Brace For Impact!

A thesis on medical care following an airplane crash

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Faculteit der Geneeskunde

Contents

Part 4. The Aftermath

Definitions and abbreviations

Abbreviated Injury Scale: A numeric system to categorise injuries according to body region and severity. Every injury corresponds to a 6 figure number, with the last number on a scale of 1-6. A minor injury is coded with number 1, 5 is a critical injury and a 6 is lethal.

Hospital Trauma Level: Hospitals are designated a trauma care level by the Dutch government, were Level I hospitals have a coordinating role in the regional trauma network. Level I hospitals are equipped with all trauma care facilities; Level II hospitals have "certain" trauma care facilities, some of which are extensive, almost to the standard of Level I hospitals; and Level-III hospitals contain basic trauma care facilities.

Injury Severity Score: A score combining the 3 highest scores on the Abbreviated Injury Scale (AIS), of 3 different body regions of a patient. The squares of these 3 numbers are added to calculate the Injury Severity Score (ISS).

Multiple Casualty Incident: A hazardous impact with as many casualties that the available orginazational and medical resources, or their management systems, are severely challenged.

Multi Trauma patient: (Dutch: poly-traumatisée) severely injured patient with multiple injuries leading to an ISS above 16.

Occupants: All people occupying the airplane.

Triage Categories: In case of a mass casualty incident (MCI), casualties are triaged at the scene following the critical/ immediate (P1), serious/urgent (P2), minor/delayed (P3) triage classification according to the Triage Sieve and Sort system used by the MIMMS (Major Incident Medical Management and Support).

Abbreviations

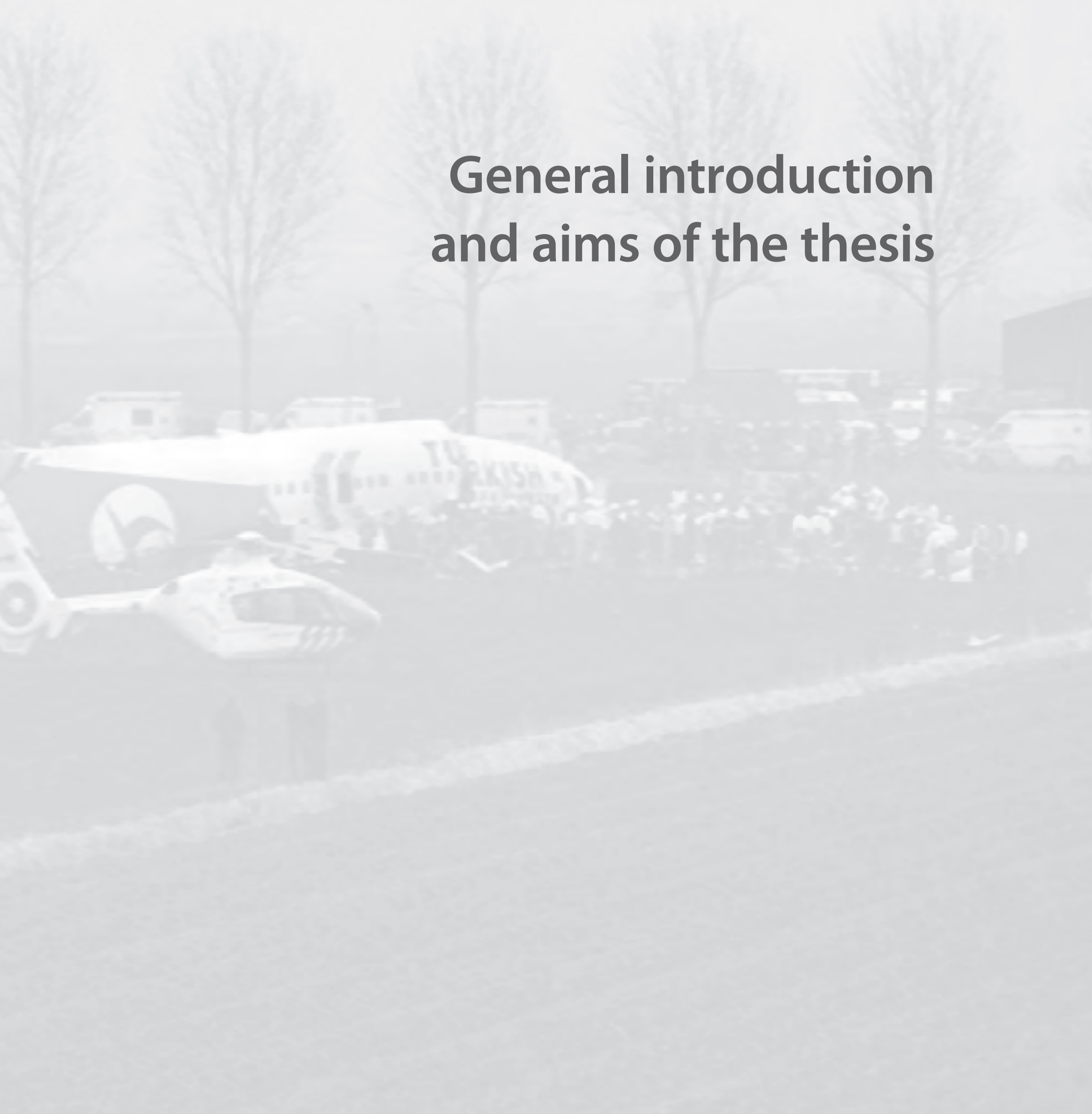
AIS: abbreviated injury scale
ATLS: advanced trauma life support®
CCC: critical care capacity (Dutch: kritische opvang capaciteit)
CCS: casualty clearing station (Dutch: gewondennest)
CHS: community health service (Dutch: GGD)
C-Spine: cervical spine
CST: critical stabilisation time (Dutch: kritische stabilisatie tijd)
DSB: Dutch safety board (Dutch: Onderzoeksraad voor Veiligheid)
ED: emergency department (Dutch: SEH)
EDC: emergency department capacity (Eerste hulp capaciteit)
EMS: emergency medical services (Dutch: Meldkamer ambulance diensten)
FAA: Federal aviation administration
FAST: focused abdominal sonography in trauma
FDR: flight data recorder
ICU: intensive care unit
ISS: injury severity score
MOTAC: medical research Turkish Airlines crash
MCI: mass casualty incident
MIMMS: major incident medical management and support
MVA: motor vehicle accident
NLDB study group: Nottingham, Leicester, Derby, Belfast study group
NTSB: National transportation safety board
PDC: patient distribution coordinator (Dutch: gewonden spreidingscoordinator)
PDP: patient distribution protocol (Dutch: gewonden spreidingsprotocol)
PSU: passenger service unit
P1, 2, 3: priority 1,2,3 (triage category) (Dutch:Triage T1, T2, T3)
TAC: Turkish Airlines crash

Part 1

General Events

Chapter 1

General introduction and aims of the thesis



At 10:26 am, on February 25, 2009, a Boeing 737-800 crashed 1.5 km from the runway of Amsterdam Schiphol Airport. Because of the proximity of the motorway reports of the crash were almost instantaneous and photos and videos made by bystanders were displayed on the internet and television in several countries. While the media was busy covering the crash, telephone communication at the regional emergency services centre was overloaded. The news reached some hospitals quicker through the media and by word of mouth than through the official channels. Nine people died, and 120 were injured.

Everybody can remember major disasters like the 2004 Madrid bombing, Hurricane Katrina in 2005, or the Japanese earthquake and tsunami in 2011. But besides these disasters, large scale accidents with multiple casualties happen more often. In 2013 at least 9 major railway accidents occurred in Europe, with 6 to as many as 200 injuries at a time. (1) The World Health Organization regional office for Europe reported 636 major (man-made) accidents from 1990-2012; either industrial or transport accidents. In these accidents 17,910 people died and they affected 105,865 people. (2) Since 2000, the Netherlands has had an average of 13 major incidents (involving ≥10 injured casualties) a year, with a peak of 19 accidents in 2003 and a peak of 945 people injured and 21 deaths in one incident in 2001. (3) In the Netherlands, multiple or mass casualty incidents (MCI's) happen on a monthly basis.

Airplane crashes are somewhat rare, but the number of flights and air travellers has increased rapidly since the start of commercial air traffic. Also, the size of the aircraft, and therefore the number of passengers on board, has increased to meet the growing demand for air trave. After a steady decrease in the number of fatal air accidents up to the 1970's, the accident rate continues to decline, but at a much slower rate. (4) Between 2002 and 2011 airplane crashes of commercial airliners happened at a worldwide average of 2.5 accidents per year in which at least one person was fatally injured. (5; 6) A common misconception is that airplane crashes are unsurvivable. On the contrary, most (73%) serious transport category airplane accidents are survivable, in which 76% of the occupants survives, according to a study by the National Transportation Safety Board (NTSB) that examined accidents in the period 1983 – 2000. (7)

In administrative and scientific terminology, two levels of major accidents have been identified; Mass Casualty Incidents (MCIs) and Disasters. MCIs are incidents/accidents with multiple casualties, the number of which is not explicitly defined; however the number must be more than is expected to be managed by the daily available infrastructure and logistics. The term 'disaster' can be explained in a variety of ways. From a medical management point of view, an MCI becomes a disaster when the number of casualties is so large that even when extra capacity is deployed by activating disaster protocols, normal standards of care cannot be met. In a highly developed society with high standards of medical care, people are entitled to high standards of care in any situation. Medical managers and practitioners should all have this goal, otherwise we allow casualties of an MCI or disaster to become victims twice.

