patients the presence of FF on CT is not reliably associated with the need for abdominal hemorrhage control. Many FF patients had abdominal (solid organ) injuries that were treated non-operatively. Of note is also the considerable number of patients that had FF without abdominal injuries (29% of FF patients and 11% of all patients). To our knowledge, the association between FF and the presence of an abdominal injury in pelvic fracture patients has not been reported before. Nevertheless, the significant rate of FF without abdominal injuries in our study was considerably higher than earlier reported in blunt abdominal trauma patients (3%) [18]. This finding is most likely attributable to factors directly related to the pelvic fracture itself. Major pelvic fractures are commonly associated with a large pelvic hematoma which may rupture or cause seepage of blood into the peritoneal cavity. These pelvic-fracture-related factors generally caused a small amount of FF to accumulate intra-abdominally.

While the presence of any amount of FF had limited predictive value (PPV 42%), the presence of a moderate-large amount of FF had a considerably higher predictive value for the need for abdominal hemorrhage control (PPV 81%). The findings in our current study illustrate the importance of quantifying the amount of FF found on imaging in major pelvic fracture patients. Measuring the size of FF can be particularly useful in pelvic fracture patients with a high-risk for significant hemorrhage. In these severely injured patients, accurate assessment of the abdomen for a potential source of hemorrhage is even more critical as it determines the need for primary abdominal versus pelvic hemorrhage control [5-9]. Similar to our findings in the overall population, in HR patients a moderate-large amount of FF had a considerably higher predictive value for the need for abdominal hemorrhage control than any FF (93% *vs* 65%).

Based on our data, we found that in patients with a small amount or no FF, an abdominal source of hemorrhage is highly unlikely (NPV 96% in all patients and 89% in HR patients). Therefore, in the presence of hemorrhagic shock a primary pelvic source of bleeding should be strongly considered.
Clearly, performing a CT scan in HR patients is potentially hazardous. This is particularly pertinent if patients have to be transported to the radiology department and their definitive treatment is further delayed. These risks have to be carefully weighed, and in some patients, further management may have to be guided by the FAST examination.

Only one earlier study examined the association between different sizes of FF and the need for a therapeutic intervention (laparotomy) in pelvic fracture patients [19]. In a patient population with comparable patient characteristics and interventions the authors found a similar FF incidence of 37% (using a slightly different measure for quantifying the amount). In 16% of all patients a laparotomy for abdominal bleeding was needed with a PPV of 39% and NPV of 98% for any amount of FF. The PPV and NPV for a large amount of FF in all patients were respectively 62% and 92% and in hypotensive patients 70% and 86%. The presence or absence of an abdominal injury in relation to FF and the need for angiographic embolization for abdominal (solid organ) injuries were not addressed in this study.

Limitations

The limitations of this study include those inherent to its retrospective design and data collection. We were unable to collect more detailed information concerning resuscitation and fluid requirement in the trauma resuscitation room. By using a widely accepted measure for hemorrhagic shock (base deficit) available immediately on arrival, we were able to identify a HR subgroup of patients with significant hemorrhage. Also, during the study our 4-slice CT scanner was upgraded to a 64-slice scanner. To an extent this may have influenced the predictive values found as more contemporary scanners are potentially able to detect smaller amounts of FF. Lastly, the decision to proceed for hemorrhage control was not predefined in a set protocol but was at the discretion of the attending trauma surgeon. Nevertheless, we feel that our clinical practice is comparable to that in other hospitals. Specific indications for performing a hemostatic intervention may differ between institutions depending on local resources and protocols. However, many hospitals have adopted a strategy of non-operative management and angiographic embolization for selected abdominal injuries that is similar to ours.

CONCLUSION

In major pelvic fracture patients, the predictive value of free fluid on CT for the need for abdominal hemorrhage control is closely related to the amount present. A moderate-large amount of FF is highly predictive for the presence of abdominal bleeding that requires hemorrhage control. Of note is the considerable number of patients with (a small amount of) FF caused by the pelvic fracture itself instead of by an abdominal injury.

REFERENCES

1. Huber-Wagner S, Lefering R, Qvick LM, Korner M, Kay MV, Pfeifer KJ, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet 2009;373:1455-61.
2. Chan O. Primary computed tomography survey for major trauma. Br J Surg 2009;96:1377-8.
3. Wurmb TE, Fruhwald P, Hopfner W, Keil T, Kredel M, Brederlau J, et al. Whole-body multislice computed tomography as the first line diagnostic tool in patients with multiple injuries: the focus on time. J Trauma 2009;66:658-65.
4. Balogh Z, King KL, Mackay P, McDougall D, Mackenzie S, Evans JA, et al. The epidemiology of pelvic ring fractures: a population-based study. J Trauma 2007;63:1066-73; discussion 72-3.
5. Verbeek D, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
6. Biffl WL, Smith WR, Moore EE, Gonzalez RJ, Morgan SJ, Hennessey T, et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 2001;233:843-50.
7. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.
8. Davis JW, Moore FA, McIntyre RC, Jr., Cocanour CS, Moore EE, West MA. Western trauma association critical decisions in trauma: management of pelvic fracture with hemodynamic instability. J Trauma 2008;65:1012-5.
9. Heetveld MJ, Harris I, Schlaphoff G, Balogh Z, D'Amours SK, Sugrue M. Hemodynamically unstable pelvic fractures: recent care and new guidelines. World J Surg 2004;28:904-9.
10. Fung Kon Jin PH, Goslings JC, Ponsen KJ, van Kuijk C, Hoogerwerf N, Luitse JS. Assessment of a new trauma workflow concept implementing a sliding CT scanner in the trauma room: the effect on workup times. J Trauma 2008;64:1320-6.
11. Sarin EL, Moore JB, Moore EE, Shannon MR, Ray CE, Morgan SJ, et al. Pelvic fracture pattern does not always predict the need for urgent embolization. J Trauma 2005;58:973-7.
12. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS, Jr., Poka A, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30:848-56.
13. Hamill J, Holden A, Paice R, Civil I. Pelvic fracture pattern predicts pelvic arterial haemorrhage. Aust N Z J Surg 2000;70:338-43.
14. Moore EE, Moore FA. American Association for the Surgery of Trauma Organ Injury Scaling: 50th anniversary review article of the Journal of Trauma. J Trauma 2010;69:1600-1.
15. Hsu JM, Hitos K, Fletcher JP. Identifying the bleeding trauma patient: predictive factors for massive transfusion in an Australasian trauma population. J Trauma Acute Care Surg 2013;75:359-64.
16. Mutschler M, Nienaber U, Brockamp T, Wafaisade A, Fabian T, Paffrath T, et al. Renaissance of base deficit for the initial assessment of trauma patients: a base deficit-based classification for hypovolemic shock developed on data from 16,305 patients derived from the TraumaRegister DGU(R). Crit Care 2013;17:R42.
17. Davis JW, Parks SN, Kaups KL, Gladen HE, O'Donnell-Nicol S. Admission base deficit predicts transfusion requirements and risk of complications. J Trauma 1996;41:769-74.
18. Rodriguez C, Barone JE, Wilbanks TO, Rha CK, Miller K. Isolated free fluid on computed tomographic scan in blunt abdominal trauma: a systematic review of incidence and management. J Trauma 2002;53:79-85.

19. Charbit J, Millet I, Martinez O, Roustan JP, Merigeaud S, Taourel P, et al. Does the size of the hemoperitoneum help to discriminate the bleeding source and guide therapeutic decisions in blunt trauma patients with pelvic ring fracture? J Trauma Acute Care Surg 2012;73:117-25.

05
CHAPTER

MANAGEMENT OF PELVIC RING FRACTURE PATIENTS WITH A PELVIC "BLUSH" ON EARLY COMPUTED TOMOGRAPHY

AMSTERDAM, THE NETHERLANDS

D.O. Verbeek,
IJ.A.J. Zijlstra,
C. van der Leij,
K.J. Ponsen,
O.M. van Delden,
J.C. Goslings

Academic Medical Center
University of Amsterdam
Amsterdam,
the Netherlands

J Trauma Acute
Care Surg 2014;
76: 374-9

2014

ABSTRACT

Background: The sliding CT scanner in our trauma resuscitation room can be used as an adjunct to the primary survey of major pelvic fracture patients. We determined the association between the presence of a pelvic blush on CT and the need for pelvic hemorrhage control (PHC). We hypothesized that many pelvic blushes found early in the resuscitation phase can be safely managed without intervention.

Methods: Contrast-enhanced CT scans of pelvic ring fracture (pelvic ring disruption) patients admitted from January 1 2004 - June 31 2012 were reviewed for the presence of a pelvic blush. PHC was defined as requiring a surgical (pelvic packing / arterial ligation) or radiological (pelvic angiographic embolization) intervention. A subanalysis was performed in "isolated" pelvic fracture/ blush patients (absence of a major non-pelvic (abdominal, thoracic or extremity) bleeding source).

Results: Overall, 68 (42%) of 162 pelvic ring fracture patients and 53 (40%) of 134 isolated pelvic fracture patients had a pelvic blush. Of those 32 (47%) and 27 (51%) patients, respectively, required PHC. In the absence of a pelvic blush, 87 (93%) of 94 of all and 77 (95%) of 81 of isolated pelvic fracture patients did not require PHC. Of all patients with a pelvic blush and of isolated pelvic blush, those with PHC had a higher Injury Severity Score (ISS) ($p = 0.01$ and $p = 0.05$), base deficit ($p = 0.03$ and $p = 0.01$), as well as 24-hour and any packed red blood cells requirement ($p < 0.001$ and $p = 0.05$; $p < 0.001$ and $p = 0.02$). In isolated pelvic blush patients, there was a trend toward a higher hospital and hemorrhage-related mortality in patients with PHC ($p = 0.06$ and $p = 0.06$).

Conclusion: In pelvic ring fracture patients, a pelvic blush on early contrast-enhanced CT is a frequent finding. Many patients with (particularly isolated) pelvic blushes have stable vital signs and can be managed without surgical or radiologic PHC. The need for an intervention for a pelvic blush seems to be determined by the presence of clinical signs of ongoing bleeding.

INTRODUCTION

In recent years the role of the computed tomography (CT) scan in the evaluation of trauma patients has changed considerably due to advances in CT technology and the introduction of multi-detector CT scanners. Contemporary CT scanners are able to rapidly generate detailed images. This feature provides the opportunity to use the CT scanner soon after patient arrival and may shorten the diagnostic work-up and time to definitive treatment [1-3]. Although there is no conclusive evidence at present, it has been reported that early whole-body CT scanning may increase the probability of survival in trauma patients [4]. In most institutions obtaining a CT scan requires potentially hazardous patient transport to the radiology department. In 2004 a multi-detector CT scanner was placed in the trauma resuscitation room of our institution. It enabled us to use the CT scan as an adjunct to the primary survey without interrupting ongoing resuscitation [5,6].

In patients with a major pelvic fracture the presence of a pelvic contrast extravasation (or "blush") on CT is widely used as an indicator for significant arterial bleeding that may require (surgical or radiological) pelvic hemorrhage control [7-12]. Depending on hospital resources and patient characteristics, either pelvic angiographic embolization or alternatively pelvic packing (or ligation of pelvic arteries) is the preferred method for immediate hemorrhage control [11,13-18].

Considering the increasing and earlier use of CT and advances in imaging resolution, it may be speculated that at present more pelvic blushes are detected. Potentially, some of these pelvic blushes do not require hemorrhage control. In major pelvic fracture patients both pelvic and "non-pelvic" (e.g. abdominal, thoracic or extremity) injuries can cause significant bleeding. In determining the clinical outcome specifically related to the presence of a pelvic blush it is important to consider these associated sources of hemorrhage as well.

In this study we examined the management and outcome of pelvic ring fracture patients who had a contrast-enhanced CT scan. We determined the association between the presence of a pelvic blush and the need for pelvic hemorrhage control in all pelvic ring fracture patients as well as in a subgroup of "isolated" pelvic fracture patients (without a major nonpelvic bleeding source). We hypothesized that many pelvic blushes found early in the resuscitation phase can be safely managed without intervention.

METHODS

All adult patients with a high-energy major pelvic fracture admitted to the trauma resuscitation room of our academic Level 1 trauma center between January 1, 2004, and June 31, 2012,

were identified from our prospective trauma registry and the hospital's DRG International Classification of Diseases-9th Rev. database. Patients who had an intravenous contrast-enhanced CT scan were considered for inclusion.
A pelvic ring fracture was defined as a disruption of the pelvic ring in at least two places. Patients with a single break of the pelvic ring (i.e., single acetabular, iliac wing, or pubic rami fractures), transfer patients, and patients declared dead on arrival were excluded from the analysis.
Medical records were reviewed for age, sex, mechanism of injury, Injury Severity Score (ISS), systolic blood pressure (SBP) and base deficit on arrival, packed red blood cell transfusion within 24 hours after arrival, and (hospital and hemorrhage-related) mortality.

Pelvic fractures were classified using the Young and Burgess classification; major ligamentous disruption (MLD) was defined as anteroposterior Type II and III, lateral compression Type III, vertical shear, and combined mechanism.[19-21]. Operative and radiology reports were examined for surgical and/or radiologic interventions performed to control pelvic or non-pelvic bleeding sources.

Patient Management and Imaging

Initial patient assessment followed our institutional protocol and advanced trauma life support (ATLS) principles. According to the local imaging protocol, all high-energy trauma patients receive a chest and pelvic radiography as well as a FAST within 5 minutes of arrival. Pelvic ring fracture patients also have an abdominopelvic intravenous contrast-enhanced CT scan. The location of the multislice CT scanner (SOMATOM Sensation 4 and 64 [from 2008], Siemens Medical Systems, Erlangen, Germany) in the trauma resuscitation room enables us to safely perform a rapid CT scan in all patients except for those with refractory hemorrhagic shock despite adequate fluid resuscitation (ATLS "nonresponders"). On arrival, patients are placed on the trauma room table, which is radiolucent and also acts as the CT table. The CT scanner is able to slide over the patient without interrupting ongoing resuscitation.[5,6]. Images are viewed in stacked mode using picture archiving and communication system.

After the CT scan is obtained, the images are immediately reviewed by the attending trauma surgeon and radiologist. An interventional radiologist is available on a 24-hour basis. The decision to proceed for surgical or radiologic hemorrhage control was typically based on the patient's hemodynamic status and presence of associated injuries. In general, patients with a pelvic blush received pelvic angiography on a liberal basis. Particularly, pelvic blush patients with signs of ongoing bleeding (clinical signs of hypovolemic shock with a continuing transfusion requirement) were considered for radiologic hemorrhage control.

Digital subtraction angiography was performed using Philips V3000 (the Netherlands) equipment. Patients with an arterial injury on pelvic angiography received pelvic angiographic embolization. Embolization was performed using a variety of platinum embolization coils, Gelatin sponge particles (Gelfoam, Upjohn, Kalamazoo, MI) or a combination of both.
Pelvic blush patients with refractory hemorrhagic shock (ATLS “nonresponders”) had immediate surgical hemorrhage control by pelvic packing or (occasionally) surgical ligation of pelvic arteries (followed by pelvic angiography if needed). Intraperitoneal pelvic packing was generally performed in patients who required a laparotomy and preperitoneal packing in patients who did not require a laparotomy (rarely at the time of study). Surgical hemorrhage control was also performed in patients with signs of pelvic hemorrhage at immediate laparotomy for abdominal hemorrhage. A pelvic external fixator was placed before laparotomy for unstable fracture patterns. The overall patient management was at the trauma surgeon’s discretion in conjunction with the anesthesiologist and interventional radiologist on call.

For the purpose of the study, all CT scans were reviewed for the presence of a pelvic blush (focal area of high-contrast density) by two senior radiology residents and a board-certified interventional radiologist in consensus. All pelvic angiographies were independently reviewed by a board-certified interventional radiologist for the presence of arterial injury (contrast extravasation, cutoff, or pseudoaneurysm).

Definitions

The need for pelvic hemorrhage control was defined as having received a surgical (pelvic packing or surgical ligation) and/or radiologic (angiographic embolization) intervention for pelvic bleeding. A major nonpelvic bleeding source was defined as an abdominal, thoracic, or extremity injury that re- quired surgical or radiologic hemorrhage control. A patient was considered to have an “isolated” pelvic fracture or blush in the absence of a major nonpelvic bleeding source.

Statistical analysis

Continuous variables are presented as median values with interquartile ranges (IQRs) and are compared using Mann-Whitney U-test or as mean values with SDs and compared with independent *t* test, depending on data distribution. Categorical values were calculated as percentage of frequency of occurrence. Discrete variables were compared using Fisher’s exact analyses. Statistical significance was declared at the
0.05 level.
Two-by-two contingency tables were constructed to calculate the diagnostic indices (sensitivity, specificity, as well as positive and negative predictive values) for the presence

of a pelvic blush on CT scan and the need for pelvic hemorrhage control in all patients as well as in the subgroup of isolated pelvic fracture patients. Results are presented with 95% confidence intervals.
All data management and statistical analysis were per- formed using Statistical Package for the Social Science (SPSS®, IBM®, Armonk, New York).

RESULTS

Overall, 172 pelvic ring fracture patients were identified, and 166 (97%) had a contrast-enhanced CT scan. Four patients were excluded owing to the nondiagnostic quality of the images or an incomplete CT examination.
In total, 162 pelvic ring fracture patients were included in the study. A pelvic blush was present in 68 patients (42%) and absent in 94 patients (58%).
The characteristics, management, and outcome of all patients by presence of a pelvic blush on CT scan are presented in **Table 1**.

Table 1. Characteristics, management and outcome of all patients by presence of a pelvic blush on CT scan

	All patients	**Pelvic blush**		***p***
		present	**absent**	
	(n=162)	**(n=68)**	**(n=94)**	
Age, mean (SD), y	41 (19)	44 (20)	38 (18)	*0.04*
Sex, male, n (%)	124 (77)	54 (79)	70 (75)	0.20
Mechanism of injury, motor vehicle collision, n (%)	35 (22)	12 (18)	23 (25)	0.25
ISS, mean (SD)	27 (14)	31 (16)	24 (12)	*0.00*
Type fracture, MLD, n (%)	56 (35)	31 (46)	25 (27)	*0.01*
SBP, mean (SD), mmHg	119 (33)	113 (40)	124 (25)	*0.04*
Base deficit, median (IQR), mEq/L	4 (5)	4 (6)	3 (4)	*0.00*
Nonpelvic hemorrhage control	28 (17)	15 (22)	13 (14)	0.12
Pelvic external fixator	86 (53)	47 (69)	39 (42)	*0.00*
Pelvic hemorrhage control	39 (24)	32 (47)	7 (7)	*0.00*
Packed red blood cells in 24 h, median (IQR), U	2 (10)	8 (19)	2 (4)	*0.00*
Any Packed red blood cell, n (%)	111 (69)	55 (81)	56 (60)	*0.00*
Hospital mortality, n (%)	19 (12)	12 (18)	7 (7)	*0.04*
Hemorrhage-related mortality, n (%)	10 (6)	8 (12)	2 (2)	*0.01*

Italics indicate statistical significance ($p < 0.05$)

Patients with a pelvic blush had a significantly higher age and ISS as well as a lower SBP and higher base deficit on arrival. Furthermore, pelvic blush patients had more complex pelvic fractures (with MLD) and required more pelvic external fixators and pelvic hemorrhage control. The sex, method of injury, and need for nonpelvic hemorrhage control was similar in both groups. Patients with a pelvic blush also had a significantly higher 24-hour and any packed red blood cells requirement and a higher hospital and hemorrhage-related mortality.

Pelvic hemorrhage control in all patients

Of 68 patients with a pelvic blush, 36 (53%) had no pelvic hemorrhage control and 32 patients (47%) had pelvic hemorrhage control (**Table 2**). Five patients had pelvic packing at laparotomy, and 27 had pelvic angiographic embolization (6 of those had both interventions). Of the 36 patients with a pelvic blush but no pelvic hemorrhage control, 10 patients (hemodynamically) stabilized after hemorrhage control for major nonpelvic bleeding, 9 had a negative pelvic angiography for arterial injury, and the remaining 17 had no intervention for hemorrhage control.

Table 2. The association between the presence of a pelvic blush on CT scan and the need for pelvic hemorrhage control in all pelvic ring fracture patients (n=162)

		Pelvic hemorrhage control		
		Yes	**No**	
Blush	Present	32	36	68
	Absent	7	87	94
		39	123	162

Of the 94 patients without a pelvic blush, 87 (93%) did not have pelvic hemorrhage control and 7 (7%) did have pelvic hemorrhage control. One patient had pelvic packing at laparotomy, and six patients had a pelvic angiography (for clinical signs of active bleeding) with subsequent embolization for an arterial injury.

The sensitivity, specificity, as well as positive and negative predictive values of a pelvic blush for the need for pelvic hemorrhage control in all patients were 82% (66-92), 71% (62-78), 47% (35-59), and 93% (85-97), respectively (**Table 3**).

Pelvic hemorrhage control in isolated pelvic fracture patients

In total, 28 patients had a major nonpelvic bleeding source. Twelve patients required surgical, and 13 required radiologic hemorrhage control for abdominal injuries, 2 patients had a thoracotomy for thoracic injuries, and 1 patient had surgical hemorrhage control for an extensive extremity injury. In the remaining 134 isolated pelvic fracture patients, the pelvic fracture was the only potential source of major hemorrhage.

Table 3. Diagnostic indices (95% confidence intervals) for the presence of a pelvic blush on CT scan and the need for pelvic hemorrhage control in all patients and in isolated pelvic fracture patients

	All patients (n=162)	**Isolated pelvic fracture (n=134)**
Sensitivity	82% (66-92)	87% (69-96)
Specificity	71% (62-78)	75% (65-83)
Positive predictive value	47% (35-59)	51% (37-65)
Negative predictive value	93% (85-97)	95% (87-98)

A pelvic blush was present in 53 patients (40%) (**Table 4**). Of those, 26 patients (49%) did not have pelvic hemorrhage control and 27 patients (51%) had pelvic hemorrhage control. Three patients had pelvic packing at laparotomy, and 24 had pelvic angiographic embolization (4 of whom had both interventions). Of the 26 patients with a pelvic blush but no pelvic hemorrhage control, 9 had a negative pelvic angiography for arterial injury and 17 had no intervention for hemorrhage control. A pelvic blush was absent in 81 patients (60%). Of those, 77 patients (95%) had no pelvic hemorrhage control and 4 (5%) did have pelvic hemorrhage control. One patient had pelvic packing at laparotomy, and three patients had pelvic angiographic embolization for clinical signs of active bleeding.

Table 4. The association between the presence of a pelvic blush on CT scan and the need for pelvic hemorrhage control in isolated pelvic fracture patients (with no other source of major hemorrhage) (n=134)

		Pelvic hemorrhage control		
		Yes	**No**	
Blush	Present	27	26	53
	Absent	4	77	81
		31	103	134

The sensitivity, specificity, as well as positive and negative predictive values of a pelvic blush for the need for pelvic hemorrhage control in isolated pelvic fracture patients were 87% (69-96), 75% (65-83), 51% (37-65), and 95% (87-98), respectively (**Table 3**).

Outcome of pelvic blush patients

The characteristics and outcome of all patients with a pelvic blush and patients with an isolated pelvic blush in relation to the need for pelvic hemorrhage control are presented in **Tables 5 and 6**.

Table 5. Characteristics and outcome of all patients with a pelvic blush by the need for pelvic hemorrhage control (n=68)

	Pelvic hemorrhage control		
	Yes (n=32)	No (n=36)	P
Age, mean (SD), y	47 (20)	44 (19)	0.10
Sex, male, n (%)	26 (81)	28 (78)	0.48
Mechanism of injury, motor vehicle collision, n (%)	3 (9)	9 (25)	0.10
ISS, mean (SD)	35 (18)	26 (11)	*0.01*
Type fracture, MLD, n (%)	14 (44)	17 (47)	0.48
SBP, mean (SD), mmHg	108 (37)	117 (42)	0.48
Base deficit, median (IQR), mEq/L	7 (6)	4 (5)	*0.03*
Packed red blood cells in 24 h, median (IQR), U	16 (21)	4 (11)	*0.00*
Any Packed red blood cell, n (%)	29 (91)	26 (72)	*0.05*
Hospital mortality, n (%)	7 (22)	5 (14)	0.30
Hemorrhage-related mortality, n (%)	5 (16)	3 (8)	0.30

Italics indicate statistical significance (*p<0.05*)

Table 6. Characteristics and outcome of patients with an isolated pelvic blush (with no other source of major hemorrhage) by the need for pelvic hemorrhage control (n=53)

	Pelvic hemorrhage control		
	Yes (n=27)	No (n=26)	*P*
Age, mean (SD), y	46 (20)	44 (21)	0.63
Sex, male, n (%)	21 (78)	19 (73)	0.47
Mechanism of injury, motor vehicle collision, n (%)	3 (11)	3 (12)	0.65
ISS, mean (SD)	33 (18)	25 (11)	*0.05*
Type fracture, MLD, n (%)	12 (44)	13 (50)	0.45
SBP, mean (SD), mmHg	109 (39)	127 (36)	0.85
Base deficit, median (IQR), mEq/L	5 (6)	3 (3)	*0.01*
Packed red blood cells in 24 h, median (IQR), U	12 (24)	1 (6)	*0.00*
Any Packed red blood cell, n (%)	24 (89)	16 (62)	*0.02*
Hospital mortality, n (%)	6 (22)	1 (4)	0.06
Hemorrhage-related mortality, n (%)	4 (15)	0 (0)	0.06

Italics indicate statistical significance (*p<0.05*)

Both in the overall pelvic blush group as well as in the isolated pelvic blush subgroup, patients with pelvic hemorrhage control had a similar age, sex, mechanism of in- jury, type of fracture, and SBP on arrival compared with patients who did not have pelvic hemorrhage control. Furthermore, in both groups, patients with pelvic hemorrhage control had a significantly higher ISS and base deficit on arrival.

In the overall pelvic blush group and in the isolated blush subgroup, the total packed red blood cells requirement in 24 hours after arrival and the need for any packed red blood cells were significantly higher in patients with pelvic hemorrhage control.
In the overall pelvic blush group, the hospital and hemorrhage-related mortality rates were similar in patients who had pelvic hemorrhage control and those who did not. In the isolated pelvic blush subgroup, there was a trend toward a higher hospital and hemorrhage-related mortality in patients who had pelvic hemorrhage control.

DISCUSSION

In this study of pelvic ring fracture patients, a pelvic blush on early contrast-enhanced CT scan was a frequent finding and an indicator of severe injury. The percentage of patients with a pelvic blush (42%) found in the present study is significantly higher than earlier reported. Previous studies of patients with a variety of (isolated) pelvic and acetabular fractures report of an incidence of up to 12% [11,22-24]. Several
factors may have contributed to this discrepancy. First, our patients had an inherently higher risk for arterial injury considering that only patients with high-energy pelvic ring fractures were included while patients with single pelvic or acetabular fractures and those with fractures from low-impact falls were excluded from the analysis. Furthermore, because of the location of the CT scanner in the trauma resuscitation room we were able to obtain a CT scan in nearly all major pelvic fracture patients without interrupting ongoing resuscitation. This included hemodynamically compromised patients who would not be considered for early CT scan in many other institutions. Second, it may be speculated that the timing of the CT scan (early in the resuscitation phase) contributed to the high rate of pelvic blushes detected. Potentially, some smaller arterial injuries would not have been detected on a more delayed CT because these may stop bleeding spontaneously. Lastly, in recent years advances in CT technology have improved imaging resolution, which may have resulted in the detection of more discrete blushes.

Our results suggest that the presence of a pelvic blush (by itself) is not reliably associated with the need for pelvic hemorrhage control in all pelvic ring fracture patients as well as in

isolated pelvic fracture patients. In both patient groups, half of pelvic blushes (53% and 49%, respectively) required no intervention. This was in part caused by the fact that some pelvic blush patients had a negative pelvic angiography for arterial injury while others showed no clinical signs of active pelvic bleeding (following nonpelvic hemorrhage control).
The need for pelvic hemorrhage control in pelvic ring fracture patients was more determined by the presence of clinical signs of ongoing bleeding than by the mere presence of a pelvic blush on CT scan. It seems that further treatment should therefore be guided primarily by hemodynamic parameters and the patient’s response to resuscitation and not by radiologic parameters only.

In the current literature, there is no agreement on whether a pelvic blush predicts the need for pelvic hemorrhage control and more specifically for pelvic arterial embolization. The limited predictive value found in our study is in concurrence with several earlier reports on pelvic fracture patients. These studies found that angiographic embolization was required in only 29% to 41% of pelvic fracture patients with a pelvic blush. [22,25,26]. However, other studies came to different conclusions and suggested that a pelvic blush on CT is a sign of arterial injury that requires angiographic embolization (in 69 and 80% of patients) [23,24]. In a study that described patients that either required angiographic embolization or emergency surgery for pelvic hemorrhage control, it was found that of 15 pelvic fracture patients with a pelvic blush, 9 (60%) required an intervention [11]. The contradictory findings in current literature are potentially a result of small sample sizes, differences in inclusion criteria, and variation in treatment strategies.

Our data also show that the absence of a pelvic blush on CT scan dismisses the need for pelvic hemorrhage control in the great majority of all major pelvic fracture patients as well as isolated pelvic fracture patients (93% and 95%). Earlier studies concur with this finding and report of a negative predictive value of 98% to 100%.[11,22-24]. It is however important to note the small number of patients in our study that did require (mainly radiological) pelvic hemorrhage control in the absence of a pelvic blush. The false negative results in these patients were potentially caused by intermittent bleeding and were detected because of an ongoing transfusion requirement.

In pelvic ring fracture patients with a pelvic blush on CT scan, the need for pelvic hemorrhage control is evident in patients with signs of ongoing pelvic bleeding (in the absence of major nonpelvic bleeding). However, there is no consensus regarding the management of pelvic blush patients with stable vital signs and a minimal transfusion requirement [7,8]. We found that many pelvic blush patients have no signs of ongoing bleeding and have a favorable outcome without the need for pelvic hemorrhage control. This finding was particularly apparent in the absence of major non-pelvic bleeding sources that can have a significant impact on clinical outcome.

While the CT scan can be a valuable tool for the overall assessment of pelvic fracture patients, the benefits of this modality should be carefully considered in light of the potential risk of transporting the patient to the CT scanner. It is evident that a CT is only indicated if it can be safely obtained in an environment with close patient monitoring and resuscitation capabilities. A specific note of caution is for pelvic fracture patients who remain unresponsive to adequate fluid resuscitation. In these unstable patients an immediate intervention is required and should not be delayed by performing a CT scan [27-29].

Limitations

This study is retrospective in design with the inherent limitations regarding data collection and selection bias. Although there was general agreement on the management strategy, no set treatment algorithm for major pelvic fracture patients was in place to standardize decision-making. The need for an intervention was determined early in the resuscitation phase based primarily on clinical signs of active bleeding and the presence of associated injuries; no patients had a delayed intervention for hemorrhage control. We were unable to examine the vital signs or transfusion requirements in detail to determine the effect certain interventions had on the patients' hemodynamic status. Lastly, the design and power of the study did not permit us to formulate reliable predictors for the need for pelvic hemorrhage control.To define more accurately what early parameters are reliable predictors for the need for pelvic hemorrhage control, a further prospective study would be needed.

CONCLUSION

In pelvic ring fracture patients, a pelvic blush on early contrast-enhanced CT scan is a frequent finding. Many patients with (particularly isolated) pelvic blushes have stable vital signs and can be managed without surgical or radiologic pelvic hemorrhage control. The need for an intervention for a pelvic blush seems to be determined by the presence of clinical signs of ongoing bleeding.

REFERENCES

1. Chan O. Primary computed tomography survey for major trauma. Br J Surg 2009;96:1377-8.
2. Wurmb TE, Fruhwald P, Hopfner W, Keil T, Kredel M, Brederlau J, et al. Whole-body multislice computed tomography as the first line diagnostic tool in patients with multiple injuries: the focus on time. J Trauma 2009;66:658-65.
3. Sierink JC, Saltzherr TP, Reitsma JB, Van Delden OM, Luitse JS, Goslings JC. Systematic review and meta-analysis of immediate total-body computed tomography compared with selective radiological imaging of injured patients. Br J Surg 2012;99 Suppl 1:52-8.
4. Huber-Wagner S, Lefering R, Qvick LM, Korner M, Kay MV, Pfeifer KJ, et al. Effect of whole-body CT during trauma resuscitation on survival: a retrospective, multicentre study. Lancet 2009;373:1455-61.
5. Fung Kon Jin PH, Goslings JC, Ponsen KJ, van Kuijk C, Hoogerwerf N, Luitse JS. Assessment of a new trauma workflow concept implementing a sliding CT scanner in the trauma room: the effect on workup times. J Trauma 2008;64:1320-6.
6. Saltzherr TP, Bakker FC, Beenen LF, Dijkgraaf MG, Reitsma JB, Goslings JC, et al. Randomized clinical trial comparing the effect of computed tomography in the trauma room versus the radiology department on injury outcomes. Br J Surg 2012;99 Suppl 1:105-13.
7. Davis JW, Moore FA, McIntyre RC, Jr., Cocanour CS, Moore EE, West MA. Western trauma association critical decisions in trauma: management of pelvic fracture with hemodynamic instability. J Trauma 2008;65:1012-5.
8. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.
9. White CE, Hsu JR, Holcomb JB. Haemodynamically unstable pelvic fractures. Injury 2009;40:1023-30.
10. van Vugt AB, van Kampen A. An unstable pelvic ring. The killing fracture. J Bone Joint Surg Br 2006;88:427-33.
11. Mohseni S, Talving P, Kobayashi L, Lam L, Inaba K, Branco BC, et al. The diagnostic accuracy of 64-slice computed tomography in detecting clinically significant arterial bleeding after pelvic fractures. Am Surg 2011;77:1176-82.
12. Verbeek D, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
13. Cothren CC, Osborn PM, Moore EE, Morgan SJ, Johnson JL, Smith WR. Preperitonal pelvic packing for hemodynamically unstable pelvic fractures: a paradigm shift. J Trauma 2007;62:834-9; discussion 9-42.
14. Heetveld MJ, Harris I, Schlaphoff G, Balogh Z, D'Amours SK, Sugrue M. Hemodynamically unstable pelvic fractures: recent care and new guidelines. World J Surg 2004;28:904-9.
15. Biffl WL, Smith WR, Moore EE, Gonzalez RJ, Morgan SJ, Hennessey T, et al. Evolution of a multidisciplinary clinical pathway for the management of unstable patients with pelvic fractures. Ann Surg 2001;233:843-50.
16. Eastridge BJ, Starr A, Minei JP, O'Keefe GE, Scalea TM. The importance of fracture pattern in guiding therapeutic decision-making in patients with hemorrhagic shock and pelvic ring disruptions. J Trauma 2002;53:446-50; discussion 50-1.
17. Velmahos GC, Chahwan S, Falabella A, Hanks SE, Demetriades D. Angiographic embolization for intraperitoneal and retroperitoneal injuries. World J Surg 2000;24:539-45.

18. Gansslen A, Giannoudis P, Pape HC. Hemorrhage in pelvic fracture: who needs angiography? Curr Opin Crit Care 2003;9:515-23.

19. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS, Jr., Poka A, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30:848-56.

20. Sarin EL, Moore JB, Moore EE, Shannon MR, Ray CE, Morgan SJ, et al. Pelvic fracture pattern does not always predict the need for urgent embolization. J Trauma 2005;58:973-7.

21. Hamill J, Holden A, Paice R, Civil I. Pelvic fracture pattern predicts pelvic arterial haemorrhage. Aust N Z J Surg 2000;70:338-43.

22. Brasel KJ, Pham K, Yang H, Christensen R, Weigelt JA. Significance of contrast extravasation in patients with pelvic fracture. J Trauma 2007;62:1149-52.

23. Stephen DJ, Kreder HJ, Day AC, McKee MD, Schemitsch EH, ElMaraghy A, et al. Early detection of arterial bleeding in acute pelvic trauma. J Trauma 1999;47:638-42.

24. Pereira SJ, O'Brien DP, Luchette FA, Choe KA, Lim E, Davis Jr K, et al. Dynamic helical computed tomography scan accurately detects hemorrhage in patients with pelvic fracture. Surgery 2000;128:678-85.

25. Diamond IR, Hamilton PA, Garber AB, Tien HC, Chughtai T, Rizoli SB, et al. Extravasation of intravenous computed tomography scan contrast in blunt abdominal and pelvic trauma. J Trauma 2009;66:1102-7.

26. Ryan MF, Hamilton PA, Chu P, Hanaghan J. Active extravasation of arterial contrast agent on post-traumatic abdominal computed tomography. Can Assoc Radiol J 2004;55:160-9.

27. Howell GM, Peitzman AB, Nirula R, Rosengart MR, Alarcon LH, Billiar TR, et al. Delay to therapeutic interventional radiology postinjury: time is of the essence. J Trauma 2010;68:1296-300.

28. Neal MD, Peitzman AB, Forsythe RM, Marshall GT, Rosengart MR, Alarcon LH, et al. Over reliance on computed tomography imaging in patients with severe abdominal injury: is the delay worth the risk? J Trauma 2011;70:278-84.

29. Clarke JR, Trooskin SZ, Doshi PJ, Greenwald L, Mode CJ. Time to laparotomy for intra-abdominal bleeding from trauma does affect survival for delays up to 90 minutes. J Trauma 2002;52:420-5.

06

CHAPTER

IMPORTANCE OF PELVIC RADIOGRAPHY FOR INITIAL TRAUMA ASSESSMENT

An orthopedic perspective

HOUSTON, U.S.A.

D.O. Verbeek,
A.R. Burgess

Memorial Hermann-Texas Medical Center Hospital, University of Texas Health-McGovern Medical School, Houston, TX, U.S.A.

J Emerg Med 2016; 50: 852-8

2016

ABSTRACT

Background: Many institutions have abandoned the routine for the selective Pelvic X-Ray (PXR) for initial imaging in blunt trauma patients undergoing CT scanning.

Objective: Our aim was to examine the association between the selective use of PXR and time to diagnosis of (major) pelvic fractures, as well as prioritization of key immediate interventions (including hip reduction and pelvic arterial embolization).

Methods: We conducted a one-year review of early management of pelvic fracture patients undergoing pelvic CT scanning. Time interval and sequence of initial imaging and key immediate interventions were recorded.

Results: Of 218 pelvic fracture patients, 79 (36%) had no initial PXR, and instead had an initial CT scan. Time to first pelvic imaging in those patients was 48 min (standard deviation [SD] = 47 min vs. 2 min [SD = 6 min] with PXR; $p < 0.001$). Of 40 hip dislocations, 15 (38%) were detected first on CT scan. Overall, 22 (55%) required a second CT scan after reduction in the emergency department. No initial PXR was performed in 42 of 120 (35%) pelvic ring fracture patients and in 16 of 61 (26%) unstable pelvic ring fractures. Time to pelvic arterial embolization was longer in 4 patients without initial PXR than in 14 patients with PXR (296 min [SD = 206 min] vs. 170 min [SD = 76 min], respectively, $p = 0.038$).

Conclusions: Selective PXR was associated with a significant delay in recognition of (major) pelvic fractures, including those with associated hip dislocations and (potential) pelvic bleeding. PXR remains a useful screening tool to rapidly determine the need for immediate interventions and to allow early planning prior to CT scanning.

INTRODUCTION

The pelvic X-ray (PXR) has traditionally been an essential component of the initial assessment of blunt trauma patients [1]. With the advent and growing use of high speed multi-detector CT scanning in trauma patients, the added value of this modality is increasingly being called into question [2-5]

It is generally agreed upon that in hemodynamically unstable blunt trauma patients, an initial PXR is required to rapidly rule out a potential pelvic source of bleeding. However, routine use of PXR in hemodynamically stable blunt trauma patients is more controversial. Previous studies have indicated that routine PXR is no longer required in the majority of patients with stable vital signs undergoing abdomino-pelvic CT scanning as part of their initial assessment [4,5]. Abandoning the routine for a more selective use of PXR may appear cost-effective in the general trauma population. However, the effect of this selective imaging strategy on the early treatment of pelvic fracture patients is largely unknown. Previous studies included few patients with a (major) pelvic fracture and the need for immediate interventions prior to CT scanning were underreported [2-5].

Therefore, we reviewed the impact of the selective use of PXR on early management of pelvic fracture patients undergoing abdomino-pelvic CT scanning. In particular, we examined the time to diagnosis of (major) pelvic fractures as well as the prioritization of key immediate interventions (i.e. hip reduction, pelvic arterial embolization and placement of a pelvic binder).

MATERIALS AND METHODS

From September 1, 2011 to August 31, 2012, all adult patients with a pelvic fracture were identified from our institution's orthopedic trauma registry. The Trauma Institute at our hospital is an American College of Surgeons– accredited Level I trauma center that admits >6,000 trauma patients annually.

Patients with a pelvic ring or acetabular fracture who underwent abdominopelvic CT- scanning as part of their initial assessment were considered for inclusion in the study. Patients who were transferred to our institution and patients with a penetrating injury were excluded.