Since these MCIs do not happen on a daily basis, there is hardly any routine in managing them. Therefore it is important to study these events, and break them down into areas applicable to MCIs or disasters of different origins. The concept of triage or patient distribution is the same whether it is an airplane crash, major explosion or collapse of a highway fly-over. The infrastructure and logistics of a hospital, and the basis of its disaster protocols remain applicable whether there are casualties with major burns or blast injuries to take care of. In times of stress and high workload, protocols and agreements must be clear. In the management of an MCI or disaster this is especially important.

After the airplane crash of February 25, 2009, medical professionals at several hospitals realised the impact of the airplane crash and the need to research this MCI. The trauma/surgical department of the four hospitals that received the most casualties decided to analyse this tragic incident, and together study the events in order to learn from it. The MOTAC study group was established. MOTAC is the acronym for the Dutch "Medisch Onderzoek Turkish Airlines Crash", which translates to Medical Research of the Turkish Airlines Crash". The crash was called the 'Polder Crash' in the media, because the airplane crashed in a ploughed field, in a polder.

In this thesis the events and management of an MCI of an airplane crash are studied from a medical point of view. The incident is broken down into areas that are applicable to other MCI's. it is believed that the detailed study of an exceptional event can provide vital information for many other kinds of exceptional events.

This thesis is presented in 4 parts. The first part describes the outline of the thesis and the general events that happened on February 25 2009. The rough data gathered in **chapter 2** are the basis of the following studies.

In the 2nd part of this thesis, the pre-hospital management of this specific crash, and MCI's in general, are studied. **Chapter 3 and 4** concern the triage and distribution of the casualties to hospitals. Difficulties in these processes are identified. In **chapter 5 and 6** a proposal is laid down for determining hospitals' critical care capacity and designing specified patient distribution protocols for MCI's in high risk areas, based on the lessons learned from, among other incidents, the February 2009 crash.

The 3rd part deals with the in-hospital management of the casualties of the crash. In **chapter 7** the radiological work-up that the casualties of the crash received and the appliance of ATLS protocol is studied and discussed**. Chapter 8** focuses on the spinal fractures which many of the patients suffered in this crash. This type of injury is quite common in airplane accidents. **Chapter 9** outlines the problems physicians face when diagnosing all injuries in the patients, immediately after the accident, especially when multiple patients have to be evaluated in a short period of time. The incidence of delayed diagnosis of injury is studied.

The last part, part 4, concerns the aftermath of an MCI. In **chapter 10** several injuries sustained in the crash are studied from a biomechanical point of view. The question: How did the structure of the aircraft and the forces applied to it, contribute to the injuries, and what can be done to prevent or mitigate them in future accidents? Is asked. After the physical injuries have healed, mental scars may remain. **Chapter 11** determines the mental health issues survivors of a crash have to deal with months or years after the incident. The final chapter, **chapter 12,** is a reflection on the lessons to be learned from this crash and how they can be applied to future incidents.

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Chapter 2

February 2009 airplane crash at Amsterdam Airport Schiphol: An overview of injuries and patient distribution

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Abstract

Objective

The objective of this study was to describe the injuries and distribution of casualties resulting from the crash of Turkish Airlines flight TK 1951 near Schiphol Airport in the Netherlands on the 25 February 2009.

Methods

This was a retrospective, descriptive study. Based on a review of the hospital records for all casualties of the airplane crash, triage at the scene, time to emergency department, Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS), mortality, length of hospital stay and surgical procedures were abstracted.

Results

Of the 135 passengers, nine died at the scene. A total of 126 survivors were examined in 15 hospitals; data for all survivors were available for the study. Median time between the crash and arrival at an emergency department was 3.5 hours (range 1.25-5.5 hours). Six passengers were uninjured and 66 were admitted to hospital. A total of 305 injuries were recorded. The majority was head and facial injuries (92), spinal injuries (35), and fractures of extremities (38). Eighteen percent of the patients had a spinal injury. The mean ISS was 6.4* (range = 1–66*). The ISS score was ≥16 for 15* patients. Surgical procedures (80) were necessary in 23 patients. There was no in-hospital mortality.

Conclusions

Although the accident was in an urban area, there was a significant delay between the time of accident and arrival of casualties at hospital emergency departments. The Turkish Airlines crash provides extensive information for research into mass-casualty or disaster management, triage, plane crash injuries, and survivability.

Introduction

On the 25 February 2009 at 10:26 hours, Turkish Airlines flight TK1951 crashed near Amsterdam Schiphol Airport, in the Netherlands, just before landing. The aircraft came to rest in a field, about 1.5 kilometres from the runway. The fuselage was torn open just in front of the wings and in front of the tail fin (vertical stabiliser) at the last row of seats, breaking the airplane into 3 sections (Figure 1). The front section with the cockpit and first seven rows was most heavily damaged. (1) Although there were initially some problems with locating the exact site of the crash, the medical response was rapid. Three helicopter trauma teams and 82 ambulances responded. Local farmers supplied agricultural machines to help evacuate the victims from the almost impassable field to the public road and the casualty clearing station.
This study describes the results of a retrospective study into the outcomes of this airplane crash. The study aimes to answer several research questions: 1. How were patients distributed among the hospitals?; and 2. How many injuries and what kind of injuries were sustained by the casualties? 3. How severe were the injuries and of what type, and how were they treated?

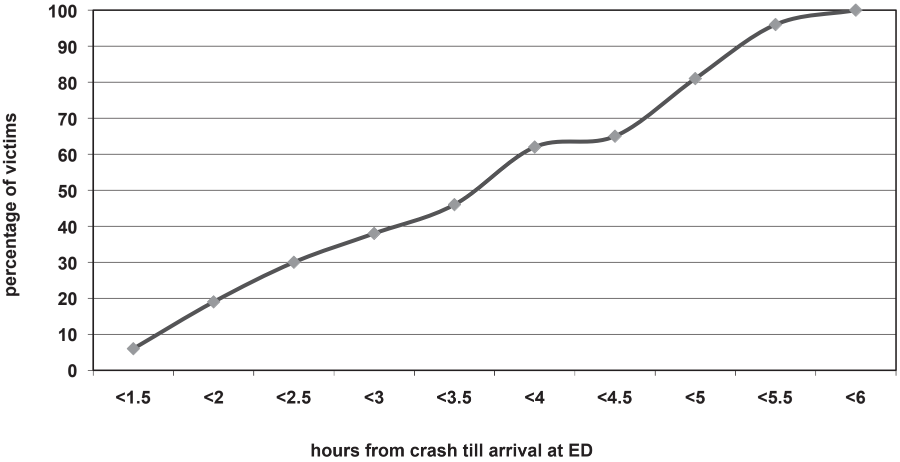
Figure 1. Aerial view of the crashed airplane.

Methods

First, patients' medical records were analysed retrospectively to assess how patients were distributed among different hospitals. In addition, ambulance records, emergency department records and hospital records of all survivors were analysed performed to retrieve information about: pre-hospital triage (Box 1); time between the crash and arrival at the emergency department; types and severities of injuries; surgical procedures performed; duration of hospital stay; intensive Care Unit (ICU) admittance; complications; follow-up until discharge and hospital mortality. Data were recorded in a Microsoft Access® [Microsoft, Inc., Redmond, WA] database.
Hospitals are designated a trauma care level by the Dutch government, were Level I hospitals have a coordinating role in the regional trauma network. Level I hospitals are equipped with all trauma care facilities; Level II hospitals have "certain" trauma care facilities, some of which are extensive, almost to the standard of Level I hospitals; and Level-III hospitals contain basic trauma care facilities.

As is common in trauma centres, the types and severity of injuries were defined using the Abbreviated Injury Scale (AIS) and Injury Severity Score (ISS). (2) The AIS is a standardised anatomical scoring system, in which injuries are scored on a scale from 1 to 6 for each body area: 1 = minor injury, 5 = critical injury, and 6 is lethal. The highest AIS scores are defined per body area, after which the ISS is calculated by taking an individual's 3 highest AIS scores, and adding up the square of each of these scores; thus resulting in an ISS score between 0 and 75. (3)

Figure 2. Time from crash to arrival at ED.



Results

The aircraft carried 135 people: 128 passengers and seven crew-members. Five passengers and four of the crew died at the scene of the accident. All survivors were transported to hospitals.

Patient Distribution

After being triaged by the emergency medical personnel according to the 'Triage Sieve and Sort' method, and evacuated from the scene of the accident, 124 patients were transported to 14 different hospitals (Table 1). These hospitals were Level I, II, or III hospitals. Two passengers left the scene of the accident by themselves, however reported to a hospital the next day. One of them reported to a hospital outside the district where the crash occurred. With the inclusion of this hospital, a total of 15 hospitals were involved (Table 1).

The first patient arrived at the emergency department at 11:40 hours, one hour and 14 minutes after the crash. The last patient (excluding the two who reported to hospital a day later) arrived at 16:13 hours (Figure 2). All 126 survivors of the crash, 83 men and 43 women, were included in this study. The mean age was 38 years (range: 11 months–76 years). There were very few records of pre-hospital triage in most cases, and the in-hospital triage records were also missing. After admission, three patients were referred to another hospital because of their type of injury: two were upgraded from a Level II hospital to a Level I hospital, and one went from a Level III hospital to a Level I hospital. For the analysis, data for these patients were abstracted from the medical records from the second hospital where they ultimately received treatment.

Injuries

Of the 126 patients, 60 patients were discharged from the emergency department, and 66 were hospitalised for a median duration of 4 days (range: 1–104 days). Fourteen patients were admitted to an ICU, five of whom required mechanical ventilation. The mean duration of ICU stay was seven days (range: 1–59 days, median: 2). Of the 126 patients, six were physically unharmed. The remaining 120 patients had a total of 305 injuries (Figure 3), and 75 of these sustained over 2 injuries. The mean ISS score was 6.4* (range: 1–66*), 15* patients were admitted with an ISS ≥16, and therefore were considered to be "multi- traumatised". (4) The most frequent injuries involved the head and face (92 injuries in 60 patients). These were mainly contusions and lacerations (48 injuries in 42 patients), cerebral concussion or contusion (20 injuries in 20 patients) and/or facial fractures (20 injuries in 14 patients). There were 35 spinal injuries (33 fractures) in 23 patients, 10 of whom required surgical stabilisation of one or more fractures. Twenty patients had a total of 38 fractures of the extremities, 25 of which needed surgical treatment.

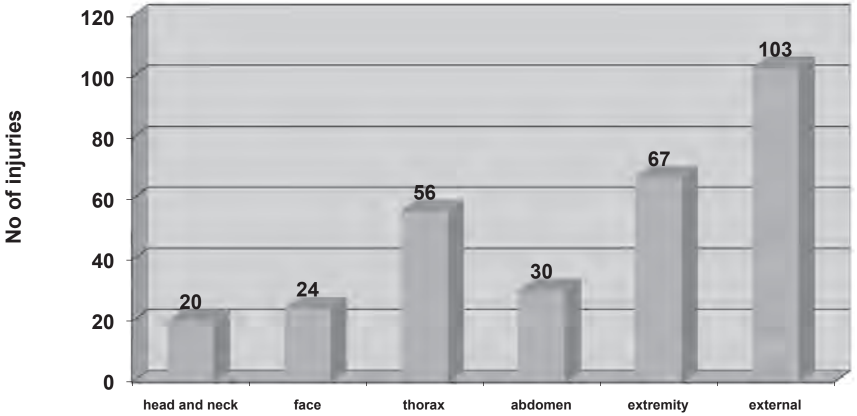
Table 1. Overview of hospitals involved and number of casualties received by each hospital

Hospital (level I, II, III)	No of casualties received
AMC (I)	19
VU (I)	25
UMCU (I)	4 (+2)*
LUMC (I)	4 (+1)*
HAGA (II)	4
KG (II)	32 (-2)**
MCA (II)	1
WFG (II)	1
SLAZ (II)	1
RKZ (II)	12
Rijnstate (II)	1
Spaarne (III)	14 (-1)**
Flevo (III)	1
Diaconessen (III)	1
Slotervaart (III)	6
Total	126

* later referred to this hospital
** later referred from this hospital

Twenty-three patients underwent 80 surgical procedures during their first admission (Table 2). Fourteen underwent 28 surgical procedures on the first day. Two patients were immediately transferred from the emergency department to the operating room due to life-threatening injuries. One of these patients suffered haemorrhagic shock due to pelvic fractures, intra-abdominal injuries, and severe injuries to extremities. Laparotomy was performed for haemorrhagic injuries of the liver and spleen. In addition, an external fixator was placed on the pelvis. The interventional radiologist performed embolisation of both internal iliac artery and splenic artery because of persistent haemodynamic instability. The second patient was also in haemorrhagic shock due to pelvic and extremity injuries. The pelvic, femur, and lower leg fractures were stabilised with external fixators, and amputation of the foot was performed because of uncontrollable bleeding with irreparable injury to the foot. Six patients had more than 5 surgeries during their hospital stay. All of these patients had a high ISS (between 13 and 66), and a combination of facial, extremity and spinal injuries. There was no in-hospital mortality.

Figure 3. Injuries per AIS region



'Head and neck' includes cervical spine injuries; 'thorax' includes thoracic spine injuries; 'abdomen' includes lumbar spine injuries

Discussion

The crash received considerable attention from the national and international media, which initially reported on the quick emergency response, the extensive availability of the emergency services and the number of victims and fatalities. From that perspective, several aspects of this study are described below.

Patient Distribution

The first patient arrived at the hospital 74 minutes after the crash. Three and a half hours after the crash, 50% of the patients had not yet reached a hospital. The circumstances at the scene, including the muddy ground and several patients being trapped in the wreckage, made it difficult to evacuate all the victims quickly. As a result, the so-called 'golden hour' for the severely and critically injured patients had elapsed. The "golden hour" is an adage in trauma surgery, which states that all life threatening injuries must be identified and treated in a hospital within one hour of the injury, in order to minimize secondary morbidity and mortality. Even though there is no strong scientific evidence for this, the adage is widely supported. (5) In fact, one of the deceased was still alive when the first Helicopter Emergency Medical Team (HEMS) arrived 54 minutes after the crash, but died shortly afterwards. (6) However, since no autopsy was performed on this victim, or on any of the other fatally injured passengers, it is not possible to comment on whether this outcome was influenced by the golden hour having elapsed.

Hospitals in the area were able to quickly upscale in order to create greater capacity to treat the injured. Because of unclear information about the number of casualties, several hospitals were upscaled according to the Dutch Hospital Disaster Plan (Dutch acronym: ZiROP). Upscaling should only be done in response to an official request, and means that the capacity for regular (non-urgent) care is reduced to provide greater capacity for a relatively large number of severely injured patients. In the present case, the patients were widely distributed amongst the 14 hospitals that initially were involved, some of which only received a few or just one patient. As a consequence, a number of hospitals lost regular care capacity unnecessarily. Further research is needed into the precise patient distribution during this event, as well as in regional and national patient distribution plans, to evaluate their efficiency and feasibility. Another point to be considered in future research includes the role of specialised major incident facilities, such as the Major Incident Hospital at the University Medical Centre Utrecht, the Netherlands.

Table 2. Surgical procedures carried out on 25 February 2009 on victims of the plane crash.

	Fractures	Viscera	Soft tissue	Total
Face	5		2	7
Abdomen	0	2	0	2
Spine	17		4	21
Pelvis	3		0	3
Upper extremity	9		3	12
Lower extremity	24		11	35
Total	58		22	80

It is important to consider the decision to transfer the victims to a hospital. Considering that all of the occupants of the plane had suffered a high energy trauma, the decision to treat all victims in a hospital would appear appropriate. However, this decision was not taken until several hours after the crash, where upon all victims who had initially been attended to at casualty clearing stations were eventually transported to a hospital; only six patients remained physically unharmed by the crash and 66 people were hospitalised. This delay in transferring patients to hospital raises some concerns that will be addressed in further research into the pre-hospital triage system used.

Finally, this study has identified some issues relating to casualty triage. Pre-hospital triage records were not available in this retrospective analysis and, for most patients, the triage classification (Box 1) could not be linked to the ISS, because very few casualty triage tags were used. The evaluation report by the Dutch Public Order and Safety Directorate in cooperation with the Dutch Health Care Inspectorate mentions 35 P1 (critically injured) casualties. This number is presumably derived from estimates issued by the hospital boards at an inquiry three days after the crash. (7) However, it is unclear whether these estimates are based on pre-hospital or in-hospital triage. The analysis of patient records carried out in this study found 15 patients to be multi-trauma patients with an ISS of ≥16. Although not each P1 victim is necessarily a multi-trauma patient, this large discrepancy between the estimated number of P1 casualties and the observed number of patients with an ISS ≥16 could indicate that there may have been some over-triage. Only three victims, all with spinal fractures, were referred to another hospital. One of these patients had an ISS of 17, and was initially taken to a Level III hospital. The other two patients, with an ISS of 8 and 9, respectively, were referred from a Level II hospital to a Level I hospital. These observations will be addressed in a more in depth study into the triage and distribution of the victims of this plane crash.

Box 1. Triage classification according to MIMMS.

P1 (red): Immediate/ Critical: ABCD unstable, in need of immediate treatment because of either: A (airway), no open airway; B (breathing), respiratory rate < 10 or >30; C (circulation), pulse rate >120; D (disability) GCS (Glasgow Coma Score) <8.

P2 (yellow): Urgent/ Severe: ABCD stable, but with possible life-threatening injuries if not treated within 6 hours.

P3 (green): Delayed/ Minor: ABCD stable, walking wounded.

Injuries

A remarkably large number of spinal and head and face injuries were found in the victims of this plane crash. Eighteen percent of all victims had one or more spinal injuries. Further analysis of the type of spinal injuries might explain the trauma mechanism: either flexion-distraction injuries due to the body flailing over the 2-point lap belt in sudden horizontal deceleration, or compression-type fractures due to the sudden vertical deceleration.

The head and facial injuries might be explained by the sudden impact, against which the passengers did not brace themselves since they had no idea they were going to crash as there had been no warning from the cockpit. Furthermore, there were few abdominal injuries. Only one patient needed a laparotomy and nine patients suffered renal contusion. These findings are in line with those from a study of a relatively similar plane crash in 1989 in the United Kingdom. (8) The nature of the trauma, being a high speed deceleration while wearing a 2-point lap belt, would be expected to cause more injuries to the vulnerable intra-abdominal viscera. Further research regarding the structural damage to the airplane, as well as the biomechanical analysis of the injuries, is outlined in chapter 10 of this thesis.