During the study period, there was no imaging protocol in place for the initial management of blunt trauma patients. In general, high-energy blunt trauma patients who were considered hemodynamically stable underwent abdominopelvic CT scanning after initial (chest) radiography and focused assessment with sonography in trauma in the trauma resuscitation room. Whether patients required an initial PXR before CT scanning was deter- mined on presentation by the trauma team leader (an emergency physician or trauma surgeon). The

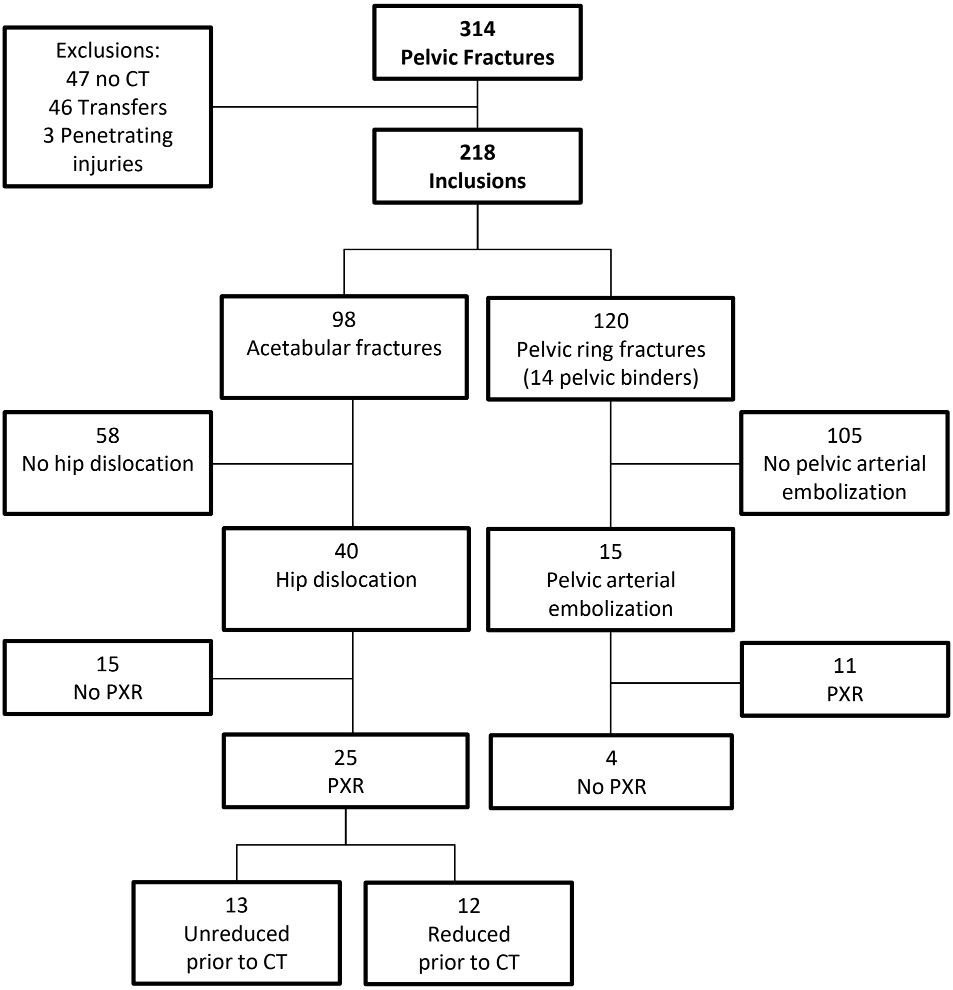


Figure 1. Flowchart illustrating the included and excluded patients, and key immediate interventions. CT= computed tomography; PXR= pelvic x-ray)

hemodynamic status of the patient and findings on physical examination are factors that were considered in the decision-making process.

Data were collected on patient demographic characteristics, the imaging performed, and the need for operative fixation of the pelvic fracture. Also, key immediate interventions and their sequential timing in relation to initial pelvic imaging were recorded. These key immediate interventions included reduction of a hip dislocation, pelvic arterial embolization, and placement of a pelvic binder. The diagnostic interval was calculated as the time from first imaging (typically chest radiography) to first pelvic imaging (PXR or CT scan). The time to intervention in patients who needed pelvic arterial embolization was calculated from first imaging to first pelvic angiography images.

Pelvic ring fractures were classified using Young and Burgess classification, with unstable pelvic ring fractures defined as lateral compression types II and III, anteroposterior compression types II and III, vertical shear, and combined mechanism [6,7]. Acetabular fractures were classified using the Letournel classification system [8]. Combined fractures were included in the acetabular fracture group.

Statistical analysis

Continuous variables are presented as mean values with standard deviations (SD) and compared with the independent *t*-test. Categorical values were calculated as percentage of frequency of occurrence. Statistical significance was declared at the 0.05 level. All management and statistical analyses were performed using the Statistical Package for the Social Sciences software, version 20.0 (IBM Corp, Armonk, NY).

RESULTS

During the 1-year study period, 314 adult patients with a pelvic ring or acetabular fracture were reviewed (**Figure 1**). Of those, 96 patients were excluded from the study; 47 patients did not have an abdominopelvic CT scan, 46 patients were transferred from outside facilities, and 3 patients had a penetrating injury.

In total, 218 (69%) pelvic fracture patients were included in the study. Mean age was 39 years (SD = 17 years) and 63% were men. Seventy-nine patients (36%) did not have an initial PXR and 139 patients (64%) had an initial PXR before CT scanning. The diagnostic interval to first pelvic imaging was 48 min (SD = 47 min) and 2 min (SD = 6 min), respectively ($p < 0.001$).

Acetabular fractures

There were 98 patients (45%) with an acetabular fracture. Mean age was 39 years (SD = 17 years) and 74% were men. The classification of the acetabular fractures is presented in **Table 1**.

Table 1. Classification of acetabular fractures in 98 patients

Fracture	n (%)
Posterior wall	35 (36)
Transverse and posterior wall	18 (18)
Both column	13 (13)
Anterior column	10 (10)
Transverse	5 (5)
Anterior wall	4 (4)
Posterior column and posterior wall	4 (4)
Anterior column and posterior hemitransverse	4 (4)
T-shaped	3 (3)
Posterior colum	2 (2)

In total, 69 patients (70%) required operative fixation of their acetabular fracture.
Of 98 acetabular fracture patients, 37 patients (38%) did not have an initial PXR and 61 patients (62%) had an initial PXR. The diagnostic interval to first pelvic imaging in these patients was 44 min (SD = 39 min) and 2 min (SD = 7 min), respectively ($p < 0.001$).

A total of 40 (41%) acetabular fracture patients had an associated hip dislocation on initial imaging (**Figure 1**). In 15 of those patients (38%), the dislocation was detected first on CT scan in the absence of an initial PXR. Of those, 13 patients had subsequent reduction in the emergency department (ED), and 2 patients required reduction in the operating room with or without immediate fixation. Twenty-five of 40 patients (63%) with a hip dislocation had an initial PXR. In 13 of 40 patients (33%), the hip dislocation was present on initial PXR, but was not reduced before the CT scan was performed. In 9 of those patients, the hip was reduced in the ED after CT scanning, and in 4 patients the femoral head was irreducible in the ED, owing to a large intra- articular fragment that obstructed reduction. These 4 patients required open reduction with removal of the fragments (1 patient) and subsequent internal fixation (3 patients).
In an additional 12 of 40 patients (30%), the hip dislocation was detected on initial PXR and was subsequently reduced before CT scanning. In total, 22 patients with a dislocated hip on CT scan (55% of all hip dislocations) required an additional (second) CT scan after reduction in the ED. Pelvic arterial embolization was performed in 3 patients (all with combined fractures) in a mean of 147 min (SD = 33 min). All 3 patients had an initial PXR.

Pelvic ring fractures

There were 120 patients (55%) with a pelvic ring fracture. Mean age was 40 years (SD = 17 years) and 55% were men. The classification of the pelvic ring fractures is presented in **Table 2**.

Table 2. Classification of pelvic ring fractures in 120 patients

Fracture	**n (%)**
Lateral compression type I	68 (57)
Anteroposterior compression type II	17 (14)
Anteroposterior compression type I	9 (8)
Lateral compression type II	8 (7)
Lateral compression type III	8 (7)
Anteroposterior compression type III	4 (3)
Vertical shear	4 (3)
Combined mechanism	2 (2)

A total of 69 patients (58%) required operative fixation of their pelvic ring fracture.
Of 120 pelvic ring fracture patients, 42 (35%) did not have an initial PXR and 78 (65%) had an initial PXR. The diagnostic interval to first pelvic imaging in these patients was 51 min (SD = 53 min) and 2 min (SD = 4 min), respectively ($p < 0.001$).

In total, 61 patients (41%) had an unstable pelvic ring fracture. Of those, 16 patients (26%) did not have an initial PXR and 45 patients (74%) had an initial PXR. The diagnostic interval to first pelvic imaging in these patients was 46 min (SD = 35 min) and 2 min (SD = 7 min), respectively ($p < 0.001$).

Pelvic arterial embolization was performed in 15 pelvic ring fracture patients (Figure 1). Of those, 4 patients (27%) had no initial PXR. In pelvic ring fracture patients who required pelvic arterial embolization, the time to intervention in patients who did not have an initial PXR vs. those who did have a PXR was similar: 296 min (SD = 206 min) in 4 patients vs. 176 min (SD = 85 min) in 11 patients, respectively ($p = 0.086$). In all 18 pelvic (ring and combined) fracture patients who needed pelvic arterial embolization, the time to intervention in patients who did not have an initial PXR was significantly longer than in patients who did have a PXR: 296 min (SD = 206 min) in 4 patients vs. 170 min (SD = 76 min) in 14 patients, respectively ($p = 0.038$).
Fourteen patients had a pelvic binder placed for a major anteroposterior compression-type fracture. Of those, 2 patients (14%) had no initial PXR.

DISCUSSION

Previous studies have questioned the need for a routine PXR in hemodynamically stable blunt trauma patients undergoing abdominopelvic CT scanning [2-5]. Some authors have concluded that this standard practice can be safely abandoned and have recommended

selecting patients for initial PXR based on physical examination [4,5]. In light of these recent findings, blunt trauma patients in our institution no longer receive a routine PXR prior to abdominopelvic CT scanning.
With the implementation of this more selective imaging strategy, we found that a substantial percentage of our pelvic fracture patients undergoing CT scanning did not have an initial PXR. As a result, pelvic fractures were not diagnosed in the trauma resuscitation room within minutes of arrival but were discovered later on CT scan. More importantly, many major pelvic fractures remained undetected before CT scanning. These included more severe fractures requiring key immediate interventions.

Acetabular fractures

A significant percentage of acetabular fracture patients in this study did not have an initial PXR. In these patients, PXR is particularly valuable for the early diagnosis of an associated hip dislocation. We found that an unacceptably high rate of hip dislocations remained undetected in the trauma resuscitation room. In the absence of an initial PXR, the hip dislocations were only detected on CT scan. This resulted in a delay to reduction (until after the CT scan) and the need for a second CT scan in most patients, adding to (unnecessary) radiation exposure and cost. CT images of acetabular fractures with an unreduced hip are challenging to interpret. For accurate preoperative planning, detailed images of the fracture pattern with a reduced hip are required.

A contributing factor to this high rate of (initially) missed hip dislocations may have been the fact that not all pelvic fracture patients had a reliable physical examination of the pelvis before transport to the CT scanner. Performing a thorough physical examination in trauma patients to exclude pelvic fracture can be challenging, particularly in the often-hectic environment of the trauma resuscitation room. In multiple injured and intubated patients, the physical examination may be unreliable [9]. Furthermore, swelling, bruising and other obvious clinical signs of a pelvic fracture or hip dislocation may be absent.

Of further note in our study, is the group of patients with a hip dislocation on initial PXR that was not reduced before CT scanning. Some of these hip dislocations were irreducible in the trauma resuscitation room. In the remaining patients with a hip dislocation, competing clinical priorities that were considered urgent (such as a head injury) might have been present. The absence of readily available personnel to provide sedation as well as to reduce the hip might have also contributed to this course of action. It also can be speculated that not all hip dislocations on PXR were immediately evident to less experienced clinicians. Currently, physicians are increasingly relying on advanced imaging technology and are becoming less familiar with the interpretation of conventional imaging.

Clearly, the reduction of a hip should not delay further management of patients with other urgent clinical priorities. However, prompt recognition of the presence of a hip dislocation is important, as it will allow for early planning and decision making. In our study, all patients with hip dislocation received an initial chest x-ray and often a variety of other x-ray studies in the trauma resuscitation room. It seems unlikely that adding PXR would result in any significant delay. To facilitate timely reduction, protocols for the immediate management of patients with a hip dislocation should be developed.

Pelvic ring fractures

Similar to our findings in acetabular fracture patients, we found an equally large percentage of (unstable) pelvic ring fracture patients who did not receive an initial PXR. The lack of a reliable physical examination to determine the need for an initial PXR may also have played an important role in these generally more severely injured patients.

The time to diagnosis of a pelvic fracture and, more importantly, an unstable pelvic ring fracture, was significantly longer in patients who did not have an initial PXR. The early identification of patients with an unstable pelvic ring fracture is particularly important. These major fractures are known to have a high risk for associated hemorrhage[7,10,11].
It is well recognized that the immediate identification of a potential pelvic source of bleeding in the trauma resuscitation room is critical [12-14]. As such, timely pelvic imaging is a crucial step in current pelvic trauma protocols. Early consultation of orthopedic surgery and interventional radiology to help provide rapid hemorrhage control, as well as prompt activation of the massive transfusion protocol, are all important aspects in the acute management of patients with pelvic hemorrhage.

In our study, we found that a considerable number of patients with pelvic ring fracture that required pelvic angiographic embolization did not have an initial PXR. In the absence of an initial PXR, the time to pelvic angiographic embolization was longer, however, this only reached statistical significance in all pelvic (ring and combined) fracture patients that required this intervention. It should be noted that this merely shows an association between the absence of an initial PXR and a delay to pelvic angiography. Although this is an important finding, it would be too premature to conclude from this retrospective study that an initial PXR would have prevented a delay to angiography in all patients.

The results of our study also showed that the majority of patients with pelvic ring fracture who required noninvasive stabilization did have an initial PXR and a pelvic binder appropriately placed before CT scanning. Rapid application of this device in the ED can help control (mainly venous) hemorrhage in selected patients.

Previous studies

A number of recent studies have examined the need for routine PXR in blunt trauma patients undergoing abdominopelvic CT scanning during their initial evaluation [2-5]. It has been found that PXR had a limited sensitivity for the detection of pelvic fractures (of 64-68%) in direct comparison to the CT scan [2,5]. Of all blunt trauma patients included in these studies a limited number had a (major) pelvic fracture. Furthermore, the number of pelvic fracture patients in need of an immediate intervention prior to CT scanning was low or not reported.
In their study, Guillamondegui et al indicated that the routine PXR prior to CT scanning could be deferred in the presence of hemodynamic stability and a negative pelvic physical examination [5]. Of the 69 pelvic fracture patients in their study, they found only one patient with a hip dislocation (missed on physical examination). The needs for a pelvic binder or pelvic embolization were not addressed in this study. Kessel et al concluded that CT is a superior diagnostic modality and can safely replace PXR despite even physical findings or the patient's neurologic condition [2]. In this study of 129 pelvic fracture patients, no PXR findings resulted in the need for an immediate intervention, although these further remained undefined. In a prospective study, Barleben et al reported that their algorithm, based on hemodynamic criteria and physical examination findings, allowed them to safely eliminate 94% of PXR's in blunt trauma patients [4]. Sixty patients in their study had a pelvic fracture. Of 4 patients with a hip dislocation, one (without a PXR) was missed on physical examination. A further, 3 patients required pelvic embolization (one without a PXR) and only one patient (without a PXR) required a pelvic binder. Finally, in a study by Fu et al, PXR did not appear to affect the decision making process in blunt abdominal trauma patients [3]. The nature of the pelvic fracture or the need for hip reduction, application of a pelvic binder or pelvic embolization was not addressed in this study.

In the general blunt trauma population, many patients sustained obvious low-energy trauma, are alert, and can be reliably examined to determine the need for a PXR. These patients most likely do not require a PXR. However, more caution is advised in patients who sustained significant high-energy trauma and may have multiple injuries, including pelvic fractures. In clinical practice, overreliance on physical examination to determine the need for an initial PXR may lead to the delayed recognition of (major) pelvic fractures. In the majority of these high-risk patients, a routine PXR remains indicated even in the presence of hemodynamic stability or the absence of significant clinical findings.
There is no question that the CT scan is able to detect (minor) pelvic fractures more accurately than PXR. However, the PXR can provide a rapid impression of the overall

morphology of the pelvic fracture in the trauma resuscitation room. In most institutions, performing a CT scan requires laborious transport to the CT scanner. Conversely, PXR is an easily accessible and inexpensive modality that can rapidly detect pelvic fractures that require immediate interventions. This modality remains a useful screening tool that allows early planning and priority setting.

Limitations

The retrospective design of our study limited our ability to clarify the precise decision-making process. Also, we were unable to collect data concerning the findings on physical examination. Furthermore, the need and prioritization of the PXR and CT scan, as well as the interventions performed, were not standardized but were at the discretion of the treating physician. Lastly, this study was not designed to determine whether a delay to diagnosis of a (major) pelvic fracture or immediate intervention was associated with worse clinical outcomes.

CONCLUSIONS

In our study, many pelvic fracture patients undergoing abdominopelvic CT scanning did not have an initial PXR. The selective use of PXR was associated with a significant delay in the recognition of (major) pelvic fractures, including those with associated hip dislocations and (potential) pelvic bleeding. The PXR remains a useful screening tool to rapidly determine the need for immediate interventions and to allow early planning prior to CT scanning.

REFERENCES

1. American College of Surgeons. Advanced Trauma Life Support: ATLS Instructor Manual 9th ed;Chicago, IL.
2. Kessel B, Sevi R, Jeroukhimov I, Kalganov A, Khashan T, Ashkenazi I, et al. Is routine portable pelvic X-ray in stable multiple trauma patients always justified in a high technology era? Injury 2007;38:559-63.
3. Fu CY, Wang SY, Hsu YP, Liao CH, Lin BC, Kang SC, et al. The diminishing role of pelvic x-rays in the management of patients with major torso injuries. Am J Emerg Med 2014;32:18-23.
4. Barleben A, Jafari F, Rose J, Jr., Dolich M, Malinoski D, Lekawa M, et al. Implementation of a cost-saving algorithm for pelvic radiographs in blunt trauma patients. J Trauma 2011;71:582-4.
5. Guillamondegui OD, Pryor JP, Gracias VH, Gupta R, Reilly PM, Schwab CW. Pelvic radiography in blunt trauma resuscitation: a diminishing role. J Trauma 2002;53:1043-7.
6. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS, Jr., Poka A, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30:848-56.
7. Manson T, O'Toole RV, Whitney A, Duggan B, Sciadini M, Nascone J. Young-Burgess classification of pelvic ring fractures: does it predict mortality, transfusion requirements, and non-orthopaedic injuries? J Orthop Trauma 2010;24:603-9.
8. Letournel E JR. Fractures of the acetabulum. 2nd ed. Elson RA, translator, editor. New York: Springer; 1993 Translation of Les fractures du cotyle.
9. Pehle B, Nast-Kolb D, Oberbeck R, Waydhas C, Ruchholtz S. [Significance of physical examination and radiography of the pelvis during treatment in the shock emergency room]. Unfallchirurg 2003;106:642-8.
10. Hamill J, Holden A, Paice R, Civil I. Pelvic fracture pattern predicts pelvic arterial haemorrhage. Aust N Z J Surg 2000;70:338-43.
11. Magnussen RA, Tressler MA, Obremskey WT, Kregor PJ. Predicting blood loss in isolated pelvic and acetabular high-energy trauma. J Orthop Trauma 2007;21:603-7.
12. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.
13. Verbeek D, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
14. Heetveld MJ, Harris I, Schlaphoff G, Balogh Z, D'Amours SK, Sugrue M. Hemodynamically unstable pelvic fractures: recent care and new guidelines. World J Surg 2004;28:904-9.

07
CHAPTER

IMAGING AND ENDOVASCULAR TREATMENT OF BLEEDING PELVIC FRACTURES

Review article

AMSTERDAM, THE NETHERLANDS

D.J. Wijffels,
D.O. Verbeek,
K.J. Ponsen,
J.C. Goslings,
O.M. van Delden

Academic Medical Center
University of Amsterdam
Amsterdam,
the Netherlands

Cardiovasc Intervent
Radiol 2019;
42: 10-18

2019

ABSTRACT

Pelvic fractures are potentially life-threatening injuries with high mortality rates, mainly due to intractable pelvic arterial bleeding. However, concomitant injuries are frequent and may also be the cause of significant blood loss. As treatment varies depending on location and type of hemorrhage, timely imaging is of critical importance. Contrast-enhanced CT offers fast and detailed information on location and type of bleeding. Angiography with embolization for pelvic fracture hemorrhage, particularly when performed early, has shown high success rates as well as low complication rates and is currently accepted as the first method of bleeding control in pelvic fracture- related arterial hemorrhage. In the current review imaging workup, patient selection, technique, results and complications of pelvic embolization are described.

INTRODUCTION

Major pelvic fractures occur in 4–9% of patients with blunt trauma, mainly high-speed traffic accidents or falls from height [1]. Considerable force is required to disrupt or fracture the pelvic ring, and over 50% of pelvic fracture patients incur multiple associated injuries [2,3]. Major pelvic fractures are life-threatening injuries, with reported mortality rates up to 46% [1,2,4-6]. Mortality is caused by ongoing pelvic bleeding in as many as 42% of patients [3,4]. However, bleeding may also occur from non-pelvic sources such as thoracic and abdominal injuries. To improve outcome, it is essential to rapidly identify the primary bleeding source. Plain films of chest and pelvis, along with focused assessment with sonography for trauma (FAST), have long been the mainstay of initial imaging assessment in hemodynamically unstable trauma patients, whereas contrast-enhanced CT (CECT) has generally been reserved for hemodynamically stable patients. CT has many advantages over FAST, and advances in CT technology as well as improved access have increased the role of CECT in hemodynamically unstable patients [7]. CECT provides detailed information about the location and type of hemorrhage as well as the extent of associated injuries and guides decisions on treatment. Controlling pelvic and other sources of hemorrhage through endovascular approaches has proven its effectiveness and is still improving, due to advances in patient selection, imaging equipment and embolization techniques [6,8-12]. In this article, we review the recent literature on optimal imaging assessment and algorithms as well as the technique, results and complications of endovascular treatment of pelvic fracture-related hemorrhage.

IMAGING ASSESSMENT

Various guidelines have been described with treatment decisions largely driven by hemodynamic status and imaging findings [6, 13-18]. Our local algorithm is shown in **Fig. 1**.

Imaging is crucial to differentiate abdominal from pelvic bleeding as well as venous from arterial bleeding as these factors determine the need for endovascular versus surgical intervention.

Over 90% of pelvic fractures are accurately diagnosed on plain films [17]. FAST detects hemoperitoneum with high sensitivity (90–93%), as a sign of significant organ injury [18]. In hemodynamically unstable pelvic trauma patients, FAST is especially useful to identify intraperitoneal bleeding which may require immediate laparotomy. FAST is unable, however, to reliably detect retroperitoneal hematoma, the presence of ongoing bleeding, the exact location of hemorrhage, and to differentiate arterial from venous bleeding [18].

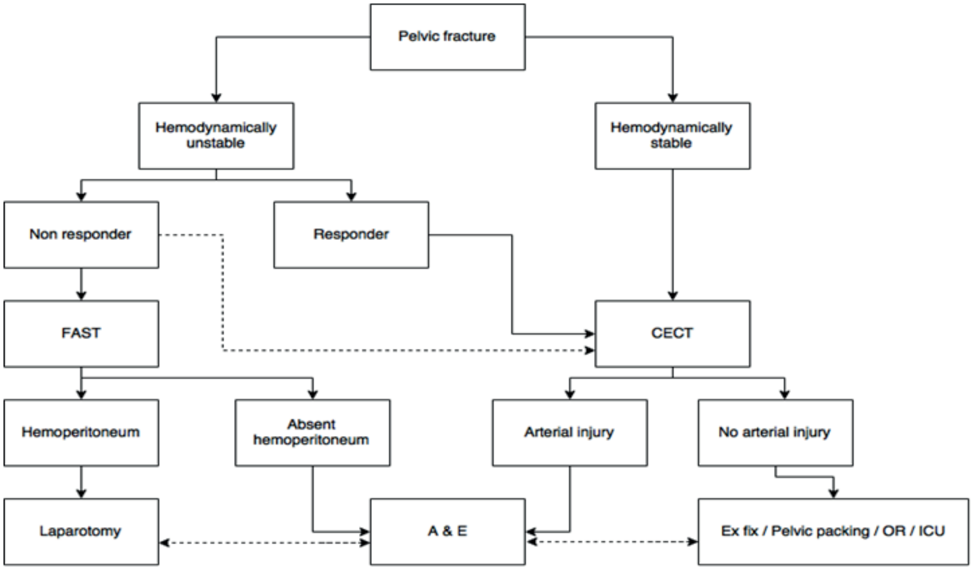


Figure 1. Local protocol for pelvic fracture work-up. A&E: Angiography and embolization. CECT: Contrast Enhanced Computed Tomography. FAST: Focused Assessment with Sonography in Trauma. (Non-) responder: To fluid resuscitation. Dashed line CECT: if hemodynamics allow. Other dashed lines: if required due to clinical condition

CECT is a much more accurate diagnostic test for the detection of arterial pelvic bleeding. The sensitivity of contrast extravasation ("blush") indicating arterial leakage is 80–90%, specificity 85–98% and accuracy 87–98% 14, [19-22]. Furthermore, an extensive and detailed map is provided on location and extent of all injuries including all pelvic bony and vascular anatomy including relevant anatomic variants.

Currently, immediate whole-body CT has become the diagnostic modality of choice in many trauma centers, even in hemodynamically unstable patients. Compared to conventional workup with selective use of CT, it has been shown to save significant time [7,24]. Retrospective studies and meta-analyses have shown an increase in the probability of survival of complex trauma patients with immediate whole-body CT scanning, although a recent multicenter randomized controlled trial failed to confirm this finding [23–26]. Various whole-body scanning protocols with sequential arterial and venous contrast phases and so-called split bolus protocols are used, in which one scanning phase combines features of arterial and venous phases. Scans are typically performed from the chest aperture to the pelvis with the arms raised over the head using 80–120 mls of contrast medium at injection rates of 4–6 mls/s. Image quality is reported to be better in sequential phase protocols com- pared to split bolus, but some studies suggest that venous phase imaging alone is reliable in detecting arterial hemorrhage, with sensitivity up to 100%, questioning the benefit of an extra-arterial phase, compared to single venous or split bolus [27,28].

Other relevant imaging findings of CT include vascular injuries such as vasospasm, false aneurysm, arteriovenous fistula or completely dissected arteries, so-called vascular "cutoff's". A large amount (>500 mL) of retroperitoneal hematoma on CT has a 45% probability for the presence of arterial injury and large transfusion requirement [29, 30].

ANGIOGRAPHY AND EMBOLIZATION

Indications

Pelvic fracture bleeding is most commonly of venous or bony origin [31, 33]. Less than 5% of patients have proven arterial injury, increasing to 59% in mechanically unstable pelvic ring fractures [1,5,6,8,10,13,33-35]. Furthermore, pelvic arterial bleeding is found in over 70% of pelvic fracture patients with transient or no response to fluid resuscitation. Angiography and embolization (AE) are currently accepted in many trauma centers as the preferred method for controlling pelvic arterial hemorrhage [8, 9, 14].

Indications for angiography include the presence of a (major) pelvic ring fracture with ongoing clinical signs of hemorrhage in the absence of a non-pelvic (thoracic or abdominal) bleeding source. Importantly, angiography should also be considered in patients with continued bleeding whose prior imaging did not demonstrate pelvic arterial bleeding [10–13, 33, 35].

Some authors advocated AE in the presence of a contrast blush irrespective of the patient's hemodynamic status [3, 19–22] and in the presence of other vascular injuries such as a large pelvic hematoma, false aneurysms or "cutoff's" may also require AE. Yet, the need for angiography in hemodynamically stable patients and a small contrast blush is a matter of continued debate. As a result of improvements in CT technology and the increased use of CT, more vascular injuries are found. Some authors have shown that not all contrast blushes seen on CT required embolization, and conversely, some patients without contrast extravasation required angiography [33, 36, 37]. Nevertheless, CT remains the gold standard for determining the presence of ongoing bleeding. In our institution, patients are generally directly referred for AE when a contrast blush is detected, with pelvic binders usually already placed. Depending on the hemodynamics and the fracture type and severity, AE is preceded or followed by external fixation of the pelvis given that AE has also been shown to be effective in patients failing to stabilize after external fixation.

Typically, injury is found to the internal iliac artery (IIA) or its branches [6, 14]. To some extent, pelvic fracture type may be related to the location of the vascular injury, with antero-posterior or so-called open book-type fractures being associated with bleeding from the posterior division of the IIA, and lateral compression or side impact fractures correlated with hemorrhage from the anterior division of the IIA. From the posterior branches of IIA, the superior gluteal artery and the lateral sacral artery are commonly injured. The superior gluteal artery is at risk with fractures involving the greater ischiadic notch [38]. Most commonly injured arteries from the anterior division of the IIA are the internal pudendal and the obturator artery [10, 14, 30]. High-grade vertical shear-type fractures are most often associated with arterial bleeding [6].

Access

The presence of a sheet wrap or pelvic binder usually does not prevent gaining access to the common femoral artery for angiography. Alternatively, a brachial artery approach can be used. Ultrasound guidance is useful for obtaining vascular access, especially in hypotensive patients with collapsed vessels and no palpable femoral pulse. Placement of a 5-Fr sheath suffices in most cases.

Angiographic technique

Procedures are generally performed with continuous monitoring of vital signs, and general anesthesia or sedation is not mandatory.

Direct selective catheterization of the IIA is mandatory as most arterial injuries are to the IIA or its branches [6, 14]. Both IIAs can usually be selected from a unilateral femoral access with standard 4 of 5-Fr diagnostic catheters. If the location of the hemorrhage is known, gaining contralateral access is advised to facilitate selecting the IIA. CT findings should act as a guide and should avoid unnecessary imaging and use of contrast, as trauma patients are prone for developing contrast-induced nephropathy (CIN) [39]. Obtaining an aortogram with a standard pigtail catheter is indicated only when the bleeding source is not detected during selective series of the IIA's or when the patient does not stabilize after embolization of a bleeding source from the IIA's. Lumbar arteries and branches of the external iliac artery should additionally be selected based on CT findings. Extravasation from the common femoral artery or side branches or contralateral vessels is uncommon but should be considered in the absence of other bleeding sources. When active extravasation is not detected at angiography, despite a contrast blush on CT, hemorrhage can be provoked by powerful selective hand injections of the suspected vessel, disrupting recently formed unstable clots. Normal blood pressure should be maintained in order to avoid obscuring the hemorrhage. However, normalization of blood pressure by aggressive resuscitation can also lead to rebleeding or disruption of newly formed blood clots elsewhere, so caution should be

exercised. Bladder catheterization may be helpful to prevent obscuring the bleeding due to a contrast-filled bladder. Subtraction artifacts due to bowel movements may hamper visibility, and unsubtracted images can be helpful.
Besides direct contrast extravasation, other signs of arterial injury, such as false aneurysms or "cutoff" should also be identified and treated as these have a high propensity for rebleeding when left untreated.

Embolization technique

Depending on the hemodynamic status of the patient and the time pressure, embolization is best performed selectively or non-selectively. Time permitting, selective embolization is preferred when there are only one or a few focal bleeding vessels (**Fig. 2**), when hemodynamics are stable. Superselective embolization, which often requires use of 2–3-Fr micro-catheters through a coaxial system, is technically more demanding and therefore time-consuming and is associated with a higher incidence of recurrent pelvic arterial hemorrhage [13].

Non-selective embolization (**Fig. 3**) is less time-consuming and can be performed using standard 4 or 5 Fr. catheters is preferred in hemodynamically unstable patients with ongoing hemorrhage. Non-selective unilateral embolization of the whole IIA or of the entire posterior or anterior division of the IIA can safely be performed in an emergency or if multiple vascular injuries or diffuse hemorrhage is found, which may occur in up to 40% of cases [10, 34]. Non-selective bilateral embolization of the entire IIA is a last resort

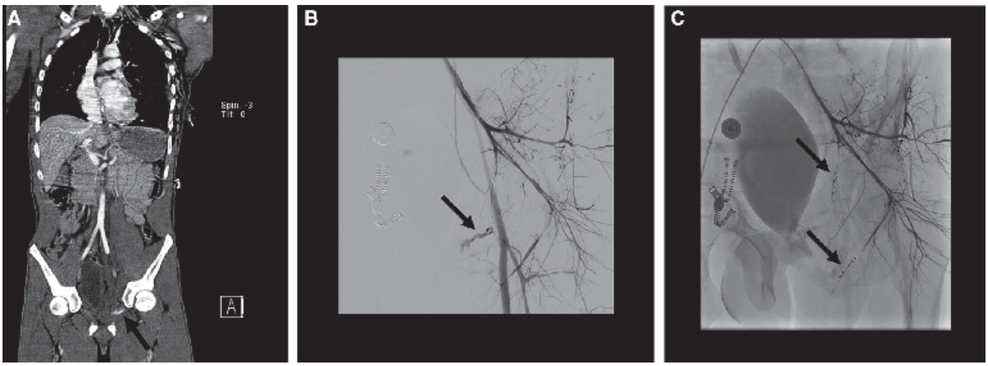


Figure 2. A. coronal whole-body CECT of a hemodynamically stable trauma patient with a fracture of the left superior pubic ramus with pelvic hematoma and a contrast blush (black arrow). B. Subsequent selective angiogram of the left internal iliac artery (with retrograde filling of the external iliac artery) shows constricted vessels and a focal contrast extravasation "blush" (black arrow) suitable for superselective embolization with coils and C. selective angiogram of the left internal iliac artery after selective embolization with coils (black arrows)

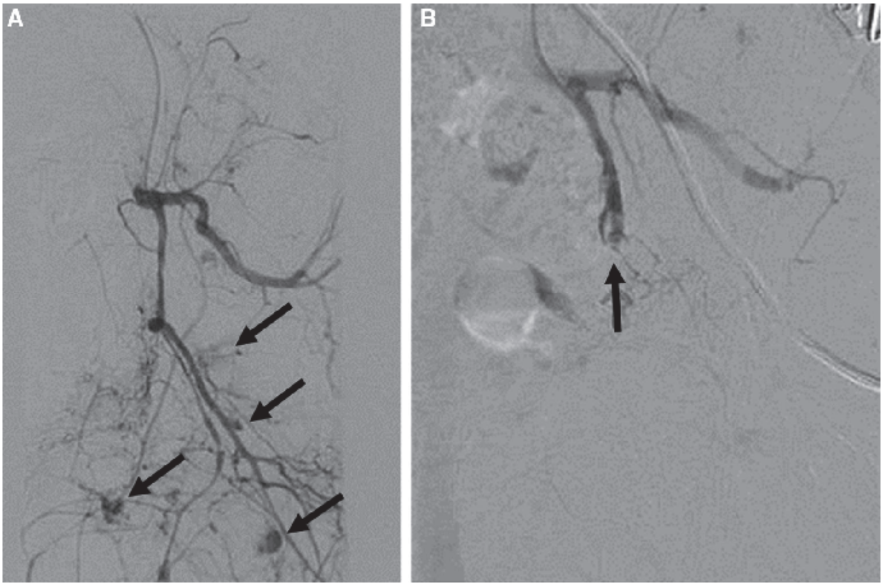


Figure 3. A. Selective angiogram of the left internal iliac artery in a hemodynamically abnormal patient with pelvic fracture shows many areas of contrast extravasation (black arrows) from the anteriordivision not suitable or superselective embolization, and B. selective angiogram of the left internal iliac artery shows complete occlusion (black arrow) of the anterior branch after embolization with gelfoam

for severe bleeding, but a widely accepted method without significant complications [40]. Superselective bilateral distal embolization is best avoided, as collateral blood supply from the contralateral IIA would be compromised, leading to an increased risk of tissue necrosis. Cessation of contrast extravasation from the affected vessel during the procedure is proof of technical success.

Embolic agents

Both resorbable embolic agents gelatin sponge and non- resorbable embolic agents (stainless steel or platinum coils, vascular plugs and liquids agents) can be used for embolization. Typically, resorbable gelatin sponge slurry is injected to avoid permanent arterial occlusion and ischemia. Gelatin sponge slurry is an emulsion of gelatin sponge (cut to small cubes or torpedoes) and contrast agent, produced by mixing them. It can easily be injected through regular diagnostic 4- or 5-French catheters or a micro- catheter using a 1-ml syringe. Advantages are the speed of use and the relative independence from coagulation, making it a suitable agent in patients with coagulopathy. As it is a relatively non-selective embolic agent, it is particularly useful in case of multiple bleeding vessels or diffuse bleeding. An additional advantage over other embolic agents is the fact that it is bio-absorbable allowing for recanalization of occluded vessels after some time.

Coils are appropriate embolic agents when there are only one or a few focal bleeding vessels and for treating false aneurysms or "cutoff" vessels [12]. The main advantage of coils is that they allow for very precise positioning. Both regular pushable (0.035") fibered coils and micro-coils can be used although vessel occlusion is usually obtained more quickly with 0.035" coils compared with micro-coils. The use of detachable coils is usually not required. A disadvantage of coils is the fact that their efficacy depends on the patient's coagulation, as clot needs to be formed in the coils before hemostasis is achieved. In the presence of coagulopathy, which frequently occurs in trauma patients, a combination of coil placement followed by injection of gelatin sponge can be very useful. Vascular plugs share many properties with coils and can also be used in some situations, where use of micro-catheters is not required. Other less frequently used agents are liquid agents like glue, which can be used fast, both selectively and non-selectively and in coagulopathic patients, but operator experience is required to prevent reflux and non- target embolization.
In rare situations, stent grafts may rarely be used in the femoral or external iliac arteries, but this is beyond the scope of the current review.

7

Results and outcome

It is difficult to assess outcome of AE as comparison between series is hampered by differences in patient population and because the outcome is often determined by other factors then pelvic hemorrhage alone, such as associated traumatic injuries. No randomized controlled trials have been conducted, and it is unlikely that these will be performed. Nevertheless, AE is found to be highly effective. Technical success is between 90 and 100% [8, 12, 16, 41, 42], while clinical success rates in terms of improved vital signs and decreased transfusion requirement are in the range of 84–100% [12, 34, 41]. Repeat angiography rates for ongoing or recurrent bleeding range between 0 and 23%, with a recent review reported 10% [13, 35, 41, 43].

Mortality rates among embolized patients vary widely between 4 and 56%, but a low number of reported deaths are due to exsanguinating pelvic hemorrhage (**Table 1**) [2]. External fixation of the pelvis to treat bleeding effectively reduces fracture displacement and decreases the volume of the pelvis, but this has not been shown to result in arterial hemorrhage control and pelvic packing compared with AE showed no significant differences in mortality and blood transfusion [44]. Others report favorable results combining both methods or using pelvic packing alone [15, 45].