Conclusions

This study described patient distribution and injuries of victims of the February 2009 Turkish Airlines aircraft crash at Schiphol, the Netherlands, in which nine of the 135 occupants died and 120 were wounded. There was no in-hospital mortality. The analysis has shown that, even though the crash occurred in the most densely populated area of the Netherlands, with numerous hospitals nearby, a considerable period of time elapsed between the crash and the arrival of the victims at the hospitals. There were hardly any records found of the pre-hospital triage and there appears to be large discrepancies in the estimated numbers of T1 patients. Finally, evaluation of the types of injuries has revealed a remarkable number of head/ facial injuries and spinal injuries. Further research is planned by the “Medical Research Turkish Airlines Crash” (MOTAC) study group into the triage, patient distribution and biomechanics of the injuries. Other relevant matters identified in the present study should provide greater insight into the events surrounding this aircraft crash.

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*During the process of the several studies, certain calculations of the ISS scores needed to be revised. The injuries and AIS scores were correct but some ISS scores had been miscalculated. This has led to minor revisions of some results, which did not lead to different conclusions. In this chapter the correct results are displayed and therefore some numbers differ from the published article. These numbers are indicated with an *asterisk. The whole data set of revised results is displayed in a table in chapter 12.

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Part 2

Pre-Hospital Phase

Chapter 3

Mass casualty triage after an airplane crash near Amsterdam

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Abstract

Introduction

Triage is an important aspect of the management of mass casualty incidents. This study describes the triage after the Turkish Airlines Crash near Amsterdam in 2009. The results of the triage and the injuries of P3 casualties were evaluated. In addition, the role of the trauma mechanism and its effect on spinal immobilisation during transport was analysed.

Methods

Investigational reports, ambulance forms, and medical charts of survivors of the crash were retrospectively analysed. Outcomes were triage classification, type of injury, AIS, ISS, emergency interventions and the spinal immobilisation during transport.

Results

A minimal documentation of pre-hospital triage was found, and no exact numbers could be collected. During in-hospital triage, 28% was triaged as P1, 10% had an ISS ≥16 and 3% met the modified Baxt criteria for emergency intervention. Forty percent was triaged P3, 72% had an ISS ≤ 8 and 63% was discharged from the emergency department after evaluation. In-hospital over-triage was up to 89%. Critical mortality rate was 0%. Nine percent of P3 casualties and 17% of 'walking' casualties had serious injuries. Twenty-two per cent of all casualties was transported with spinal immobilisation. Of the casualties diagnosed with spinal injury, 22% was not transported with spinal immobilisation.

Conclusion

After the Turkish Airlines Crash, documentation of pre-hospital triage was minimal. According to the Baxt criteria the over-triage was high. Injuries sustained by airplane crash survivors that seemed minimally harmed, must not be underestimated. Considering the high energy trauma mechanism, too little consideration was given to spinal immobilisation during transport.

Introduction

In a disaster or mass casualty incident (MCI), a rapid assessment and treatment of the injured is important. On February 25, 2009 a Turkish Airlines Boeing 737-800 crashed with 135 people aboard, nine people died at the scene. One hundred and twenty six casualties needed triage. Emergency services in the Netherlands have experience with MCIs, e.g. 245 casualties in the Volendam café fire in 2001 and 944 casualties in the Enschede fireworks explosion in 2000. (1-3) In previous MCIs difficulties with triage occurred, such as pre-hospital services employing different or inadequate triage methods (2-7) pp. 50–52. At the Volendam café fire, few triage scores were documented at the scene of the accident: the pre-hospital triage of the burns casualties was inadequate and did not lead to treatment and transport priorities. (2; 3)

The two-fold purpose of triage for trauma casualties is first to allocate casualties to the appropriate hospital, thus reducing the changes of secondary mortality and morbidity of individual casualties, and secondly to be as cost effective as possible. (8; 9) In an everyday situation there is no need to consider the 'greatest good for the greatest number of people'. A difference with triage during disasters and large MCIs is that medical capacity is limited, resulting in a need for lower over-triage rates in order to prevent an overburdened medical system. (10; 11) In MCIs of bomb blasts, the critical mortality rate (number of critically injured casualties that die on the way to, or in hospital) has proven to be directly related to over-triage. (10; 12; 13)

The Triage Sieve and Sort Algorithm is a component of the Major Incident Medical Management and Support (MIMMS) course based on physiological parameters such as ability to walk, airway patency, breathing rate and pulse rate, and was (and still is) the practice used in MCIs in the Netherlands during the Turkish Airlines Crash (TAC) in 2009 (Figure 1). (14; 15) p. 53

The guidelines for field triage, as supposed by the American College of Surgeons, describe mechanisms of injury that might indicate a high energy impact. It is suggested that casualties of such an injury mechanism should be transported to a trauma centre for Advanced Trauma Life Support (ATLS®) resuscitation and subsequent treatment of their injuries. (8; 9) As an airplane crash deviates from regular trauma mechanisms, medical personnel might not be familiar with expected injuries in casualties of an airplane crash.

In this study several triage-related issues after the TAC are evaluated. The research questions were:

Triage process:

1. What were the results of the pre-hospital and in-hospital triage process of the casualties of the TAC crash?
2. How did triage classifications relate to clinical criteria?

P3 and walking wounded:

3. What were the injuries of the P3 casualties and 'walking' casualties?
4. What was the expected severity of their injuries?

Mechanism of injury and spinal immobilisation:

5. Did trauma mechanism play part in this mass casualty triage?
6. If so, how did this affect spinal immobilisation rate during transport?

This retrospective study has been approved by the Institutional Review Board of the Academic Medical Centre Amsterdam.

Figure 1. The scene of the accident.

Setting

Turkish Airlines flight TK1951 crashed at 10:26 am in a field 1.5 km from the runway of Amsterdam Airport Schiphol (Figure 2). Nine people did not survive the impact of the crash. Casualties were transported to a total of 14 hospitals ranging from 5.8 km to 53.5 km from the crash site. The majority (86%) was transported to a hospital within a 25 km distance. (16)

Box 1. Triage Sieve classification according to MIMMS

P1 (red): Immediate/ Critical: ABCD unstable, in need of immediate treatment because of either: A (airway), no open airway; B (breathing), respiratory rate < 10 or >30; C (circulation), pulse rate >120; D (disability) GCS (Glasgow Coma Score) <8.

P2 (yellow): Urgent/ Severe: ABCD stable, but with possible life-threatening injuries if not treated within 6 hours.

P3 (green): Delayed/ Minor: ABCD stable, walking wounded.

Methods

A retrospective analysis was carried out of available ambulance forms, the registered information of the 3 deployed Helicopter Emergency Medical Service (HEMS) teams and the present triage cards of the casualties. The collected data of the events, as described in investigational reports of the Dutch Health Inspectorate and Dutch Safety Board, were also used. (17-19) The pre-hospital data collected were: gender, age, vital signs and revised trauma score (RTS), triage classification, use of triage cards, time of transport and arrival at emergency department and medical interventions. In-hospital data included: trauma level of the receiving hospital, in-hospital triage classification, documented injuries, Abbreviated Injury Scale (AIS), Injury Severity Score (ISS) and medical procedures. The in-hospital triage classifications reported in the investigational reports of the Dutch Health Inspectorate and Dutch Safety

Board were utilised for the study purposes. These data were not documented per individual casualty but only as a group and therefore no comparison with individual diagnosis or ISS was possible. The data consisted of estimations reported during evaluation interviews by the hospitals involved and cross-checked with the collection of individual injuries and ISS scores in our own database.

An indicator of the performance of triage is the critical mortality rate, representing the number of critical casualties (P1) that died on the way to or in the hospital. (4; 10; 12; 20)

Triage classification

The triage classifications with 2 clinical criteria; Injury Severity Score (ISS) and the modified Baxt criteria were compared. (21-23) For the comparison with ISS we analysed how the P1 category correlated with an ISS ≥16, P2 with an ISS 9–15, and P3 with an ISS ≤ 8. Secondly, we used the modified Baxt criteria (from now on called 'Baxt criteria') and hospital admission shown in Figure 3. The Baxt criteria consist of emergency interventions patients have undergone in order to treat acute life threatening injuries. Patients who met the Baxt criteria were considered P1. Patients who did not meet Baxt criteria but were admitted to hospital for at least 24 h were considered P2. Patients that did not meet Baxt criteria and were discharged within 24 h were considered P3. (21; 22; 23) We evaluated the processes of triage and different outcomes from pre-hospital and in-hospital triage. Over-triage was calculated by dividing the number of non-critical casualties triaged as P1, by the total number of P1 triaged casualties. (12; 20; 22) Under-triage was calculated as the ratio of critically injured casualties, and casualties with an ISS ≥16 that were not transported to a level one trauma centre. (9; 24)

Box 2. Modified Baxt criteria.