Table 1. Overview of recent literature analyzing pelvic fracture related hemorrhage

Author	P#	Angio.	Embol.	T.S.	C.S.	Mortal.	Repeat	Compl	OM	PRM
Agolini [8]	806	35 (4.3%)	15 (43%)	15 (100%)	100%	7/15 (47%)	0	NA	74/806 (9.2%)	0
Wong [9]	507	22 (4.3%)	17 (77%)	17 (100%)	100%	3/17 (17.6%)	0	0	NA	0
Velmahos [12]	100	100 (100%)	80 (80%)	95%	NA	2 (14%)	4 (5%)	5 (6.3%)	NA	0
Cook [6]	150	23 (15%)	18 (78%)	18 (100%)	16 (89%)	10/18 (56%)	NA	2 (11%)	33/77 (43%)	0
Hagiwari [14]	234	81 (35%)	61 (75%)	NA	NA	13/61 (21%)	NA	NA	13/234 (5.6%)	NA
Kimbrell [11]	1017	92 (9%)	55 (60%)	55 (100%)	NA	10/55 (18%)	7/55 (13%)	4/55 (7.3%)	14/92 (15%)	NA
Shapiro [43]	678	31 (4.6%)	16 (52%)	17/20 (85%)	NA	2/16 (13%)	7/31 (23%)	NA	66/678 (9.7%)	NA
Fangio [34]	311	32 (10.3%)	25 (78%)	24/25 (96%)	21 (84%)	9/25 (36%)	0	1 (4%)	10/32 (31%)	NA
Totterman [10]	1260	46 (3.7%)	31 (67%)	29/31 (94%)	29/31 (94%)	5/31 (16%)	3/31 (9.7%)	0	NA	0
Verbeek [37]	217	58 (26.7%)	48 (83%)	46/48 (96%)	46/48 (96%)	2/48 (4.2%)	5/58 (8.6%)	NA	69/217 (32%)	2/48
Salim [55]	603	137 (23%)	85 (62%)	85/85 (100%)	NA	10/85 (11.8%)	NA	1 (1.2%)	54/603 (9%)	NA
Osborn [44]	20	20 (100%)	13 (65%)	NA	NA	NA	NA	NA	6/20 (30%)	2
Fang [13]	964	174 (18%)	140 (80%)	140/140 (100%)	NA	26/140 (18.6%)	26/140 (18.6%)	0	NA	12
Jeske [15]	1476	42 (2.8%)	41 (98%)	41/42 (98%)	NA	13/41 (31.7%)	3/41 (7.3%)	10 (24%)	NA	0
Hauschild [3]	152	17 (11.2%)	17 (100%)	17/17 (100%)	17 (100%)	3/17 (17.6%)	0	6 (35%)	NA	0
Tanizaki [46]	140	68 (49%)	68 (100%)	NA	NA	12/68 (17.6%)	0	0	NA	1
Ierardi [41]	168	NA	160	160 (100%)	133 (95%)	15 (9.4%)	3 (1.9%)	0	NA	7
Lustenberger [16]	173	16 (9.2%)	16 (100%)	16 (100%)	16 (100%)	4/16 (25%)	NA	0	NA	0

NA: data not available, P#: Number of pelvic fractures, Angio: Angiography performed, Embol.: Embolization, T.S.: Technical success, C.S.: Clinical success, Mortal.: Mortality in embolization group, Repeat: Angiography, Compl.: Number of complications, OM: Overall mortality. PRM: Pelvic related mortality

An important predictor for the outcome in pelvic trauma patients is the time between arrival in the trauma bay and angiography suite. Tanizaki showed that patients who arrived late in angiography suite had a higher mortality than those arriving within 60 min [46]. Agolini found a mortality of 14% if the patient's arrival in the angiosuite was within 3 h, increasing to 75% after 3 h [8]. In patients undergoing repeat angiography, blood transfusion rate, ICU stay and mortality were significantly higher than in those who underwent a single procedure [10, 12, 13, 35, 43]. Increased age, initial hemodynamic instability and the need for blood transfusion have also been also positively correlated with an increased mortality [8, 9, 14].

Complications

In more than 95% of the embolized patients, no significant complications directly related to the procedure are observed [12, 33, 34, 42, 47, 48].

Angiography complications including contrast allergy, contrast-induced nephropathy (CIN) and puncture site related complications (hematoma, false aneurysm and infection) have been reported, but data are very limited and the actual prevalence may be higher due to underreporting [6, 12]. CIN has been reported in 5.1% of trauma patients after CECT [49], but recent studies show an incidence of 20–24% in trauma patients undergoing CECT and subsequent

AE [15, 39]. Hypovolemic shock, multi-organ failure and volume depletion may also contribute to renal impairment.

Embolization complications are predominantly ischemic. Ischemia and necrosis of gluteal muscle, sacral skin and bladder wall, uterus, femoral head and leg have been reported [6, 15, 34, 50, 51]. Gluteal muscle ischemia or necrosis has a reported incidence of 3–6% [6, 15, 47, 48, 52], but the initial trauma itself also disrupts local vasculature. Although embolization of the IIA may worsen recovery, gluteal ischemia has only been reported after bilateral embolization of the IIA. Erectile dysfunction has frequently been described after bilateral embolization [47], but is probably due to the injury itself rather than the embolization [48, 53, 54]. Neurologic complications including lower leg paresthesia and paresis have been described, but no significant differences have been observed between embolized and non-embolized patients [3, 48].

CONCLUSION

Pelvic angiography and subsequent embolization is a safe, rapid and effective technique for patients with pelvic fracture-related arterial hemorrhage in both hemodynamically stable and unstable patients. The choice between selective or non-selective embolization is dictated by the level of urgency and angiographic findings, and a variety of embolic agents can be used. CECT is crucial to show and localize arterial bleeding.

REFERENCES

1. Demetriades D, Karaiskakis M, Toutouzas K, Alo K, Velmahos G, Chan L. Pelvic fractures: epidemiology and predictors of associated abdominal injuries and outcomes. J Am Coll Surg 2002;195:1-10.
2. Giannoudis PV, Grotz MR, Tzioupis C, Dinopoulos H, Wells GE, Bouamra O, et al. Prevalence of pelvic fractures, associated injuries, and mortality: the United Kingdom perspective. J Trauma 2007;63:875-83.
3. Hauschild O, Strohm PC, Culemann U, Pohlemann T, Suedkamp NP, Koestler W, et al. Mortality in patients with pelvic fractures: results from the German pelvic injury register. J Trauma 2008;64:449-55.
4. Holstein J, Culemann U, Pohlemann T. What are Predictors of Mortality in Patients with Pelvic Fractures? Clin Orthop Relat Res. 2012;470:2090-7.
5. Poole GV, Ward EF, Muakkassa FF, Hsu HS, Griswold JA, Rhodes RS. Pelvic fracture from major blunt trauma. Outcome is determined by associated injuries. Ann Surg 1991;213:532-8; discussion 8-9.
6. Cook RE, Keating JF, Gillespie I. The role of angiography in the management of haemorrhage from major fractures of the pelvis. J Bone Joint Surg Br 2002;84:178-82.
7. Fung Kon Jin PH, Goslings JC, Ponsen KJ, van Kuijk C, Hoogerwerf N, Luitse JS. Assessment of a new trauma workflow concept implementing a sliding CT scanner in the trauma room: the effect on workup times. J Trauma 2008;64:1320-6.
8. Agolini SF, Shah K, Jaffe J, Newcomb J, Rhodes M, Reed JF, 3rd. Arterial embolization is a rapid and effective technique for controlling pelvic fracture hemorrhage. J Trauma 1997;43:395-9.
9. Wong YC, Wang LJ, Ng CJ, Tseng IC, See LC. Mortality after successful transcatheter arterial embolization in patients with unstable pelvic fractures: rate of blood transfusion as a predictive factor. J Trauma 2000;49:71-5.
10. Totterman A, Dormagen JB, Madsen JE, Klow NE, Skaga NO, Roise O. A protocol for angiographic embolization in exsanguinating pelvic trauma: a report on 31 patients. Acta orthopaedica 2006;77:462-8.
11. Kimbrell BJ, Velmahos GC, Chan LS, Demetriades D. Angiographic embolization for pelvic fractures in older patients. Archives of surgery (Chicago, Ill : 1960) 2004;139:728-32; discussion 32-3.
12. Velmahos GC, Toutouzas KG, Vassiliu P, Sarkisyan G, Chan LS, Hanks SH, et al. A prospective study on the safety and efficacy of angiographic embolization for pelvic and visceral injuries. J Trauma 2002;53:303-8; discussion 8.
13. Fang JF, Shih LY, Wong YC, Lin BC, Hsu YP. Repeat transcatheter arterial embolization for the management of pelvic arterial hemorrhage. J Trauma 2009;66:429-35.
14. Hagiwara A, Minakawa K, Fukushima H, Murata A, Masuda H, Shimazaki S. Predictors of death in patients with life-threatening pelvic hemorrhage after successful transcatheter arterial embolization. J Trauma 2003;55:696-703.
15. Jeske HC, Larndorfer R, Krappinger D, Attal R, Klingensmith M, Lottersberger C, et al. Management of hemorrhage in severe pelvic injuries. The Journal of trauma 2010;68:415-20.
16. Lustenberger T, Wutzler S, Stormann P, Laurer H, Marzi I. The role of angio-embolization in the acute treatment concept of severe pelvic ring injuries. Injury 2015;46 Suppl 4:S33-8.
17. Resnik CS, Stackhouse DJ, Shanmuganathan K, Young JW. Diagnosis of pelvic fractures in patients with acute pelvic trauma: efficacy of plain radiographs. AJR American journal of roentgenology 1992;158:109-12.
18. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. The utility of FAST for initial abdominal screening of major pelvic fracture patients. World journal of surgery 2014;38:1719-25.

19. Shanmuganathan K, Mirvis SE, Sover ER. Value of contrast-enhanced CT in detecting active hemorrhage in patients with blunt abdominal or pelvic trauma. AJR American journal of roentgenology 1993;161:65-9.
20. Cerva DS Jr, Mirvis SE, Shanmuganathan K, Kelly IM, Pais SO. Detection of bleeding in patients with major pelvic fractures: value of contrast-enhanced CT. AJR Am J Roentgenol. 1996;166(1):131–5.
21. Stephen DJ, Kreder HJ, Day AC, et al. Early detection of arterial bleeding in acute pelvic trauma. J Trauma. 1999;47(4):638–42.
22. Pereira SJ, O'Brien DP, Luchette FA, et al. Dynamic helical computed tomography scan accurately detects hemorrhage in patients with pelvic fracture. Surgery. 2000;128(4):678–85.
23. Huber-Wagner S, Lefering R, Qvick L-M, et al. Effect of whole- body CT during trauma resuscitation on survival: a retrospective, multicentre study. The Lancet. 2009;373(9673):1455–61.
24. Sierink JC, Treskes K, Edwards MJ, et al. Immediate total-body CT scanning versus conventional imaging and selective CT scanning in patients with severe trauma (REACT-2): a randomised controlled trial. Lancet. 2016; 388(1045):673-83.
25. Caputo ND, Stahmer C, Lim G, Shah K. Whole-body computed tomographic scanning leads to better survival as opposed to selective scanning in trauma patients: a systematic review and meta-analysis. J Trauma Acute Care Surg. 2014;77(4):534–9.
26. Huber-Wagner S, Biberthaler P, Haberle S, et al. Whole-body CT in haemodynamically unstable severely injured patients,a retrospective, multicentre study. PLoS ONE. 2013;8(7).
27. Boscak AR, Shanmuganathan K, Mirvis SE, et al. Optimizing trauma multidetector CT protocol for blunt splenic injury: need for arterial and portal venous phase scans. Radiology. 2013;268(1):79–88.
28. Beenen LF, Sierink JC, Kolkman S, et al. Split bolus technique in polytrauma: a prospective study on scan protocols for trauma analysis. Acta Radiol. 2015;56(7):873-80
29. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. Predicting the need for abdominal hemorrhage control in major pelvic fracture patients: the importance of quantifying the amount of free fluid. J Trauma Acute Care Surg. 2014;76(5):1259–63.
30. Sheridan MK, Blackmore CC, Linnau KF, Hoffer EK, Lomos- chitz F, Jurkovich GJ. Can CT predict the source of arterial hemorrhage in patients with pelvic fractures? Emerg Radiol. 2002;9(4):188–94.
31. Huittinen VM, Slatis P. Postmortem angiography and dissection of the hypogastric artery in pelvic fractures. Surgery. 1973;73(3):454–62.
32. Dyer GS, Vrahas MS. Review of the pathophysiology and acute management of haemorrhage in pelvic fracture. Injury. 2006;37(7):602–13.
33. Miller PR, Moore PS, Mansell E, Meredith JW, Chang MC. External fixation or arteriogram in bleeding pelvic fracture: initial therapy guided by markers of arterial hemorrhage. J Trauma. 2003;54(3):437–43.
34. Fangio P, Asehnoune K, Edouard A, Smail N, Benhamou D. Early embolization and vasopressor administration for manage- ment of life-threatening hemorrhage from pelvic fracture. J Trauma. 2005;58(5):978–84
35. Gourlay D, Hoffer E, Routt M, Bulger E. Pelvic angiography for recurrent traumatic pelvic arterial hemorrhage. J Trauma. 2005;59(5):1168–73
36. Brasel KJ, Pham K, Yang H, Christensen R, Weigelt JA. Significance of contrast extravasation in patients with pelvic fracture. J Trauma. 2007;62(5):1149–52.
37. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. Management of pelvic ring fracture patients with a pelvic "blush" on early computed tomography. J Trauma Acute Care Surg. 2014;76(2):374–9.
38. Slater SJ, Barron DA. Pelvic fractures—a guide to classification and management. Eur J Radiol. 2010;74(1):16–23.

39. van der Vlies CH, Saltzherr TP, Reekers JA, Ponsen KJ, van Delden OM, Goslings JC. Failure rate and complications of angiography and embolization for abdominal and pelvic trauma. J Trauma Acute Care Surg. 2012;73(5):1208–12.

40. Velmahos GC, Chahwan S, Hanks SE, et al. Angiographic embolization of bilateral internal iliac arteries to control life- threatening hemorrhage after blunt trauma to the pelvis. Am Surg. 2000;66(9):858–62.

41. Ierardi AM, Piacentino F, Fontana F, et al. The role of endovascular treatment of pelvic fracture bleeding in emergency settings. Eur Radiol. 2015; 25 (7): 1854-64

42. Papakostidis C, Kanakaris N, Dimitriou R, Giannoudis PV. The role of arterial embolization in controlling pelvic fracture haemorrhage: a systematic review of the literature. Eur J Radiol. 2012;81(5):897–904.

43. Shapiro M, McDonald AA, Knight D, Johannigman JA, Cuschieri J. The role of repeat angiography in the management of pelvic fractures. J Trauma. 2005;58(2):227–31.

44. Osborn PM, Smith WR, Moore EE, et al. Direct retroperitoneal pelvic packing versus pelvic angiography: a comparison of two management protocols for haemodynamically unstable pelvic fractures. Injury. 2009;40(1):54–60.

45. Tai DK, Li WH, Lee KY, et al. Retroperitoneal pelvic packing in the management of hemodynamically unstable pelvic fractures: a level I trauma center experience. J Trauma. 2011;71(4):E79–86.

46. Tanizaki S, Maeda S, Matano H, Sera M, Nagai H, Ishida H. Time to pelvic embolization for hemodynamically unstable pelvic fractures may affect the survival for delays up to 60 min. Injury. 2014;45(4):738–41.

47. Matityahu A, Marmor M, Elson JK, et al. Acute complications of patients with pelvic fractures after pelvic angiographic embolization. Clin Orthop Relat Res. 2013;471(9):2906–11.

48. Travis T, Monsky WL, London J, et al. Evaluation of short-term and long-term complications after emergent internal iliac artery embolization in patients with pelvic trauma. J Vasc Interv Radiol. 2008;19(6):840–7.

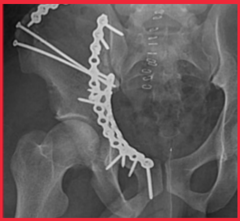
49. Hipp A, Desai S, Lopez C, Sinert R. The incidence of contrast- induced nephropathy in trauma patients. Eur J Emerg Med. 2008;15(3):134–9.

50. Sieber PR. Bladder necrosis secondary to pelvic artery embolization: case report and literature review. J Urol. 1994;151(2):422.

51. Obaro RO, Sniderman KW. Case report: avascular necrosis of the femoral head as a complication of complex embolization for severe pelvic haemorrhage. Br J Radiol. 1995;68(812):920–2.

52. Takahira N, Shindo M, Tanaka K, Nishimaki H, Ohwada T, Itoman M. Gluteal muscle necrosis following transcatheter angiographic embolisation for retroperitoneal haemorrhage associated with pelvic fracture. Injury. 2001;32(1):27–32.

53. Ramirez JI, Velmahos GC, Best CR, Chan LS, Demetriades D. Male sexual function after bilateral internal iliac artery embolization for pelvic fracture. J Trauma. 2004;56(4):734–9.



PART II

LATE OUTCOME AFTER ACETABULAR FRACTURE FIXATION

08

Modified Stoppa approach for operative treatment of acetabular fractures

09

Postoperative CT is superior for acetabular fracture reduction assessment and reliably predicts hip survivorship

10

Predictors for long-term hip survivorship following acetabular fracture surgery

08
CHAPTER

MODIFIED STOPPA APPROACH FOR OPERATIVE TREATMENT OF ACETABULAR FRACTURES

10-year experience and mid-term follow-up

AMSTERDAM, THE NETHERLANDS

D.O. Verbeek,
K.J. Ponsen,
M. van Heijl,
J.C. Goslings

Academic Medical Center
University of Amsterdam,
Amsterdam,
the Netherlands

Injury 2018;
49: 1137-40

2018

ABSTRACT

Introduction

The (modified) Stoppa approach for acetabular fracture surgery has gained significant popularity and early results have been encouraging but clinical outcome at extensive follow-up is scarce. The purpose of this study is to provide an update on our experience with this approach for operative treatment of acetabular fractures and to assess clinical outcome at mid-term follow-up.

Methods

In this retrospective study, all patients treated operatively for an acetabular fracture using the Stoppa approach over a 10-year period were included. Surgery details were reviewed and patients were contacted and requested to return for follow-up. Primary outcome was native hip survivorship, secondary outcome measures included; functional outcome (Merle d'Aubiginé, Harris hip) scores, health-related quality of life (short-form 36) and radiographic outcome (heterotopic ossification, hip osteoarthritis).

Results

Forty-five patients received operative fixation for 47 acetabular fractures using the Stoppa approach. Complications requiring surgical intervention were found in one patient (with a vascular lesion) intra-operatively and 3 patients (with wound infections (2) and diffuse bleeding (1)) post-operatively. Follow-up was 83% and 29/39 (74%) native hips survived at mean 59 months (SD 49) postoperatively. Excellent-good functional scores were found in 88% (Merle d'Aubiginé) and 76% (Harris hip) of patients who had retained their native hip. Most (6/8) short-form 36 indices in these patients were comparable to population norms. Of 29 native hips with radiographic follow-up (mean 59 months (SD 49), 4 (86%) had no-minimal radiographic abnormalities.

Conclusion

This study confirms that the Stoppa approach is a safe and effective technique for acetabular fracture fixation. Moreover, at mid-term follow-up, this approach is associated with satisfactory results in terms of hip survivorship as well as functional and radiographic outcome. As such, our findings reinforce the notion that this less invasive technique presents a valuable alternative to the ilioinguinal approach for the surgical treatment of acetabular fractures.

INTRODUCTION

In recent years, the (modified) Stoppa approach for the operative treatment of acetabular fractures has gained significant popularity. This intra-pelvic approach is particularly useful for treating acetabular fractures with anterior column involvement and is by some considered to be a superior alternative to the more traditionally used ilioinguinal exposure [1-3].

We previously shared our early experience with the Stoppa approach for the treatment of pelvic and acetabular fractures [4]. Over the past two decades it has been our preferred anterior approach to the acetabulum and has largely replaced the ilioinguinal exposure in our institution.

Advantages of the Stoppa approach have been well described and include its less invasive nature and improved visualization in the area of the quadrilateral plate and the posterior column [1-3,5]. The increased access to the acetabulum specifically allows direct (medial) buttressing of fractures with associated central protrusion of the femoral head. While several authors have reported early (radiographic) results of the Stoppa approach, clinical outcome at more extensive follow-up is scarce [2,5-7].

The purpose of this study was to provide an update on our experience with the Stoppa approach for operative treatment of acetabular fractures and to assess clinical outcome at mid-term follow-up. We primarily sought to determine native hip survivorship and secondarily evaluated functional outcome scores, health-related quality of life and radiographic outcome.

METHODS

After having obtained approval from our hospital's Institutional Review Board (NL 39690.018.12), patients who received operative treatment for an acetabular fracture over a 10-year period in our Level-1 trauma center were identified from our trauma database using operative procedure codes. Based on review of the operative reports, all consecutive patients who received open reduction and internal fixation utilizing the Stoppa approach were included in this study.

General indications for operative treatment of an acetabular fracture included more than 2 mm of displacement in the weightbearing dome and/or an incongruent hip joint.
The Stoppa approach was utilized for the same acetabular fracture types that may otherwise be treated through an ilioinguinal exposure. More specifically, fracture patterns

with involvement of the anterior column such as anterior column-posterior hemitransverse, associated both column and isolated anterior column or wall fractures, but also some T-shaped or transverse types were indicated for this surgical approach.

The surgical technique for the Stoppa approach as utilized in our institution has previously been described in detail [4]. In contrast to earlier descriptions, we routinely use a midline incision and isolate the femoral artery and vein. Also, the psoas muscle is mobilized circumferentially as needed. Our technique obviates the need for a separate lateral window in the majority of cases. All surgeries were performed by three experienced fellowship-trained surgeons including two of the senior authors (KP, JG).

Medical records of all included patients were reviewed for baseline characteristics, injury severity score (ISS), mechanism of injury (high or low-energy), time to surgery, duration of surgery, blood loss, transfused packed red blood cells, cell saver reinfusion, major complications (requiring surgical intervention), length of hospital stay and in-hospital mortality. Acetabular fractures were classified according to Letournel's system based on preoperative imaging [8].

The amount of residual displacement was measured on direct postoperative pelvic radiographs in the three standard (anteroposterior and iliac and obturator oblique) views by one of the co-authors (DV) who was not involved with the initial care of patients. Reductions were subsequently graded as anatomic (0-1mm), imperfect (2-3mm) or poor (>3mm) based on Matta's criteria [9].

Outcome measures

For the primary outcome of hip survivorship, patients were contacted through repeat mailings and by telephone to determine the most recent status of their operated hip. In patients who could not be reached, the most recent available pelvic radiographs were used for this purpose. To determine native hip survivorship, only patients were included with ≥1 year of follow-up or early (< 1 year) conversion to total hip arthroplasty (THA).

For the secondary outcomes of physical function and quality of life, patients who had retained their native hip and had ≥1 year follow-up were invited for clinical evaluation. Physical examination was performed by one of the co-authors (DV) and an investigator and functional outcome was assessed utilizing the Merle d'Aubiginé and Harris Hip score [10,11]. According to the Merle d'Aubiginé system, total scores for pain, gait and motion indicate an excellent (17-18 points), good (15-16 points), fair (13-14 points) or poor (<13 points) result. Similarly, for the Harris Hip score, results are graded as excellent (>90 points), good (80–89 points), fair (70–79 points) or poor (<70 points). Patients were also requested to complete the short form (SF)-36 as a measure of quality of life [12]. The SF-36 is a validated survey containing 36 health-related questions with higher scores in the various dimensions representing superior outcome. Additionally, patients who returned to clinic underwent pelvic radiography in the three standard views.

For radiographic outcome, the most recent available pelvic radiographs were examined by one of the co-authors (MH) for the presence of heterotopic ossification and osteoarthritis of the operatively treated hip. Patients with less than 1 year follow-up and those who had converted to THA were excluded from this analysis. Heterotopic ossification was classified utilizing the Brooker classification on the anteroposterior pelvic radiographs (Class I: Islands of bone within the soft tissues about the hip, Class II: bone spurs from the pelvis or proximal end of the femur, leaving at least 1 cm between opposing bone surfaces, Class III: bone spurs from the pelvis or proximal end of the femur, reducing the space between opposing bone surfaces to 1 cm and Class IV: apparent ankylosis of the hip) [13]. The presence of hip osteoarthritis was noted according to the Kellgren-Lawrence Grading Scale (Grade 1: doubtful narrowing of joint space and possible osteophytic lipping, Grade 2: definite osteophytes, definite narrowing of joint space, Grade 3: moderate multiple osteophytes, definite narrowing of joints space, some sclerosis and possible deformity of bone contour and Grade 4: large osteophytes, marked narrowing of joint space, severe sclerosis and definite deformity of bone contour [14].

Statistical analysis

Continuous variables are presented as mean (standard deviation; SD) or as median (interquartile range; IQR) depending on data distribution (Kolmogorov-Smirnov test) and nominal data as total numbers (n) with percentages (%). Independent t-tests were performed for comparing continuous variables, and chi-square tests or Fisher's exact tests were used for nominal variables (depending on frequency of occurrence within each subgroup). Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 19.0 (IBM Software, Armonk, NY). A p-value of <0.05 was considered to indicate a statistically significant result.

RESULTS

In total, 45 patients who received operative fixation for 47 acetabular fractures utilizing the Stoppa approach were included in the study. Mean age was 51 years (SD 17), 71% were male and the median ISS was 16 (IQR 21). Most patients (69%) had a high-energy mechanism of injury and the most common fracture type was an associated both column (68%), followed by T-shaped (16%), Transverse (8%), anterior column-posterior hemitransverse (5%) and anterior wall (3%).

Surgery details of all included patients are listed in **Table 1**. One patient required multiple transfusions for intra-operative bleeding resulting from an iliac vein injury. Three patients had at least one major postoperative complication. One patient had ongoing postoperative bleeding requiring surgical exploration (no obvious source was found). A further 2 patients developed a deep wound infection requiring multiple washouts. Prior to this, one of these patients had loss of reduction of the posterior column requiring revision surgery. Overall, patients remained admitted for a mean duration of 23 days (IQR 13) and no patients had deceased in hospital.

Table 1. Surgery details in 45 patients (47 acetabular fractures)

Time to surgery (days), median (IQR)	7 (7)
Duration of surgery (minutes), median (IQR)	221 (62)
Blood loss (ml), median (IQR)	1850 (1750)
Blood transfusion (packed cells), median (IQR)	0 (2)
Cell saver reinfusion (ml), median (IQR)	230 (800)
Postoperative fracture reduction, n (%)	
Anatomic (≤1mm)	23 (49)
Imperfect (1-3mm)	16 (34)
Poor (>3mm)	8 (17)

IQR: interquartile range

Hip survivorship

Native hip survivorship could be determined in 39 of 47 (83%) operatively treated acetabular fractures with a mean follow-up of 59 (SD 49; range 5-165) months. Of those, 10 hips (26%) had converted to THA resulting in a 74% hip survivorship rate. Indications for conversion to THA were symptomatic osteoarthritis (9 hips) and avascular necrosis of the femoral head (1 anatomically reduced hip). One hip converted early to THA (5 months postoperatively) for symptomatic osteoarthritis. In one patient operative fixation was performed in planned preparation for THA placement.

Overall, 2 (9%) anatomically, 5 (31%) imperfectly and 4 (50%) poorly reduced hips converted to THA. Patients who converted to THA were older (58 *vs* 46 years, p=0.02) and more frequently had a non-anatomic (imperfect or poor) reduction (42% *vs* 5%; p=0.01). Injury severity score (p=1.00), gender (p=0.49), mechanism of injury (p=0.58) and fracture pattern (associated *vs* elementary) (p=0.40) were not associated with conversion to THA.

Functional outcome

A total of 17 patients who had retained their native hip returned to clinic for evaluation at a mean of 93 (SD 48; range 31-165) months following acetabular fracture fixation. The Merle d'Aubiginé score was graded as excellent in 6 (35%), good in 9 (53%) and fair in 2 (12%) patients and the Harris Hip score was excellent in 10 (59%), good in 3 (18%), fair in 3 (18%) and poor in 1 (6%) patient (median 94; IQR 19). In total, excellent or good clinical outcome according to both scoring systems was found in respectively 88% and 76% of patients who had retained their native hip. Health-related quality of life scores by the various dimensions are presented in **Table 2**.

Table 2. Health-related quality of life in 17 patients who retained their native hip

	Study cohort	Prior studies [24,25]	Population norm [26]
Short Form-36, median (IQR)[a]			
Physical functioning	75 (45)	69-82	83
RL physical health	50 (100)	50-85	76
RL emotional problems	100 (33)	67-100	82
Vitality	65 (30)	58-77	69
Emotional well-being	80 (28)	80-87	77
Social functioning	88 (38)	88-92	84
Pain	78 (45)	62-85	75
General health	75 (35)	72-76	71

[a] Higher scores reflect better outcomes, RL: role limitations

Radiographic outcome

Adequate radiographic follow up was available in 29 native hips (mean follow-up 59 (SD 49; range 12-165) months). Two patients had moderate-severe signs of both heterotopic ossification (Class 3-4) and hip osteoarthritis (Grade 4-5). An additional two patients had one of these two findings in isolation. Overall, 86% of patients who had retained their native hip had no or only minimal radiographic abnormalities at follow-up.

DISCUSSION

Approximately ten years ago we presented our early results with the use of the Stoppa approach for pelvic fracture surgery and found it to be a safe and useful alternative to the ilioinguinal exposure [4]. In our current updated cohort of patients who received operative treatment for acetabular fractures, we found that those preliminary conclusions held up. In keeping with prior studies, surgery details related to procedure time and blood loss as well as major perioperative complications appeared at least equivalent between the two approaches [3,6,15-18]. We did however identify that the percentage of poor acetabular reductions (17%) was at the high end of rates found earlier in larger studies reporting on the Stoppa (7-16%) or other approaches (10-16%) [1-3,5-7,9,17,19,20].

While early advantages of the Stoppa over the ilioinguinal approach have been previously reported, clinical results in terms of native hip survivorship or functional and radiographic outcome at mid-to-long term follow-up have generally been lacking [1-3,5].

In the current study, hip survivorship at an average of 4.9 years (59 months) was 74% with 26% of hips converting to THA. To our knowledge, only four studies with a mean follow-up greater than 2 years reported this outcome measure following use of the Stoppa approach [2,5-7]. These prior studies found conversion rates of 10% (2/21) at 4.2 years, 15% (25/164) at 3.9 years, 16% (7/43) at 2.7 years and 17% (6/36) at 2.7 years [2,5-7]. In larger long-term follow-up studies of patients treated through various approaches conversion rates have however been slightly higher ranging from
16-24% [19-21].

The results in this study further demonstrate that functional outcome in patients who had retained their native hip at follow-up was particularly favorable. The great majority of these patients achieved good-excellent Merle d'Aubiginé and Harris Hip scores (88% and 76%). Prior Stoppa studies with mainly short-term follow-up have reported a great variety of functional results with good-excellent scores ranging from 50%-90% [1-3,5-7,17,18]. However, in concurrence with our investigation, most large acetabular fracture studies show that roughly three quarters of patients reach good-excellent functional outcome at mid-to long-term follow-up [19,22,23]. Our data with respect to quality of life further shows that most indices, apart from the physical components, reach values comparable to the general population, which is in keeping with previous publications in acetabular fracture surgery (table 2) [24-26].

In terms of radiographic outcome, it appears that the majority of our patients (86%) who retain their native hip at mid-term follow-up have (close to) normal appearing pelvic radiographs. Moderate-severe heterotopic ossification or hip osteoarthritis both occurred in 10% of our patients compared to respectively 4% and 19% in patients treated through various approaches [27].

Comparing clinical and radiographic outcome between acetabular fracture studies remains problematic. Clearly, duration of follow-up has a significant impact on hip survivorship (and other outcome measures) but baseline and fracture characteristics need to be considered as well. In the present cohort, patient age was relatively high and the great majority of patients had associated (both column) type fractures. Both these factors are known to be associated with poor postoperative reductions and unsatisfactory clinical outcome, potentially related to a higher prevalence of fracture impaction and comminution [3,5,6,16,21]. Also, associated fractures with involvement of the posterior column are generally more challenging to reduce through an anterior approach. Our results confirm that age and non-anatomic reductions are associated with conversion to THA. However, an associated fracture pattern was not correlated with this outcome given that elementary fracture types were uncommon in our cohort. Other important factors that need to be considered include selection bias such as whether patients are excluded who receive operative fixation prior to planned THA placement (one such patients was included in this study). This study was not designed to specifically determine the association between surgical approach and clinical outcome but when considering these various influencing factors it could be argued that in itself the Stoppa approach was likely only a minor (independent) contributor to the satisfactory mid-term results found in this study.

Limitations of this study include its retrospective design and the relatively small sample size. Furthermore, a considerable percentage of patients were lost to follow-up for our secondary outcome analysis. As mentioned previously selection bias may also have influenced our results. In terms of strengths of this study, we were able to determine the primary outcome of hip survivorship as well as radiographic outcome in most patients and it appears that our findings are generally well supported by prior acetabular fracture studies (particularly when taking prior considerations into account).

CONCLUSION

In conclusion, this study confirms that the (modified) Stoppa approach is a safe and effective technique for acetabular fracture fixation. Moreover, at mid-term follow-up, this intra-pelvic approach was associated with satisfactory results in terms of hip survivorship as well as functional and radiographic outcome. As such, our findings reinforce the notion that this less invasive technique presents a valuable alternative to the ilioinguinal approach for the surgical treatment of acetabular fractures.

REFERENCES

1. Cole JD, Bolhofner BR. Acetabular fracture fixation via a modified Stoppa limited intrapelvic approach. Description of operative technique and preliminary treatment results. Clin Orthop Relat Res 1994:112-23.
2. Hirvensalo E, Lindahl J, Kiljunen V. Modified and new approaches for pelvic and acetabular surgery. Injury 2007;38:431-41.
3. Sagi HC, Afsari A, Dziadosz D. The anterior intra-pelvic (modified rives-stoppa) approach for fixation of acetabular fractures. J Orthop Trauma 2010;24:263-70.
4. Ponsen KJ, Joosse P, Schigt A, Goslings JC, Luitse JS. Internal fracture fixation using the Stoppa approach in pelvic ring and acetabular fractures: technical aspects and operative results. J Trauma 2006;61:662-7.
5. Isaacson MJ, Taylor BC, French BG, Poka A. Treatment of acetabulum fractures through the modified Stoppa approach: strategies and outcomes. Clin Orthop Relat Res 2014;472:3345-52.
6. Laflamme GY, Hebert-Davies J, Rouleau D, Benoit B, Leduc S. Internal fixation of osteopenic acetabular fractures involving the quadrilateral plate. Injury 2011;42:1130-4.
7. Bastian JD, Tannast M, Siebenrock KA, Keel MJ. Mid-term results in relation to age and analysis of predictive factors after fixation of acetabular fractures using the modified Stoppa approach. Injury 2013;44:1793-8.
8. Letournel E. Acetabulum fractures: classification and management. Clin Orthop Relat Res 1980:81-106.
9. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 1996;78:1632-45.
10. Merle D’Aubigne R, Postel M. [Results of arthroplasty in coxitis and dislocation of the hip with four year experience]. Mem Acad Chir (Paris) 1953;79:460-8.
11. Harris WH. Traumatic arthritis of the hip after dislocation and acetabular fractures: treatment by mold arthroplasty. An end-result study using a new method of result evaluation. J Bone Joint Surg Am 1969;51:737-55.
12. Ware JE, Jr., Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med Care 1992;30:473-83.
13. Brooker AF, Bowerman JW, Robinson RA, Riley LH, Jr. Ectopic ossification following total hip replacement. Incidence and a method of classification. J Bone Joint Surg Am 1973;55:1629-32.
14. Kellgren JH, Lawrence JS. Radiological assessment of osteo-arthrosis. Ann Rheum Dis 1957;16:494-502.
15. Andersen RC, O’Toole RV, Nascone JW, Sciadini MF, Frisch HM, Turen CW. Modified stoppa approach for acetabular fractures with anterior and posterior column displacement: quantification of radiographic reduction and analysis of interobserver variability. J Orthop Trauma 2010;24:271-8.
16. Shazar N, Eshed I, Ackshota N, Hershkovich O, Khazanov A, Herman A. Comparison of acetabular fracture reduction quality by the ilioinguinal or the anterior intrapelvic (modified Rives-Stoppa) surgical approaches. J Orthop Trauma 2014;28:313-9.
17. Ma K, Luan F, Wang X, Ao Y, Liang Y, Fang Y, et al. Randomized, controlled trial of the modified Stoppa versus the ilioinguinal approach for acetabular fractures. Orthopedics 2013;36:e1307-15.
18. Hammad AS, El-Khadrawe TA. Accuracy of reduction and early clinical outcome in acetabular fractures treated by the standard ilio-inguinal versus the Stoppa/iliac approaches. Injury 2015;46:320-6.
19. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years’ follow-up. J Bone Joint Surg Br 2011;93:229-36.

20. Verbeek DO, van der List JP, Villa JC, Wellman DS, Helfet DL. Postoperative CT Is Superior for Acetabular Fracture Reduction Assessment and Reliably Predicts Hip Survivorship. J Bone Joint Surg Am 2017;99:1745-52.
21. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am 2012;94:1559-67.
22. Matta JM, Mehne DK, Roffi R. Fractures of the acetabulum. Early results of a prospective study. Clin Orthop Relat Res 1986:241-50.
23. Mayo KA. Open reduction and internal fixation of fractures of the acetabulum. Results in 163 fractures. Clin Orthop Relat Res 1994:31-7.
24. Jeffcoat DM, Carroll EA, Huber FG, Goldman AT, Miller AN, Lorich DG, et al. Operative treatment of acetabular fractures in an older population through a limited ilioinguinal approach. J Orthop Trauma 2012;26:284-9.
25. Borg T, Berg P, Larsson S. Quality of life after operative fixation of displaced acetabular fractures. J Orthop Trauma 2012;26:445-50.
26. Aaronson NK, Muller M, Cohen PD, Essink-Bot ML, Fekkes M, Sanderman R, et al. Translation, validation, and norming of the Dutch language version of the SF-36 Health Survey in community and chronic disease populations. J Clin Epidemiol 1998;51:1055-68.
27. Giannoudis PV, Grotz MR, Papakostidis C, Dinopoulos H. Operative treatment of displaced fractures of the acetabulum. A meta-analysis. J Bone Joint Surg Br 2005;87:2-9.

09
CHAPTER

POSTOPERATIVE CT IS SUPERIOR FOR ACETABULAR FRACTURE REDUCTION ASSESSMENT AND RELIABLY PREDICTS HIP SURVIVORSHIP

NEW YORK CITY, U.S.A.

D.O. Verbeek,
J.P. van der List,
J.C. Villa,
D.S. Wellman,
D. L. Helfet

Hospital for Special Surgery and New York Presbyterian Hospital, Weill Cornell Medicine, New York City, NY, USA

J Bone Joint Surg Am 2017; 99: 1745-52

2017

ABSTRACT

Background: Postoperative pelvic radiographs are routinely used to assess acetabular fracture reduction. We compared radiographs and computed tomography (CT) with regard to their ability to detect residual fracture displacement. We also determined the association between the quality of reduction as assessed on CT and hip survivorship and identified risk factors for conversion to total hip arthroplasty (THA).

Methods: Patients were included in the study who had undergone acetabular fracture fixation between 1992 and 2012, who were followed for ≥ 2 years (or until early THA), and for whom radiographs and a pelvic CT scan were available. Residual displacement was measured on postoperative radiographs and CT and graded according to Matta's criteria (0 to 1 mm indicating anatomic reduction; 2 to 3 mm, imperfect reduction; and >3 mm, poor reduction) by observers who were blinded to patient outcome. Kaplan-Meier survivorship curves were plotted and log-rank tests were used to assess statistical differences in survivorship curves between adequate (anatomic or imperfect) and inadequate reductions on CT. Cox proportional hazard regression analysis was used to identify risk factors for conversion to THA. Two hundred and eleven patients were included. At mean of 9.0 years (standard deviation [SD], 5.6; median, 7.9; range, 0.5 to 23.3 years) postoperatively, 161 patients (76%) had retained their native hip.

Results: Compared with radiographs, CT showed worse reduction in 124 hips (59%), the same reduction in 79 (37%), and better reduction in 8 (4%). Of the 99 patients graded as having adequate reduction on CT, 10% underwent conversion to THA in comparison with 36% of those with inadequate reduction, and there was a significant difference between the survivorship curves ($p < 0.001$). Mean hip survivorship was shorter in patients ≥50 years of age ($p < 0.001$) and in those with an inadequate reduction on CT ($p < 0.001$). Independent risk factors for conversion to THA were age (hazard ratio [HR] = 4.46, 95% confidence interval [CI] = 2.07 to 9.62; $p < 0.001$), inadequate reduction (HR = 3.57, 95% CI = 1.71 to 7.45; $p = 0.001$), and posterior wall involvement (HR = 1.81, 95% CI = 1.00 to 3.26; $p = 0.049$). Sex, fracture type (elementary versus associated), and year of surgery did not influence hip survivorship.

Conclusion: CT is superior to radiographs for detecting residual displacement after acetabular fracture fixation. Hip survivorship is greater in patients with adequate (anatomic or imperfect) reduction on CT. Along with older age and posterior wall involvement, an inadequate reduction on CT is a risk factor for conversion to THA.

INTRODUCTION

Residual displacement after acetabular fracture surgery is thought to be an important predictor for clinical outcome. Traditionally, the quality of acetabular reduction has been assessed on pelvic radiographs, and graded as anatomic, imperfect or poor based on the basis of Matta's criteria [1]. Although overall this grading system has been found to be reasonably well associated with clinical outcome [2-5], up to 32% of patients with a seemingly anatomic reduction on radiographs have a poor outcome and ultimately require total hip arthroplasty (THA) [1, 4, 6]. This apparent discrepancy may be a result of the limited ability of radiographs to detect residual displacement following acetabular fracture surgery. Preoperative computed tomography (CT) has been found to be significantly more accurate in detecting even minimal acetabular fracture displacement [5, 7]. Furthermore, there is some evidence to suggest that postoperative CT is a superior modality for predicting clinical outcome in patients with posterior wall acetabular fractures [5].

In this study, we compared radiography and CT with regard to their ability to detect residual displacement following acetabular fracture surgery. We also determined the association between the quality of reduction as assessed on CT and hip survivorship and identified independent risk factors for conversion to THA.

METHODS

After institutional review board approval was obtained, all consecutive adult patients who had undergone operative fixation within 3 weeks after an acute isolated acetabular fracture over a 21-year period (from January 1992 to December 2012) were identified from our Orthopaedic Trauma Service (OTS) registry. The OTS registry at our tertiary referral hospital contains the patients' demographic data, key operative details, and fracture type as classified by the senior author (D.L.H.) using the classification system described by Letournel and Judet [4]. Indications for open reduction and internal fixation (ORIF) of the acetabular fracture were based on radiographs as well as preoperative pelvic CT scans and included ± 2 mm of fracture displacement in the weight-bearing dome (upper 1cm of the acetabulum), a posterior wall fracture that was substantial (involving ≥ 40% of the wall) and/or was unstable (based on radiographic stress examination), and an incongruent hip joint. All surgical procedures were performed by a single surgeon (D.L.H.). Patients at our institution routinely undergo both radiography and a pelvic CT scan following acetabular fracture surgery. A total of 473 adult patients underwent operative fixation for an acute acetabular fracture during the study period. We excluded 205 patients who were lost to follow-up within 2 years but included those who underwent conversion to THA in <2 years. Also excluded were 51 patients with an incomplete set of postoperative images—i.e., radiographs and a pelvic CT scan (either digital DICOM [Digital Imaging and Communication in Medicine] or predigital imaging). In addition, 2 patients with an associated pelvic ring fracture and 4 with a femoral head (Pipkin) fracture were excluded to create a uniform cohort (**Fig. 1**).

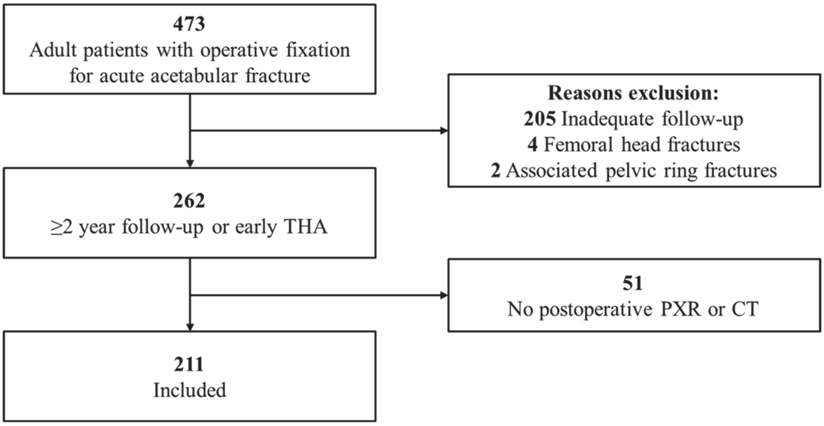


Figure 1. Flow diagram of included and excluded patients. PXR=pelvic x-rays (radiographs)

All patients were contacted through repeated mailings and by telephone to request completion of patient questionnaires in order to determine the most current status of the operatively treated hip. Hip survivorship in patients who could not be contacted was determined on the basis of their most recent clinic visit and follow-up radiographs. Overall, 211 (45%) of 473 eligible patients were included in this retrospective study.

Quality of reduction

Residual displacement was measured on postoperative radio- graphs in all 3 (anteroposterior and Judet [obturator oblique and iliac oblique]) views, and the quality of reduction was graded according to Matta's criteria as anatomic (0 to 1 mm of displacement), imperfect (2 to 3 mm), or poor (>3 mm)[1]. Next, postoperative CT scans made in the axial, sagittal, and coronal planes were independently assessed for the quality of reduction using a method that will be described in detail in an upcoming report. In short, this CT-based technique standardizes measurements of gap and step displacement at the level of the joint using a template to fit the articular surface. Gap displacement is measured along the articular surface, and step displacement is measured perpendicular to it. Both digital (DICOM) and predigital CT images were used and measurements were performed with correction for magnification on the predigital CT scans using the pro- vided scale. Displacement was considered only in the weight-bearing dome except in posterior wall fractures, where it was considered in the middle third of the acetabular wall as well. The same Matta criteria were then applied to the CT scan. For the reduction to qualify as anatomic, all 3 re- formatted images (axial, sagittal, and coronal) had to show a concentric reduction with no more than 1 mm of gap or step displacement. Two observers who were blinded to the clinical outcome and uninvolved in the initial surgical care of the patients assessed the postoperative radiographs and CT scans in consensus.

Over the course of the study, a variety of CT scanners was used. Older-generation CT scanners were used in our institution prior to 2004, 16-slice CT scanners were generally used from 2005 to 2008, and 64-slice CT scanners were introduced in 2009. Overall, the reduction was assessed on digital images in 58% of the patients. Slice thickness was generally 1 mm.

Statistical analysis

Continuous variables are presented as means with standard deviations (SDs), medians, and ranges and were compared using the independent t test. A contingency table was constructed to compare the quality of reduction according to Matta's criteria (anatomic, imperfect, or poor) as assessed on radiographs versus CT.

For hip survivorship analysis, anatomic and imperfect reductions were collapsed into an "adequate reduction" category and compared with the "inadequate (poor) reduction" category using chi-square tests. Kaplan-Meier survivorship curves were plotted and log-rank tests were used to assess statistical differences in hip survivorship curves between variables. Cox proportional hazard regression analysis was used to identify adjusted risk factors for conversion to THA. Variables that were examined as possible risk factors were age (<50 versus 50 years), sex, fracture type (elementary versus associated), posterior wall involvement, and quality of reduction on CT (adequate versus inadequate). The time period in which the surgery was per- formed (1992 through 1996, 1997 through 2001, 2002 through 2006, or 2007 through 2012) was also included as a potential confounder to adjust for advances in CT technology over the duration of the study. Results are presented as hazard ratios (HRs) with 95% confidence intervals (CIs).

A p value of <0.05 was considered to indicate a significant result. Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 19.0 (IBM).

RESULTS

The mean age of the 211 included patients was 50 years (SD, 18; median, 51; range, 18 to 92 years); 52% were ≥50 years of age, and 65% were male. Overall, 63% had an associated fracture type and 45% had posterior wall involvement. The patients included in the cohort were older than the excluded patients ($p = 0.007$) and more included patients than excluded patients were treated since 2002 rather than before 2012 ($p < 0.001$); other baseline characteristics were similar between the groups (**Table I**). Most patients (60%) who were lost to follow-up had the surgery between 1992 and 2001.

Table I. Baseline characteristics of the study cohort and excluded patients

Variables	Study cohort* (n=211)	Excluded (n=262)	P Value
Mean age ± SD (yr)	50.3 ± 17.8	45.6 ± 20.0	0.007
Male sex	137 (65%)	182 (69%)	0.297
Fracture type			0.544[a]
Elementary			
Anterior Column	12 (6%)	15 (6%)	
Anterior Wall	3 (1%)	2 (1%)	
Posterior Column	0 (0%)	2 (1%)	
Posterior Wall	48 (23%)	69 (26%)	
Transverse	15 (7%)	16 (6%)	
Associated			
T-type	7 (3%)	11 (4%)	
Transverse with Posterior Wall	41 (19%)	47 (18%)	
Posterior Column with Posterior Wall	5 (2%)	14 (5%)	
Anterior Column with Posterior Hemitransverse	44 (21%)	26 (10%)	
Associated Both Column	36 (17%)	52 (20%)	
Unknown	0 (0%)	8 (3%)	
Year of Surgery			<0.001[b]
1992 – 1996	34 (16%)	82 (31%)	
1997 – 2001	57 (27%)	78 (29%)	
2002 – 2006	61 (29%)	59 (22%)	
2007 – 2012	59 (28%)	43 (16%)	

*The values are given as the number of patients with the percentage in parentheses unless otherwise indicated. independent t tests were performed for continuous variables, and chi-square tests or Fisher exact tests were performed for nominal data (depending on the number of patients in the subgroups). a Chi-square comparison of elementary versus associated fracture type. [b] Chi-square comparison of 1992-2001 versus 2002-2012.

Patients were followed for a mean duration of 9.0 years (SD, 5.6; median, 7.9; range, 0.5 to 23.3 years), and 161 patients (76%) still had their native hip at the time of follow-up. Of the 50 patients who had undergone THA, 25 (50%) had had an early failure (20 had a poor reduction and 5 had an imperfect reduction on CT). Four patients (in the early failure group) developed osteonecrosis of the femoral head, and 1 had a postoperative deep infection (all had poor reduction on CT). Based on radiographs, 119 (56%) of the 211 patients had anatomic reduction, 58 (27%) had imperfect reduction, and 34 (16%) had poor reduction (**Table II**). Compared with the radiographs, CT showed worse reduction in 124 patients (59%), the same quality of reduction in 79 (37%), and better reduction in 8 (4%).

Table II. Quality of reduction as assessed on radiographs compared with CT in all 211 patients

		Reduction on CT*			
		Anatomic	**Imperfect**	**Poor**	**Total**
Reduction on radiographs	Anatomic	30 (25%)	43 (36%)	46 (39%)	119 (100%)
	Imperfect	5 (9%)	18 (31%)	35 (60%)	58 (100%)
	Poor	0 (0%)	3 (9%)	31 (91%)	34 (100%)
	Total	35 (17%)	64 (30%)	112 (53%)	211 (100%)

*The values are given as the number of patients with the percentage in parentheses.

9

The overall hip survivorship was 88% (95% CI = 84% to 93%) at 2 years, 84% (95% CI = 79% to 89%) at 5 years, 74% (95% CI = 67% to 81%) at 10 years, and 62% (95% CI = 48% to 75%) at 20 years (**Fig. 2**).

Overall, 3% (1) of the 35 patients with anatomic reduction on CT had conversion to THA compared with 14% (9) of the 64 patients with imperfect reduction and 36% (40) of the 112 with poor reduction. The relationships between adequate and inadequate reductions on CT and hip survivorship are presented in **Table III**.

Table III. Quality of reduction as assessed on CT in relation to hip survivorship*

		Hip survivorship		
		Yes	**No**	**Total**
Reduction on CT	Adequate	89 (90%)	10 (10%)	99 (100%)
	Inadequate	72 (64%)	40 (36%)	112 (100%)
	Total	161 (76%)	50 (24%)	211 (100%)

*p<0.001, chi-square test. The values are given as the number of patients with the percentage in parentheses.

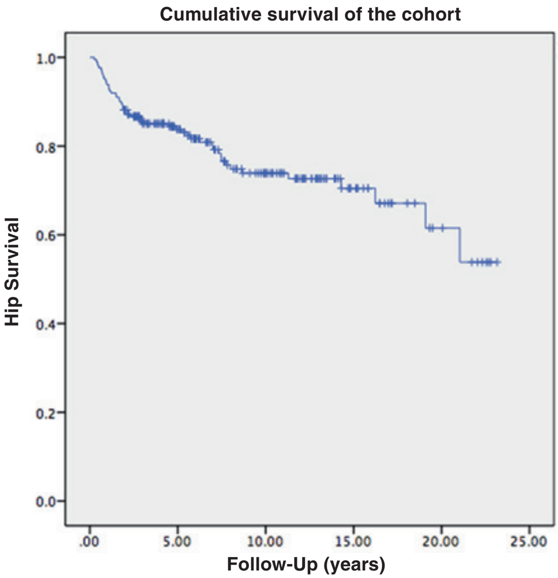


Figure 2. Hip survivorship curve for all 211 patients.

Ten percent of the patients with adequate reduction had conversion to THA in comparison with 36% of those with inadequate reduction ($p < 0.001$). The hip survivorship curves differed significantly between the adequate and inadequate reductions ($p < 0.001$) (**Fig. 3**).

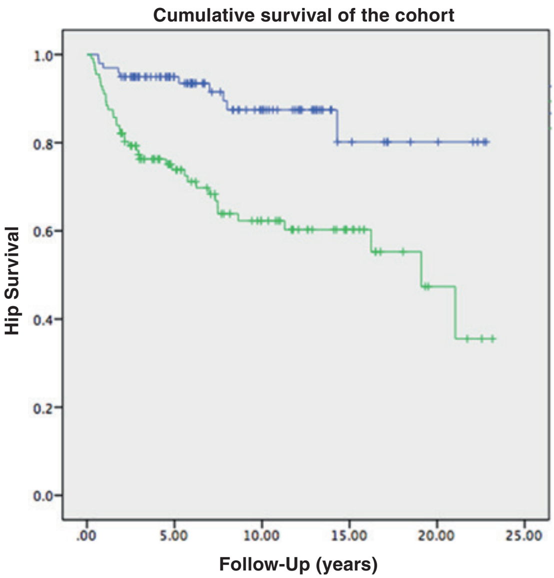


Figure 3. Hip survivorship curves for adequate (blue) versus inadequate (green) reductions on CT (log-rank test, $p < 0.001$)

The mean hip survivorship was significantly shorter in patients who were ≥50 years of age and in patients with inadequate reduction on CT (**Table IV**). Sex, fracture type, posterior wall involvement, and the time period in which the surgery was performed did not influence hip survivorship.

Cox proportional hazard regression analysis showed that age (≥50 years) (HR = 4.46, 95% CI = 2.07 to 9.62; $p < 0.001$), posterior wall involvement (HR = 1.81, 95% CI = 1.00 to 3.26; $p = 0.049$), and inadequate reduction (HR = 3.57, 95% CI =1.71 to 7.45; $p = 0.001$) were independent risk factors for conversion to THA (**Table V**) when adjusting for sex, fracture type, and time period in which the surgery was performed.

Table IV. Mean hip survivorship in individual subgroups

Variables	No. (%)	Mean duration of Hip survivorship (95% CI) (yr)	P Value
Age			<0.001
<50 years	102 (48%)	20.4 (18.9-21.9)	
≥50 years	109 (52%)	11.2 (9.8-12.7)	
Sex			0.103
Male	137 (65%)	17.8 (16.1-19.5)	
Female	74 (35%)	15.5 (13.1-17.9)	
Fracture Type			0.198
Elementary	78 (37%)	17.8 (15.7-19.9)	
Associated	133 (63%)	16.5 (14.7-18.4)	
Posterior wall involvement			0.841
Yes	94 (45%)	17.1 (15.1-19.2)	
No	117 (55%)	16.8 (14.9-18.8)	
Time period of surgery*			
1992-1996	34 (16%)	18.4 (15.6-21.2)	0.354
1997-2001	57 (27%)	14.7 (12.9-16.7)	0.780
2002-2006	61 (29%)	11.3 (10.1-12.4)	0.355
2007-2012	59 (28%)	7.1 (6.2-8.0)	0.092
Reduction on CT			<0.001
Adequate	99 (47%)	19.9 (18.1-21.7)	
Inadequate	112 (53%)	14.5 (12.5-16.6)	

* Compared with the remaining time periods

9

Table V. Cox proportional hazard regression analysis for conversion to THA

Category	Hazard Ratio (95% CI)	P Value
Age (≥50 vs. <50 yr)	4.46 (2.07-9.62)	<0.001
Sex (female vs. male)	1.26 (0.71-2.23)	0.440
Fracture type (associated vs. elementary)	1.07 (0.56-2.03)	0.844
Posterior wall involvement (yes vs. no)	1.81 (1.00-3.26)	0.049
Time period of surgery		
1992-1996 (vs. 2007-2012)	2.00 (0.76-5.28)	0.161
1997-2001 (vs. 2007-2012)	1.82 (0.84-3.92)	0.129
2002-2006 (vs. 2007-2012)	1.97 (0.88-4.40)	0.099
Reduction on CT (inadequate vs. adequate)	3.57 (1.71-7.45)	0.001

DISCUSSION

The results of this study suggest that, compared with radiographs, CT may be a superior tool for detecting residual displacement following acetabular fracture surgery. Moreover, the quality of reduction as assessed on CT was significantly associated with hip survivorship.

Few studies have compared the accuracy of postoperative CT with that of radiographs following reduction of an acetabular fracture [5,7]. In a previous study of 67 patients with a posterior wall acetabular fracture, postoperative radiographs showed anatomic reduction in 97% of the patients but CT confirmed this finding in only 22% [5]. Similarly, in the present study, only 25% of the anatomic reductions seen on radiographs were substantiated by CT while the remainder were seen to be imperfect or poor on CT (**Fig. 4**).

Overall, more than half of the patients (59%) had worse reduction on CT than on radiographs. These results suggest that postoperative CT is superior to radiographs for detecting articular malreduction after acetabular fracture surgery. This finding was corroborated by a prior study of 15 patients with a variety of acetabular fractures[7].

An unexpected result was that some patients (4%) were seen to have better reduction on CT than on radio- graphs. It is possible that implants obstructed assessment of the articular surface on the radiographs in these cases and a poor reduction was assumed on the basis of extra-articular displacement.

Historically, radiography has been used to assess acetabular reduction following surgery [1,3,4,8-12]. While to some extent the quality of reduction seen on radiographs has been found to be predictive of clinical outcomes, up to 32% of patients with apparently anatomic acetabular reduction go on to have a poor clinical outcome [1,4,6]. On the basis of these findings, it has

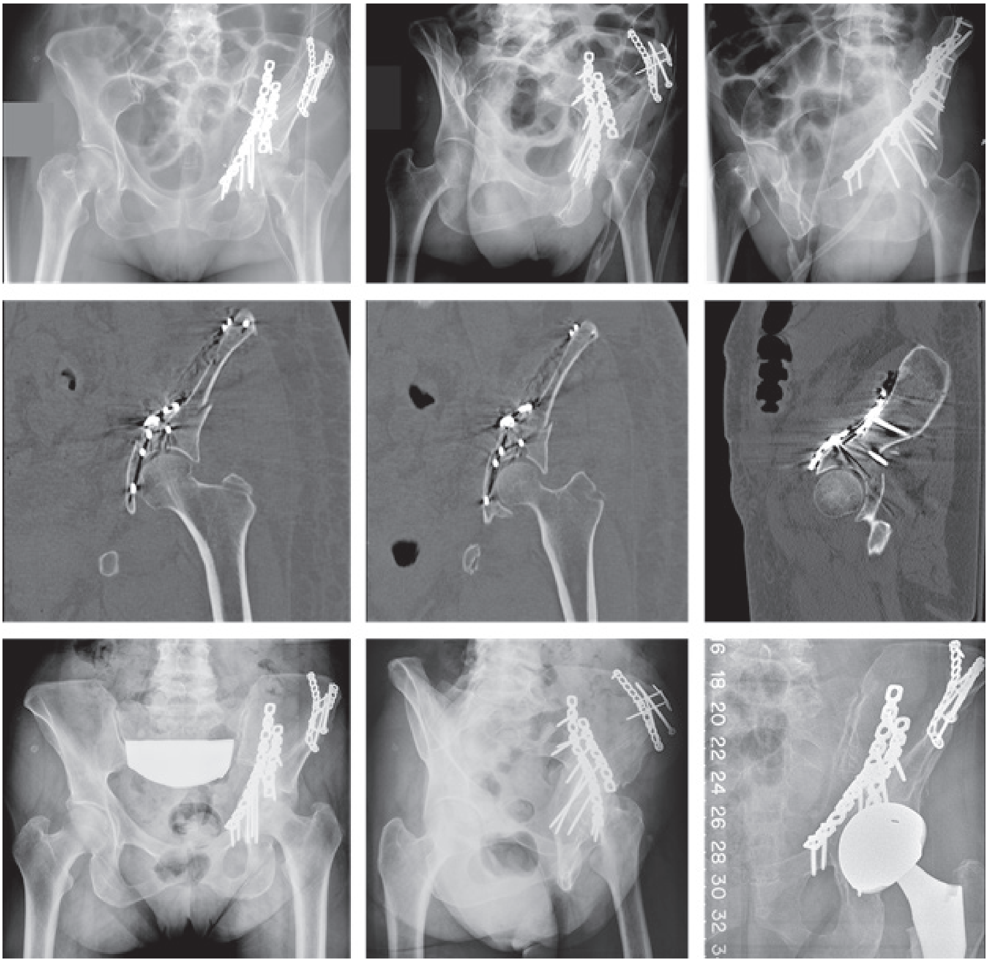


Figure 4. Postoperative images of a 61-year-old woman treated for an anterior column-posterior hemitransverse acetabular fracture. Radiographs appeared to show anatomic reduction (top row). However, CT revealed poor reduction (middle row). The patient developed posttraumatic arthritis and ultimately required THA (bottom row).

been noted that perhaps radiographs cannot detect smaller but still clinically relevant articular imperfections, particularly in posterior wall fractures.

In this study, THA was performed in only 3% of patients with anatomic reduction on CT and 14% of patients with imperfect reduction on CT, whereas 36% of patients with poor reduction underwent THA. Because only 35 anatomic reductions were seen on CT, they were grouped with the imperfect reductions into an “adequate reduction” category for further analysis. Hip survivorship was superior in patients with adequate reduction on CT as well as in younger patients.

We are aware of only 1 prior study that investigated the relationship between postoperative CT findings and clinical outcomes following acetabular fracture surgery [5]. In that study, in which the patients had a posterior wall acetabular fracture, the quality of reduction as assessed on CT was highly predictive of the clinical outcome according to the modified Merle d'Aubigne´ score. However, the issue of hip survivorship was not addressed specifically in that report.

An import finding in the current study was that a large proportion of patients (64%) with a poor reduction on CT had not undergone THA at the time of follow-up. It should be noted that we used Matta's grading system, which was based on radiographic measurements, to assess the quality of reduction on both the radiographs and the CT scans, and it is possible that use of a grading system specifically based on CT measurements would have improved the performance of the CT. In an earlier, not yet published, study, we found a technique to standardize CT measurements of residual acetabular displacement following surgery to have excellent interobserver reliability. In order to further develop and validate such a CT-based system, future research should focus on delineating alternative criteria for grading the quality of reduction based on the more accurate and reliable CT measurements. Apart from the overall size of residual displacement, other factors that would have to be considered are the nature (gap versus step) and location of displacement in relation to the weight-bearing dome [5,13,14]. A CT-based grading system would also provide the opportunity to introduce alternative terminology. It may be more appropriate to grade reductions as "excellent," "good," and "fair" to better reflect the actual quality of reduction and the effort on the part of the surgeon.

When assessing the relationship between reduction quality and the need for THA, it is important to consider the indication for the THA. While conversion to THA appeared to be mostly due to progressive osteoarthritis, other reasons such as osteonecrosis of the femoral head or infection were also found in a limited number of patients. These and other indications (such as debilitating heterotopic bone formation) are perhaps less likely to be influenced by reduction quality.

A multitude of variables may influence conversion to THA. In our study, we found that an inadequate reduction on CT as well as older age and posterior wall involvement were independent risk factors for THA. These and other factors have also been implicated in other studies [2,3,15]. We recognize that not all previously acknowledged confounders for conversion to THA were included in this study. We did not adjust for a number of variables such as initial fracture displacement, preexisting osteoarthritis, chondral injury, race, or insurance status. Radiographic evidence of incongruency has also been implicated as a predictor of outcome. However, this finding was rare in our series, possibly because we consider hip joint congruency to be a prerequisite for an “acceptable” reduction prior to leaving the operating room. Lastly, it is possible that (unknown) confounders that have not been identified previously could have influenced our results.

Routine use of postoperative CT following acetabular fracture surgery is not without controversy, mostly because of concerns about cost and radiation [16,17]. A previous study demonstrated that CT scanning after acetabular fracture surgery rarely showed the need for secondary intervention [16]. Despite limited evidence to support routine postoperative CT, it appears that this imaging modality is widely used to assess acetabular fracture reduction. In our institution, a postoperative CT scan is performed regardless of suspicion of an inaccurate reduction, intra-articular screws, or “loose bodies.” In concurrence with earlier findings, our experience has been that the decision to remove implants has rarely been based on CT findings alone. In most cases, the position of screws as seen on intraoperative fluoroscopy was merely confirmed on CT. Per protocol, screws that were thought to be too close to the femoral head were removed prior to the patient commencing full weight-bearing. A noteworthy development in this regard is the introduction of intraoperative CT scanning in some institutions, which allows direct revisions as needed on the basis of CT findings. We consider postoperative CT scanning to be particularly useful for counseling patients concerning their prognosis, to provide valuable information to improve the individual surgeon’s technique, and to rigorously assess outcome following the introduction of newly developed techniques and approaches.

Several limitations are present in this study. The rate of conversion to THA in our patients (24%) was relatively high compared with previous large studies with similar durations of follow-up (15% to 16% [2,3]). However, the patients in the current study were considerably older than those in previous studies [1-4,8,18], and higher age is known to increase the risk for THA as was also shown in this study. Furthermore, this study was a single-surgeon study, which may have influenced its external validity. Although a variety of CT scanners were used and CT technology improved considerably over time, this did not appear to have a significant impact on our results. Another important limitation of our study is the sizable number of patients who were lost to follow-up. Lastly, the size of our patient cohort did not allow further stratification of our results according to the 10 different fracture types.

CONCLUSION

In conclusion, CT appears to be superior to radiography for detecting residual displacement after acetabular fracture fixation. A substantial number of patients with apparently anatomic acetabular reduction on pelvic radiography have an imperfect or poor reduction according to CT. In addition, the quality of reduction as assessed on postoperative CT is significantly associated with hip survivorship. Along with an older age and posterior wall involvement, inadequate reduction on CT appears to be an independent risk factor for conversion to THA. Finally, we found that patients with an adequate (anatomic or imperfect) reduction on CT had a low rate of conversion to THA (10%) at a mean of 9 years.

REFERENCES

1. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am. 1996 Nov;78(11):1632-45.
2. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am. 2012 Sep 5;94(17):1559-67.
3. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br. 2011 Feb;93(2):229-36.
4. Letournel E JR. Fractures of the acetabulum. 2nd ed. Elson RA, translator, editor. New York: Springer; 1993 Translation of Les fractures du cotyle.
5. Moed BR, Carr SE, Gruson KI, Watson JT, Craig JG. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J Bone Joint Surg Am. 2003 Mar;85-A(3):512-22.
6. Moed BR, WillsonCarr SE, Watson JT. Results of operative treatment of fractures of the posterior wall of the acetabulum. J Bone Joint Surg Am. 2002 May;84-A(5):752-8.
7. Borrelli J, Jr., Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma. 2005 May-Jun;19(5):299-304.
8. Dailey SK, Phillips CT, Radley JM, Archdeacon MT. Achieving Anatomic Acetabular Fracture Reduction-When is the Best Time to Operate? J Orthop Trauma. 2016 Aug;30(8):426-31.
9. Mayo KA. Open reduction and internal fixation of fractures of the acetabulum. Results in 163 fractures. Clin Orthop Relat Res. 1994 Aug(305):31-7.
10. Carroll EA, Huber FG, Goldman AT, Virkus WW, Pagenkopf E, Lorich DG, et al. Treatment of acetabular fractures in an older population. J Orthop Trauma. 2010;24(10):637-44.
11. Helfet DL, Borrelli J, Jr., DiPasquale T, Sanders R. Stabilization of acetabular fractures in elderly patients. J Bone Joint Surg Am. 1992;74(5):753-65.
12. Jeffcoat DM, Carroll EA, Huber FG, Goldman AT, Miller AN, Lorich DG, et al. Operative treatment of acetabular fractures in an older population through a limited ilioinguinal approach. J Orthop Trauma. 2012;26(5):284-9.
13. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Radiographic Measurement of Displacement in Acetabular Fractures: A Systematic Review of the Literature. J Orthop Trauma. 2016 Jun;30(6):285-93.
14. Olson SA, Matta JM. The computerized tomography subchondral arc: a new method of assessing acetabular articular continuity after fracture (a preliminary report). J Orthop Trauma. 1993;7(5):402-13.
15. Giannoudis PV, Grotz MR, Papakostidis C, Dinopoulos H. Operative treatment of displaced fractures of the acetabulum. A meta-analysis. J Bone Joint Surg Br. 2005 Jan;87(1):2-9.
16. Archdeacon MT, Dailey SK. Efficacy of Routine Postoperative CT Scan After Open Reduction and Internal Fixation of the Acetabulum. J Orthop Trauma. 2015 Aug;29(8):354-8.
17. O'Shea K, Quinlan JF, Waheed K, Brady OH. The usefulness of computed tomography following open reduction and internal fixation of acetabular fractures. J Orthop Surg (Hong Kong). 2006 Aug;14(2):127-32.
18. Ochs BG, Marintschev I, Hoyer H, Rolauffs B, Culemann U, Pohlemann T, et al. Changes in the treatment of acetabular fractures over 15 years: Analysis of 1266 cases treated by the German Pelvic Multicentre Study Group (DAO/DGU). Injury. 2010 Aug;41(8):839-51.

10
CHAPTER

PREDICTORS FOR LONG-TERM HIP SURVIVORSHIP FOLLOWING ACETABULAR FRACTURE SURGERY

Importance of gap compared with step displacement

NEW YORK CITY, U.S.A.

D.O. Verbeek,
J.P. van der List,
C.M. Tissue,
D. L. Helfet

Hospital for Special Surgery and New York Presbyterian Hospital,
Weill Cornell Medicine,
New York City, NY, USA

J Bone Joint Surg Am
2018; 100: 922-29

2018

ABSTRACT

Background: Historically, the greatest residual (gap or step) displacement is used to predict clinical outcome following acetabular fracture surgery. Gap and step displacement may, however, impact the outcome to different degrees. We assessed the individual relationship between gap or step displacement and hip survivorship and determined their independent association with conversion to total hip arthroplasty.

Methods: Patients who had acetabular fracture fixation (from 1992 through 2014), follow-up of ≥2 years (or early conversion to total hip arthroplasty), and postoperative computed tomography (CT) scans were included. Of 227 patients, 55 (24.2%) had conversion to total hip arthroplasty at a mean follow-up (and standard deviation) of 8.7 ± 5.6 years. Residual gap and step displacement were measured using a standardized CT-based method, and assessors were blinded to the outcome. Kaplan-Meier survivorship curves for the hips were plotted and compared (log-rank test) using critical cutoff values for gap and step displacement. These values were identified using receiver operating characteristic curves. Multivariate analysis was performed to identify independent variables associated with conversion to total hip arthroplasty. Subgroup analysis was performed in younger patients (<50 years old).

Results: The critical CT cutoff value for total hip arthroplasty conversion was 5 mm for gap and 1 mm for step displacement. Hip survivorship at 10 years was 82.0% for patients with a gap of <5 mm compared with 56.5% for a gap of ≥5 mm ($p < 0.001$) and 80.0% for a step of <1.0 mm versus 65.5% for a step of ≥1.0 mm ($p = 0.012$). A gap of ≥5 mm (hazard ratio [HR], 2.3; $p = 0.012$) and an age of ≥50 years (HR, 4.2; $p < 0.001$) were independently associated with conversion to total hip arthroplasty in all patients. In the subgroup of younger patients, only a step of ≥1 mm (HR, 6.4;$p = 0.017$) was an independent factor for conversion to total hip arthroplasty.

Conclusions: Residual gap and step displacement as measured on CT scans are both related to long-term hip survivorship, but step displacement (1 mm) is tolerated less than gap displacement (5 mm). Of the 2 types of displacement, only a large gap displacement (≥5 mm) was independently associated with conversion to total hip arthroplasty. In younger patients who had less articular impaction with smaller residual gaps, only step displacement (≥1 mm) appeared to be associated with this outcome.

INTRODUCTION

In acetabular fracture surgery, achieving an accurate articular reduction is critical to improving the clinic al outcome [1-4]. A high-quality reduction at the level of the joint decreases the risk for progressive osteoarthritis and the subsequent need for total hip arthroplasty.

The quality of reduction has historically been determined on the basis of the greatest residual (gap or step) displacement as measured on pelvic radiographs [5]. Reductions are graded as anatomic, imperfect, or poor without distinguishing between the two specific types of displacement. Acetabular fracture displacement can occur in line with the circumference of the articular surface (gap) or perpendicular to it (step) [6]. Biomechanical and clinical evidence has suggested that gap and step displacement should be considered as two separate entities in terms of the impact on load distribution within the joint as well as clinical outcome [7-10].

Previous studies have demonstrated that measurements of both gap and step displacement are more accurate when they are based on computed tomography (CT) rather than plain pelvic radiography [6,9,11,12]. This advanced imaging modality is able to generate more detailed images of the articular surface in three different planes, providing a more precise measure for the quality of reduction [12].

The objective of the present study was to assess the relationship between residual gap and step displacement on CT and long-term hip survivorship following acetabular fracture surgery. Furthermore, the independent association of these two types of displacement and conversion to total hip arthroplasty was determined.

METHODS

Study design

All patients who received operative treatment, from January 1992 to December 2014, for an isolated acetabular fracture within 3 weeks after injury were identified from our Orthopedic Trauma Service registry. This database includes baseline demographics and acetabular fracture type according to the Letournel and Judet classification system [2]. Indications for operative fixation included fracture displacement of ≥2 mm in the weight-bearing dome, substantial (≥40%) and/or unstable posterior wall fractures, and an incongruent hip joint. All surgeries were performed by a single surgeon (D.L.H.) at a tertiary-care referral center. Surgery was performed typically utilizing a (limited) ilioinguinal or Kocher-Langenbeck (or rarely a combined or extensile) approach as proposed by Letournel and Judet [2,13,14]. Areas of superomedial dome impaction were generally not addressed separately. At our institution, patients routinely receive pelvic radiographs with Judet views as well as postoperative CT scans to assess reduction regardless of suspected malreduction or intra- articular screws.

Patient Selection

Patients were considered for inclusion if they had a minimum follow-up of 2 years or early (<2 years) conversion to total hip arthroplasty. Of 483 eligible patients, 204 (42%) were lost to follow-up within 2 years. Additionally, patients without a postoperative CT scan (digital DICOM [Digital Imaging and Communication in Medicine] or predigital imaging) available for review (n = 44) and patients with associated femoral head fractures (n = 5) or associated pelvic ring disruptions (n = 3) were excluded.

All patients were contacted through repeat mailings and by telephone to determine the status of the operatively treated hip. For patients who were unable to be reached, the most recent imaging available was used for this assessment.

Imaging Review

Postoperative reduction was assessed using CT imaging in consensus by 3 observers (D.O.V., J.P.v.d.L., and C.M.T.) in the axial, sagittal, and coronal planes. Observers were blinded with respect to the clinical outcome and were not involved in the surgical care of the patients. A standardized procedure that is shown to have high interobserver reliability for measuring postoperative step and gap displacement on CT was used [12]. This measurement method utilizes a circular template and only considers displacement in the weight-bearing dome (the upper 1 cm of the acetabulum) and extending down to the middle of the posterior wall (when involved). In some cases, this area may not correlate with the site of most acetabular fracture displacement. However, previous work has shown that displacement that occurs within the critical location as noted is the most clinically relevant [9,15,16]. With the use of a circular template to fit along the acetabular joint surface, fracture separation (or impaction) was measured along the circumference or perpendicular to it, respectively, as gap displacement and step displacement (**Figs. 1 and 2**). The presence of other radiographic features, including posterior wall impaction, superomedial dome impaction, and loss of hip joint congruity (or femoral head subluxation), was also recorded.

Statistical Analysis

Continuous variables are presented as the mean and the standard deviation. Independent t tests were performed for continuous variables, and chi-square tests or Fisher exact tests were used for nominal data (depending on the frequency of occurrence within each subgroup).Receiver operating characteristic (ROC) curves were con- structed for residual gap and step displacement associated with conversion to total hip arthroplasty, and the area under the curve was calculated. Critical cutoff values were determined by identifying the point that maximized sensitivity and specificity and are presented with positive and negative likelihood ratios (LRs). Kaplan-Meier survivorship curves were then plotted, and log-rank tests were used to assess significant differences in hip survivorship curves between gap and step displacement utilizing these cutoff values.

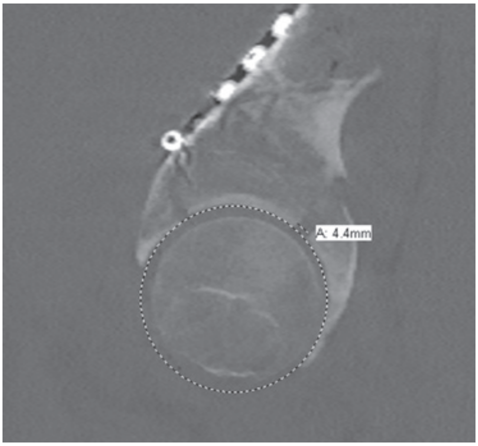


Figure 1. Sagittal CT cut of the acetabulum illustrating the measurement of residual gap displacement using a digital circular template.

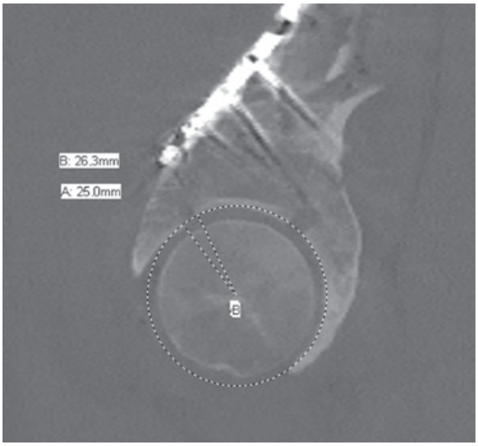


Figure 2. Sagittal CT cut of the acetabulum illustrating the measurement of residual step displacement using a digital circular template. A is subtracted from B, which results in a residual step-off of 1.3 mm. (Reproduced, with modification, from: Verbeek DO, van der List JP, Moloney GB, Wellman DS, Helfet DL. Assessing postoperative reduction following acetabular fracture surgery: a standardized digital CT-based method. J Orthop Trauma. 2018 Feb 23. [Epub ahead of print]. Reproduced with permission.)

Cox proportional hazard regression analysis was performed with significant dependent variables to identify independent risk factors associated with conversion to total hip arthroplasty. Within our patient cohort, the proportion of elderly patients with (larger) areas of joint impaction was expected to be relatively sizeable. In contrast to older patients with lower demands, it could be argued that younger, more active patients would be less tolerant of (smaller) joint incongruencies. For these reasons, a subgroup analysis (using ROC curve analysis) was performed for patients who were <50 years old.

CT imaging in this study was performed over an extended period of time, during which CT technology improved considerably. To account for this factor, goodness-of-fit statistics were compared for the regression models with and without the effect of the year of surgery in the model (operationalized as 5 categorical blocks of time). In analyzing the -2 log-likelihood values, the model fit did not change by >10%. Additionally, when looking at the gap and step variables, the change in hazard ratio (HR) for each variable was also not >10%. A p value of <0.05 was considered to indicate a significant result. Results are presented with p values and HRs with 95% confidence intervals (CIs). Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS, version 19.0; IBM Software).

In- and Excluded patients

A total of 227 patients were included in the study. The mean age was 51.2 ± 17.8 years, 64.3% were male, and 63.4% had an associated type of acetabular fracture. Included patients were older than excluded patients (45.1 ± 19.9 years) ($p < 0.001$), but sex ($p = 0.111$) and fracture type ($p = 0.343$) were similar between study groups (**Table I**).

Table I. Baseline characteristics of included and excluded patients

	Included Patients (N = 227)	Excluded Patients (N = 256)	P Value
Age* (yr)	51.2 (17.8)	45.1 (19.9)	<0.001
Male (no. [%])	146 (64.3%)	182 (71.1%)	0.111
Fracture types (no. [%])			0.343†
Elementary	83 (36.6%)	102 (39.8%)	
Anterior Column	13 (5.7%)	14 (5.5%)	
Anterior Wall	3 (1.3%)	2 (0.8%)	
Posterior Column	0 (0.0%)	2 (0.8%)	
Posterior Wall	51 (22.5%)	69 (27.0%)	
Transverse	16 (7.0%)	15 (5.9%)	
Associated	144 (63.4%)	148 (57.8%)	
T-shaped	8 (3.5%)	11 (4.3%)	
Transverse with posterior wall	42 (18.5%)	46 (18.0%)	
Posterior column with posterior wall	5 (2.2%)	14 (5.5%)	
Anterior column with posterior hemitransverse	47 (20.7%)	24 (9.4%)	
Both column	42 (18.5%)	53 (20.7%)	
Missing	0 (0.0%)	6 (2.3%)	

*The values are given as the mean and the standard deviation. †Chi-square test regarding the prevalence of elementary and associated fracture types between the groups.

In total, 105 patients (46.3%) were <50 years old. Compared with older patients, fewer younger patients had an associated fracture type (53.3% compared with 72.1%; $p = 0.004$) or superomedial dome impaction (8.6% compared with 27.0%; $p < 0.001$) or required conversion to total hip arthroplasty (11.4% compared with 35.2%; $p < 0.001$). An equal percentage of younger compared with older patients were male (66.7% compared with 63.3%, respectively; $p = 0.579$), had posterior wall involvement (86.7% compared with 81.1%, respectively; $p = 0.284$), had posterior wall impaction (31.4% and 36.9%, respectively; $p = 0.404$), or had femoral head subluxation (1.0% compared with 1.6%, respectively; $p > 0.999$).