Modified Baxt criteria

- Chest decompression (needle or tube thoracostomy)
- Intravenous fluid for a systolic blood pressure <90 mmHg, or absence radial pulse
- Blood transfusion
- Assisted ventilation or open airway procedure
- Invasive central nervous system monitoring with brain imaging or other evidence of increased cranial pressure
- Non-orthopaedic operation (or pelvis stabilization) with positive findings within 6 hours

P1:	ISS≥16:	One of more modified Baxt criteria apply within 6 hours of the crash.
P2:	ISS 9-15:	No Baxt criteria but admission > 24 hours.
P3:	ISS≤8:	No Baxt criteria and discharged < 24hours.

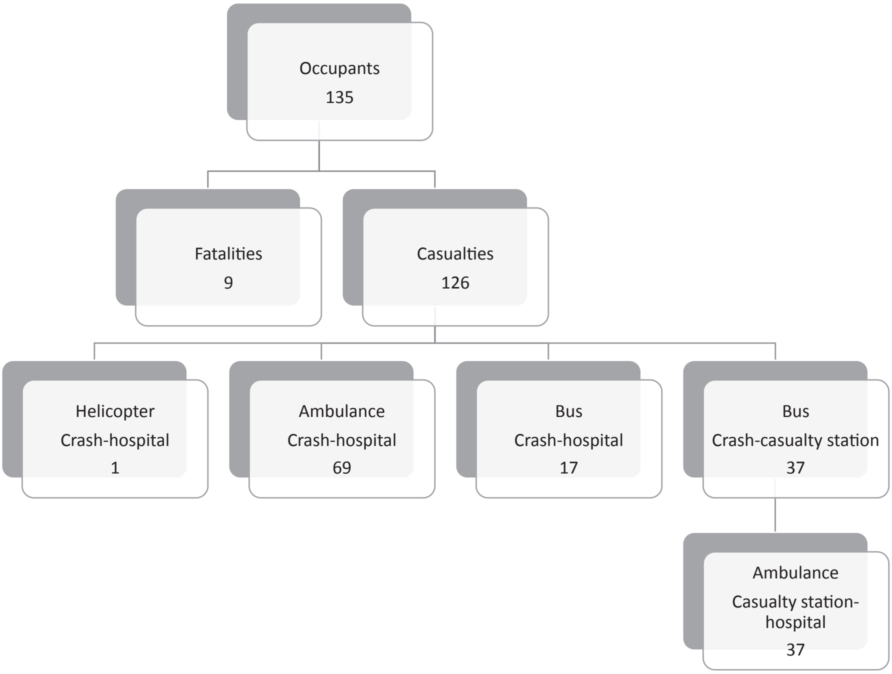
Pre-hospital P3 and 'walking' casualties

Casualties triaged as P3 (delayed) were determined by either a documented P3 triage classification on the ambulance form or on the triage tag. Another sub-group of P3 casualties was determined by documentation of their presence in the last casualty clearing station. In this casualty clearing station, casualties triaged P3 were initially gathered in order to be reunited with their families. Later it was decided that these casualties also needed in-hospital evaluation because of the high energy trauma mechanism. (19; 18) Duplicates within both groups were filtered out and the subgroups were analysed together as one. The injuries and treatment of this group were analysed.

In the Triage Sieve algorithm the first determination is done by noting whether the casualty is walking. (15) When walking, casualties are triaged as either P3 (if injured) or uninjured. We identified casualties that were reported (by documentation on ambulance form) to have come 'walking' from the aircraft wreckage or crash site. We also made calculations for these groups (P3 and walking wounded) combined (taken out duplicates) in order to study the value of estimation of the injuries of this category. To be able to see if the frequently used triage term 'walking wounded' is accurate in excluding major injuries, their injuries and treatments (operative or non-operative) were analysed.

In order to report the extent of the injuries and possible need for hospital evaluation, the highest AIS score of each of the P3 casualties and each of the walking wounded was determined.

Figure 2. Transportation



Trauma mechanism and spinal immobilisation

All casualties were eventually considered to have been subjected to a high energy trauma mechanism, during the triage process. Documentation from the ambulance forms of spinal immobilisation during transport and diagnosis of spinal injury and the in-hospital treatment, were gathered.

The data were collected, stored and analysed using SPSS® 16.0 (SPSS® for Windows® version 16.0, IBM® corporation, U.S.A.).

Table 1. Triage disposition according to location and injury criteria

	P1	P2	P3	total
Pre-hospital triage*	?	≥2	≥34	124
In-hospital triage	35 (28%)	40 (32%)	49 (40%)	124
ISS	13 (10%)	22 (18%)	89 (72%)	124
Baxt (see also figure 3)	4 (3%)	42 (34%)	78 (63%)	124

*From the pre-hospital triage, documentation of 36 casualties(2P2, 34 P3) was found

Results

Events

A house and 2 barns next to the crash site functioned as improvised casualty clearing stations (CCS). About 20 of the most severely injured casualties (in the investigational reports called P1) were taken to the house, and about 70–75 of the less severely and minimally injured (in the investigational reports referred to as P2 and P3) were assigned to the 2 barns. (19; 18) Some casualties were trapped in de wreckage. At least 37 minimally injured casualties (in the investigational reports referred to as P3) were later transported to a third CCS in a sports centre, which was the pre-assigned CCS in the MCI protocols. This CCS is supposed to be mainly used for P3 casualties. Here during re-triage, 2 casualties were found to be critically injured (P1) and 17 to have severe injuries (P2). It was then decided, that because all casualties had suffered a high energy trauma, they should all be evaluated in hospital according to ATLS® principles.

Two casualties left the crash site by themselves and were not triaged but reported to a hospital later that day and the day after the crash. They are not accounted for in the results. The other 124 occupants were transported to 14 different hospitals within a median time of 3.5 h after the crash. Ambulance forms of 91 patients, which contained heterogeneous and incomplete data were retrieved.

In this article, the crash site, the house and two barns, which were the first improvised CCS, together are referred to as 'the scene of the accident'. The third CCS, being the pre-assigned sports centre, is referred to as the CCS. The means of transport are summarised in Figure 2.

Triage classification

Documentation of a pre-hospital triage classification was found on 27 of the 91 ambulance forms (30%, 2 P2 and 25 P3). Few triage tags were used and only 11 were retrieved. (19; 18) The result of the triage classification, ISS and Baxt criteria are shown in Table 1. It was reported at the scene that there were 20 P1 casualties. (19; 18) When considering an ISS ≥16 as a measure of P1 casualties, 7 (35%) of those 20 casualties should not have been triaged P1. Using the Baxt criteria the pre-hospital over-triage was 80%. The in-hospital over-triage would have been 63% if it had been calculated with ISS and 89% with the Baxt criteria. All casualties were evaluated in a hospital, and all casualties who needed emergency intervention (Baxt criteria) were transported to a level 1 trauma centre. Eighty nine percent of the casualties with triaged P1 in-hospital and 92% of casualties with ISS ≥16 were transported to a level 1 trauma centre, giving an under-triage rate of 11% and 8% respectively. No casualties died on the way to or in hospital; therefore the critical mortality rate was 0%.

Table 2. Results of P3 and 'walking' casualties

	P3 and walking (n=50)
Mean ISS (median; IQR; range)	4.1 (2; IQR 1/5; 0-22)
Hospitalised	17 (34%)
Mean number of days in hospital (median; IQR; range)	7 days (3; 2/10; 1-17)
Fracture	11 (22%)
Spinal fracture	7 (14%)
Surgery	7 (14%)
Surgery for spinal fracture	5
At least 1 moderate injury (AIS ≥2)	22 (44%)
At least 1 serious injury (AIS≥3)	6 (12%)

P3 and walking wounded

Thirty-three casualties were identified as P3 either by documentation on their ambulance form or because they went through the CCS. Among those were several victims that were later re-triaged as P2 or P1, because of an existing injury, not because of clinical deterioration (information by word of mouth). We could not identify those casualties that were upgraded in triage classification. One P3 patient was later diagnosed with a bilateral lung contusion, a spinal fracture, and an ankle fracture, resulting in an ISS of 22.

On the ambulance forms of 23 casualties it was reported that they came walking from the wreckage by themselves. One of those 'walking' casualties was later diagnosed with a tibia fracture, 2 spinal fractures, and a kidney contusion (ISS 17). Combining these two groups and extracting duplicates 50 casualties were identified within this category. The results of clinical outcomes in this category are in Table 2. The injuries with an AIS ≥3 that were diagnosed in this group were a fracture of the odontoid of the 2nd cervical vertebra, 5 thoracolumbar spine fractures (in 3 casualties), a fracture of the sternum, 2 tibia fractures (bilateral in 1 patient), 2 cerebral contusions and 1 retina laceration.

Table 3: Transportation to 1st receiving hospital

	Spinal Injury	No spinal injury	Total
Full immobilization	11 (61%)	7 (9%)	**18 (17%)**
Only spine board	3 (17%) (no C-spine collar)	3 (4%)	**6 (6%)**
Only collar	0	1 (1%)	**1 (1%)**
No immobilisation	4 (22%)	54(83%)	**58+17* (75%)**
Total	**18****	**65**	**100***

*assuming 17 patients transferred together in a casualty bus were without spinal immobilisation.
** excluding 5 patients with unknown immobilisation.
N= 100; number of casualties with documentation about spinal immobilisation

Spinal immobilisation

Documentation on transport with or without spinal immobilisation was found for 83 casualties. It can be assumed (and it was reported verbally to the author) that the 17 patients transported together in a bus had no spinal immobilisation. Of the 126 survivors, 23 had a spinal injury, 4 of whom we determined received no immobilisation on transport. Ten patients needed surgical treatment for their spinal injury 1 of whom was not immobilised during initial transport. The data on spinal immobilisation during transport are shown in Table 3.