RESULTS

The mean follow-up for all 227 included patients was 8.7 ± 5.6 years. Total hip arthroplasty was performed in 55 patients (24.2%), of whom 30 had an early (<2-year) failure. Six patients had total hip arthroplasty for osteonecrosis of the femoral head, and 1 had total hip arthroplasty for a postoperative deep infection. In total, 206 patients (90.7%) had a mean gap displacement of 5.2 ± 5.6 mm on CT, and 112 patients (49.3%) had a mean step displacement of 1.3 ± 1.8 mm. There was a significant association between the presence of gap and step dis- placement ($p = 0.001$). Gap displacement was present in 97.3% (109) of 112 patients with step displacement, and step dis- placement was present in 52.9% (109) of 206 patients with gap displacement. No residual (gap or step) displacement was found in 7.9% (18) of all 227 patients.

In the 55 patients who had conversion to total hip arthroplasty, the mean residual gap and step displacement were significantly higher (9.0 ± 7.7 mm and 2.2 ± 2.4 mm, respectively) than in patients without total hip arthroplasty (4.0 ± 4.1 mm and 1.1 ±mm) ($p < 0.001$ and $p = 0.002$, respectively).

The 105 younger patients had smaller mean residual gap displacement than the older patients (3.7 ± 4.0 mm and 6.5 ± 6.4 mm, respectively; $p < 0.001$) but equivalent residual step displacement (1.1 ± 1.5 mm compared with 1.5 ± 2.0 mm; $p = 0.06$). The 12 younger patients who had conversion to total hip arthroplasty had significantly higher mean residual step dis- placement than those who had not (2.1 ± 1.5 mm and 1.0 ± 1.4 mm, respectively; $p = 0.019$). The mean gap displacement was similar between the groups (4.9 ± 2.9 mm and 3.6 ± 4.1 mm, respectively; $p = 0.276$).

ROC curves showed an area under the curve of 0.747 (95% CI, 0.673 to 0.821; $p < 0.001$) for residual gap displacement and 0.639 (95% CI, 0.551 to 0.728; $p = 0.002$) for residual step displacement (**Fig. 3**).
A critical cutoff value of 5 mm for gap displacement (sensitivity of 69.1%, specificity of 73.3%, positive LR of 2.59, and negative LR of 0.42) and 1 mm for step displacement (sensitivity of 61.8%, specificity of 59.3%, positive LR of 1.52, and negative LR of 0.64) was identified on the basis of these curves (**Table II**).

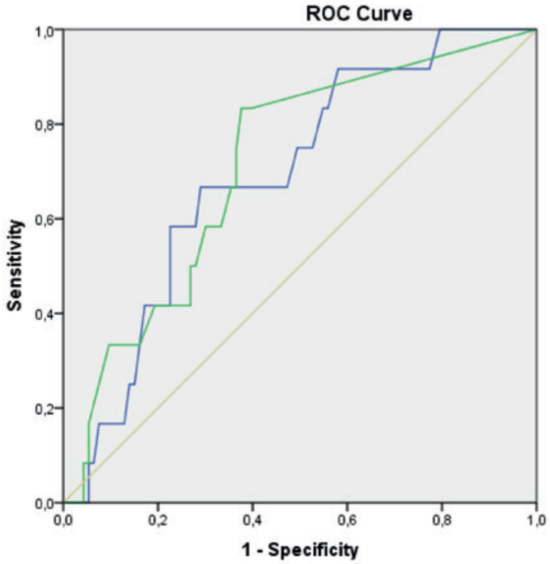


Figure 3. Receiver Operating Characteristic (ROC) curves for residual gap (blue) and step (green) displacement associated with conversion to total hip arthroplasty. The diagonal line is the reference line.

Table II. Sensitivity and specificity associated with critical cutoff values for residual gap and step displacement based on Receiver Operating Characteristic curves

	Cut-off* (mm)	Sensitivity (%)	Specificity (%)
Residual gap	1	98.2	19.2
	3	80.0	50.0
	5	69.1	73.3
	7	43.6	85.5
	9	36.4	90.1
Residual step	0	63.6	55.2
	1	61.8	59.3
	2	43.6	75.6
	3	27.3	90.7
	4	16.4	95.3

*The critical cutoff value that maximized sensitivity and specificity for conversion to total hip arthroplasty was 5 mm for residual gap and 1 mm for residual step displacement

Hip survivorship

For all 227 patients, the 5-year and 10-year hip survival rates were 93.9% (95% CI, 90.0% to 97.8%) and 82.0% (95% CI, 74.0% to 90.0%), respectively, for patients with a residual gap of <5 mm and 61.8% (95% CI, 50.8% to 72.8%) and 56.5% (95% CI, 44.9% to 68.1%) for patients with a residual gap of ≥5 mm. Hip survivorship curves for this cutoff value were significantly different using the log-rank test ($p < 0.001$) (**Fig. 4**).

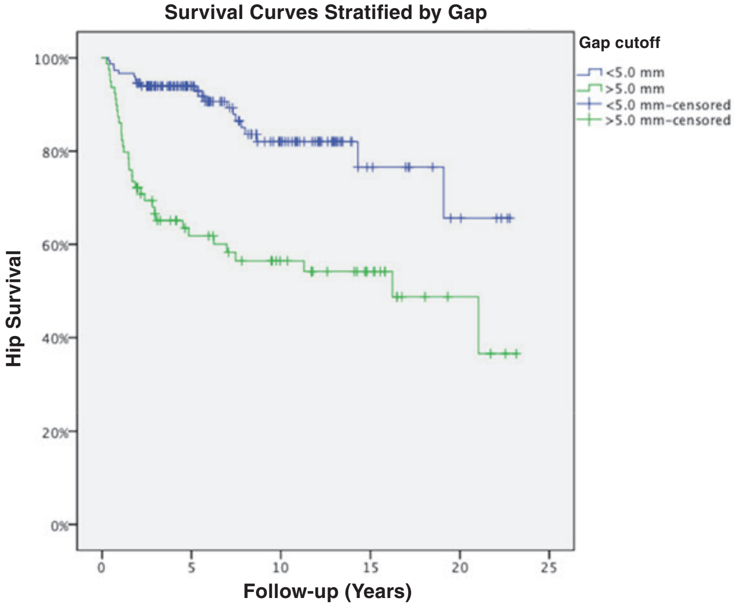


Figure 4. Hip survivorship curves for all 227 patients comparing those with residual gap displacement of <5 mm and those with ≥5 mm (log rank, $p < 0.001$).

The 5-year and 10-year hip survival rates were 88.0% (95% CI, 81.9% to 94.1%) and 80.0% (95% CI, 71.4% to 88.7%), respectively, for patients with a residual step of <1.0 mm compared with 76.4% (95% CI, 68.2% to 84.6%) and 65.5% (95% CI, 55.1% to 75.9%) for patients with a residual step of ≥1.0 mm. Hip survivorship curves for this cutoff value were also significantly different using the log-rank test ($p = 0.012$) (**Fig. 5**).

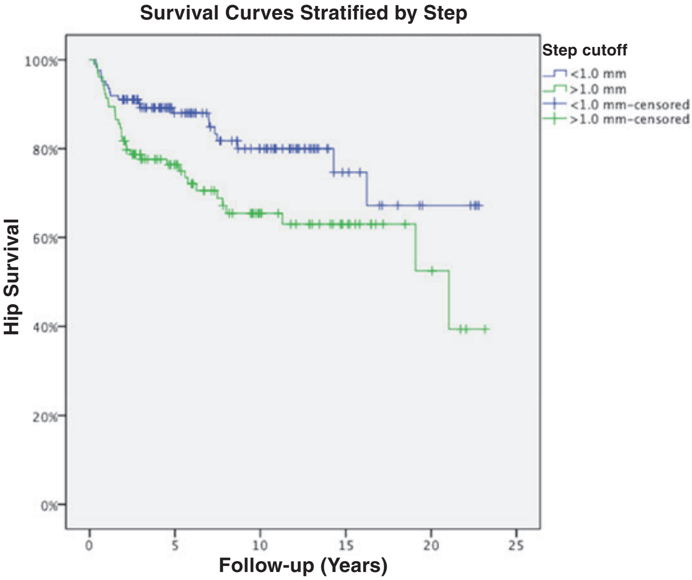


Figure 5. Hip survivorship curves for all 227 patients comparing those with residual step displacement of <1 mm and those with ≥1 mm (log rank, p = 0.012).

In the younger cohort of 105 patients, the 5-year and 10- year hip survival rates were 97.5% (95% CI, 94.0% to 100%) and 87.8% (95% CI, 78.2% to 97.4%), respectively, for patients with a residual gap of <5.0 mm and 87.9% (95% CI, 75.0% to 100%) and 83.0% (95% CI, 67.7% to 98.3%) for patients with a gap of ≥5.0 mm. Hip survivorship curves for this cutoff value were not significantly different (p = 0.421) (**Fig. 6**).

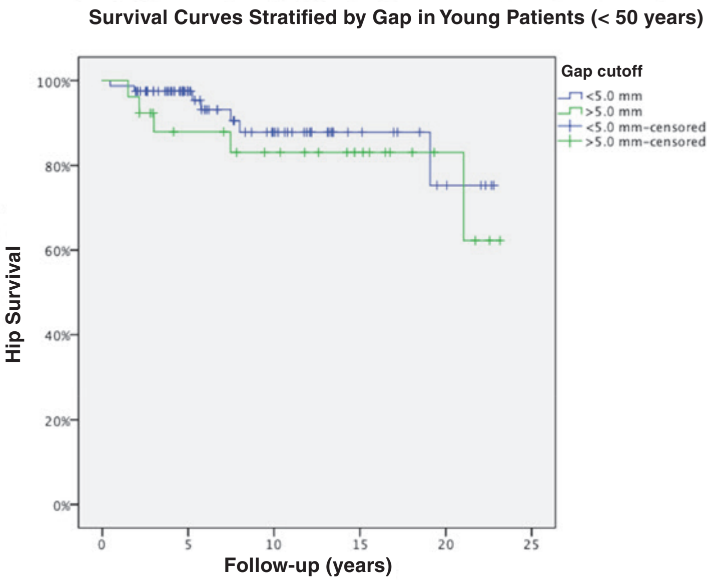


Figure 6. Hip survivorship curves for 105 younger patients comparing those with residual gap displacement of <5 mm and those with ≥5 mm (log rank, p = 0.421).

The 5-year and 10-year hip survival rates were 98.3% (95% CI, 95.0% to 100%) and 95.2% (95% CI, 88.3% to 100%), respectively, for patients with a residual step of <1.0 mm compared with 90.8% (95% CI, 82.2% to 99.4%) and 76.8% (95% CI, 62.1% to 91.5%) for patients with a residual step of

≥1.0 mm. Hip survivorship curves for this cutoff value were significantly different (p = 0.006) (**Fig. 7**).

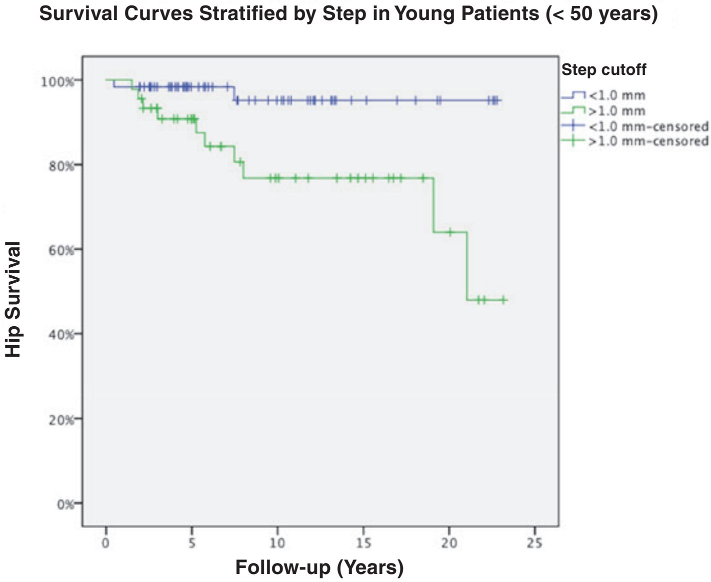


Figure 7. Hip survivorship curves for 105 younger patients comparing those with residual step displacement of <1 mm and those with ≥1 mm (log rank, p = 0.006).

Risk factors for Total Hip Arthroplasty

Among other risk factors, greater residual gap (p < 0.001) and step (p = 0.012) displacement were risk factors for conversion to total hip arthroplasty in univariate analysis (**Table III**). Of these factors, larger residual gap displacement (HR, 2.3; p = 0.012) along with age (HR, 4.2; p < 0.001) were independently associated with conversion to total hip arthroplasty in multi- variate analysis (**Table IV**).

Table III Cox regression analysis for dependent risk factors associated with conversion to total hip arthroplasty in all 227 patients

Variables	Unadjusted Hazard ratio (95% CI)	P Value
Age (≥50 yrs)	4.8 (2.4-9.7)	<0.001
Sex (female)	1.5 (0.9-2.5)	0.169
Gap (≥5.0 mm)	3.6 (2.1-6.3)	<0.001
Step (≥1.0 mm)	2.0 (1.1-3.4)	0.012
Fracture type (associated)	1.4 (0.8-2.4)	0.275
Posterior wall involvement	1.0 (0.5-2.2)	0.929
Posterior wall impaction	2.1 (1.3-3.6)	0.005
Superomedial dome impaction	2.8 (1.6-4.9)	<0.001
Femoral head subluxation	4.0 (1.0-16.6)	0.057

Table IV Cox regression analysis for risk factors independently associated with conversion to total hip arthroplasty

Variables	Adjusted Hazard ratio (95% CI)	P Value
Age (≥50 yrs)	4.2 (2.0-8.6)	<0.001
Gap (≥5.0 mm)	2.3 (1.2-4.4)	0.012
Step (≥1.0 mm)	1.4 (0.8-2.5)	0.219
Posterior wall impaction	1.4 (0.8-2.7)	0.175
Superomedial dome impaction	1.3 (0.7-2.4)	0.425

In 105 younger patients, greater residual step ($p = 0.017$) displacement was the only (dependent and independent) risk factor for conversion to total hip arthroplasty. Fracture pattern was not a significant predictor for total hip arthroplasty con- version in this analysis (**Table V**).

Table V Cox regression analysis for dependent risk factors associated with conversion to total hip arthroplasty in 105 younger patients

Variables	Unadjusted Hazard ratio (95% CI)	P Value
Sex (female)	0.7 (0.2-2.7)	0.636
Gap (≥5.0 mm)	1.6 (0.5-5.1)	0.425
Step (≥1.0 mm)	6.4 (1.4-29.1)	0.017
Fracture type (associated)	0.8 (0.3-2.6)	0.752
Posterior wall involvement	26.0 (0.2-28026.5)	0.360
Posterior wall impaction	3.2 (1.0-10.7)	0.059
Superomedial dome impaction	2.0 (0.4-9.1)	0.390
Femoral head subluxation*	NA	NA

*One patient had femoral head subluxation. NA= not applicable.

DISCUSSION

The results of this study indicate that residual gap and step displacement are associated with long-term hip survivorship to different degrees. Indeed, the critical cutoff value for this outcome measure as assessed on CT imaging was considerably larger for residual gap displacement (5 mm) than for step displacement (1 mm). As such, it appears that residual gaps are tolerated more than steps and the displacement should be considered as 2 separate entities in terms of their impact on clinical outcome.

10

Assessment of acetabular fracture reduction is traditionally performed utilizing the grading system described by Matta [5]. This system is based on measurements from plain pelvic radiography, and it makes no distinction between gap and step displacement. A rigorous scientific basis for the Matta grading system and proposed cutoff values, however, appears to be lacking. Our results indicate that, in contrast to the traditionally set single value of 3 mm, the critical cutoff value by which to define a poor reduction is greater for gap displacement (5 mm) but smaller for step displacement (1 mm) as assessed on CT.

In an earlier study of select patients with posterior wall acetabular fractures, the critical cutoff value for gap displacement associated with poor outcome was as large as 10 mm as measured on CT [9]. In a recent long-term follow-up study of patients with nonoperatively treated acetabular fractures, both gap and step displacement (≥2 mm) were related to poor clinical outcome [10]. It remains unclear, however, how those authors derived a (single) cutoff value of 2 mm, and the measurements were not based on CT imaging.

There is some biomechanical evidence to support the contention that gap and step displacement represent two separate entities [7,8]. Step displacement occurs perpendicular to the acetabular surface and results in substantially increased contact pressures within the joint, which may result in the development of osteoarthritis [7]. Indeed, an earlier biomechanical study concluded that step displacement of ≥1 mm at the acetabular articular surface resulted in substantially increased contact pressure [8]. This figure is identical to the cutoff value found in our study.

Gap displacement may result from separation of fracture fragments in line with the acetabular surface, owing to inadequate reduction or lack of interfragmentary compression [6]. However, it is our contention that larger gaps are more likely a result from areas of impaction or discarded osteochondral fragments. Consequently, gaps can result either in a relatively “wider” joint, causing subtle loss of congruity, or in less contact area between the femoral head and the acetabular dome. An earlier biomechanical study showed that gap displacement (≤4 mm) appears to alter load distribution within the joint but does not result in significantly increased contact pressure [7]. This assertion appears to support our finding that residual gaps are tolerated to a greater degree than steps.

In our overall study population, we found that, in terms of residual displacement, only gap displacement (5 mm) was an independent risk factor for conversion to total hip arthroplasty at long-term follow-up. In interpreting this finding, it is important to consider the characteristics of our patient cohort. Our study population was somewhat skewed because of a considerable proportion of older patients with relatively large postoperative gaps resulting from areas of superomedial dome impaction [17]. In contrast, steps occurred less frequently in our study patients and were significantly smaller in size, which is similar to earlier findings [9]. This disparity in our study may have reduced the relative importance of residual step displacement. In support of this contention, we found that, in younger patients (with smaller residual gaps), only step displacement was independently associated with conversion to total hip arthroplasty, although the associated confidence interval was large.

Prior studies that have investigated the independent predictive value of residual gap compared with step displacement have yielded contradictory results, most likely as a result of the inclusion of different patient cohorts and treatment strategies as well as varying measurement techniques and outcome measures [9,10]. In a study of posterior wall acetabular fractures [9], the main risk factor for a poor clinical result was residual gap width, which was similar to the findings in our study. Residual step displacement did not appear to be associated with clinical outcome, although those authors noted a low prevalence of this finding. In contrast, in nonoperatively treated acetabular fractures, both gap and step displacement predicted poor clinical outcome; however, only step displacement was a significant independent risk factor[10].

Another factor independently associated with conversion to total hip arthroplasty was age, a finding that is consistent with earlier reported risk factors for poor clinical outcome or conversion to total hip arthroplasty [1,3,4,9]. Earlier studies have also indicated that superomedial dome impaction, which occurs predominantly in elderly patients, is a predictor for poor outcome [18-20]. Although in our study the presence of this radiographic feature was associated with conversion to total hip arthroplasty, it was not found to be an independent risk factor when other confounders (such as the size of residual gap dis- placement) were considered. We recognize that clinical recommendations in favor of total hip arthroplasty are related to patient age.

Limitations of the present study include the substantial percentage of patients lost to follow-up and the fact that we may not have adjusted for all confounders (such as comorbidities, preexisting osteoarthritis, and delamination or subtle impaction of the femoral head) in our multivariate analysis for conversion to total hip arthroplasty. Also, some patients (particularly those who are elderly) would have developed osteo- arthritis at long-term follow-up regardless of their acetabular fracture surgery. Although we described a relatively older patient cohort, the rate of associated fracture types and conversion to total hip arthroplasty (or poor clinical outcome) are comparable with rates in earlier reports with long-term follow-up [1,3]. Last, the measurement technique we employed has its shortcomings as displacement can occur obliquely and fragments can tilt and rotate in planes not exactly parallel to any of the 3 views used to perform measurements.

In conclusion, both residual gap and step displacement are associated with long-term hip survivorship. However, critical CT-based cutoff values show that step displacement (1 mm) is tolerated less than gap displacement (5 mm). Of these 2 types of displacement, only a large residual gap (≥5 mm) was independently associated with conversion to total hip arthroplasty in all patients. The relatively large proportion of older patients with substantial residual gaps in our study likely influenced this finding. Indeed, in younger patients, it appeared that only residual step displacement (≥1 mm) was associated with conversion to total hip arthroplasty.

Residual gap and step displacement after acetabular fracture surgery should be considered as two separate entities, given that they impact clinical outcome to different degrees. However, more research is needed in larger patient cohorts to confirm our findings. Also, the importance of gaps resulting from superomedial dome impaction warrants further clarification.

REFERENCES

1. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am 2012;94:1559-67.
2. Letournel E JR. Fractures of the acetabulum. 2nd ed. Elson RA, translator, editor. New York: Springer; 1993 Translation of Les fractures du cotyle.
3. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br 2011;93:229-36.
4. Giannoudis PV, Grotz MR, Papakostidis C, Dinopoulos H. Operative treatment of displaced fractures of the acetabulum. A meta-analysis. J Bone Joint Surg Br 2005;87:2-9.
5. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 1996;78:1632-45.
6. Borrelli J, Jr., Goldfarb C, Catalano L, Evanoff BA. Assessment of articular fragment displacement in acetabular fractures: a comparison of computerized tomography and plain radiographs. J Orthop Trauma 2002;16:449-56; discussion 56-7.
7. Hak DJ, Hamel AJ, Bay BK, Sharkey NA, Olson SA. Consequences of transverse acetabular fracture malreduction on load transmission across the hip joint. J Orthop Trauma 1998;12:90-100.
8. Malkani AL, Voor MJ, Rennirt G, Helfet D, Pedersen D, Brown T. Increased peak contact stress after incongruent reduction of transverse acetabular fractures: a cadaveric model. J Trauma 2001;51:704-9.
9. Moed BR, Carr SE, Gruson KI, Watson JT, Craig JG. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J Bone Joint Surg Am 2003;85-A:512-22.
10. Clarke-Jenssen J, Wikeroy AK, Roise O, Ovre SA, Madsen JE. Long-Term Survival of the Native Hip After a Minimally Displaced, Nonoperatively Treated Acetabular Fracture. J Bone Joint Surg Am 2016;98:1392-9.
11. Borrelli J, Jr., Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma 2005;19:299-304.
12. Helfet DL, Schmeling GJ. Management of complex acetabular fractures through single nonextensile exposures. Clin Orthop Relat Res 1994:58-68.
13. Jeffcoat DM, Carroll EA, Huber FG, Goldman AT, Miller AN, Lorich DG, et al. Operative treatment of acetabular fractures in an older population through a limited ilioinguinal approach. J Orthop Trauma 2012;26:284-9.
14. Verbeek DO, van der List JP, Moloney GB, Wellman DS, Helfet DL. Assessing postoperative reduction following acetabular fracture surgery: a standardized digital CT-based method. J Bone Joint Surg Am 2017:In submission.
15. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Radiographic Measurement of Displacement in Acetabular Fractures: A Systematic Review of the Literature. J Orthop Trauma 2016;30:285-93.
16. Olson SA, Matta JM. The computerized tomography subchondral arc: a new method of assessing acetabular articular continuity after fracture (a preliminary report). J Orthop Trauma 1993;7:402-13.
17. Helfet DL, Borrelli J, Jr., DiPasquale T, Sanders R. Stabilization of acetabular fractures in elderly patients. J Bone Joint Surg Am 1992;74:753-65.
18. Anglen JO, Burd TA, Hendricks KJ, Harrison P. The "Gull Sign": a harbinger of failure for internal fixation of geriatric acetabular fractures. J Orthop Trauma 2003;17:625-34.
19. Tosounidis TH, Stengel D, Giannoudis PV. Anteromedial dome impaction in acetabular fractures: Issues and controversies. Injury 2016;47:1605-7.
20. Laflamme GY, Hebert-Davies J. Direct reduction technique for superomedial dome impaction in geriatric acetabular fractures. J Orthop Trauma 2014;28:e39-43.

PELVIC & ACETABULAR FRACTURES
EARLY MANAGEMENT & LATE OUTCOME

11 CHAPTER

SUMMARY

2019

PELVIC AND ACETABULAR FRACTURES

Early management and late outcome

SUMMARY

This thesis presents a collection of international research from the Netherlands (Amsterdam), Australia (Sydney) and the United States (New York City and Houston). It describes evolving aspects and current challenges in pelvic ring and acetabular fracture care.

To begin, epidemiology data from the Netherlands is offered that highlights the imminent health care challenge presented by the growing elderly pelvic fracture population. This is followed by two parts, in which several important issues related to early management of pelvic trauma as well as definitive treatment of acetabular fractures are addressed.

In the first part, challenges with respect to initial assessment and urgent treatment of pelvic fracture patients are featured, including those resulting from a lack of standards of care. Additionally, indications on CT imaging for immediate hemorrhage control for abdominal and pelvic bleeding are further defined and practice guidelines provided.
In the second part, outcome results are presented following the use of the (modified) Stoppa approach for acetabular fracture surgery. Furthermore, the value of postoperative CT scanning for predicting late outcome following acetabular fracture fixation is emphasized.

Below are the key findings from the various chapters.

Key findings

Chapter 2, shows that the annual incidence of pelvic fractures in the Netherlands (14.3 per 100 000 persons) is lower than reported previously in other countries and that the majority of pelvic fracture patients (62%) is above the age of 65. Compared to younger individuals (< 65 years), the elderly have a markedly higher occurrence of (mostly minor) pelvic fractures and they have a disproportionally high in-hospital mortality rate. In the overall pelvic fracture population, advanced age is the greatest independent predictor for mortality.

Part I Early management of major pelvic trauma patients

Chapter 3 indicates that acute management strategies for haemodynamically unstable pelvic trauma patients are suboptimal and vary widely between trauma centers across Australia and New Zealand. In particular, adequate abdominal assessment is problematic and many patients receive negative laparotomies. Hemorrhage related mortality is unacceptably high, particularly in patients who undergo primary laparotomy (29%). **Chapter 4** demonstrates that quantifying the amount of intraperitoneal free fluid on CT aids to better predict the need for laparotomy (or endovascular intervention) for abdominal hemorrhage control. Larger amounts of fluid are highly predictive for active abdominal bleeding requiring intervention. **Chapter 5** shows that a pelvic "blush" is a relatively frequent finding (42%) on contemporary multi-detector CT scanners used early in the resuscitation phase. Contrary to previous understanding, the mere presence of a pelvic "blush" on CT does not warrant urgent pelvic hemorrhage control. **Chapter 6** serves as a word of caution for overreliance on CT imaging in initial assessment of pelvic fracture patients. It demonstrates that an imaging strategy of selective plain pelvic radiography (as opposed to routine use) prior to CT scanning is associated with delayed identification of major pelvic fractures, hip dislocations and (potential) pelvic bleeding. Finally, **Chapter 7**, offers an overview of literature regarding contemporary early management strategies for bleeding pelvic fracture patients. Specifically, preferred initial radiographic assessment and patient selection for endovascular pelvic hemorrhage control are described and clinical practice guidelines provided.

Part II Late outcome following acetabular fracture fixation

Chapter 8 indicates that the (modified) Stoppa approach for operative treatment of acetabular fractures is relatively safe and produces satisfactory (radiographic and clinical) results at mid-term follow-up (5 years). As such, it supports the increasing use of this approach.

Chapter 9 indicates that postoperative CT is superior in detecting acetabular incongruencies in comparison to plain pelvic film. Even more, it demonstrates that an inadequate reduction based on CT assessment is an independent predictor for long-term (9 years) conversion to total hip arthroplasty. **Chapter 10** further explores the independent association of two different types of residual displacement (gap and step) with long-term hip survivorship. It shows correlation for both gap and step displacement but the latter is tolerated much less (up to 1mm) than the former (up to 5mm). In the large patient cohort described, only significant gap displacement (≥5mm) is independently associated with long-term conversion to total hip arthroplasty while in a subgroup of younger patients (with less impaction) only step displacement (≥1mm) appears correlated.

12

CHAPTER

GENERAL DISCUSSION

2019

GENERAL DISCUSSION

Compounding the challenges surrounding the management of pelvic ring and acetabular fractures is their relative infrequent occurrence, which is particularly pertinent for more complex pelvic injury types [1].

As indicated by our work and that of others, elderly individuals are more likely than their younger counterparts to suffer pelvic fractures. With the rapidly ageing population, it is expected that an increasing number of older pelvic fracture patients will be admitted to Dutch hospitals [2]. It is clear that preventative measures such as osteoporosis screening and fall prevention programs are much needed in effort to confront this immediate health care concern [3].

Although older individuals predominantly present with less severe, minor pelvic fractures, clinical outcomes in terms of morbidity and mortality are known to be particularly grave, as highlighted in our findings [4,5]. Given that their physiological condition is variable, treatment strategies in the elderly must be specifically designed to fit the individual patient's needs. The primary goal should be rapid pain relief to allow early mobilization. Operative fixation of the pelvic ring using less invasive (percutaneous) techniques may be effective for this purpose in carefully selected patients but conclusive evidence to support this claim is lacking [6,7].

Relative to minor pelvic fractures, major pelvic fractures occur much less, even more so in the Netherlands [8]. Presumably associated with factors such as traffic safety and preferred modes of transportation, the incidence of complex, high-speed pelvic injuries was even lower in our study in comparison to prior reports from other (considerably less densely populated) countries [8-10].

Following the 1999 regionalization of trauma care in the Netherlands, the great majority of patients with high-energy (pelvic) injuries are now transported to Level I trauma centers. These major trauma centers have adequate resources and highly trained personnel available around the clock to treat the most severely injured patients. Major pelvic trauma patients, in particular, are best treated at such specialized facilities given the complexity of the pelvic fracture itself, in addition to the high risk for associated (bleeding) injuries demanding urgent multidisciplinary care [11,12].

Pelvic ring fractures

Major pelvic trauma is known to be associated with considerable in-hospital mortality [13]. Intractable bleeding is an important contributor to this poor outcome and may originate from multiple pelvic and extra-pelvic (e.g. thoracic, abdominal) sources. Promptly identifying the principal source of bleeding in hemodynamically unstable pelvic fracture patients may therefore pose a complex challenge.

In the absence of standards of care, the decision-making process and early management strategy in these difficult situations is prone to be individualized between surgeons and trauma centers. This was clearly shown in our multi-institutional review of pelvic trauma care based on data from various Level I trauma facilities in Australia and New Zealand. At the time of data collection, there was considerable variability in practice patterns and fundamental treatment principles were not consistently abided by. More recently, an equally large multi-center pelvic trauma study from the United States came to similar results and supported our significant findings [14].

In the early management of pelvic trauma patients, it is generally agreed upon that timely execution of certain key interventions is critical to improve survival [15]. Hemostatic resuscitation with correction of coagulopathy is evidently essential in this regard. Equally important is the prompt application of a sheet or pelvic binder to stabilize the pelvic ring and to tamponade (venous and bony) bleeding. Furthermore, rapid assessment for abdominal bleeding is necessary to determine the need for immediate laparotomy. Yet, abdominal clearance, in particular, proved to be quite problematic in our review of pelvic fracture care.

Focused assessment with sonography in trauma (FAST) is a readily available and practical method to triage pelvic fracture patients for immediate laparotomy [15,16]. This screening tool allows for rapid detection of intra-abdominal free fluid, which is predictive for the need for abdominal hemorrhage control.

The growing use of Computed Tomography (CT) early in the resuscitation phase has, to some extent, moderated the importance of FAST for abdominal clearance. But to date, CT indications for immediate abdominal (as well as pelvic) interventions have not been adequately delineated. In comparison to FAST, CT scanning allows for a more detailed abdominal evaluation, which includes offering specifics related to the precise amount and location of intra-abdominal free fluid. In our study, this advanced capability proved to be particularly useful, as larger amounts of free fluid on early CT were found to be more closely associated with the need for abdominal hemorrhage control.

In addition to intra-abdominal free fluid (and traumatic injuries), contrast enhanced CT is able to detect signs of pelvic arterial bleeding. The presence of a so-called "blush" on pelvic CT is indicative of arterial injury, which is widely considered to require pelvic hemorrhage control [15,17]. In our cohort study, however, many major pelvic fracture patients had a CT "blush" and a sizable number of those were ultimately "self-limiting". This finding was recently confirmed by a large pelvic trauma study with similar design, which also found a high detection rate of clinically irrelevant pelvic "blushes" [18]. It is likely that these latest results are secondary to current trends of routine and earlier CT scanning as well as the use of more modern multi-detector scanners. As such, it appears that a CT pelvic "blush" in itself, is presently insufficient to warrant an urgent intervention. When deciding whether to proceed for pelvic hemorrhage control, this CT finding should rather be taken in conjunction with clinical signs of ongoing bleeding.

The preference for early CT scanning has also impacted the more conventional use of plain pelvic radiography for initial trauma assessment. Along with the apparent diminishing role of FAST, routine pelvic radiography appears to have lost much appeal in favor for CT in the primary evaluation phase. In examining this development in pelvic fracture patients who undergo CT scanning, we found that selective use of pelvic radiography introduces its own specific impediments. This concern was also highlighted in a more recent study, which emphasized the importance of early detection of hip dislocations and the need to reduce radiation exposure [19]. It is our contention that, depending on the local situation, plain pelvic radiography remains a useful screening tool to rapidly determine the need for (non-invasive) interventions such as application of a pelvic binder or hip reduction. This modality also allows for early planning and prioritization, which is particularly important in patient with potential pelvic fracture-related bleeding.

The implementation of evidence-based clinical practice guidelines is an important step towards improving outcome in major pelvic trauma patients. Standards of care should delineate a step-by-step strategy to streamline early imaging assessment and treatment. A number of such highly effective guidelines have previously been published and we have provided an updated algorithm for early imaging assessment and treatment [15,17,20].

In the process of designing clinical practice guidelines, it is paramount to consider local circumstances. Some of the fundamental principles mentioned previously are universally applicable but the successful introduction of particularly more advanced techniques for hemorrhage control will be highly dependent on the institution's resources and expertise [11,13,14]. The extent to which CT can be used as an early triage tool is clearly related to the location of the CT scanner. In many institutions, limited access to CT remains a major issue precluding its widespread use early in the resuscitation phase. The same applies to pelvic angiographic embolization, although a very appealing and effective technique, its successful use relies heavily on the rapid availability of skilled interventional radiology personnel. Indeed, in some trauma centers, immediate pelvic packing is currently the preferred method for hemorrhage control given that endovascular treatment would result in lengthy delays [21,22].

In major pelvic trauma patients in whom the challenges of the initial resuscitation phase are adequately met and who are sufficiently physiologically stabilized, a plan for definitive fixation is formulated. At this point, attention shifts largely from patient survival to preventing disability and complete functional recovery. In acetabular fracture patients, difficulties are specifically encountered in this successive stage of care. In this thesis a number of ongoing developments in acetabular fracture surgery are specifically addressed. These are related to the optimal surgical exposure and areas of (radiographic and clinical) outcome assessment and prediction.

Acetabular fractures

In terms of preferred surgical exposure for operative fixation of acetabular fractures, the (modified) Stoppa approach has presently taken center stage [23]. Mid-term results in our study deliver much credence to this development and support the growing use of this purportedly less-invasive approach. In conjunction with the mounting popularity of this technique, specialized equipment and anatomically shaped plates have been developed to better fit the contours of the pelvis and to provide a buttress for the quadrilateral plate [23-25].

Upon introduction of novel surgical techniques and implants and for purposes of quality assurance and scientific research, critical appraisal of radiographic and clinical outcome is essential. Each of these aspects of outcome assessment, however, present with their own unique challenges. Early determination of success of acetabular fracture treatment has traditionally been based on radiographic measurements of residual displacement [26]. Quality of reduction is preferably assessed based on more accurate CT imaging instead of plain pelvic radiography, as emphasized in our study [27,28]. But even further, it is decidedly necessary to use a reliable uniform measurement technique for this purpose (Addendum I) [29]. Performing accurate postoperative measurements within a concave structure such as the acetabulum remains difficult and our proposed method, as such, is perhaps not perfect. Yet, this more reliable digital standardized CT-based technique provides important improvements over previously used methods [29].

Assessment of clinical outcome following acetabular fracture fixation is an area that is evolving quickly. A wide variety of patient reported outcome measures are currently available resulting in inconsistent reporting in acetabular fracture research [30]. Of late, it has generally been recommended to use one generic (general health related, quality of life) and one (hip) joint specific outcome instrument [31,32]. In addition, hip survivorship is considered to be an important gauge for determining surgical success. Although an imperfect outcome measure (largely related to a lack of uniform indications) conversion to total hip arthroplasty (THA) following acetabular fracture fixation is a significant complication from the patient's perspective. Long-term hip survivorship rates, however, are infrequently reported particularly in patient cohorts of sufficient size to allow multivariate analysis [33,34].

Our large acetabular fracture study suggests that, among other factors such as age, inadequate reductions as assessed on CT imaging are independently predictive for THA placement at long-term follow up. This finding is significant as it indicates that CT not only allows for a more detailed evaluation of the joint surface following fixation, but also that the detected (smaller) incongruencies are indeed clinically relevant. Even more, it is shown that the specific type of displacement matters, as intra-articular steps are tolerated much less than gaps. Likewise, it has previously been suggested in cadaver studies that each of these types of displacement has a distinctive effect on load distribution within the hip joint and therefore may affect outcome to a different extent [35,36]. This notion challenges the currently most widely used grading system for reduction quality proposed by Matta, which considers gap and step displacement as equal [26].

CONCLUSION

Management of pelvic ring and acetabular fracture patients has undoubtedly come a long way since the pioneering years of the early 1960's. The past decades have brought many advancements that have significantly impacted treatment of these complex patients. In the current age of rapidly accelerating changes in technology, evolution of care has been even more profound. As underscored in this thesis, innovations in (CT) imaging capabilities have made a large contribution to improving treatment of pelvic ring and acetabular fractures in all stages of care, from early treatment and definitive fixation to (radiographic) outcome assessment. Nonetheless, countless challenging aspects in the management of these difficult injuries remain and a myriad of urgent questions will innately emanate from this thesis. Some of these unresolved matters will be outlined in the following future perspectives section.

MAIN MESSAGES

- The growing elderly pelvic fracture population presents an imminent health care concern

- A Dutch pelvic trauma registry is fundamental to advance research on effective preventative and treatment strategies in pelvic trauma

- In major pelvic trauma patients
  - Clinical practice guidelines are essential to provide a standardized systematic approach aimed at rapid hemorrhage control
  - Larger amounts of free fluid on early CT are highly predictive for the need for abdominal hemorrhage control
  - The sole presence of a pelvic "blush" on early CT does not demand immediate pelvic hemorrhage control
  - Plain pelvic radiography remains a useful screening tool for initial trauma assessment
  - Endovascular pelvic hemorrhage control is safe and effective but protocols should be in place to allow rapid intervention

- In acetabular fracture patients
  - The (modified) Stoppa approach presents a relatively safe and effective technique for acetabular fracture fixation
  - CT is superior to pelvic radiography for detecting acetabular fracture displacement after operative fixation and reliably predicts outcome
  - Residual gap and step displacement should be considered as two separate entities as they impact outcome to different degrees
  - Residual step displacement within the acetabulum is tolerated much less than gap displacement

REFERENCES

1. Yoshihara H, Yoneoka D. Demographic epidemiology of unstable pelvic fracture in the United States from 2000 to 2009: Trends and in-hospital mortality. J Trauma Acute Care Surg 2014;76:380-5.
2. Nanninga GL, de Leur K, Panneman MJ, van der Elst M, Hartholt KA. Increasing rates of pelvic fractures among older adults: The Netherlands, 1986-2011. Age Ageing 2014;43:648-53.
3. Kanakaris NK, Greven T, West RM, Van Vugt AB, Giannoudis PV. Implementation of a standardized protocol to manage elderly patients with low energy pelvic fractures: can service improvement be expected? Int Orthop 2017;41:1813-24.
4. van Dijk WA, Poeze M, van Helden SH, Brink PR, Verbruggen JP. Ten-year mortality among hospitalised patients with fractures of the pubic rami. Injury 2010;41:411-4.
5. Ayoung-Chee P, McIntyre L, Ebel BE, Mack CD, McCormick W, Maier RV. Long-term outcomes of ground-level falls in the elderly. J Trauma Acute Care Surg 2014;76:498-503.
6. Hopf JC, Krieglstein CF, Muller LP, Koslowsky TC. Percutaneous iliosacral screw fixation after osteoporotic posterior ring fractures of the pelvis reduces pain significantly in elderly patients. Injury 2015;46:1631-6.
7. Booth A, Ingoe HMA, Northgraves M, Coleman E, Harden M, Kassam J, et al. Effectiveness of surgical fixation for lateral compression type one (LC-1) fragility fractures of the pelvis: a systematic review. BMJ Open 2019;9:e024737.
8. Balogh Z, King KL, Mackay P, McDougall D, Mackenzie S, Evans JA, et al. The epidemiology of pelvic ring fractures: a population-based study. J Trauma 2007;63:1066-73; discussion 72-3.
9. Melton LJ, 3rd, Sampson JM, Morrey BF, Ilstrup DM. Epidemiologic features of pelvic fractures. Clin Orthop Relat Res 1981:43-7.
10. Ragnarsson B, Jacobsson B. Epidemiology of pelvic fractures in a Swedish county. Acta Orthop Scand 1992;63:297-300.
11. Oliphant BW, Tignanelli CJ, Napolitano LM, Goulet JA, Hemmila MR. American College of Surgeons Committee on Trauma verification level affects trauma center management of pelvic ring injuries and patient mortality. J Trauma Acute Care Surg 2019;86:1-10.
12. Morshed S, Knops S, Jurkovich GJ, Wang J, MacKenzie E, Rivara FP. The impact of trauma-center care on mortality and function following pelvic ring and acetabular injuries. J Bone Joint Surg Am 2015;97:265-72.
13. Duchesne J, Costantini TW, Khan M, Taub E, Rhee P, Morse B, et al. The effect of hemorrhage control adjuncts on outcome in severe pelvic fracture: A multi-institutional study. J Trauma Acute Care Surg 2019;87:117-24.
14. Costantini TW, Coimbra R, Holcomb JB, Podbielski JM, Catalano R, Blackburn A, et al. Current management of hemorrhage from severe pelvic fractures: Results of an American Association for the Surgery of Trauma multi-institutional trial. J Trauma Acute Care Surg 2016;80:717-23; discussion 23-5.
15. Tran TL, Brasel KJ, Karmy-Jones R, Rowell S, Schreiber MA, Shatz DV, et al. Western Trauma Association Critical Decisions in Trauma: Management of pelvic fracture with hemodynamic instability-2016 updates. J Trauma Acute Care Surg 2016;81:1171-4.
16. Christian NT, Burlew CC, Moore EE, Geddes AE, Wagenaar AE, Fox CJ, et al. The focused abdominal sonography for trauma examination can reliably identify patients with significant intra-abdominal hemorrhage in life-threatening pelvic fractures. J Trauma Acute Care Surg 2018;84:924-8.
17. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.

18. Ramin S, Hermida M, Millet I, Murez T, Monnin V, Hamoui M, et al. Limits of intravascular contrast extravasation on computed tomography scan to define the need for pelvic angioembolization in pelvic blunt trauma: a specific assessment on the risk of false positives. J Trauma Acute Care Surg 2018;85:527-35.
19. Walker MR, El Naga AN, Atassi OH, Perkins CH, Mitchell SA. Effect of initial emergency room imaging choice on time to hip reduction and repeat imaging. Injury 2019;50:686-9.
20. Black SR, Sathy AK, Jo C, Wiley MR, Minei JP, Starr AJ. Improved Survival After Pelvic Fracture: 13-Year Experience at a Single Trauma Center Using a Multidisciplinary Institutional Protocol. J Orthop Trauma 2016;30:22-8.
21. Tesoriero RB, Bruns BR, Narayan M, Dubose J, Guliani SS, Brenner ML, et al. Angiographic embolization for hemorrhage following pelvic fracture: Is it “time” for a paradigm shift? J Trauma Acute Care Surg 2017;82:18-26.
22. Matsushima K, Piccinini A, Schellenberg M, Cheng V, Heindel P, Strumwasser A, et al. Effect of door-to-angioembolization time on mortality in pelvic fracture: Every hour of delay counts. J Trauma Acute Care Surg 2018;84:685-92.
23. Guy P. Evolution of the anterior intrapelvic (Stoppa) approach for acetabular fracture surgery. J Orthop Trauma 2015;29 Suppl 2:S1-5.
24. Gras F, Marintschev I, Grossterlinden L, Rossmann M, Graul I, Hofmann GO, et al. The Anterior Intrapelvic Approach for Acetabular Fractures Using Approach-Specific Instruments and an Anatomical-Preshaped 3-Dimensional Suprapectineal Plate. J Orthop Trauma 2017;31:e210-e6.
25. Tosounidis TH, Giannoudis PV. What is new in acetabular fracture fixation? Injury 2015;46:2089-92.
26. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 1996;78:1632-45.
27. Moed BR, Carr SE, Gruson KI, Watson JT, Craig JG. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J Bone Joint Surg Am 2003;85-A:512-22.
28. Borrelli J, Jr., Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma 2005;19:299-304.
29. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Radiographic Measurement of Displacement in Acetabular Fractures: A Systematic Review of the Literature. J Orthop Trauma 2016;30:285-93.
30. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Assessment of functional outcomes of surgically managed acetabular fractures: a systematic review. Bone Joint J 2016;98-B:690-5.
31. Lieberman JR, Bozic KJ, Mallon WJ, Goldfarb CA. It Is All About Value Now: The Data You Need to Collect and How to Do It: AOA Critical Issues. J Bone Joint Surg Am 2018;100:e110.
32. Group M. Patient-Reported Outcomes in Orthopaedics. J Bone Joint Surg Am 2018;100:436-42.
33. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am 2012;94:1559-67.
34. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br 2011;93:229-36.
35. Malkani AL, Voor MJ, Rennirt G, Helfet D, Pedersen D, Brown T. Increased peak contact stress after incongruent reduction of transverse acetabular fractures: a cadaveric model. J Trauma 2001;51:704-9.
36. Hak DJ, Hamel AJ, Bay BK, Sharkey NA, Olson SA. Consequences of transverse acetabular fracture malreduction on load transmission across the hip joint. J Orthop Trauma 1998;12:90-100.

13
CHAPTER

FUTURE PERSPECTIVES

2019

FUTURE PERSPECTIVES

At present, trends in pelvic fracture management in the Netherlands remain unknown and regrettably the current Dutch trauma registry lacks important detail to clarify this matter. Although relatively comprehensive, it does not specifically capture data with regards to pelvic ring and acetabular fracture treatment. This leaves central questions unanswered such as those related to the rate of (radiological and surgical) interventions performed in pelvic and acetabular fracture patients. Previously, it was thought that roughly 150 pelvic surgeries were performed in the Netherlands, annually [1]. However, more recent estimates, based on the incidence of complex pelvic injuries (as found in our study) and anecdotal data from a number of Dutch Level I trauma centers, suggest that an annual rate closer to 600 pelvic surgeries may be more accurate.

Initiatives are currently being undertaken for a nationwide pelvic registry which would be able to shed some light on this fundamental question as well as other important issues. A comparable enterprise in Germany has yielded a large inclusive database with specifics related to radiological and surgical interventions, medical and surgical complications as well as radiological and functional outcomes. The German Pelvic trauma registry has proven to be highly useful for purposes of quality assurance, benchmarking and research [2-4]. A Dutch Pelvic trauma registry could ultimately be used for similar purposes.

Here are some of the research topics that are currently especially relevant in pelvic and acetabular fracture care:

Pelvic ring fractures

The need for early operative fixation of osteoporotic pelvic ring fractures is debatable. Currently, it has been insufficiently established that timely surgical intervention will allow for rapid mobilization and will ultimately result in reduced mortality in elderly pelvic fracture patients.

In terms of acute management of major pelvic trauma patients, there is ongoing interest in effective early and definitive methods to control pelvic fracture related bleeding. The use of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in particular, has attracted much attention. Yet, given the limited experience with this relatively new device, its role for temporary hemorrhage control in bleeding pelvic fracture patients remains to be defined [5]. Whether patients should preferably be transported to the angiography suite (for endovascular intervention) or operating theatre (for surgical intervention) for definitive hemorrhage control is a difficult dilemma. In the coming years, this controversy may, however, become less relevant as a growing number of major trauma centers have begun installing hybrid operating rooms. These suites allow both endovascular and surgical methods for hemorrhage control to be employed simultaneously. But potential improvements in care that contemporary hybrid operating rooms may bring will need to be investigated. Lastly, clinical practice guidelines to standardize early treatment in major pelvic trauma remains topical and the development and implementation of these evidence-based recommendations should continue to be the focus of future research [5,6].

Acetabular fractures

With respect to definitive fixation of acetabular fractures, alternative surgical exposures, such as the pararectus approach, and new plate designs and production techniques, such as 3-D printing, appear to have much potential [7,8]. Yet, results remain preliminary and conclusive evidence to support the use of these innovative approaches and implants is obviously necessary.

The vexing question whether “to fix (and) or replace” in elderly acetabular fracture patients continues to be hotly debated. Although there appears to be agreement on select indications for immediate hip replacement, further indications are invariably disagreed upon. It is likely that only a large prospective multicenter study will be able to provide satisfactory answers in this regard.

A number of new developments in areas of clinical and radiographic outcome assessment following acetabular fracture surgery are noteworthy. Regarding postoperative clinical evaluation, all eyes are on the Patient-Reported Outcomes Measurement Information System (PROMIS) as developed by the National Institutes of Health (NIH) [9-11]. This collection of measures evaluates domains of patient reported health based on item (question) banks. Using computer adaptive testing (CAT) the response burden is reduced, without losing high measurement precision, making PROMIS CAT attractive to use in orthopedic (trauma) practice [10,12]. Ultimately, this may render numerous, more time consuming generic and pelvic specific outcome measures redundant.

In terms of radiographic outcome assessment, it is evidently important to externally validate our proposed CT cut off values for assessing reduction quality following acetabular fracture fixation. For future research purposes, a grading system specifically designed for CT assessment is much needed.

Postoperative CT scanning in acetabular fracture surgery remains surrounded by controversy. But the introduction of intra-operative CT (or fluoroscopy) imaging, with or without navigational capabilities, may prove to be pivotal [13,14]. These more advanced imaging modalities may aid to achieve more accurate reductions and improve implant placement as they allow immediate revisions to be made before patients leave the operating room.

Steps towards improving treatment of pelvic ring and acetabular fracture patients in the Netherlands have lately included establishment of a “pelvic expert group” (for consultation and referral services) and progressive centralization of treatment. In addition to benefits for clinical care, these developments have also created exciting opportunities and appear to have renewed interest in pelvic trauma research [8,15,16]. In conjunction with a well-designed Dutch Pelvic trauma registry and much needed collaboration in multicentered studies, these advances should provide ample prospect to address the aforementioned critical issues.

Key questions for future research

- Which elderly pelvic fracture patients may benefit from early operative stabilization and which osteoporotic fractures are most suited for fixation?
- Is pelvic and acetabular fracture care in higher volume (Level I) centers associated with reduced mortality and superior functional recovery?
- What is the role of Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA) in controlling pelvic fracture-related bleeding?
- Are certain emerging technological advances (e.g. 3-D printed plates, CT navigation) in pelvic fracture surgery associated with improved outcomes and are they cost-effective?
- Which elderly acetabular fracture patients are best treated with primary total hip arthroplasty as opposed to acetabular reconstruction?
- What exact size of gap and step displacement on CT is acceptable for conservative management of acetabular fractures?

REFERENCES

1. Ridder VAd, Leenen LPH. [Acetabular and pelvic fractures, statistics and practice in the Netherlands]. Nederlands Tijdschrift voor Traumatologie 2010;18:122.
2. Herath SC, Pott H, Rollmann MFR, Braun BJ, Holstein JH, Hoch A, et al. Geriatric Acetabular Surgery: Letournel's Contraindications Then and Now-Data From the German Pelvic Registry. J Orthop Trauma 2019;33 Suppl 2:S8-S13.
3. Schmal H, Froberg L, M SL, Sudkamp NP, Pohlemann T, Aghayev E, et al. Evaluation of strategies for the treatment of type B and C pelvic fractures: results from the German Pelvic Injury Register. Bone Joint J 2018;100-B:973-83.
4. Rollmann MF, Holstein JH, Pohlemann T, Herath SC, Histing T, Braun BJ, et al. Predictors for secondary hip osteoarthritis after acetabular fractures-a pelvic registry study. Int Orthop 2018.
5. Duchesne J, Costantini TW, Khan M, Taub E, Rhee P, Morse B, et al. The effect of hemorrhage control adjuncts on outcome in severe pelvic fracture: A multi-institutional study. J Trauma Acute Care Surg 2019;87:117-24.
6. Costantini TW, Coimbra R, Holcomb JB, Podbielski JM, Catalano R, Blackburn A, et al. Current management of hemorrhage from severe pelvic fractures: Results of an American Association for the Surgery of Trauma multi-institutional trial. J Trauma Acute Care Surg 2016;80:717-23; discussion 23-5.
7. Keel MJB, Siebenrock KA, Tannast M, Bastian JD. The Pararectus Approach: A New Concept. JBJS Essent Surg Tech 2018;8:e21.
8. Merema BJ, Kraeima J, Ten Duis K, Wendt KW, Warta R, Vos E, et al. The design, production and clinical application of 3D patient-specific implants with drilling guides for acetabular surgery. Injury 2017;48:2540-7.
9. Group M. Patient-Reported Outcomes in Orthopaedics. J Bone Joint Surg Am 2018;100:436-42.
10. Rothrock NE, Bass M, Blumenthal A, Gershon RC, Hanson B, Joeris A, et al. AO Patient Outcomes Center: Design, Implementation, and Evaluation of a Software Application for the Collection of Patient-Reported Outcome Measures in Orthopedic Outpatient Clinics. JMIR Form Res 2019;3:e10880.
11. Lieberman JR, Bozic KJ, Mallon WJ, Goldfarb CA. It Is All About Value Now: The Data You Need to Collect and How to Do It: AOA Critical Issues. J Bone Joint Surg Am 2018;100:e110.
12. Hung M, Stuart AR, Higgins TF, Saltzman CL, Kubiak EN. Computerized Adaptive Testing Using the PROMIS Physical Function Item Bank Reduces Test Burden With Less Ceiling Effects Compared With the Short Musculoskeletal Function Assessment in Orthopaedic Trauma Patients. J Orthop Trauma 2014;28:439-43.
13. Routt MLC, Jr., Gary JL, Kellam JF, Burgess AR. Improved Intraoperative Fluoroscopy for Pelvic and Acetabular Surgery. J Orthop Trauma 2019;33 Suppl 2:S37-S42.
14. Elnahal WA, Ward AJ, Acharya MR, Chesser TJS. Does Routine Postoperative Computerized Tomography After Acetabular Fracture Fixation Affect Management? J Orthop Trauma 2019;33 Suppl 2:S43-S8.
15. Brouwers L, Teutelink A, van Tilborg F, de Jongh MAC, Lansink KWW, Bemelman M. Validation study of 3D-printed anatomical models using 2 PLA printers for preoperative planning in trauma surgery, a human cadaver study. Eur J Trauma Emerg Surg 2018.
16. Hermans E, Brouwers L, van Gent T, Biert J, de Jongh MAC, Lansink KWW, et al. Quality of life after pelvic ring fractures: Long-term outcomes. A multicentre study. Injury 2019;50:1216-22.

14

CHAPTER

SUMMARY IN DUTCH (SAMENVATTING)

2019

BEKKEN- EN ACETABULUMFRACTUREN

Vroege behandeling en Late uitkomst

SAMENVATTING

De bekkenring bestaat uit het heiligbeen (sacrum) en de twee heupbeenderen welke de beide heupkommen (acetabula) bevatten. Breuken van het bekken komen weinig voor en kunnen bestaan uit een breed scala aan letsel. Dit beslaat minimale, enkelvoudige (acetabulum) breuken tot aan ernstige en instabiele letsels van de bekkenring. Minder ernstige breuken zijn veelal een gevolg van een val in huis bij oudere patiënten met osteoporose. Meer ernstige breuken komen daarentegen vaker voor bij jongere patiënten met meervoudig letsel en kunnen levensbedreigend zijn.

Het doel van dit proefschrift is om inzicht te geven in een aantal actuele ontwikkelingen en uitdagingen bij de zorg voor patiënten met een bekkenring- of acetabulumfractuur. Het bestaat uit meerdere internationale studies uitgevoerd op verschillende locaties in Nederland (Amsterdam), Australië (Sydney) en de Verenigde Staten (New York City en Houston).

Allereerst, wordt de epidemiologie van bekkenfracturen in Nederland beschreven. Hierbij wordt het dringende probleem, de zorgwekkende groei van de oudere patiëntenpopulatie, voor de gezondheidszorg belicht. Hierna komen, in twee delen, verscheidene belangrijke kwesties omtrent (1) de opvang van patiënten met een ernstig bekkenringletsel en (2) de definitieve behandeling van patiënten met een acetabulumfractuur aan bod.

In het eerste deel worden problemen bij de initiële beoordeling en acute behandeling van patiënten met een bekkenringfractuur benadrukt zoals het gebrek aan gestandaardiseerde zorg en (evidence-based) protocollen. Bovendien worden Computed Tomography (CT)-indicaties voor directe (hemostatische) interventies beschreven om verbloeding uit respectievelijk abdomen en bekken te stoppen en worden aanbevolen behandelrichtlijnen weergegeven.

In het tweede deel worden de resultaten gegeven na het gebruik van de Stoppa benadering voor operatieve behandeling van acetabulumfracturen. Daarnaast wordt de waarde van het postoperatief gebruik van CT voor het voorspellen van lange termijn uitkomst na acetabulumchirurgie uiteengezet.

Hieronder staan de belangrijkste bevindingen uit de verschillende hoofdstukken beschreven.

BELANGRIJKSTE BEVINDINGEN

In **hoofdstuk 2** wordt vastgesteld dat de jaarlijkse incidentie van bekkenfracturen in Nederland (14.3 per 100 000 inwoners) lager is dan eerder in andere landen werd gerapporteerd en dat de meerderheid (62%) van de patiënten ouder is dan 65 jaar. In vergelijking tot jongere patiënten (< 65 jaar), komen bij de oudere populatie (meestal minder ernstige) bekkenfracturen aanzienlijk vaker voor en overlijdt een onevenredig hoog aantal in het ziekenhuis. In de totale groep van patiënten is gevorderde leeftijd de grootste voorspeller voor sterfte.

Deel I Vroege behandeling van patiënten met ernstig bekkenletsel

In **Hoofdstuk 3** wordt beschreven dat de initiële beoordeling en acute behandeling van hemodynamisch instabiele patiënten met ernstig bekkenletsel in Australië en Nieuw-Zeeland suboptimaal is. Bovendien verschilt de behandeling in grote mate tussen de diverse traumacentra in deze twee landen. Vooral een adequate abdominale beoordeling blijkt lastig en veel patiënten krijgen uiteindelijk een negatieve laparotomie. Mortaliteit als gevolg van verbloeding blijkt onaanvaardbaar hoog te zijn, met name bij patiënten die primair een laparotomie ondergaan (29%). Uit **Hoofdstuk 4** blijkt het nut van het bepalen van de hoeveelheid vrij vocht op CT. Grotere hoeveelheden vrij vocht zijn voorspellend voor de aanwezigheid van een actieve abdominale bloeding die direct ingrijpen (laparotomie of endovasculaire interventie) vereist. Zoals beschreven in **hoofdstuk 5** is een "blush" in de regio van het bekken een relatief frequente bevinding op hedendaagse multi-detector CT-scans, die vroeg in de reanimatie fase worden vervaardigd (42%). In tegenstelling tot eerdere inzichten, blijkt een interventie, bij patiënten bij wie louter een "blush" wordt gevonden, niet altijd noodzakelijk om een bekkenbloeding te stoppen. **Hoofdstuk 6** dient als waarschuwing om bij trauma opvang van patiënten met (verdenking op) een bekkenfractuur niet alleen uit te gaan van CT-beeldvorming. Er wordt aangetoond dat als bij de initiële beoordeling alleen op indicatie een bekken röntgenfoto wordt gemaakt (selectieve strategie), voorafgaand aan het verrichten van een CT-scan, ernstige bekkenletsels, heup dislocaties en (potentiële) bekkenbloedingen verlaat worden vastgesteld. Het blijft dus waardevol om standaard een bekken röntgenfoto te vervaardigen (routinematige strategie). Tot slot, bestaat **Hoofdstuk 7** uit een literatuuroverzicht aangaande (diagnostische) work-up en behandelstrategieën voor patiënten met een bloedend bekkenletsel. Er wordt uiteengezet welke beeldvorming bij opvang de voorkeur heeft, en wat bij een bekkenbloeding de patiënt selectiecriteria zijn voor een endovasculaire interventie. Daarnaast werden er praktijkgerichte richtlijnen in opgenomen.

Deel II Late uitkomst na operatieve behandeling van acetabulumfracturen

In **hoofdstuk 8** wordt aangetoond dat de, minder invasieve, (gemodificeerde) Stoppa benadering voor operatieve behandeling van acetabulumfracturen relatief veilig is en daarnaast op midden lange termijn (5 jaar) aanvaardbare (radiologische en klinische) resultaten geeft.

De hierop volgende hoofdstukken bespreken de kwaliteit van de repositie van acetabulumfracturen. In sommige gevallen is deze niet optimaal en sluiten de fractuurdelen niet goed op elkaar aan met een opening (“gap”) of een trap (“step”) in het heupgewricht tot gevolg. In **Hoofdstuk 9** wordt bevestigd dat postoperatieve CT inderdaad superieur is voor het detecteren van deze onregelmatigheden in het acetabulum in vergelijking met bekken röntgenfoto’s. Bovendien wordt aangetoond dat een niet-adequate repositie van de fractuur op basis van de CT-beoordeling een belangrijke voorspeller is voor het plaatsen van een totale heupprothese op de lange termijn (9 jaar). In **Hoofdstuk 10** wordt aangetoond dat een postoperatieve “gap” of “step” in het acetabulum, onafhankelijke van elkaar, voorspellers zijn voor een heupprothese op de lange termijn. De klinische afkapwaardes voor een optimale voorspelling liggen voor een “step” (1 mm) veel lager dan voor een “gap” (5 mm). Een “step” wordt in het gewricht dus minder goed getolereerd dan een “gap”, ze moeten beschouwd worden als twee separate entiteiten. Uit daaropvolgende (multivariate) analyses met gebruik van de afkapwaardes blijkt dat, in het totale patiënten cohort, een significant “gap” (≥ 5 mm) geassocieerd is met conversie naar totale heupprothese op de lange termijn. Terwijl in een subgroep van jongere patiënten alleen een significante “step” (≥1mm) gecorreleerd lijkt.

CONCLUSIE

In de afgelopen decennia is er veel veranderd in de zorg voor patiënten met een bekkenring- of acetabulumfractuur. Dit proefschrift laat zien dat progressieve technologische ontwikkelingen en innovaties op het vlak van (CT) beeldvorming een belangrijke bijdrage geleverd hebben aan het verbeteren van de behandeling voor deze complexe letsels. Deze hebben zowel de vroege opvang van patiënten met een bekkenringfractuur als de definitieve operatieve behandeling van patiënten met een acetabulumfractuur ten gunste beïnvloedt. De behandeling van patiënten met een bekkenring- of acetabulumfractuur blijft desondanks uitdagend en vele vragen zijn nog onbeantwoord.

"Take home messages"

- De zorgwekkende groei van de oudere patiëntenpopulatie met een bekkenfractuur vormt een dringend probleem voor de gezondheidszorg

- Het tot stand brengen van een Nederlands bekkentrauma register is van fundamenteel belang voor het doen van verder onderzoek

- Bij patiënten met ernstig bekkenletsel:
  - is het essentieel om richtlijnen te ontwikkelen gericht op de behandeling van acute bloeding
  - is een grotere hoeveelheid vocht in de buik op CT voorspellend voor de noodzaak een abdominale bloeding te stoppen
  - is het bij alleen een bekken "blush" op CT niet altijd noodzakelijk om direct in te grijpen voor een bekkenbloeding
  - blijft het waardevol om een bekken röntgenfoto te vervaardigen bij de initiële trauma opvang
  - zijn endovasculaire interventies om bekkenbloedingen te stoppen veilig en effectief maar zijn protocollen nodig om snelle behandeling mogelijk te maken

- Bij patiënten met een acetabulumfractuur
  - is de (modified) Stoppa benadering een veilige en effectieve chirurgische benadering voor fixatie van acetabulumfracturen
  - is postoperatieve CT superieur ten opzichte van röntgenfoto's voor het detecteren onregelmatigheden in het acetabulum
  - moeten een postoperative "step" en "gap" in het gewricht beschouwd worden als twee separate entiteiten, omdat deze de uitkomst in verschillende mate beïnvloeden
  - wordt een "step" in het gewricht minder goed getolereerd dan een "gap"

TOEKOMST

Om gedegen (multicenter) onderzoek te kunnen doen, is een goed opgezet Nederlands bekkentrauma register van cruciaal belang. Bij de opvang van patiënten met bekkenringfracturen, zijn nieuwe strategieën en methoden om bloedingen (tijdelijk) te stoppen, zoals Resuscitative Endovascular Balloon Occlusion of the Aorta (REBOA), belangwekkende onderwerpen. Als het gaat om de operatieve behandeling van patiënten met een acetabulumfractuur, is er nog veel onderzoek nodig op het vlak van nieuwe chirurgische benaderingen, het ontwerpen en de productie van implantaten (3D printen), intra-operatieve beeldvormende technieken (navigatie), indicatiestelling voor specifieke operaties (heupprothese) en de evaluatie van (radiologische en klinische) uitkomst. Rondom klinische uitkomsten is met name het gebruik van het Patient-Reported Outcomes Measurement Information System (PROMIS) gebaseerd op computer adaptive testing (CAT) voor deze patiëntengroepen een aantrekkelijke innovatie. Tot slot, valt er ook rondom het ontwikkelen en implementeren van praktijkgerichte richtlijnen nog veel winst te behalen.

I

addendum

ASSESSING POSTOPERATIVE REDUCTION AFTER ACETABULAR FRACTURE SURGERY

A standardized digital Computed Tomography-based method

NEW YORK CITY, U.S.A.

D.O. Verbeek,
J.P. van der List,
G.B. Moloney,
D.S. Wellman,
D. L. Helfet

Hospital for Special Surgery and New York Presbyterian Hospital, Weill Cornell Medicine, New York City, NY, USA

J Orthop Trauma 2018; 32: e284-8

2018

SUMMARY

Quality of reduction following acetabular fracture surgery is an important predictor for clinical outcome. Computed tomography (CT) is likely superior to plain pelvic radiography for assessment of postoperative reduction, but interobserver reliability may be limited in the absence of a widely adopted technique. We describe a standardized digital CT-based method for measuring residual (gap and step) displacement on CT following acetabular fracture surgery. In a selection of patients, we determined the interobserver reliability for measuring displacement and grading quality of reduction on postoperative pelvic radiography and CT with and without the use of this novel technique.

INTRODUCTION

In concurrence with a range of other fractures involving the joint, it is widely recognized that the quality of articular reduction after acetabular fracture surgery is a crucial predictor for clinical outcome [1-4]. In most studies, postoperative pelvic radiography is used to measure residual gap and step displacement and assess quality of reduction [1-3,5,6].
Computed tomography (CT) imaging, compared to plain radiography, has been shown to be superior for assessing postoperative reduction in a number of intra-articular fractures [7,8]. This advanced modality is however not routinely used for postoperative assessment following acetabular fracture surgery but may be highly predictive for clinical outcome [9-11]. For CT to be of value in future research, measurements of residual acetabular displacement will not only need to be accurate but also reproducible [5].
The overwhelming majority of studies on acetabular fracture surgery lack a proper description of the technique used to measure residual displacement and the issue of reliability of measurements is rarely addressed [5]. In the current literature, no standardized measurement methodology that would allow testing of reliability has been widely adopted. It is only after adequate reliability of CT-based measurements of residual displacement is determined, that an attempt can be made to correlate these findings with clinical outcome.

In this study, we describe a standardized digital CT-based method for measuring residual (gap and step) displacement on CT following acetabular surgery. In a selection of patients, we determined the interobserver reliability for measuring displacement and grading quality of reduction on postoperative pelvic radiography and CT with and without the use of this novel technique.

STANDARDIZED DIGITAL COMPUTED TOMOGRAPHY-BASED METHOD

To create a standardized method of assessment for digital [digital imaging and communications in medicine (DICOM)] CT scans, radiographic findings considered most clinically relevant based on current literature and expert opinion were selected. As such, assessment is limited to include only residual displacement present in the weight-bearing dome [5,12]. In this 1 cm area of the superior acetabular dome (or “subchondral arch”), the greatest gap or step displacement in any of the axial, sagittal, or coronal plane views is measured. In fractures with posterior wall involvement, displacement in the middle one-third of the acetabular wall is also considered [9]. Displacement in the area of the cotyloid fossa is not included.

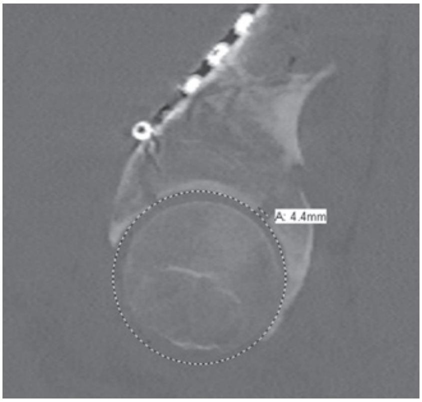


Figure 1. Residual gap displacement (of 4.4 mm) is measured in-line with a digital circular template matched to fit the intact portion of the acetabular dome.

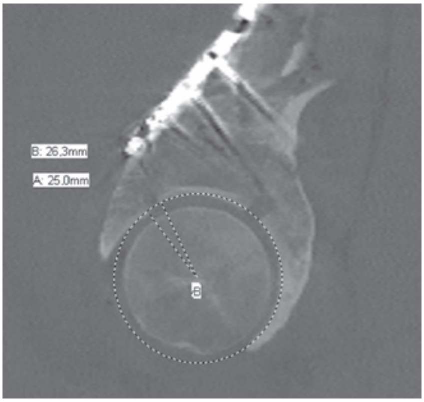


Figure 2. Residual step displacement (of 1.3 mm) is measured by subtracting the distance from the intact portion of the acetabular dome to the center of the template (26.3 mm in this example) by the distance from the displaced fragment to the center of the template (25.0 mm in this example)

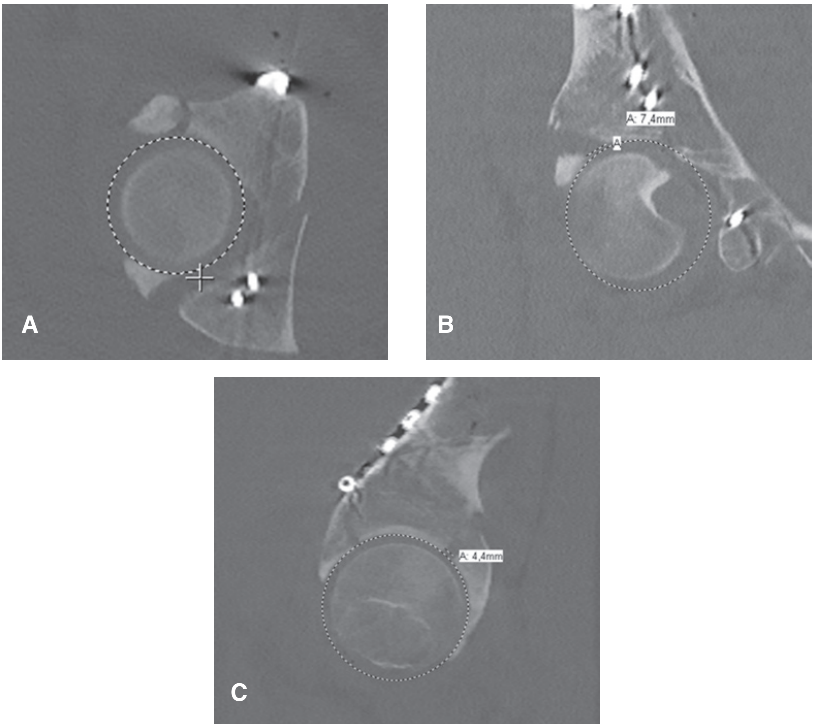


Figure 3. A- C, Three views of the acetabulum showing that in this example, displacement cannot be measured reliably on the axial view (the cursor in digital tracking mode indicates the gap) (A), the coronal view (B) shows a faulty (diagonal) measurement (of 7.4 mm) of the same gap displacement and the sagittal view (C) shows the correct measurement (of 4.4 mm)

By using the digital tracking mode while scrolling through the axial CT images, the level of the cuts can be determined on the reformatted (coronal and sagittal) views. This allows observers to identify the location of displacement relative to the weightbearing dome or middle one-third of the posterior wall. For example, in CT scans with 1mm cuts, ten mouse clicks while scrolling through the axial views represents 1cm in distance.

Based on previous work in distal radius fractures and modified for acetabular fractures, a gap is defined as an area of the acetabular dome where the head is not supported either due to separation of fracture fragments along the circumference of the dome or due to an area of marginal impaction [13]. A step is defined as separation of fracture fragments perpendicular to the circumference of the acetabular dome. With use of a digital circular template created to match the intact (or largest) portion of the acetabular dome, residual gap is thus measured in-line (along) with the acetabular dome (**Fig. 1**). Perpendicular (step) measurements are performed by measuring the distance from the subchondral bone of the displaced fragment (at the point of most displacement) to the center of the circular template as well as from the subchondral bone of the intact (or largest) portion of the dome to the center of the circular template and subtracting the two measurements (**Fig. 2**). This is similar to a technique described earlier for measuring displacement in acetabular fractures prior to surgery [14].

Performing precise measurements can be complicated when CT cuts are angled relative to the direction of displacement instead of in the same plane. This can lead to inadvertently larger measurements being made diagonally across (**Figure 3A-C**). These faulty measurements can be avoided by using the digital tracking mode and moving the cursor along the digital ruler at the location of the intended measurement. By observing the movement and direction of the cursor in the other two reformatted views the correct measurement can be identified.

CLINICAL SERIES

A cohort of patients who received operative treatment for an acetabular fracture between January 2004 and December 2012 were identified from our Orthopedic Trauma Database. This registry comprises over 1000 acetabular and pelvic cases treated operatively by the senior author. Data for the registry is collected prospectively and includes the baseline demographics, the acetabular fracture classification as classified by the senior author as well as surgery specifics [6]. This study was approved by our Institutional Review Board (2016-244).

One of the study co-authors randomly selected patients from the database of surgically treated acetabular fracture patients and verified presence of a complete set of pelvic radiographs and digital (DICOM) CT imaging. Patients were included in the study if all required imaging was available for review. This process was continued in reverse-chronologically (starting with most recent CT's) until a total of 40 patients was reached. All patients at our institution routinely receive both postoperative pelvic radiographs in the three standard (antero-posterior, iliac and obturator oblique) radiographic views as well as pelvic CT scan imaging to assess postoperative reduction and implant positioning. Axial CT images are obtained with 1-2 mm slice thickness and coronal and sagittal images are reconstructed using a standardized protocol.

Patients

Mean patient age was 53.8 years (SD 16.7 and range 23–82 years) and 70% were male. Patients most frequently had an anterior column-posterior hemitransverse type acetabular fracture (10 patients; 25%) followed by an associated both column (8 patients; 20%), a transverse-posterior wall (8 patients; 20%), a posterior wall (7 patients; 18%), an anterior column (3 patients; 8%), an anterior column-anterior wall (2 patients; 5%), a T-type (1 patient; 3%) and a transverse type fracture (1 patient; 3%). The most common surgical approach was the ilio-inguinal (26 patients; 65%) followed by the Kocher-Langenbeck approach (12 patients; 30%), and two patients (5%) required both approaches.

Imaging review

Four observers independently reviewed all postoperative imaging studies. None were involved with the initial surgery. The observers were one fellowship-trained orthopaedic trauma surgeon with more than 5 years of experience in acetabular surgery, two orthopaedic trauma fellows and one orthopaedic resident.

Observers were requested to assess postoperative reduction at the acetabular subchondral bone level on pelvic radiography (in the three standard views) and on CT scan (in the axial, sagittal, and coronal planes). For each imaging modality, the size of the greatest intra-articular gap and step displacement detected in any of the three different views was measured and recorded (in millimeters). Quality of reduction was subsequently graded according to Matta's criteria (anatomical; 0–1 mm, imperfect; 2–3 mm, or poor; >3 mm) utilizing the largest of the two (gap or step) measurements [1]. Earlier studies lack any specific description of the measurement technique, in concurrence, we provided no other instructions than described above [5].

Residual gap and step displacement was measured first on pelvic radiography and next on postoperative CT scans. Finally, observers assessed postoperative CT scans according to the standardized digital methodology described above. A written description of the standardized technique was provided to observers. Also, the location and use of the digital tracking and circular template features on the workstations were shown in one example patient.

STATISTICS

Continuous variables are presented as mean with SD; (range, median). Comparison of postoperative pelvic radiography versus CT measurements by all observers was performed by conducting a Wilcoxon signed ranks test. This test was used because the limited sample population was not normally distributed (Kolmogorov-Smirnov test).

Interobserver reliability for measuring residual gap and step displacement was analyzed using a two-way-mixed intraclass correlation coefficient (ICC), whereas interobserver reliability for grading the quality of reduction was analyzed using the kappa statistic. Intraclass correlation coefficient and kappa represent a measure of agreement between observers adjusted for the agreement based on chance alone for continuous and categorical variables, respectively. The (multiple rater) kappa was calculated as the mean for each individual observer pair [15]. Results are presented with 95% confidence intervals (95% CIs).

Given the number of patients with gap or step displacement of 0–1 mm on CT was expected to be small, the categories of anatomical and imperfect reductions were also collapsed into one category to create a modified Matta score. Interobserver reliability was then analyzed using the same methodology for anatomical/imperfect reductions as opposed to poor reductions.

Interpretation of ICC and kappa was based upon guidelines outlined by Landis and Koch [15,16]. Values represent poor (0.01), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80) or almost perfect (0.81–1.00) agreement. A p-value of <0.05 was considered statistically significant. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) version 19.0 (IBM Software, Armonk, NY).

I

RESULTS

Measurement characteristics

On postoperative pelvic radiography, the observers measured a mean gap displacement of 2.6±4.3mm (range 0.0–25.0, median 1.0 mm) and a mean step displacement of 0.3±0.8mm (range 0.0–4.0, median 0.0 mm*)*. On postoperative CT, they measured a mean gap displacement of 7.6±6.9mm (range 0.0–28.0, median 5.3 mm) and a mean step displacement of 1.7±1.7mm (range 0.0–7.0, median 1.3 mm). Both measurements on CT were significantly greater (by mean 5.0±5.9 mm and 1.4±1.7 mm, respectively) than on pelvic radiography ($p<0.001$).

Using the standardized digital CT-based method the observers measured a mean gap displacement of 7.5±7.4mm (range 0.0–28.0, median 4.4 mm*)* and a mean step displacement of 1.3±1.4mm (range 0.0–6.8, median 1.0 mm). Both measurements were likewise significantly greater (by mean 2.9±6.6 mm and 1.0±1.5 mm, respectively) than on pelvic radiography ($p<0.001$).

Interobserver reliability for pelvic radiography

The interobserver reliability for both residual gap and step measurements on postoperative pelvic radiography was moderate (ICC=0.49 (range 0.33–0.65) and ICC=0.41 (range 0.25–0.58), respectively) (**Table 1**). The interobserver reliability for grading the quality of reduction on pelvic radiography according to the Matta criteria was fair (kappa 0.32 (range 0.10–0.54)). When anatomical and imperfect reductions were collapsed into one category (modified Matta), the level of interobserver reliability remained fair (kappa 0.35 (range 0.04–0.66)) (**Table 2**).

Table 1. Intra-class correlation coefficient (interobserver agreement, 95% CI) for measuring acetabular gap and step displacement on postoperative imaging

	Intra-class correlation coefficient	
	Gap	**Step**
Pelvic radiography	0.49 (range 0.33–0.65)	0.41 (range 0.25–0.58)
Computed tomography	0.57 (range 0.42–0.71)	0.44 (range 0.28–0.61)
CT-standardized method	0.78 (range 0.67–0.86)	0.51 (range 0.35–0.67)

Table 2. Kappa (interobserver agreement, 95% CI) for grading quality of acetabular reduction according to the Matta criteria and the modified Matta criteria

	Kappa	
	Matta*	**Modified Matta†**
Pelvic radiography	0.32 (range 0.10–0.54)	0.35 (range 0.04–0.66)
Computed tomography	0.35 (range 0.12–0.58)	0.47 (range 0.19–0.75)
CT- standardized method	0.71 (range 0.53–0.90)	0.84 (range 0.68–1.00)

*anatomical versus imperfect versus poor † anatomical or imperfect versus poor

Interobserver reliability for computed tomography

Interobserver reliability for both residual gap and step measurements on postoperative CT was also moderate (ICC=0.57 (range 0.42–0.71) and ICC=0.44 (range 0.28–0.61), respectively) (**Table 1**). The interobserver reliability for grading the quality of reduction on CT according to the Matta criteria was fair (kappa 0.35 (range 0.12–0.58)). When anatomical and imperfect reductions were collapsed into one category (modified Matta) the level of reliability was moderate (Kappa 0.47 (range 0.19–0.75)) (**Table 2**).

Interobserver reliability for standardized digital CT based method

Using the standardized digital CT-based method, the interobserver reliability for residual gap measurements on postoperative CT scan was substantial (ICC=0.78 (range 0.67–0.86)), for step measurements the level of reliability was moderate (ICC=0.51 (range 0.35–0.67)) (**Table 1**).