Two (6%) of the P3 casualties were later diagnosed with spinal injury, but were not immobilised during transport. Apart from these 2, there were also 2 (9%) of the 'walking' casualties with a spinal fracture that were not immobilised. One of them needed operative treatment for the spinal injury.

Discussion

Before beginning the discussion on the individual topics, it should be noted that this paper is in no way intended to criticise the individual work of the emergency responders all who contributed to saving lives and minimising harmful results of the crash. This evaluation is performed mostly by hospital professionals and might therefore insufficiently capture the complexity of pre-hospital work-flow.

Triage

The evaluation of the triage process after the TAC was difficult because there was a small amount of individualised data on pre-hospital and in-hospital triage. It is remarkable how few triage tags were used, namely in 12% of casualties for whom we found pre-hospital data. Evaluations of other MCIs around the world have shown the same. (25; 26) The National Protocol Ambulance Care does prescribe the use of casualty/triage tags (15)p.20. There has been criticism on the layout of triage tags themselves and also on the fact that ambulance personnel are unfamiliar with the use in daily practice. In the management of an MCI, deviation from daily routine has shown to be difficult. (18; 25) This has been mentioned as an explanation for why the tags were not used in the TAC. In the TAC 'only' 126 casualties needed evaluation. In larger incidents, with greater numbers of casualties (e.g. Madrid bombing 2004 with more than 2000 casualties) practical sorting methods of triaged casualties are indispensable. Some plead for geographical triage instead of using triage tags, because in MCIs with >20–25, casualties triage tags could be impractical. (27) In a way this was done at the TAC for most of the P3 casualties who were transferred to a separate CCS. The use of triage tags and feasibility of implementation in daily practice should be investigated. This asks for a casualty/triage tag with enough space for identification information, medical information and triage category which can be altered during the process. The goal should be to create a tag/card (maybe digital) that can be used during day to day casualty management and is also applicable in MCIs.

In the research of the TAC we focused on the possible over-triage of P1 casualties and the possible underestimation of the injuries of P3 casualties. In an MCI where there is no shortage of medical care, non-life threatening injuries have a greater importance than in disasters, especially in developed countries with high standards of medical care.

Over-triage was not defined by the designated trauma care level of trauma of the hospital to which casualties were transported, because ambulance personnel could have chosen to transport casualties with minor or moderate injuries to a level 1 trauma centre because of its large capacity rather than because of the specialised care. (9; 28) Because all casualties were eventually evaluated in a hospital, no under-triage was present in that way. Therefore under-triage was evaluated to standards of daily practice, not MCIs, which determines whether critically injured casualties are transported to the highest level of care in the region. (9) Over-triage rates are high (80–89%) when considering the Baxt criteria, but when using the ISS as a measure, the rates were lower (35–63%). However, an ISS ≥16 can consist of all none (acutely) life-threatening injuries and ISS should not be used as a sole means to define critically injured casualties as in the P1 triage classification. (21; 22)

In daily practice, a certain amount of over-triage is accepted, as a way to reduce under triage. It has been stated that in MCIs and disasters, an over-triage rate of

50% must be accepted, to produce an under-triage rate of zero. (12) However, the American College of Surgeons states that in daily practice an under-triage of 5% is acceptable with an associated over-triage rate of 25–50%. (9; 27) The over-triage rate of P1 casualties in TAC of up to 89% is high, as is the under-triage rate of P1 casualties of up to 12%. This was not reflected in the critical mortality rate (0%), which could be due to the large availability of medical resources in this setting. (29) In descriptions of other MCIs the under-triage rates are mostly not evaluated. Our 12% under-triage is calculated from a daily practice standard, and can be considered low for an MCI.

The high in-hospital over-triage rates could be due to inaccurate use of the P1 triage classification. In an evaluation report, a major trauma centre mentions to having received '5 P1 casualties of whom 2 had acute life threatening injuries. (30) According to the MIMMS Triage Sieve, the 3 casualties without acute life threatening injuries should not have been triaged P1.

P3 and 'walking' casualties

In the TAC medical management, it appears to have been unclear how to manage casualties triaged as P3, as 37 P3 casualties were almost sent home, but were later assigned entitlement to in-hospital evaluation. In the patient distribution plan of the region it is stated that in-hospital treatment only applies to major injuries (P1 and P2). Casualties with less serious injuries (P3) are only seen as a hindrance at the scene of the accident and at the hospital entrance. (31; 32) The investigational report of the Dutch Health Care Inspectorate mentions that 'P3 casualties can be treated at the scene by medical assistance teams. (19) In our opinion, this is an incorrect interpretation of the MIMMS triage method, which determines that P3 casualties have no transport priority and need not necessarily be initially transported by ambulance. MIMMS does not advocate that in-hospital evaluation of P3 casualties should be withheld (14).

Our data show that casualties from an airplane crash who are walking and/or triaged as P3 can still have major injuries, including spinal fractures. Some casualties might not immediately experience the physical pain caused by these injuries because of high levels of stress hormones released directly after the survival of such an accident. Repeated evaluation of casualties (re-triage), as was done in the CCS, is therefore necessary.

If all P3 and walking wounded in the TAC had not been evaluated in hospital an increase in morbidity and possibly mortality could have resulted. Use of contradictory terms and protocols must be avoided in managing MCIs. It must also be clear to everyone in the field what the definition of terms used in these protocols is. For example 'walking wounded' should not be explained as 'not injured' or 'not entitled to hospital evaluation.'

Trauma mechanism and spinal immobilisation

According to the field triage rules by the American College of Surgeons, all casualties of a high energy impact should be considered for evaluation in a major trauma centre rather than a level II or III trauma centre, based on the expected severity of the injuries. (9) In everyday practice in the Netherlands, if expected injuries are less severe, high energy trauma casualties can also be transported to level II hospitals. (15) The criteria of high energy impact are defined for more common trauma mechanisms such as falls from a high height or motor vehicle accidents, but not for rare accidents such as airplane crashes. (9) The one criterion most applicable for this airplane crash was 'death in the same passenger compartment,' as 6 people who were seated in the passenger compartment did not survive the impact of the crash. The decision that all casualties should be evaluated in hospital on the basis of the high energy trauma criteria was therefore justifiable.

In the TAC, 75% of the casualties had no spinal immobilisation during transport to hospital, and 22% of the casualties eventually diagnosed with spinal injury were not transported with immobilisation. The MIMMS states that 'full spinal immobilisation is impractical for all casualties of, for example, a rail crash, even though they are exposed to the same mechanism of injury. Clinical judgement must be exercised to a greater extent than in a single casualty blunt trauma incident. (14) The trauma mechanism of this airplane crash put several parts of the spinal column at risk of injury. Ninety-two of the 126 survivors had a head or facial injury, probably due to a blow to the head by flying loose objects or by hitting the head itself against the airplane's interior, putting the cervical spine at risk. (33) The crash could have been assumed to have been accompanied by horizontal and vertical deceleration forces. (17) This might have resulted in a blow to the thorax by hitting the seat in front compressing the thorax and/or flailing over the seatbelt compromising the lumbar spine in the horizontal deceleration force. Considering a possible vertical deceleration, a direct compression force is applied to the entire spine especially in a sitting position. For decision making about cervical spine immobilisation, the NEXUS criteria are the basis of the Dutch ambulance protocol. (15) In this type of trauma, the NEXUS criteria seem to be incomplete. In the TAC, availability of medical resources such as ambulances and immobilisation material was not sparse, so more casualties could have been transported with spinal immobilisation. In hindsight the Dutch ambulance protocol also appears to be insufficient to clear the spine as a whole. The mechanism of injury must be accompanied by symptoms such as pain in the spine, being unalert (GCS < 15 or intoxication), distracting injury, neurological deficit, facial (not head) injury or suspicion of basilar skull fracture, in order for the ambulance personnel to immobilise the spine. (15) If the trauma mechanism had been considered at an earlier stage, emergency medical personnel at the scene probably would have immobilised more casualties.

In conclusion the TAC was not a disaster, since there was enough medical capacity to manage all casualties with high standards of care. This is reflected in the critical mortality rate of 0%. When a crash like this happens, the magnitude cannot fully be predicted in the first moments of pre-hospital care. Therefore it is sensible to start triaging as if it is a disaster where a lack of capacity is expected. This means that at first (all) P1 casualties should be identified by physiological parameters as with the Triage Sieve. The rest, being P2 and P3 casualties can wait. Later, when the scale of the incident is clear, and it can be assumed that there is enough capacity for high standards of care to be delivered to every casualty, the incident should be downgraded to an MCI where normal triage and standards of care can be applied. This takes into account not only physiological parameters and injury type, but also mechanism of injury. In hindsight, this is in fact what happened at the management of the TAC.

Conclusion

After the Turkish Airlines Crash, documentation of triage was minimal. According to the Baxt criteria there was a high percentage of over-triage (up to 89%), which is acceptable in daily practice to minimise under-triage, but is less desirable in MCIs and disasters. Over- and under-triage did not result in an increase of mortality, since the critical mortality rate was 0%. The possible injuries sustained by the P3 casualties should not be underestimated, as major injuries were diagnosed in this group. In an airplane accident, such as described in this study, spinal immobilisation for transport should be considered for all survivors.