The interobserver reliability for grading quality of reduction according to the Matta criteria was substantial (kappa 0.71 (range 0.53–0.90)) when using this method. Furthermore, when anatomical and imperfect reductions were collapsed into one category (modified Matta) the level of reliability increased to almost perfect (kappa 0.84 (range 0.68–1.00)) (**Table 2**).

DISCUSSION

The method for assessing residual displacement after acetabular fracture surgery should be both precise and reliable to allow measurements to be dependably correlated to clinical outcome.

Our clinical series show that, observers overall underestimated the size of both residual gap and step displacement on plain pelvic radiography compared to pelvic CT scan ($p<0.001$). An older study also found CT to be a superior tool for assessing the size of residual displacement in healed acetabular fractures and a study on posterior wall fractures came to a similar conclusion [9,18]. Computed tomography was however associated with a similar limited interobserver reliability as plain radiography when no standardized measurement technique was utilized. This finding further underscores that the lack of a specifically described method of measuring displacement in current published studies is a major concern [5].

The difficulty of reliably measuring acetabular displacement on postoperative plain radiography and on CT lies in a variety of factors. An apparent challenging aspect is the three-dimensional anatomy of the acetabulum and the fact that displacement can occur in different planes along its circumferential surface [13,14,19]. For exact measurements to be performed the plane of displacement needs to be perpendicular to the radiological or CT views (or in line with the cuts). Furthermore, there appears to be no consensus on the precise definition of gap and step displacement, specifically how it should be measured and what area of the acetabular surface is considered clinically relevant. A final complicating factor is the presence of implants that may obstruct views of the acetabulum particularly in plain pelvic radiography.
In an attempt to address these issues, we developed a standardized method of assessment for digital (DICOM) CT scan imaging. This method describes where, what and how residual displacement should be measured. We feel that each of these individual components is important and contributes equally to improve inter-observer reliability.

Our clinical series indicates that the standardized digital methodology for measuring acetabular fracture reduction on postoperative CT is associated with significant interobserver reliability. In particular, this method resulted in a high level of agreement on grading quality of reduction according to Matta's criteria (from fair to substantial). Greater agreement was found (to almost perfect) when anatomical and imperfect reductions were collapsed into one category.

Although CT is widely used for the preoperative assessment of acetabular fractures it is infrequently used on a routine basis following acetabular fracture surgery, most likely for concerns related to cost, availability and radiation. A recent study indicated that routine postoperative CT scanning resulted in revision surgery in only a minority (2.5%) of acetabular fracture patients [20]. It should be recognized however that apart from identifying patients for secondary surgical intervention, CT is an essential tool to postoperatively evaluate novel surgical techniques or implants in a research setting and to draw valuable lessons from that may be of benefit for subsequent patients. Furthermore, CT might allow better counseling of patients concerning their prognosis [9]. However, future studies will have to examine whether a CT-based standardized digital technique can indeed be used to more accurately predict outcome. Also, evidence of particularly the relative importance of the nature of displacement (gap versus step) is inconclusive and warrants further investigation [9,21].

Limitations of this clinical series include the limited sample size of 40 fractures. However, with 4 observers this yielded a sufficient number of 160 data points. Also, we did not determine whether a standardized technique would improve reliability of radiographic measurements as this has been shown previously, moreover, we predicted that radiography would be a less exact modality than CT scan imaging [18]. Of note is also the finding that both for plain radiography and for CT the overall interobserver reliability for step measurements was limited compared to gap measurements. This may have been related to the larger size of residual gap as opposed to step displacement. A further shortcoming is the fact that not all CT scans were performed with the same (1mm) slice thickness, which may have impacted the measurement of particularly smaller displacements. Lastly, it should be considered that our distribution of fracture types may not be reflective of those treated in other institutions. However, our randomly selected sample appears representative of patients described in other larger studies, with an occurrence of associated fracture types of 77% (versus 59%-79%) and an occurrence of fractures that involve the posterior wall of 38% (versus 33%-47%) [3,4,6].

CONCLUSION

Postoperative CT scan imaging is superior in detecting the size of residual (gap and step) displacement after acetabular fracture surgery compared to plain radiographs but is associated with similar limited interobserver agreement. A digital technique that standardizes CT measurements is however associated with substantial interobserver agreement and can be considered a highly reliable method to assess postoperative articular reduction on CT following acetabular fracture surgery.

REFERENCES

1. Matta JM. Fractures of the acetabulum: accuracy of reduction and clinical results in patients managed operatively within three weeks after the injury. J Bone Joint Surg Am 1996;78:1632-45.
2. Moed BR, WillsonCarr SE, Watson JT. Results of operative treatment of fractures of the posterior wall of the acetabulum. J Bone Joint Surg Am 2002;84-A:752-8.
3. Briffa N, Pearce R, Hill AM, Bircher M. Outcomes of acetabular fracture fixation with ten years' follow-up. J Bone Joint Surg Br 2011;93:229-36.
4. Tannast M, Najibi S, Matta JM. Two to twenty-year survivorship of the hip in 810 patients with operatively treated acetabular fractures. J Bone Joint Surg Am 2012;94:1559-67.
5. Dodd A, Osterhoff G, Guy P, Lefaivre KA. Radiographic Measurement of Displacement in Acetabular Fractures: A Systematic Review of the Literature. J Orthop Trauma 2016;30:285-93.
6. Letournel E JR. Fractures of the acetabulum. 2nd ed. Elson RA, translator, editor. New York: Springer; 1993 Translation of Les fractures du cotyle.
7. Catalano LW, 3rd, Barron OA, Glickel SZ. Assessment of articular displacement of distal radius fractures. Clin Orthop Relat Res 2004:79-84.
8. Garner MR, Fabricant PD, Schottel PC, Berkes MB, Shaffer AD, Ni A, et al. Standard perioperative imaging modalities are unreliable in assessing articular congruity of ankle fractures. J Orthop Trauma 2015;29:e161-5.
9. Moed BR, Carr SE, Gruson KI, Watson JT, Craig JG. Computed tomographic assessment of fractures of the posterior wall of the acetabulum after operative treatment. J Bone Joint Surg Am 2003;85-A:512-22.
10. Verbeek DO, van der List JP, Villa JC, et al. Postoperative CT is superior for acetabular fracture reduction assessment and reliably predicts hip survivorship. J Bone Joint Surg Am 2017;99:1745–1752.
11. Verbeek DO, van der List JP, Tissue CM, et al. Predictors of long-term hip survivorship following acetabular fracture surgery: importance of gap compared with step displacement. In press. doi: 10.2106/JBJS.17.00692.
12. Olson SA, Matta JM. The computerized tomography subchondral arc: a new method of assessing acetabular articular continuity after fracture (a preliminary report). J Orthop Trauma 1993;7:402-13.
13. Cole RJ, Bindra RR, Evanoff BA, Gilula LA, Yamaguchi K, Gelberman RH. Radiographic evaluation of osseous displacement following intra-articular fractures of the distal radius: reliability of plain radiography versus computed tomography. J Hand Surg Am 1997;22:792-800.
14. Borrelli J, Jr., Goldfarb C, Catalano L, Evanoff BA. Assessment of articular fragment displacement in acetabular fractures: a comparison of computerized tomography and plain radiographs. J Orthop Trauma 2002;16:449-56; discussion 56-7.
15. Conger A. Integration and generalization of kappas for multiple raters. Psychological Bulletin 1980;88:322-8.
16. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
17. Warner SJ, Fabricant PD, Garner MR, Schottel PC, Helfet DL, Lorich DG. The Measurement and Clinical Importance of Syndesmotic Reduction After Operative Fixation of Rotational Ankle Fractures. J Bone Joint Surg Am 2015;97:1935-44.
18. Borrelli J, Jr., Ricci WM, Steger-May K, Totty WG, Goldfarb C. Postoperative radiographic assessment of acetabular fractures: a comparison of plain radiographs and CT scans. J Orthop Trauma 2005;19:299-304.

19. Kreder HJ, Rozen N, Borkhoff CM, Laflamme YG, McKee MD, Schemitsch EH, et al. Determinants of functional outcome after simple and complex acetabular fractures involving the posterior wall. J Bone Joint Surg Br 2006;88:776-82.
20. Archdeacon MT, Dailey SK. Efficacy of Routine Postoperative CT Scan After Open Reduction and Internal Fixation of the Acetabulum. J Orthop Trauma 2015;29:354-8.
21. Clarke-Jenssen J, Wikeroy AK, Roise O, Ovre SA, Madsen JE. Long-Term Survival of the Native Hip After a Minimally Displaced, Nonoperatively Treated Acetabular Fracture. J Bone Joint Surg Am 2016;98:1392-9.

II

addendum

HIGH-ENERGY PELVIC RING DISRUPTIONS WITH COMPLETE POSTERIOR INSTABILITY

Contemporary reduction and fixation strategies

HOUSTON, U.S.A.

D.O. Verbeek,
M.L. Routt

Hospital for Special Surgery and New York Presbyterian Hospital, Weill Cornell Medicine, New York City, NY, USA

J Bone Joint Surg Am
2018; 100: 1704-12

2018

SUMMARY

- Accurate reduction and rigid internal fixation of anterior pelvic ring injuries enhances overall stability of the pelvic ring and augments posterior fixation constructs.

- Closed reduction techniques can be highly effective for unstable pelvic ring disruptions and are preferable over open reduction methods.

- Percutaneous iliosacral screw fixation is a generally safe and effective method of fixation of posterior pelvic ring injuries.

- Multiple and longer (transiliac-transsacral) screws at both sacral segments are required to create a stronger screw construct for complete posterior pelvic disruptions.

- Lumbopelvic fixation substantially augments iliosacral screw fixation and is particularly useful for comminuted transforaminal sacral fractures with associated vertical instability.

INTRODUCTION

High-energy traumatic pelvic ring disruptions generally occur in young adult patients and are associated with considerable morbidity and mortality [1-4]. A complete disruption of the anterior and posterior pelvic osteoligamentous structures produces multidirectional (vertical and rotational) instabilities of the pelvic ring. It is widely recognized that non-operative management of these highly unstable pelvic ring traumatic injuries is associated with numerous long term complications including lower back pain, gait abnormalities, and sitting imbalance [5-7]. Surgical intervention is the preferred method of treatment since it restores and stabilizes the pelvic anatomy. Accurate pelvic reduction and stable fixation decreases pelvic related bleeding, protects vulnerable local soft tissue structures, improves comfort, allows early mobilization, and prevents deformity [5,7-9].

Accomplishing and maintaining adequate reduction of completely unstable pelvic ring injuries is challenging to even the most experienced surgeon. Vertical instability is a well-recognized risk factor for fixation failure, particularly in the presence of a comminuted sacral fracture [10,11]. Over the past 30 years multiple fixation strategies for the posterior pelvic ring have been described attempting to solve this problem. These fixation methods historically included an open reduction and the application of numerous posterior plates or transiliac-transsacral screw implants [12-18]. More recently in concert with intraoperative imaging advances, closed reduction techniques along with percutaneous iliosacral screw stabilization and lumbo-pelvic fixation have been introduced successfully [19-24].

To date, the optimal surgical strategy for treating acute high-energy traumatic pelvic ring disruptions with associated complete posterior instability has not been agreed on. Questions concerning injury site sequencing, the need for open or closed reduction, acceptable residual displacements, as well as reliable closed reduction techniques and the optimal fixation construct remain unanswered.
In this review we will specifically explore these controversies and propose a definitive surgical treatment strategy involving contemporary reduction and fixation techniques for posterior pelvic ring disruptions.

INJURY CHARACTERISTICS

Considerable force is required to completely disrupt the pelvic ring. Energy application and bone quality determine the injury patterns [25,26]. Within the spectrum of pelvic injuries, vertically unstable (or OTA/AO type 61-C27) injuries are among the most devastating pelvic ring disruptions. These injuries display mechanical instability owing to complete disruptions of the posterior osseous and/or ligamentous structures combined with an unstable anterior pelvic ring injury [26]. Unstable posterior pelvic injuries include sacroiliac joint dislocations, sacral fractures, “crescent” iliac fracture-sacroiliac joint dislocations, complete iliac fractures, or combinations of these sites.

RADIOGRAPHIC SIGNS OF INSTABILITY

Comprehensive assessment of pelvic ring injuries relies on high-quality imaging. Even in the modern age of high-speed computed tomography (CT), plain pelvic radiography remains a low-cost, readily available, and effective primary diagnostic tool, especially during the initial evaluation to identify injury sites and deformities [28,29].

For patients with complete, unstable posterior pelvic ring injuries, mechanical instability can be categorized within two main groups. Radiographically obvious mechanical instability occurs when the traumatic injury produces substantial dis- placement and deformity that is clearly visible on pelvic imaging studies. Signs of complete posterior instability on CT scans include the presence of a substantially displaced sacroiliac joint, sacral fracture, or combination injuries. Radiographically obvious instability is most easily identified when the posterior pelvic injury is distracted as opposed to impacted [19,30]. Furthermore, L5 to S1 facet joint disruptions correlate with posterior pelvic vertical instability [19].

Radiographically occult instability occurs when the traumatic injury results in a mechanically unstable pelvic ring that is not easily identifiable on initial pelvic imaging. For example, in some fracture patterns associated with an expansion (versus collapse) of the pelvic ring, displacements may not be readily apparent because the injury sites have been reduced by circumferential pelvic binding prior to imaging [31,32]. In some patients with lateral compression injuries, a “recoil reduction” can occur such that the instability is not notable on the initial radiographs. Applying a circumferential pelvic wrap in these situations may conversely cause displacement, revealing such radiographically occult instability [33,34]. Pelvic radiography and CT scanning provide static images of what can be a minimally displaced but very unstable injury. It is advisable to examine all pelvic images that may have been made prior to the application of the circumferential wrap or binder or repeat pelvic imaging after these devices have been removed. For some patients with initially unrecognized instability, a pelvic examination under anesthesia is indicated. This stress

examination involves manipulative maneuvers to internally and externally rotate the hemipelvis as well a “push-pull” technique through the lower extremities under fluoroscopic imaging to disclose sites of (rotational and/or vertical) instability [33].

EARLY TREATMENT CONSIDERATIONS

Initial treatment of an unstable traumatic pelvic ring injury is determined by a variety of factors, but mostly the overall condition of the patient and the injury pattern details.

Many patients with completely unstable pelvic ring injuries have hemodynamic instability, craniocerebral injuries, and thoracoabdominal trauma that must be prioritized [8,9,35]. Pelvic reduction and stabilization using a circumferential pelvic wrap or external fixator, especially for patients with expanding pelvic ring disruptions (associated with an increase of intrapelvic volume), is integral to the resuscitation effort. Anterior pelvic external fixation should be considered when the circumferential pelvic wrap or binder has failed to achieve the reduction, is causing pressure-related soft-tissue problems, or obstructs perineal access. Pelvic external fixation can also be used for unstable injuries with associated open perineal traumatic wounds, for unstable pelvic fractures with associated bladder or rectal injury, prior to urgent laparotomy, and in patients with a large pelvic hematoma with active pelvic fracture-related bleeding. Many surgeons also use the anterior pelvic external fixator to support internal fixation implants, especially when the anterior pelvic ring is comminuted.

Unfortunately, for completely unstable pelvic ring disruptions, anterior pelvic external fixators alone do not provide sufficient mechanical stability and may cause further displacement of the posterior pelvic injuries. In such cases, maintaining the pelvic wrap, inserting iliosacral lag screws, or applying a posterior pelvic C-clamp can improve the posterior pelvic reduction [36].

DEFINITIVE TREATMENT STRATEGY

Once temporary stabilization of the pelvic ring is accomplished, and the patient is sufficiently resuscitated, a detailed preoperative plan for definitive surgical treatment should be formulated. For this purpose, the surgeon should take the specific injury site details, associated injuries, as well as the body habitus and overall condition of the patient into account. Prior surgical procedures such as herniorrhaphy, laparotomy, fecal diversion, and cystotomy impact the operative tactic. Closed degloving injuries, abrasions, and lacerations are also important factors that may complicate definitive pelvic reconstruction.

Injury Site Sequencing

Determining the sequence of reduction and fixation is difficult since both the anterior and posterior pelvic ring injury sites are unstable.

An initial dorsal surgical exposure for posterior pelvic open reduction and internal fixation (ORIF) with the patient positioned prone, followed by supine positioning for surgical treatment of the anterior injury, has been advocated [12-14]. This recommendation is based on

the contention that an anatomic reduction of the posterior injury is an absolute prerequisite for superior clinical
outcome. However, in patients with a complete posterior disruption and less extensive anterior pelvic ring injury, an initial anatomic reduction and stable fixation of the anterior injury is much more practical, especially for patients with associated injuries [37]. Early anterior ORIF often produces an excellent indirect reduction of the posterior ring so that percutaneous posterior pelvic fixation is possible while the patient remains in the supine position

Closed reduction technique

In recent years, a treatment method comprising closed reduction techniques and percutaneous pelvic fixation has gained wide acceptance [20,21,38,39]. Currently, this less invasive strategy is considered the method of choice for treating unstable posterior pelvic ring injuries whenever possible.
Closed reduction is preferable over open reduction for several reasons. Posterior pelvic ORIF has been associated with wound complications in up to 27% of patients [40,41]. One study found a markedly lower rate of deep wound infections (3%) following posterior pelvic ORIF in selected low-risk patients [42]. An open posterior approach requires prone patient positioning, which is often complicated, for example, when there are anterior pelvic external fixators or unstable vertebral fractures. Furthermore, prone positioning of a multiply injured patient does not allow combined (thoracoabdominal) procedures to be performed, may exacerbate the cardiopulmonary condition of the patient, and limits airway access for the anesthesiologist [43,44].
Closed reduction efforts in unstable pelvic ring injuries are often complicated by multiplanar pelvic deformities. First obtaining an anatomic reduction of the anterior pelvic injury helps to correct posterior pelvic rotational deformity. Sheets or binders create circumferential pressure around the pelvis and may also be effective for this purpose (**Fig. 1**).

Percutaneous iliosacral screws can be inserted through working portals cut into the circumferential wrap (**Fig. 2**). Cranial displacement of the hemipelvis can be corrected by applying distal femoral longitudinal skeletal traction (**Fig. 1**).

To accomplish this, it is preferable to place patients supine on a radiolucent table that allows skeletal traction. An effective method to counteract subsequent distal movement of the patient with unilateral injuries may be to place the uninjured extremity in a traction boot with the knee in extension [21]. Also, specifically designed pelvic reduction frames that anchor the uninjured hemipelvis to the operating table have been described [45]. Residual sagittal plane deformity may be corrected by flexing the hip while maintaining longitudinal traction. Further

Figure 1. Sheets or binders can be used to correct rotational pelvic deformity while simultaneous (bilateral) distal femoral longitudinal skeletal traction can help to correct cranial displacement of the hemipelvis.

reduction adjustments are possible using bonpins, or by the precise placement of (partially threaded) iliosacral lag screws to compress the fracture or joint gap (**Figs. 3-A, 3-B, and 3-C**).

Overall excellent reductions of the posterior pelvic ring can be achieved by utilizing carefully executed closed reduction techniques [21,45,46]. Moreover, it appears that postoperative reductions accomplished through closed methods are at least equivalent to those accomplished through open techniques [21].

It is important to note that in pelvic ring disruptions, early intervention may facilitate closed reduction efforts [47]. In patients who are not candidates for early definitive treatment, the application of timely traction to prevent (further) vertical cranial hemipelvic displacement may increase the chances of obtaining an acceptable closed reduction.

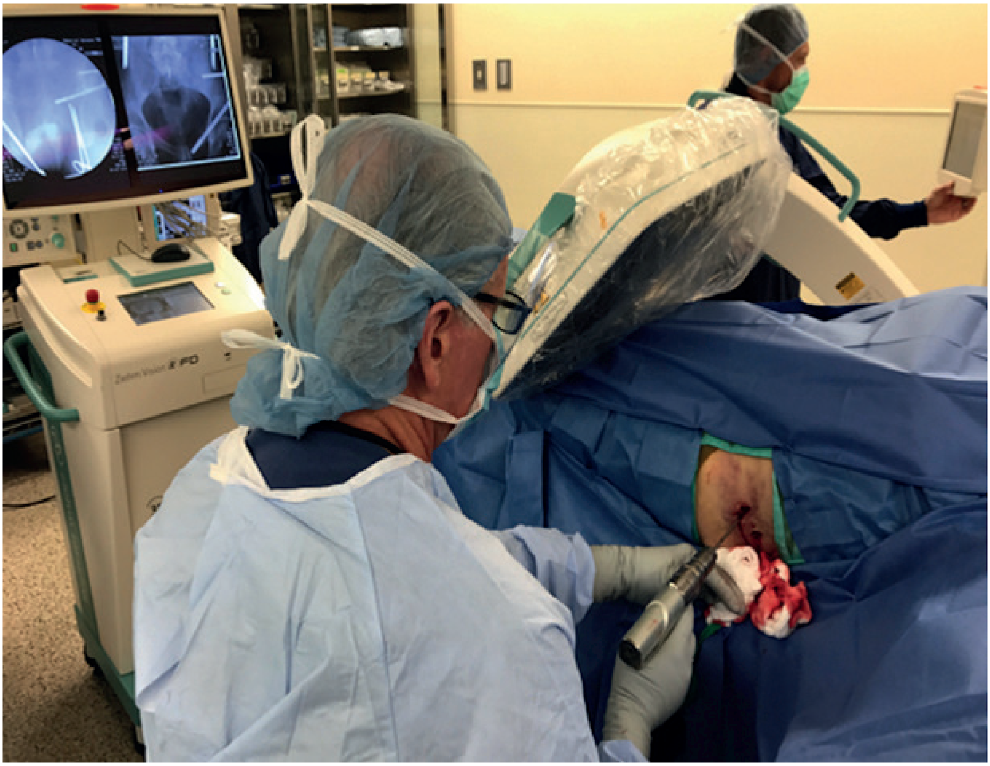


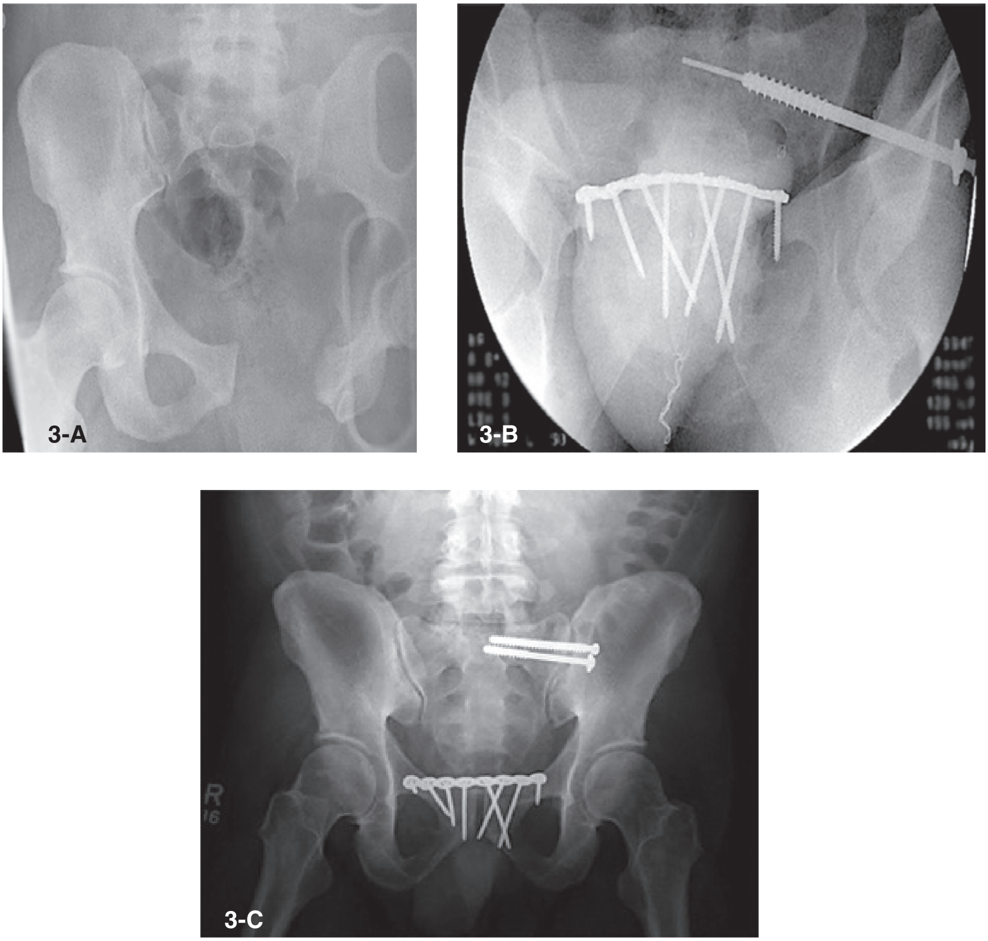
Figure 2. Percutaneous iliosacral screws can be inserted through working portals cut into circumferential wraps.

Acceptable residual displacement

How much residual posterior displacement is acceptable after closed reduction is controversial. An adequate reduction of the pelvic ring is an obvious critical component of a mechanically stable construct. However, whether an exact or "anatomic" posterior reduction is required for superior clinical outcome is largely unknown.

Most studies have noted that reduction of posterior pelvic ring injuries within 1 cm of combined residual displacement is sufficient to yield a satisfactory functional outcome [6,12,37,48,49]. However, it has also been stated that the amount of posterior displacement should be no greater than 5 mm for a favorable result [2]. Other studies have suggested that sacroiliac joint dislocations should be considered separate from other posterior ring injuries in that these specifically require an anatomic reduction for an optimal outcome [3,37].

The discrepancy in the available literature in terms of what degree of residual displacement is acceptable is most likely a result of the inclusion of diverse injury patterns and heterogeneous patient cohorts as well as the absence of standardized outcome measures



Figures 3-A, 3-B, and 3-C. A 37-year-old male patient with complete pelvic instability due to symphyseal and left sacroiliac joint traumatic disruptions as well as an intraperitoneal bladder injury. Fig. 3-A Preoperative radiograph. Fig. 3-B The patient was positioned supine on a radiolucent operating table. First, the general surgeons used a laparotomy to repair the bladder. The symphysis injury was then accessed, reduced, clamped, and fixed with a plate using the lower portion of the midline laparotomy wound. The disrupted sacroiliac joint was noted to be distracted, but otherwise well aligned. Using a targeted iliosacral lag screw technique, the sacroiliac joint was reduced accurately by the lag screw alone. Fig. 3-C A second, fully threaded iliosacral screw was inserted to further stabilize the sacro- iliac joint and overall fixation construct.

and methods to assess reduction [50,51]. Consequently, no conclusive recommendations in this regard can be made. It appears reasonable, however, to suggest that an anatomic reduction of the posterior pelvic ring is not an absolute requirement. Certain extensive posterior pelvic injury patterns are not amenable to anatomic reduction.

Open surgical approach

Indications for open reduction of posterior pelvic ring injuries include failure of closed manipulative techniques. In patients with an “unsuccessful” closed posterior pelvic reduction, the benefits of an open reduction through a posterior approach in terms of direct manipulation and visualization at the injury site should be weighed against the complication risks and issues related to prone positioning.

Minimizing the risk of soft-tissue complications following an open posterior exposure requires attention to detail. Severe soft-tissue degloving injuries demand meticulous surgical technique, thorough removal of dead tissues, and focused soft-tissue defect management using drains or other techniques [42,52,53]. Postoperative wound infections are associated with degloving lesions but mostly after lengthy surgical delays. Early surgical intervention is therefore advised when the overall condition of the patient allows [53,54].

As opposed to sacral and certain crescent iliac fractures, the disrupted sacroiliac joint is surgically accessible anteriorly with the patient positioned supine using the lateral surgical interval of the ilioinguinal exposure. This anterior approach is considered to have less risk of soft-tissue complications than the open posterior approach required for other posterior pelvic injuries.

A further indication for an open posterior approach to the pelvic ring may be a situation in which direct pressure from sacral fracture fragments is causing symptomatic compromise of the lumbosacral roots. It is well recognized that evidence of a neurologic deficit is the most important factor in determining inferior functional outcome in pelvic ring disruptions [1,2,55]. Decompression of the spinal canal with removal of debris and fracture fragments is thought to create an optimal environment for nerves to recover, which may ultimately improve the clinical outcome [56,57].

OPTIMAL MECHANICAL CONSTRUCT

The choice of implant to stabilize complete posterior pelvic ring disruptions depends on many patient and injury-related factors such as the physiologic status and body habitus of the patient, associated injuries, pelvic osteology, bone quality, and soft-tissue injuries.

Studies have shown that injury characteristics of the posterior pelvic ring are an important predictor for fixation failure in patients with a pelvic fracture [11,30]. Particularly, high- energy pelvic ring disruptions with transforaminal comminuted sacral fractures are highly unstable and challenging to treat. To create a mechanically stable construct, each unstable injury within the pelvic ring should be sufficiently stabilized.

Anterior fixation

Accurate reduction and stable internal fixation of anterior pelvic ring injuries augments posterior fixation constructs and has been found to enhance overall stability of the pelvic ring [7,11,12,58,59].

For fixation of symphyseal disruptions, a single pelvic reconstruction plate contoured to fit the local anatomy is usually sufficient. Alternatively, manufactured, precontoured symphyseal plates can be used. Locked plating of the pubic symphysis does not offer any advantages over non-locked plating [60]. In pubic rami fractures, plate fixation and medullary pubic ramus screws are selected, depending on the location of the fracture and the anatomy of the pubic ramus [61,62]. Parasymphyseal fractures may be best treated with plate fixation or an (intramedullary) pubic screw placed in retrograde fashion in the superior pubic ramus. For ramus fractures located more laterally, it may also be preferable to place (antegrade or retrograde) pubic screws to avoid an extensive surgical exposure. A combined fixation technique with both plate and pubic screw fixation can be effective in pubic rami fractures with associated symphyseal injury. Subcutaneously applied external fixators have been described for multiple pubic rami fractures; these internal frames are generally removed within the 3 to 6-month time frame as they are palpable and are irritating in maximum hip flexion [63].

Percutaneous transiliac-transsacral screw fixation

With increased knowledge of sacral anatomy and improved surgical technique over the past years, fluoroscopically assisted placement of cannulated iliosacral screws has become the preferred technique for treating posterior pelvic ring injuries [11,38,39]. In younger patients with high-energy pelvic ring disruptions, percutaneous iliosacral screw fixation has proven to be a generally safe and effective method of fixation [43,64,65]. However, in complete pelvic ring disruptions, several studies have demonstrated that unilateral single percutaneous iliosacral screw fixation is insufficient to maintain reduction [10-12]. Malunion and loss of reduction has been reported in up to 44% of these vertically unstable injuries treated with a single iliosacral screw [11].

Several strategies are available to create a stronger screw construct for complete posterior pelvic disruptions. These techniques are of particular value for the treatment of unstable comminuted sacral fractures. In 2006, the introduction of cannulated 7-mm-diameter screws with lengths of 135 to 180 mm allowed surgeons to use transsacral screws so that the contralateral sacroiliac joint and lateral iliac cortical bone could be accessed to increase the

II

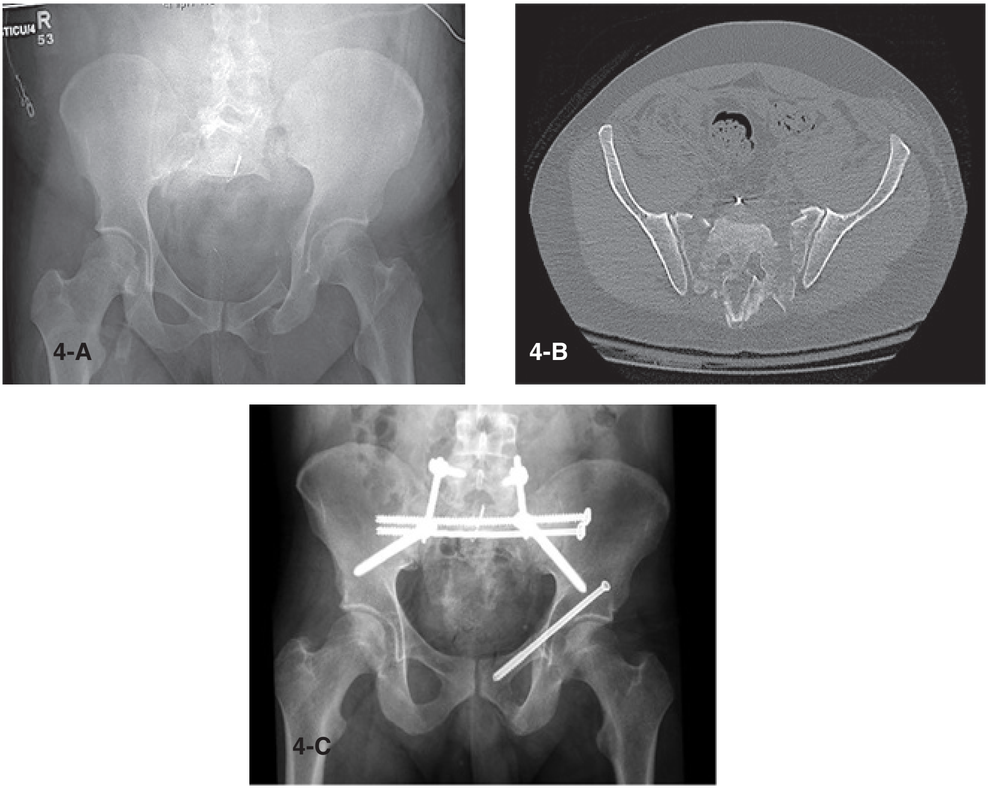
screw construct stability [20,66]. It is thought that, by placing longer screws, the lever arm is extended, the load is distributed more evenly, and superior fixation is achieved by capturing the relatively dense bone of the sacral body and 3 additional cortical fixation points [20,66-68]. These factors combined may result in greater resistance to vertical shear forces [69,70].

The technical aspects of percutaneously placing full- length iliosacral screws have been well described previously [20]. Concerns that violating the contralateral, uninjured sacroiliac joint would lead to contralateral pelvic pain or inferior clinical outcome appear unsubstantiated [71,72]. Using multiple (transsacral) screws at the first and second sacral segments (S1 and S2) whenever possible increases both vertical and rotational stability. Fixation failures are diminished when multiple transsacral ilio- sacral screws are used at both levels [69,70,73-76].
Complete knowledge of the posterior pelvic osteology and its intraoperative imaging details are absolute prerequisites for safe iliosacral screw insertion. The available safe osseous pathways in the upper sacrum are obliquely oriented in patients with sacral dysmorphism. As a result, these oblique upper sacral dysmorphic pathways are improper and unsafe for transiliac transsacral screws while the second sacral segment usually is safe [77-79].
High-quality, unobstructed fluoroscopic imaging is mandatory for safe insertion of all pelvic screws. The various images also must be correctly interpreted. Clearly, the placement of longer and multiple iliosacral screws is more demanding, and adequate surgical experience is required to eliminate technical complications [20,43,46,79]. A screw position error risks local nerve root or vascular structure injury and has been reported in 3% of patients with percutaneously placed iliosacral screws [64]. The use of CT navigation may reduce the rate of screw error but is not available in all institutions [80].
Early postoperative mobilization of patients with a type- C pelvic fracture is crucial but often precluded by associated injuries. Adequate transiliac-transsacral screw (with supplemental anterior ring) fixation allows initial toe-touch weight- bearing followed by progressive (at 8 weeks) weight-bearing on the affected side and full weight-bearing on the contralateral side in most patients.

Lumbo-pelvic fixation

Lumbopelvic fixation is a powerful internal fixation method that augments iliosacral screw fixation, and can also be used independently [19,23,81,82]. By adding this construct, a triangular osteosynthesis is achieved, substantially increasing the overall stability of the posterior construct in the horizontal and vertical planes (**Figs. 4-A, 4-B, and 4-C**) [81,82].

Lumbopelvic fixation is particularly useful for the surgical treatment of comminuted transforaminal sacral fractures with associated vertical instability [19,23,83]. Maintenance of reduction in these highly unstable fractures is achieved by connecting the injured hemipelvis



Figures 4-A, 4-B, and 4-C A patient with spinopelvic dissociation, which included a vertically unstable pelvic ring injury with severely displaced pubic rami fractures and a bilateral sacral fracture with associated cranial displacement of the left hemipelvis. Fig. 4-A Preoperative radiograph. Fig. 4-B A CT scan showing a highly comminuted bilateral H-type sacral fracture. Fig. 4-C Closed reduction and percutaneous fixation was performed by using a circumferential pelvic sheet along with bilateral distal femoral traction (see Figures 1 and 2). The patient was then positioned prone and the lumbo- pelvic fixation was also inserted percutaneously.

directly to the axial skeleton. Lumbopelvic fixation uses contoured strong rods and pedicle screw instrumentation to connect the lower lumbar spine to the ilium so that the fracture zone is bypassed and vertical displacement of the hemipelvis is resisted [19]. Studies have shown that this construct is stiffer than plates and bars to such an extent that it allows early, full weight-bearing following surgery [82,84].

As with any open posterior technique, the physiology of the patient and associated injuries must allow prone positioning. For those patients with an accurate posterior pelvic closed reduction, the lumbopelvic fixation construct can be applied percutaneously [24,85]. Technical problems that have arisen from the use of lumbopelvic fixation include delayed union or nonunion of the sacral fracture (resulting from insufficient compression across the fracture zone prior to application of the construct) and lumbar scoliosis or tilting of the L5 vertebral body (resulting from distraction along the spinopelvic rod) [83]. Removal of lumbopelvic instrumentation has been recommended at 6 months for all patients (with healed fractures) to restore physiologic mobility in the L5 to S1 and sacroiliac joints [19].

Other posterior fixation techniques

Through the years, a variety of alternative implants to stabilize the posterior pelvic ring have been described. Prior techniques of posterior pelvic fixation included sacral bars and posterior iliac crest spanning implants [16-18,86]. A limited number of studies have described favorable clinical results for transiliac posterior plate constructs [54,87]. However, these spanning plates, used in isolation, may be insufficient to reliably stabilize completely unstable pelvic ring injuries compared with the placement of additional iliosacral screws [75,88]. Also, posterior plates may cause wound complications, and may be symptomatic because of their location [54,87,88].

Overall, it appears that most of these techniques and implants have been surpassed by the more modern fixation strategies described above. Indeed, the widespread use of (long) percutaneous iliosacral screws and the advent of lumbopelvic fixation have rendered most other implants for the posterior pelvic ring obsolete.

CONCLUSION

High-energy pelvic ring disruptions with associated complete posterior instability remain challenging to treat. A wide variety of factors influence the definitive surgical treatment plan. Key elements of contemporary treatment include early and preferably closed reduction of the posterior pelvic ring. Posterior reduction is facilitated by an anatomic reduction of the anterior ring component supplemented with carefully executed closed reduction maneuvers. Posterior fixation of the pelvic ring is accomplished most effectively with the percutaneous placement of multiple and longer (transiliac-transsacral) screws at both sacral segments.
Stronger screw constructs are created by adding internal fixation of the anterior injury and can be further facilitated by adding lumbo-pelvic fixation to neutralize shear forces.

A proposed treatment strategy including grades of recommendation is outlined in **table 1** [89]**.**

Table I Grades of recommendation for treatment of high-energy pelvic ring disruptions with associated complete posterior instability

Proposed Treatment Strategy	**Grade of Recommendation***
Accurate reduction and stable fixation of the anterior pelvic ring injury to augment posterior fixation construct	B
Closed reduction of posterior pelvic ring (if feasible)	B
Percutaneous placement of multiple and longer (transiliac-transsacral) screws at S1 and S2 to create stronger posterior screw constructs	B
Addition of lumbopelvic fixation to posterior screw constructs to neutralize shear forces (as needed)	B

*According to Wright[89], grade A indicates good evidence (Level-I studies with consistent findings) for or against recommending intervention; grade B, fair evidence (Level-II or III studies with consistent findings) for or against recommending intervention; grade C, poor-quality evidence (Level-IV or V studies with consistent findings) for or against recommending intervention; and grade I, insufficient or conflicting evidence not allowing a recommendation for or against intervention.

REFERENCES

1. Tornetta P, 3rd, Matta JM. Outcome of operatively treated unstable posterior pelvic ring disruptions. Clin Orthop Relat Res 1996:186-93.
2. Pohlemann T, Bosch U, Gansslen A, Tscherne H. The Hannover experience in management of pelvic fractures. Clin Orthop Relat Res 1994:69-80.
3. Dujardin FH, Hossenbaccus M, Duparc F, Biga N, Thomine JM. Long-term functional prognosis of posterior injuries in high-energy pelvic disruption. J Orthop Trauma 1998;12:145-50; discussion 50-1.
4. Kabak S, Halici M, Tuncel M, Avsarogullari L, Baktir A, Basturk M. Functional outcome of open reduction and internal fixation for completely unstable pelvic ring fractures (type C): a report of 40 cases. J Orthop Trauma 2003;17:555-62.
5. Matta JM, Dickson KF, Markovich GD. Surgical treatment of pelvic nonunions and malunions. Clin Orthop Relat Res 1996:199-206.
6. Semba RT, Yasukawa K, Gustilo RB. Critical analysis of results of 53 Malgaigne fractures of the pelvis. J Trauma 1983;23:535-7.
7. Tile M. Pelvic ring fractures: should they be fixed? J Bone Joint Surg Br 1988;70:1-12.
8. van Vugt AB, van Kampen A. An unstable pelvic ring. The killing fracture. J Bone Joint Surg Br 2006;88:427-33.
9. Verbeek DO, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
10. Griffin DR, Starr AJ, Reinert CM, Jones AL, Whitlock S. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? J Orthop Trauma 2006;20:S30-6; discussion S6.
11. Keating JF, Werier J, Blachut P, Broekhuyse H, Meek RN, O'Brien PJ. Early fixation of the vertically unstable pelvis: the role of iliosacral screw fixation of the posterior lesion. J Orthop Trauma 1999;13:107-13.
12. Matta JM, Saucedo T. Internal fixation of pelvic ring fractures. Clin Orthop Relat Res 1989:83-97.
13. Matta JM, Tornetta P, 3rd. Internal fixation of unstable pelvic ring injuries. Clin Orthop Relat Res 1996:129-40.
14. Templeman D, Goulet J, Duwelius PJ, Olson S, Davidson M. Internal fixation of displaced fractures of the sacrum. Clin Orthop Relat Res 1996:180-5.
15. Comstock CP, van der Meulen MC, Goodman SB. Biomechanical comparison of posterior internal fixation techniques for unstable pelvic fractures. J Orthop Trauma 1996;10:517-22.
16. Shaw JA, Mino DE, Werner FW, Murray DG. Posterior stabilization of pelvic fractures by use of threaded compression rods. Case reports and mechanical testing. Clin Orthop Relat Res 1985:240-54.
17. Ebraheim NA, Coombs R, Hoeflinger MJ, Zeman C, Jackson WT. Anatomical and radiological considerations in compressive bar technique for posterior pelvic disruptions. J Orthop Trauma 1991;5:434-8.
18. Albert MJ, Miller ME, MacNaughton M, Hutton WC. Posterior pelvic fixation using a transiliac 4.5-mm reconstruction plate: a clinical and biomechanical study. J Orthop Trauma 1993;7:226-32.
19. Sagi HC. Technical aspects and recommended treatment algorithms in triangular osteosynthesis and spinopelvic fixation for vertical shear transforaminal sacral fractures. J Orthop Trauma 2009;23:354-60.
20. Gardner MJ, Routt ML, Jr. Transiliac-transsacral screws for posterior pelvic stabilization. J Orthop Trauma 2011;25:378-84.

21. Lindsay A, Tornetta P, 3rd, Diwan A, Templeman D. Is Closed Reduction and Percutaneous Fixation of Unstable Posterior Ring Injuries as Accurate as Open Reduction and Internal Fixation? J Orthop Trauma 2016;30:29-33.
22. Schildhauer TA, Josten C, Muhr G. Triangular osteosynthesis of vertically unstable sacrum fractures: a new concept allowing early weight-bearing. J Orthop Trauma 2006;20:S44-51.
23. Jazini E, Klocke N, Tannous O, Johal HS, Hao J, Salloum K, et al. Does Lumbopelvic Fixation Add Stability? A Cadaveric Biomechanical Analysis of an Unstable Pelvic Fracture Model. J Orthop Trauma 2017;31:37-46.
24. Williams SK, Quinnan SM. Percutaneous Lumbopelvic Fixation for Reduction and Stabilization of Sacral Fractures With Spinopelvic Dissociation Patterns. J Orthop Trauma 2016;30:e318-24.
25. Burgess AR, Eastridge BJ, Young JW, Ellison TS, Ellison PS, Jr., Poka A, et al. Pelvic ring disruptions: effective classification system and treatment protocols. J Trauma 1990;30:848-56.
26. Pennal GF, Tile M, Waddell JP, Garside H. Pelvic disruption: assessment and classification. Clin Orthop Relat Res 1980:12-21.
27. Marsh JL, Slongo TF, Agel J, Broderick JS, Creevey W, DeCoster TA, Prokuski L, Sirkin MS, Ziran B, Henley B, Audig´e L. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma 2007;21(10)(Suppl):S1-133.
28. Verbeek DO, Burgess AR. Importance of Pelvic Radiography for Initial Trauma Assessment: An Orthopedic Perspective. J Emerg Med 2016;50:852-8.
29. Mostafavi HR, Tornetta P, 3rd. Radiologic evaluation of the pelvis. Clin Orthop Relat Res 1996:6-14.
30. Griffin DR, Starr AJ, Reinert CM, Jones AL, Whitlock S. Vertically unstable pelvic fractures fixed with percutaneous iliosacral screws: does posterior injury pattern predict fixation failure? J Orthop Trauma 2003;17:399-405.
31. Gabbe BJ, Esser M, Bucknill A, Russ MK, Hofstee DJ, Cameron PA, et al. The imaging and classification of severe pelvic ring fractures: Experiences from two level 1 trauma centres. Bone Joint J 2013;95-B:1396-401.
32. Clements J, Jeavons R, White C, McMurtry I. The Concealment of Significant Pelvic Injuries on Computed Tomography Evaluation by Pelvic Compression Devices. J Emerg Med 2015;49:675-8.
33. Sagi HC, Coniglione FM, Stanford JH. Examination under anesthetic for occult pelvic ring instability. J Orthop Trauma 2011;25:529-36.
34. Suzuki T, Morgan SJ, Smith WR, Stahel PF, Flierl MA, Hak DJ. Stress radiograph to detect true extent of symphyseal disruption in presumed anteroposterior compression type I pelvic injuries. J Trauma 2010;69:880-5.
35. Cullinane DC, Schiller HJ, Zielinski MD, Bilaniuk JW, Collier BR, Como J, et al. Eastern Association for the Surgery of Trauma practice management guidelines for hemorrhage in pelvic fracture--update and systematic review. J Trauma 2011;71:1850-68.
36. Wollgarten M, Keel MJ, Pape HC. Editorial: Emergency fixation of the pelvic ring using the pelvic C clamp--has anything changed? Injury 2015;46 Suppl 3:S1-2.
37. Mullis BH, Sagi HC. Minimum 1-year follow-up for patients with vertical shear sacroiliac joint dislocations treated with iliosacral screws: does joint ankylosis or anatomic reduction contribute to functional outcome? J Orthop Trauma 2008;22:293-8.
38. Routt ML, Jr., Kregor PJ, Simonian PT, Mayo KA. Early results of percutaneous iliosacral screws placed with the patient in the supine position. J Orthop Trauma 1995;9:207-14.
39. Giannoudis PV, Tzioupis CC, Pape HC, Roberts CS. Percutaneous fixation of the pelvic ring: an update. J Bone Joint Surg Br 2007;89:145-54.
40. Goldstein A, Phillips T, Sclafani SJ, Scalea T, Duncan A, Goldstein J, et al. Early open reduction and internal fixation of the disrupted pelvic ring. J Trauma 1986;26:325-33.

41. Kellam JF, McMurtry RY, Paley D, Tile M. The unstable pelvic fracture. Operative treatment. Orthop Clin North Am 1987;18:25-41.
42. Stover MD, Sims S, Matta J. What is the infection rate of the posterior approach to type C pelvic injuries? Clin Orthop Relat Res 2012;470:2142-7.
43. Routt ML, Jr., Simonian PT, Mills WJ. Iliosacral screw fixation: early complications of the percutaneous technique. J Orthop Trauma 1997;11:584-9.
44. Shuler TE, Boone DC, Gruen GS, Peitzman AB. Percutaneous iliosacral screw fixation: early treatment for unstable posterior pelvic ring disruptions. J Trauma 1995;38:453-8.
45. Lefaivre KA, Starr AJ, Barker BP, Overturf S, Reinert CM. Early experience with reduction of displaced disruption of the pelvic ring using a pelvic reduction frame. J Bone Joint Surg Br 2009;91:1201-7.
46. Routt ML, Jr., Simonian PT. Closed reduction and percutaneous skeletal fixation of sacral fractures. Clin Orthop Relat Res 1996:121-8.
47. Browner BD, Cole JD, Graham JM, Bondurant FJ, Nunchuck-Burns SK, Colter HB. Delayed posterior internal fixation of unstable pelvic fractures. J Trauma 1987;27:998-1006.
48. Henderson RC. The long-term results of nonoperatively treated major pelvic disruptions. J Orthop Trauma 1989;3:41-7.
49. McLaren AC, Rorabeck CH, Halpenny J. Long-term pain and disability in relation to residual deformity after displaced pelvic ring fractures. Can J Surg 1990;33:492-4.
50. Lefaivre KA, Blachut PA, Starr AJ, Slobogean GP, O'Brien PJ. Radiographic displacement in pelvic ring disruption: reliability of 3 previously described measurement techniques. J Orthop Trauma 2014;28:160-6.
51. Nystrom LM, McKinley TO, Marsh JL. Accuracy in radiographic assessment of pelvic ring fracture deformity: analysis of current methods. J Orthop Trauma 2013;27:708-15.
52. Hak DJ, Olson SA, Matta JM. Diagnosis and management of closed internal degloving injuries associated with pelvic and acetabular fractures: the Morel-Lavallee lesion. J Trauma 1997;42:1046-51.
53. Tseng S, Tornetta P, 3rd. Percutaneous management of Morel-Lavallee lesions. J Bone Joint Surg Am 2006;88:92-6.
54. Suzuki T, Hak DJ, Ziran BH, Adams SA, Stahel PF, Morgan SJ, et al. Outcome and complications of posterior transiliac plating for vertically unstable sacral fractures. Injury 2009;40:405-9.
55. Suzuki T, Shindo M, Soma K, Minehara H, Nakamura K, Uchino M, et al. Long-term functional outcome after unstable pelvic ring fracture. J Trauma 2007;63:884-8.
56. Zelle BA, Gruen GS, Hunt T, Speth SR. Sacral fractures with neurological injury: is early decompression beneficial? Int Orthop 2004;28:244-51.
57. Schildhauer TA, Bellabarba C, Nork SE, Barei DP, Routt ML, Jr., Chapman JR. Decompression and lumbopelvic fixation for sacral fracture-dislocations with spino-pelvic dissociation. J Orthop Trauma 2006;20:447-57.
58. Sagi HC, Ordway NR, DiPasquale T. Biomechanical analysis of fixation for vertically unstable sacroiliac dislocations with iliosacral screws and symphyseal plating. J Orthop Trauma 2004;18:138-43.
59. Wild JJ, Jr., Hanson GW, Tullos HS. Unstable fractures of the pelvis treated by external fixation. J Bone Joint Surg Am 1982;64:1010-20.
60. Moed BR, O'Boynick CP, Bledsoe JG. Locked versus standard unlocked plating of the symphysis pubis in a Type-C pelvic injury: a cadaver biomechanical study. Injury 2014;45:748-51.
61. Starr AJ, Nakatani T, Reinert CM, Cederberg K. Superior pubic ramus fractures fixed with percutaneous screws: what predicts fixation failure? J Orthop Trauma 2008;22:81-7.

62. Routt ML, Jr., Simonian PT, Grujic L. The retrograde medullary superior pubic ramus screw for the treatment of anterior pelvic ring disruptions: a new technique. J Orthop Trauma 1995;9:35-44.
63. Cole PA, Dyskin EA, Gilbertson JA. Minimally-invasive fixation for anterior pelvic ring disruptions. Injury 2015 Sep;46(Suppl 3):S27-34.
64. Zwingmann J, Hauschild O, Bode G, Sudkamp NP, Schmal H. Malposition and revision rates of different imaging modalities for percutaneous iliosacral screw fixation following pelvic fractures: a systematic review and meta-analysis. Arch Orthop Trauma Surg 2013;133:1257-65.
65. Osterhoff G, Ossendorf C, Wanner GA, Simmen HP, Werner CM. Posterior screw fixation in rotationally unstable pelvic ring injuries. Injury 2011;42:992-6.
66. Beaule PE, Antoniades J, Matta JM. Trans-sacral fixation for failed posterior fixation of the pelvic ring. Arch Orthop Trauma Surg 2006;126:49-52.
67. Vanderschot P, Meuleman C, Lefevre A, Broos P. Trans iliac-sacral-iliac bar stabilisation to treat bilateral lesions of the sacro-iliac joint or sacrum: anatomical considerations and clinical experience. Injury 2001;32:587-92.
68. Kraemer W, Hearn T, Tile M, Powell J. The effect of thread length and location on extraction strengths of iliosacral lag screws. Injury 1994;25:5-9.
69. Zhao Y, Li J, Wang D, Liu Y, Tan J, Zhang S. Comparison of stability of two kinds of sacro-iliac screws in the fixation of bilateral sacral fractures in a finite element model. Injury 2012;43:490-4.
70. Fu S, Zhao Y, Lian W, Zou D, Sun T, Zhao Y, et al. Comparison of the risk of breakage of two kinds of sacroiliac screws in the treatment of bilateral sacral fractures. Eur Spine J 2014;23:1558-67.
71. Mardam-Bey SW, Beebe MJ, Black JC, Chang EY, Kubiak EN, Bishop JA, et al. The Effect of Transiliac-Transsacral Screw Fixation for Pelvic Ring Injuries on the Uninjured Sacroiliac Joint. J Orthop Trauma 2016;30:463-8.
72. Heydemann J, Hartline B, Gibson ME, Ambrose CG, Munz JW, Galpin M, et al. Do Transsacral-transiliac Screws Across Uninjured Sacroiliac Joints Affect Pain and Functional Outcomes in Trauma Patients? Clin Orthop Relat Res 2016;474:1417-21.
73. Min KS, Zamorano DP, Wahba GM, Garcia I, Bhatia N, Lee TQ. Comparison of two-transsacral-screw fixation versus triangular osteosynthesis for transforaminal sacral fractures. Orthopedics 2014;37:e754-60.
74. van Zwienen CM, van den Bosch EW, Snijders CJ, Kleinrensink GJ, van Vugt AB. Biomechanical comparison of sacroiliac screw techniques for unstable pelvic ring fractures. J Orthop Trauma 2004;18:589-95.
75. Yinger K, Scalise J, Olson SA, Bay BK, Finkemeier CG. Biomechanical comparison of posterior pelvic ring fixation. J Orthop Trauma 2003;17:481-7.
76. Moed BR, Geer BL. S2 iliosacral screw fixation for disruptions of the posterior pelvic ring: a report of 49 cases. J Orthop Trauma 2006;20:378-83.
77. Conflitti JM, Graves ML, Chip Routt ML, Jr. Radiographic quantification and analysis of dysmorphic upper sacral osseous anatomy and associated iliosacral screw insertions. J Orthop Trauma 2010;24:630-6.
78. Miller AN, Routt ML, Jr. Variations in sacral morphology and implications for iliosacral screw fixation. J Am Acad Orthop Surg 2012;20:8-16.
79. Gras F, Gottschling H, Schroder M, Marintschev I, Hofmann GO, Burgkart R. Transsacral Osseous Corridor Anatomy Is More Amenable To Screw Insertion In Males: A Biomorphometric Analysis of 280 Pelves. Clin Orthop Relat Res 2016;474:2304-11.
80. Zwingmann J, Konrad G, Kotter E, Sudkamp NP, Oberst M. Computer-navigated iliosacral screw insertion reduces malposition rate and radiation exposure. Clin Orthop Relat Res 2009;467:1833-8.
81. Schildhauer TA, Ledoux WR, Chapman JR, Henley MB, Tencer AF, Routt ML, Jr. Triangular osteosynthesis and iliosacral screw fixation for unstable sacral fractures: a cadaveric and biomechanical evaluation under cyclic loads. J Orthop Trauma 2003;17:22-31.

82. Schildhauer TA, Josten C, Muhr G. Triangular osteosynthesis of vertically unstable sacrum fractures: a new concept allowing early weight-bearing. J Orthop Trauma 1998;12:307-14.
83. Sagi HC, Militano U, Caron T, Lindvall E. A comprehensive analysis with minimum 1-year follow-up of vertically unstable transforaminal sacral fractures treated with triangular osteosynthesis. J Orthop Trauma 2009;23:313-9; discussion 9-21.
84. Shinohara K, Takigawa T, Tanaka M, Sugimoto Y, Arataki S, Ito Y, et al. Biomechanical Comparison of Posterior Fixation Using Spinal Instrumentation and Conventional Posterior Plate Fixation in Unstable Vertical Sacral Fracture. Acta Med Okayama 2016;70:97-102.
85. Koshimune K, Ito Y, Sugimoto Y, Kikuchi T, Morita T, Mizuno S, et al. Minimally Invasive Spinopelvic Fixation for Unstable Bilateral Sacral Fractures. Clin Spine Surg 2016;29:124-7.
86. Stocks GW, Gabel GT, Noble PC, Hanson GW, Tullos HS. Anterior and posterior internal fixation of vertical shear fractures of the pelvis. J Orthop Res 1991;9:237-45.
87. Krappinger D, Larndorfer R, Struve P, Rosenberger R, Arora R, Blauth M. Minimally invasive transiliac plate osteosynthesis for type C injuries of the pelvic ring: a clinical and radiological follow-up. J Orthop Trauma 2007;21:595-602.
88. Berber O, Amis AA, Day AC. Biomechanical testing of a concept of posterior pelvic reconstruction in rotationally and vertically unstable fractures. J Bone Joint Surg Br 2011;93:237-44.
89. Wright JG, Einhorn TA, Heckman JD. Grades of recommendation. J Bone Joint Surg Am 2005;87:1909-10.

AMSTERDAM
SYDNEY
HOUSTON
NEW YORK CITY

AUTHOR CONTRIBUTIONS

PH.D. PORTFOLIO

PUBLICATIONS

WORDS OF THANKS (DANKWOORD)

ABOUT THE AUTHOR

PELVIC & ACETABULAR FRACTURES

EARLY MANAGEMENT & LATE OUTCOME

AUTHOR CONTRIBUTIONS

D design
C collection of data
A analysis or interpretation of data
W writing or revising manuscript

Chapter 2
Diederik O. Verbeek: D, C, A, W; Kornelis J. Ponsen: D, A, W; Marta Fiocco: C, A; Sonia Amodio: C, A; Luke P.H. Leenen: D, A, W; J. Carel Goslings: D, A, W

Chapter 3
Diederik O. Verbeek: D, C, A, W; Michael Sugrue: D, A, W; Zsolt Balogh: D, A, W; [Danny Cass, Ian Civil, Ian Harris, Thomas Kossmann, Steve Leibman, Valerie Malka, Anthony Pohl, Sudhakar Rao, Martin Richardson, Michael Schuetz, Caesar Ursic, Vanessa Wills]; C

Chapter 4
Diederik O. Verbeek: D, C, A, W; IJsbrand A.J. Zijlstra: C; Christaan van der Leij: C; Kornelis J. Ponsen: D, A, W; Otto M. van Delden: D, A, W; J. Carel Goslings: D, A, W

Chapter 5
Diederik O. Verbeek: D, C, A, W; IJsbrand A.J. Zijlstra: C; Christaan van der Leij: C; Kornelis J. Ponsen: D, A, W; Otto M. van Delden: D, A, W; J. Carel Goslings: D, A, W

Chapter 6
Diederik O. Verbeek: D, C, A, W; Andrew R. Burgess: D, A, W

Chapter 7
Diederik J. Wijffels †: D, C, A, W; Diederik O. Verbeek: D, C, A, W; Kornelis J. Ponsen: D, A, W; J. Carel Goslings: D, A, W; Otto M. van Delden: D, A, W

Chapter 8
Diederik O. Verbeek: D, C, A, W; Kornelis J. Ponsen: D, A, W; Mark van Heijl: C
J. Carel Goslings: D, A, W

Chapter 9
Diederik O. Verbeek: D, C, A, W; Jelle P. van der List: D, C, A, W; Jordan C. Villa: C; David S. Wellman: D, A, W; David L. Helfet: D, A, W

Chapter 10

Diederik O. Verbeek: D, C, A, W; Jelle P. van der List: D, C, A, W; Camden M. Tissue: C; David L. Helfet: D, A, W

Addendum I

Diederik O. Verbeek: D, C, A, W; Jelle P. van der List: D, C, A, W; Gele B. Moloney: C; David S. Wellman: D, C, A, W; David L. Helfet: D, A, W

Addendum II

Diederik O. Verbeek: D, C, A, W; Milton L. Routt: D, A, W

PHD PORTFOLIO

Name PhD student: Diederik Otto Ferdinand Verbeek
Name PhD supervisor: Prof dr. J.C. Goslings, Prof. dr. O.M. van Delden

PhD training	Year	Workload (ECTS)
General courses		
Basiscursus Regelgeving Organisatie Klinisch onderzoekers (BROK)	2019	0.9
Specific courses		
AO Trauma North America: Advanced upper extremity trauma	2019	1.0
AO Trauma Masters: Polytrauma and soft tissue management	2016	1.0
AO Trauma North America: Pelvic and acetabular fractures	2015	1.0
AO Trauma North America: Non and malunions	2015	1.0
AO Trauma North America: Fellows cadaver Symposium	2015	1.0
Advanced Cardiac Life Support (ACLS)	2014	1.0
Emergency Management of Severe Burns (EMSB)	2013	1.0
Definitive Surgical Trauma Care (DSTC).	2011	1.0
AO Trauma Davos: Advances in operative fracture management	2010	1.0
Fundamental Critical Care Support (FCCS)	2008	1.0
Advanced Trauma Life Support (ATLS): Instructor course	2007	1.0
Oral presentations		
OTA Vancouver: Assessing quality of reduction after acetabular fracture surgery: Importance of gap versus step displacement	2017	0.5
Traumadagen Amsterdam: Beoordeling van postoperatieve reductie na acetabulum chirurgie: belang van gap versus step verplaatsing	2017	0.5
Traumadagen Amsterdam: CT is een betere modaliteit voor het beoordelen van articulaire reductie na acetabulumchirurie	2016	0.5
Chirurgendagen Veldhoven: Association of time to surgery with morbidity, length of stay and mortality in hip fracture patients	2005	0.5

Poster presentations		
OTA Washington: Postoperative computed tomography is a superior modality for assessment of acetabular fracture reduction	2016	0.5
Traumadagen Amsterdam: Epidemiologie van bekkenfracturen in Nederland	2015	0.5
ECTES Malmo: Early angiographic embolization in major pelvic trauma, too little too late	2006	0.5
AAST New Orleans: The acute management of haemodynamically unstable patients with a pelvic fracture in Australia and New Zealand	2006	0.5
RACS Perth: The development of a mini network wireless system to monitor continuous abdominal perfusion pressure in intensive care	2005	0.5
Other		
Traumanight Alkmaar: Bekken en acetabulumfracturen: nieuwe inzichten en oude koeien	2017	0.5
ZWOT Rotterdam: Bekken en acetabulumchirurgie in Nederland: past, present and future	2016	0.5

Teaching	Year	Workload (ECTS)
Lecturing		
Master students EMC	2015-2017	0.5
Surgical residents EMC	2015-2017	1.5
AO Table instructor	2013	0.5
ATLS instructor	2007-present	

PUBLICATIONS

1. Verbeek DO, van der List JP, Helfet DL. Computed tomography versus plain radiography assessment of acetabular fracture reduction is more predictive for native hip survivorship. Arch Orthop Trauma Surg 2019.
2. Verbeek DO, Routt ML, Jr. High-Energy Pelvic Ring Disruptions with Complete Posterior Instability: Contemporary Reduction and Fixation Strategies. J Bone Joint Surg Am 2018;100:1704-12.
3. Wijffels DJ, Verbeek DO, Ponsen KJ, Carel Goslings J, van Delden OM. Imaging and Endovascular Treatment of Bleeding Pelvic Fractures: Review Article. Cardiovasc Intervent Radiol 2019;42:10-8.
4. Verbeek DO, van der List JP, Tissue CM, Helfet DL. Predictors for Long-Term Hip Survivorship Following Acetabular Fracture Surgery: Importance of Gap Compared with Step Displacement. J Bone Joint Surg Am 2018;100:922-9.
5. Verbeek DO, van der List JP, Tissue CM, Helfet DL. Long-term patient reported outcomes following acetabular fracture fixation. Injury 2018;49:1131-6.
6. Crijns TJ, Janssen SJ, Davis JT, Ring D, Sanchez HB, Science of Variation G. Reliability of the classification of proximal femur fractures: Does clinical experience matter? Injury 2018;49:819-23.
7. Verbeek DO, Ponsen KJ, van Heijl M, Goslings JC. Modified Stoppa approach for operative treatment of acetabular fractures: 10-year experience and mid-term follow-up. Injury 2018;49:1137-40.
8. Brouwers L, Pull ter Gunne AF, de Jongh MAC, van der Heijden FHWM, Leenen LPH, Spanjersberg WR, et al. The value of 3D printed models in understanding acetabular fractures. 3D Printing and Additive Manufacturing 2018.
9. Verbeek DO, van der List JP, Moloney GB, Wellman DS, Helfet DL. Assessing postoperative reduction following acetabular fracture surgery: A standardized digital CT-based method. J Orthop Trauma 2018.
10. Verbeek DO, van der List JP, Villa JC, Wellman DS, Helfet DL. Postoperative CT Is Superior for Acetabular Fracture Reduction Assessment and Reliably Predicts Hip Survivorship. J Bone Joint Surg Am 2017;99:1745-52.
11. Verbeek DO, Ponsen KJ, Fiocco M, Amodio S, Leenen LPH, Goslings JC. Pelvic fractures in the Netherlands: epidemiology, characteristics and risk factors for in-hospital mortality in the older and younger population. Eur J Orthop Surg Traumatol 2018;28:197-205.
12. Zwiers R, Weel H, Mallee WH, Kerkhoffs G, van Dijk CN, Ankle Platform Study Collaborative - Science of Variation G. Large variation in use of patient-reported outcome measures: A survey of 188 foot and ankle surgeons. Foot Ankle Surg 2018;24:246-51.
13. Mellema JJ, Mallee WH, Guitton TG, van Dijk CN, Ring D, Doornberg JN, et al. Online Studies on Variation in Orthopedic Surgery: Computed Tomography in MPEG4 Versus DICOM Format. J Digit Imaging 2017.
14. Verbeek DO, Ponsen KJ. Percutane schroeffixatie voor osteoporotische sacrumfracturen bij oudere patiënten. Ned Tijdschr voor Traumachirurgie 2016; 24: 9-12.
15. Hickerson LE, Verbeek DO, Klinger CE, Helfet DL. Anterolateral Approach to the Pilon. J Orthop Trauma 2016;30 Suppl 2:S39-40.
16. Verbeek DO, Hickerson LE, Warner SJ, Helfet DL, Lorich DG. Low Profile Mesh Plating for Patella Fractures: Video of a Novel Surgical Technique. J Orthop Trauma 2016;30 Suppl 2:S32-3.
17. Verbeek DO, Burgess AR. Importance of Pelvic Radiography for Initial Trauma Assessment: An Orthopedic Perspective. J Emerg Med 2016;50:852-8.
18. Mellema JJ, Doornberg JN, Molenaars RJ, Ring D, Kloen P, Traumaplatform Study C, et al. Interobserver reliability of the Schatzker and Luo classification systems for tibial plateau fractures. Injury 2016;47:944-9.

19. Mellema JJ, Doornberg JN, Molenaars RJ, Ring D, Kloen P, Traumaplatform Study C, et al. Tibial Plateau Fracture Characteristics: Reliability and Diagnostic Accuracy. J Orthop Trauma 2016;30:e144-51.
20. Meijer DT, de Muinck Keizer RJ, Doornberg JN, Sierevelt IN, Stufkens SA, Kerkhoffs GM, et al. Diagnostic Accuracy of 2-Dimensional Computed Tomography for Articular Involvement and Fracture Pattern of Posterior Malleolar Fractures. Foot Ankle Int 2016;37:75-82.
21. Claessen FM, Peters RM, Verbeek DO, Helfet DL, Ring D. Factors associated with radial nerve palsy after operative treatment of diaphyseal humeral shaft fractures. J Shoulder Elbow Surg 2015;24:e307-11.
22. Janssen SJ, Teunis T, Guitton TG, Ring D, Science of Variation G. Do Surgeons Treat Their Patients Like They Would Treat Themselves? Clin Orthop Relat Res 2015;473:3564-72.
23. Mellema JJ, Doornberg JN, Guitton TG, Ring D, Science of Variation G. Biomechanical studies: science (f)or common sense? Injury 2014;45:2035-9.
24. Tosti R, Ilyas AM, Mellema JJ, Guitton TG, Ring D, Science of Variation G. Interobserver variability in the treatment of little finger metacarpal neck fractures. J Hand Surg Am 2014;39:1722-7.
25. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. The utility of FAST for initial abdominal screening of major pelvic fracture patients. World J Surg 2014;38:1719-25.
26. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. Predicting the need for abdominal hemorrhage control in major pelvic fracture patients: the importance of quantifying the amount of free fluid. J Trauma Acute Care Surg 2014;76:1259-63.
27. Verbeek DO, Ponsen KJ, van Delden OM, Goslings JC. The need for pelvic angiographic embolisation in stable pelvic fracture patients with a “blush” on computed tomography. Injury 2014;45:2111.
28. Neuhaus V, Bot AG, Guitton TG, Ring DC, Science of Variation G, Abdel-Ghany MI, et al. Scapula fractures: interobserver reliability of classification and treatment. J Orthop Trauma 2014;28:124-9.
29. Verbeek DO, Zijlstra IA, van der Leij C, Ponsen KJ, van Delden OM, Goslings JC. Management of pelvic ring fracture patients with a pelvic “blush” on early computed tomography. J Trauma Acute Care Surg 2014;76:374-9.
30. Veltman ES, van den Bekerom MP, Doornberg JN, Verbeek DO, Rammelt S, Steller EP, et al. Three-dimensional computed tomography is not indicated for the classification and characterization of calcaneal fractures. Injury 2014;45:1117-20.
31. Gradl G, Neuhaus V, Fuchsberger T, Guitton TG, Prommersberger KJ, Ring D, et al. Radiographic diagnosis of scapholunate dissociation among intra-articular fractures of the distal radius: interobserver reliability. J Hand Surg Am 2013;38:1685-90.
32. Verbeek DO, Sugrue M, Balogh Z, Cass D, Civil I, Harris I, et al. Acute management of hemodynamically unstable pelvic trauma patients: time for a change? Multicenter review of recent practice. World J Surg 2008;32:1874-82.
33. Verbeek DO, Ponsen KJ, Goslings JC, Heetveld MJ. Effect of surgical delay on outcome in hip fracture patients: a retrospective multivariate analysis of 192 patients. Int Orthop 2008;32:13-8.

WORDS OF THANKS (DANKWOORD)

Over the course of many years numerous people have, directly and indirectly, helped me bring this thesis come to fruition. Some have provided a scientific contribution, while others offered more general support and inspiration. To all those patient, energizing, creative, methodical, funny and smart people, I owe a great debt of gratitude as without them I would never have been able to make it this far.

In particular, I would like to thank the following people:

Door de jaren heen zijn er velen die, direct of indirect, hebben meegeholpen aan de totstandkoming van dit proefschrift. Sommigen leverden een wetenschappelijke bijdrage, terwijl anderen meer steun boden en inspireerden. Ik ben die geduldige, stimulerende, creatieve, kritische, humoristische en slimme mensen bijzonder dankbaar want zonder hen was ik nooit zo ver gekomen.

Graag wil ik onderstaande personen in het bijzonder bedanken:

Mijn promotores

Prof. dr. Carel Goslings en Prof. dr. Otto van Delden: Het heeft een aanzienlijke tijd geduurd voordat dit proefschrift prioriteit en zijn definitieve vorm kreeg. Dit vroeg om een lange adem en soms een pragmatische aanpak om uiteindelijk tot afronding te komen. Gedurende dit traject heb ik veel aan jullie begeleiding en inbreng gehad, juist op die momenten dat het nodig was. Heel veel dank voor jullie analytische blik, scherpe inzichten, oog voor detail en kritische commentaren.

Mijn co-promotores

Dr. Kees-Jan Ponsen: Je aanstekelijke enthousiasme en passie voor het vak gekoppeld aan een energieke en warme persoonlijkheid maken je tot een groot voorbeeld. Op congressen blijf je traditiegetrouw tot laat aan de bar om, de volgende dag weer vroeg vooraan bij de bekkensessies plaats te nemen. Ik ben erg blij dat ik nog een periode in Alkmaar met je heb mogen samenwerken en dank je zeer voor alle ideeën, adviezen en steun zowel binnen dit promotiekader als daarbuiten.

Prof. dr. Michiel Verhofstad: Je bent pas in een later stadium betrokken geraakt bij mijn promotie maar je input is evenzogoed zeer waardevol geweest. Na mijn terugkomst uit New York heb je me in Rotterdam alle ruimte en bovenal vertrouwen en onafhankelijkheid gegeven om mij verder te ontwikkelen als traumachirurg. Ik waardeer je geduldig sturende manier van managen en je analytische geest. Ik heb veel van je geleerd en heb met ontzettend veel plezier in het Erasmus MC gewerkt!

Leden van de promotiecommissie

Prof. dr. Peter Kloen; mijn verre orthopedische voorganger in Hospital for Special Surgery; Prof. dr. Victor de Ridder en Dr. Jan Biert; grondleggers en vaandeldragers van de bekkenchirurgie in Nederland en Prof. dr. Mario Maas en Dr. Susan van Dieren; respectievelijk radioloog en epidemioloog: Ik ben erg vereerd dat jullie zitting hebben willen nemen in mijn promotiecommissie.

Special thanks to:

Prof. dr. David Helfet: Five years ago, you took a leap of faith by accepting a Dutch general surgeon into your orthopedic trauma fellowship program. This provided me with the opportunity to spend an incredible year training in New York. During my time at Hospital for Special Surgery *and up to this day you have been a great mentor and example to me. You are not only an outstanding surgeon but also a sociable and generous person, whom I deeply respect. I am proud to have been your fellow and I greatly appreciate you flying over to Amsterdam for my Ph.D. defense. Thank you for your continued support and for, somehow, always finding time to catch up during my various random visits to the city!*

Mijn mede-auteurs

Marta Fiocco, Sonia Amodio, Prof. dr. Loek Leenen, IJsbrand Zijlstra, Christaan van der Leij en Mark van Heij: Heel veel dank voor jullie wetenschappelijke bijdrage.

In het bijzonder wil ik Diederik Wijffels noemen met wie ik kort prettig heb samengewerkt aan ons review artikel. In 2017 is Diederik plotseling en veel te jong overleden.

Other co-authors

Jordan Villa, Camden Tissue and David Wellman: Thank you guys for all the hard work and the great times!

Further special thanks to:

Prof. dr. Chip Routt and Prof. dr. Andrew Burgess: It was a great honor to have spent time with y'all in Houston. I very much appreciate you showing me the intricacies of (percutaneous) pelvic surgery and I am very proud of our research collaboration! Dr Routt, your attention to detail during surgery as well as your (sheet) artistry prior to it is legendary, you are an awesome and dedicated teacher. Big Texas thanks!

Prof. dr. Michael Sugrue and Prof. dr. Zsolt Balogh: Many years ago and likely without you realizing it, you put me on the path that ultimately led me to the writing of this thesis. My time in Sydney and Australia was defining in so many ways. Thanks for contributing to that.

Craig Klinger: Thank you for putting up with Jelle (and me ☺) and for making the many hours spent in the research office bearable. I very much appreciate you helping out with our ever-expanding research projects and really enjoyed the many prolonged lunches at Lenny's and Bareburger. It was always a challenge trying to get you to join us for Friday (or any other day of the week) drinks at the Pony bar but I am happy we occasionally succeeded!

Joseph Nguyen and Brenda Chang: Your support for statistical analysis is greatly appreciated.

Geoff Wilkin and Lindsay Hickerson; co-fellows at HSS: My unforgettable experience in New York was shaped in no small way by you guys. The friendly, smart and measured Canadian and the fun, direct, "mincing no words" West Virginian. I really enjoyed spending time with you all, especially on our trips to Vegas and San Francisco. We made a great team, thanks for all the good times!

Traumachirurgen Erasmus Medisch Centrum, Rotterdam; Dennis den Hartog, Pim Oprel, Oscar van Waes, Philippe de Rooij, Tjebbe Hagenaars en Mathieu Wijffels: Veel dank voor de fantastische samenwerking, gezelligheid en onmisbare support; ik heb veel geleerd en minstens zoveel gelachen!

Mijn Paranimfen

Jelle van der List: Wat hebben we een mooie tijd gehad in New York en wat ben je "volwassen" geworden sindsdien! Jouw tomeloze energie en eindeloze drive maar ook prettig gestoorde "gein" is legendarisch. Van de research office tot het hockeyveld of de bar, je was onstuitbaar. Ik kijk met heel veel plezier terug op onze trainingsrondjes rennen in Central Park na een lange dag foto's beoordelen en de vele IPA's die we soldaat hebben gemaakt. Jouw bijdrage aan dit boekje is niet te overtreffen, thanks mate!

Gregory Sprenger: My brother from another mother, na vele surftrips op Bali en, al meer dan 10 jaar, in Peniche is de gesprekstof nog lang niet op. De tijd in het tropische water zal nu wel wat minder worden met de komst van de kleine, maar ik ben waanzinnig blij voor jullie en surfen onder de rook van Tata Steel is ook mooi! Ik vind het te gek dat je hebt ingestemd om mijn paranimf te zijn, al hoop ik wel dat je je lach kan inhouden tijdens de plechtigheid.

Mijn familie, schoonfamilie, vrienden en vriendinnen in Amsterdam, New York buddies, Cape Town crew, oud-studiegenoten en sportmaten
Bedankt voor alle afleiding en briljante herinneringen! Jullie onvoorwaardelijke steun maar ook ongezouten kritiek en relativerende humor is en blijft onontbeerlijk.

Pap, mam, Marieke, Rutger, Ymke en Maarten, jullie zijn de basis waar ik altijd op terug kan vallen. Ik ben jullie ontzettend dankbaar voor alle warme en liefdevolle belangstelling, de aanmoediging en de soms turbulente gezelligheid die bij het familieleven hoort..

Lotte, lieve schat, jij gaf mij die extra duw in de rug om eindelijk dat proefschrift af te ronden en wat heb je me geholpen op alle vlakken! Ik denk dat jij de enige bent die sommige stukken in mijn boekje echt (nauwkeurig) gelezen heeft. Jij was geduldig als ik ongeduldig was en precies wanneer ik slordig was. Wat ben ik blij met jou in mijn leven en wat hebben we het mooi samen!

ABOUT THE AUTHOR

Diederik Otto Ferdinand Verbeek (July 3,1976, Nijmegen) grew up in Aerdenhout, near Haarlem, the Netherlands. He graduated from Kennemer High School, Overveen, and moved to the United States to attend Niskayuna High School, in upstate New York, as an exchange student (1994).

The following year he was admitted to medical school (Academic Medical Center (AMC), University of Amsterdam) and instantly developed a profound interest in trauma surgery (1995). This eventually led him to pursue an elective at the Trauma Unit of Johannesburg General Hospital (2003). Riding the waves of South Africa's Jeffreys Bay on a sizable board, he also became passionate about surfing. The (rookie) surfer's path ultimately led him to Bondi Beach, Sydney for a research fellowship (Dr. M. Sugrue; 2004-2005). At Liverpool hospital, one of the city's trauma centers, the foundation for this thesis was laid.

General surgery residencies were next completed in Amsterdam, at the AMC and Sint Lucas Andreas Hospital (prof. O.R.C. Busch, Dr. E.Ph. Steller; 2006-2012). In the interim, various foreign electives in major trauma centers in Philadelphia, Cape Town and New York City (AO fellowship) were undertaken. After the 2010 earthquake that struck Port-au-Prince he also travelled to Haiti as a member of the AMC response team.

As large urban trauma centers always held great appeal to him, he then moved back to the United States for (clinical) fellowship training (2014-2015). At an earlier stage, he had passed the US Medical Licensing Examinations with this specific purpose in mind (2008). During a 1.5-year period, he completed (orthopaedic) trauma fellowships in Houston (Memorial Hermann Hospital, prof. M.L. Chip Routt) and New York City (Hospital for Special Surgery, prof. D.L. Helfet).

Upon return from the US, he held a post as a trauma surgeon (fellow) in Rotterdam (Erasmus University Medical Center, prof. M.H.J. Verhofstad; 2015-2019). More recently, his main focus has been on the daunting task of finalizing the current thesis. The care for major trauma patients and treatment of complex fractures continue to hold his interest both in clinical practice and research.

Nowadays, Diederik, still an average surfer at best, occasionally finds time to ride the mushy waves of “Wijkiki” (Wijk aan Zee), but clearly prefers Portugal or Bali. He lives together with Lotte Haverman, in the city that tops them all; his hometown of Amsterdam.