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Chapter 4

Patient distribution in a mass casualty event of an airplane crash

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Abstract

Introduction

Difficulties have been reported in the patient distribution during Mass Casualty Incidents. In this study the regional Patient Distribution Protocol (PDP) and the actual patient distribution after the 2009 Turkish Airlines crash near Amsterdam was analysed.

Methods

Analysis of the patient distribution of 126 surviving casualties of the crash was carried out by collecting data on medical treatment capacity, number of patients received per hospital, triage classification, Injury Severity Score (ISS), secondary transfers, distance from the crash site, and the critical mortality rate.

Results

The PDP contains ambiguous definitions of medical treatment capacity and was not followed. There were 14 receiving hospitals (distance from crash: 5.8–53.5 km); four hospitals received 133–213% of their medical treatment capacity, and 5 hospitals received 1 patient. Three hospitals within 20 km of the crash did not receive any casualties. Level I trauma centres received 89% of the 'critical' casualties and 92% of the casualties with ISS ≥ 16. Only 3 casualties were secondarily transferred, and no casualties died in, or on the way to hospital (critical mortality rate = 0%).

Conclusion

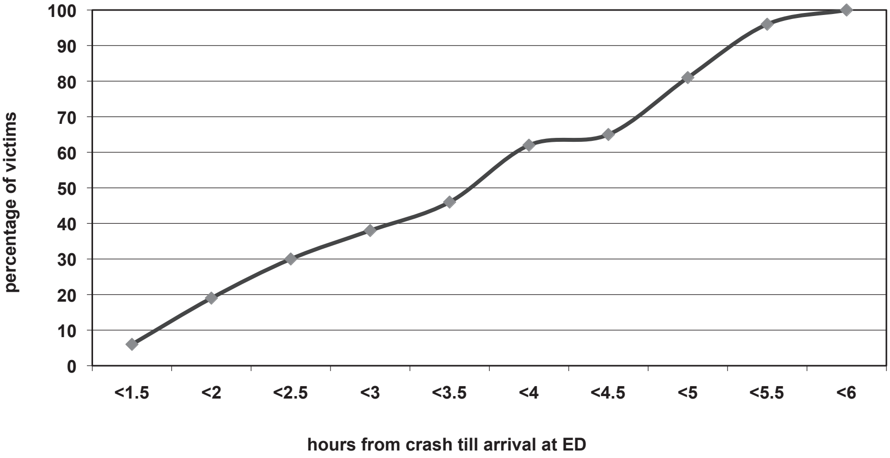
Patient distribution worked well after the crash as secondary transfers were low and the critical mortality rate was zero. However, the regional PDP was not followed in this MCI and casualties were unevenly distributed among hospitals. The PDP is unclear, and should be updated in co-operation between emergency services, surrounding hospitals, and Amsterdam Airport Schiphol as a high risk area.

Introduction

On February 25, 2009 flight TK1951 crashed near Amsterdam Airport Schiphol, the Netherlands. One hundred and thirty five occupants were aboard, 126 survived the crash. When dealing with a large amount of casualties with a high energy trauma mechanism, management of patient distribution is a challenge. Preparation for disasters and Mass Casualty Incidents (MCIs) is a difficult but important task. Numerous casualties must be triaged, transported and treated at the appropriate hospital without overwhelming any of the hospitals. Disaster protocols are developed to offer guidance in executing these tasks. Research literature highlights different kinds of problems in patient distribution during MCIs, but more importantly, the same errors seem to be repeated in subsequent disasters or MCIs. (1-6) To prepare for MCIs, it is important to evaluate and report the outcomes of previous MCIs. In this study, the patient distribution after the MCI of the Turkish Airlines crash on February 25 2009, near Amsterdam was evaluated. This paper describes the analysis of the following research questions:

1. How is medical response to Mass Casualty Incidents (MCIs) and patient distribution organised in the Netherlands, with special attention to high risk areas such as Amsterdam Airport Schiphol?
2. How was the patient distribution executed in this MCI and was it carried out according to the regional Patient Distribution Protocol (PDP)?

Figure 1: Time of arrival at Emergency Department



Methods

We collected the national and regional MCI plans and protocols that were applicable to the airplane crash, in order to analyse the general MCI response plans and specifically the regional patient distribution protocol (PDP). (7-11) Since the crash some protocols have already been in revision. In this analysis the situation as it was at the time of the crash was studied.

For the second question we analysed the events on the day of the crash, by studying evaluation reports of the Dutch Safety Board and the evaluation report of the Public Order and Safety Inspectorate in co-operation with the Health Inspectorate. (12-14) The medical charts of ambulances and hospitals of all casualties of the crash were analysed. We specifically looked at the number of casualties the hospitals received, whether these hospitals had activated their hospital disaster plan and the distance from the crash site to the receiving hospital. The latter was calculated with the route planner of the ANWB (Dutch Automobile Association). (15)

Additionally the triage classification (P1, P2, P3; box 1 chapter 2) of the casualties and their Injury Severity Score (ISS) were collected. (16-18) To evaluate the patient distribution outcome, the secondary transfers and critical mortality rate were studied. (1; 2) The critical mortality rate expresses the quality of triage and patient distribution as a ratio between critically injured casualties and in-hospital (or on transport) mortality. This is based on the fact that critically injured casualties benefit the most from rapid transport to an appropriate facility. We compared the data of the patient distribution after the crash to the regional PDP.

Results

The system

The Netherlands (16.7 million inhabitants, 41,526 square km) is divided into 25 Safety Regions. The safety regions have their own Emergency Services Centre (ESC), with 215 ambulance stations for almost 700 ambulances. (19) Each Safety Region is responsible for its regional disaster protocol, which should be in accordance with the national disaster protocols. Different high risk areas, involving different kinds of risks (e.g. North Sea Channel, chemical industry areas), all have their own protocols. Some high risk areas involve several safety regions. When an incident involves an airplane crash at Amsterdam Airport Schiphol the Aircraft Accident Schiphol

(AAS, Dutch acronym VOS) protocol is used. The medical response of this system is presented in Table 1. The ESC of each safety region, receives calls for emergency assistance and coordinates the dispatches of these emergency responders (police, fire department, and ambulance services).

In the Netherlands hospitals are equipped according to Level I, II or III standards. Level I hospitals have full trauma care facilities. When an MCI occurs, a number of hospitals can be put on alert by the ESC (Table 1) or can be requested to activate their hospital disaster plan (Dutch acronym: ZiROP). When the hospital disaster plan is activated, extra capacity is created to receive and treat casualties. The Netherlands also has a Major Incident Hospital situated at the Military Hospital in Utrecht, with a liaison with the University Medical Centre Utrecht. Within 30 min they are ready to receive 100 patients. If needed, this facility is able to upscale to 250– 300 patients, within 1 hour (20).

Table 1: Airplane Accident Schiphol (AAS)

Scale	Type of incident	Medical Response
AAS 1	Pan-pan call	2 Ambulances 1 Medical Officer
AAS 2-4	Mayday call	5-14 Ambulances; 1 Medial Combination Team*; 1-2 Medical officers; 1-6 Hospitals
AAS 5	Crash <50 occupants	25 Ambulances; 1 Medial Combination Team*; 2 Medical Officers; 7-13 Hospitals
AAS 6	Crash 50-250 occupants	64 Ambulances; 5 Medical Combination Teams*; 4 Medical Officers; 7-13 Hospitals
AAS 7	Crash >250 occupants	126 Ambulances; 10 Medical Combination Teams*; 7 Medical Officers; 13-22 Hospitals

*Medical Combination Team: 1 trauma team (doctor + nurse), 2 ambulance teams, 1 Rapid Response Team for Medical Assistance, (Dutch acronym, SIGMA team).

In case of an MCI, casualties are triaged at the scene following the critical/immediate (P1), serious/urgent (P2), and minor/delayed (P3) triage classification according to the Triage Sieve and Sort system used by the MIMMS (Major Incident Medical Management and Support). (16) Then the casualties are transported to hospital according to priority. The distribution of the casualties among different hospitals is executed according to the regional Patient Distribution Protocol (PDP) of the safety region involved.

Since 2008, Amsterdam Airport Schiphol has fallen under the responsibility of safety region Kennemerland. Geographically though, Schiphol lies on the border of 2 safety regions. The regional PDP was last updated in 2008. When the number of casualties is high and exceeds the co-ordinating capacity of ambulance personnel and centralists, a special patient distribution coordinator is sent to the scene. (9; 11; 21)

In the existing PDP, the general medical treatment capacity (MTC) per hospital is defined as one critically or seriously injured patient (P1 or P2) per emergency team per hospital in the first hour. In the second hour an extra 2 P1 or P2 patients can be received per emergency team in Level I or II trauma centres. The PDP does not describe the number of emergency teams per hospital. (9)

The PDP mentions that, according to government requirements, in case of an MCI, hospitals should be able to clear 3% of their total bed capacity. However, the PDP also states that in daily practice hospitals only agree to clearing 1%, because 3% does not appear to be reasonably possible. We consider this 3% medical treatment capacity as the maximum number of casualties able to be presented at the emergency department. In the regional PDP of safety region Kennemerland, there is information about 30 hospitals with a (presumed) total bed capacity of 14,398 beds. These total bed capacity numbers, however, are actually outdated because of the mergers of several hospitals and the increase in outpatient treatments. In the PDP, medical treatment capacity numbers are mentioned based on 1% and 3% of total bed capacity. The receiving hospitals and their medical treatment capacity are in Table 2.

The distribution of casualties is further decided upon by the triage classification of the casualties and the proximity of the hospitals. The PDP has the rationale that, in MCIs in the primary distribution phase, no consideration is given to injury type or severity (e.g. burn injuries). Only in the secondary (definitive) distribution phase may patients be transferred to specialised centres if necessary.

The Events

After the Turkish Airlines crash, the first reports of the accident came into the Emergency Services Centre (ESC) one minute after the crash at 10:27 a.m. (12; 14) Eighty two ambulances from different regions were dispatched, as were the medical officers (Dutch acronym OvDG) and 3 Helicopter Emergency Medical Service teams (HEMS, Dutch acronym MMT). Difficulties in communication and distribution of tasks led to some response units being informed late. The first ambulance was alerted in 2 minutes and the first to arrive at the crash did so after 18 minutes. The first helicopter emergency medical team was alerted 35 minutes after the crash and arrived 55 minutes after the crash.

The person that was on call as the patient distribution coordinator was, at the moment of the crash, also working as an operator at the ESC and could therefore not execute his task as patient distribution coordinator. An ambulance nurse at the scene was appointed, ad hoc, as a substitute coordinator, but was not acquainted with the regional PDP. It was later reported by officials that the actual patient distribution coordinator on call was also not familiar with the actual PDP. (14)
Approximately one hour after the crash, the estimation of the number of casualties was 16 P1, 30 P2 and about 80 P3. At 14:00 (3.5 h after the crash) the reports were 25 P1, approximately 25 P2, about 60 P3 and 9 fatalities. (12; 14) At first, about half of the casualties were transported directly to hospitals by ambulance or casualty bus. At a casualty clearing station, some of the previously triaged P3 casualties were found to have major injuries at re-triage.

Table 2. Hospitals, distance, Medical Treatment Capacity (MTC), Hospital Disaster Plan (HDP)

Hospital (Trauma Level)	Distance from crash (km.)	1% MTC	3% MTC	No of casualties	HDP in action?
VU Medical Centre (I)	14.7	6	17	**25** (147%)	Yes
Academic Medical Centre (I)	23.8	9	26	**19** (73%)	Yes
Leiden University Medical Centre (I)	32.9	9	25	**4** (16%)	no
University Medical Centre Utrecht (I)	53.5	8	24	**4** (17%)	No
Kennemergasthuis (II)	5.8	6	15	**32** (213%)	yes
St Lucas Andreas Hospital (II)	10.6	6	18	**1** (6%)	No
Red Cross Hospital (II)	16.8	4	9	**12** (133%)	Yes
Medical Centre Alkmaar (II)	34.1	9	26	**1** (4%)	Yes
Westfriesgasthuis (II)	47.4	5	15	**1** (7%)	No
Haga Hospital (II)	51.5	Not in PDP	Not in PDP	**4**	No
Spaarne Hospital (III)	8.7	4	9	**13** (144%)	Yes
Slotervaart Hospital (III)	11.6	4	12	**6** (50%)	Yes*
Diaconessen Hospital (III)	32.5	2	9	**1** (11%)	No
Flevo Hospital (III)	44.3	2	5	**1** (20%)	No
Total		74	210	**124**	

Hospitals close but not used: OLVG (II) 17.1 km, de Heel ZMC (III) 19.1 km, BovenIJ 19.6 km, Amstelland (III) 17.7 km.

* no official request

At this point all remaining casualties were also transported to hospital.
It was difficult to retrieve much precise information about triage. Most pre-hospital triage information was either not well documented or lost. In-hospital triage information was based on retrospective interviews with receiving hospitals and was published in the evaluation report of the Dutch Public Order and Safety

Inspectorate. (12) The ISS (Injury Severity Scores) (calculated from the medical records off all patients) are presented in Table 3. One of the 13 patients with an ISS ≥16 was not immediately transported to a Level I trauma centre, but was first evaluated at a Level III hospital. When the extent and type of his injuries were known and the patient was stable, he was transferred to a Level I trauma centre. Another 2 patients were transferred from a Level II hospital to a Level I hospital because the receiving hospital lacked the specialised facilities to treat their injuries.

Results of the time until presentation at the emergency department in Figure 1. Nine people did not survive the crash; they all died at the scene. No casualties died in or on the way to hospital; the 'critical mortality rate' therefore was 0%. (1; 2; 22)

The ambulances transported the casualties to 14 different hospitals varying from 5.8 to 53.5 km from the crash site (Table 2). There were 4 hospitals (1 Level II, 3 Level III) within 25 kilometres of the crash that did not receive any casualties. Two casualties left the crash site by themselves, but came to a hospital later for a physical examination. These 2 casualties are not included in our results.

At first 3 regional hospitals (level II and III) were alerted by the ESC 24 minutes after the crash. About 15 minutes later, two 2 Level I hospitals received a request to put their disaster plan into action, as did another 4 smaller hospitals (3 of which were alerted earlier). (14) One other hospital close to the crash site (11.6 km) put its disaster plan into action, without formal request from the ESC. The hospitals are presented in Table 2. The Major Incident Hospital in Utrecht was not requested to prepare to receive casualties.

Four hospitals with activated disaster plans received more patients (147–213%) than their 3% medical treatment capacity. Five hospitals, one of which was officially requested to activate the hospital disaster plan, only received 1 patient. It was orally reported to the authors that, because of a failing communication system and the lack of patient distribution co-ordination, ambulance personnel transported patients to hospitals at their own discretion. This was often to the hospital they were most acquainted with.

Table 3: No. of casualties per hospital

	Level I	Level II	Level III	Total
P1	31 (89%)	4 (11%)	-	35
P2	23 (57%	7 (18%)	10 (25%)	40
P3	5 (10%)	37 (79%)	7 (14%)	49
ISS≥16	12 (92%) (+1*)	-	1 (8%)(-1*)	13
ISS 8-15	14 (64%) (+2*)	6 (27%)(-2*)	2 (9%)	22
ISS<8	26 (29%)	45 (51%)	18 (20%)	89
	52	51	21	124

Row 1-3: estimated numbers as reported in investigational reports (12; 14)
* +1, +2 and -1, -2: refers to secondary transfers

Discussion

This study found that without formally using a PDP, a critical mortality rate of 0% can be accomplished in an MCI with 126 casualties. It was not possible however to evaluate the effects on morbidity. However patient distribution would be faster and safer if a clear protocol was implemented by the emergency services.

The impact zone of the runways and approach routes of Schiphol Airport extend into 4 safety regions. Only 3 hospitals, out of 11 situated within 25 km of Schiphol Airport, are within the geographical borders of the safety region concerned with the management of an MCI at the airport. The 82 responding ambulances came from at least 5 different safety regions. This shows that in the Netherlands, patient distribution in an MCI, especially in high risk areas like an international airport, almost automatically involves several safety regions.

The existing PDP is based on a rationale of primary distribution without attention to specific injuries and specialisations available in hospitals. In this MCI the patients were casualties of an airplane crash that ended up in a field. It was difficult for the walking casualties to get away on their own, so emergency services had good control over patient distribution. If an MCI were to take place in an urban setting, casualties would be taken to hospitals in civilian cars or the 'walking wounded' would go on foot. This would result in an uncontrolled flow of casualties at the nearest hospital. (1; 23; 24)This must be taken into consideration when planning patient distribution.

The existing regional PDP does not clearly define how many casualties each hospital can receive and how many emergency teams are present. The 3% medical treatment capacity is based on total bed capacity, but does not reflect the true treatment capacity of hospitals' emergency department. The medical treatment capacity of the 2 Level I trauma centres in Amsterdam, as reported in the Patient Distribution Plan, is 26 and 17. In practice their actual treatment capacity in a Mass Casualty Incident (MCI) is likely to be different, if treatment capacity were based on available resources, like the number of trauma teams, trauma room capacity, operating theatre, ICU capacity, etc. (3; 25)

The execution of the patient distribution after the Turkish Airlines crash was sub-optimal, partially because of problems in communication, as has been reported in many other MCIs. (4; 6; 24-28) It also appears to have been difficult to implement the patient distribution protocol (PDP) because the patient distribution co-ordinator on call was not able to take upon his function and it later appeared that the assigned co-ordinators were not properly familiarised with the PDP of the safety region. The patient distribution co-ordinator and other officers on call must therefore be free from all other tasks, to be able to take on this duty in case of an MCI. Everyone involved in the management of an MCI should be properly trained for the individual task and this training should be repeated in MCI drills every few years.

The Dutch government has stated that ambulances should be able to reach 95% of all inhabitants within 15 minutes. (29) Despite the short distance, the first ambulance to reach the crash site in the Turkish airline crash, did so in 18 minutes, 3 minutes later than required. (14) The government also states that the assistance of the helicopter emergency medical services is only useful when they can provide this assistance within 30 minutes. (30-29) In this crash the helicopter emergency medical services were called upon only after 35 minutes. The first helicopter to arrive after 55 min also did not meet the current national standards.

Only 4 (11%) of the critically injured (P1) casualties and 1 multi-trauma casualty (ISS ≥16) were not initially transported to a Level I trauma centre (Table 3). Just 3 secondary transfers were needed which demonstrates good patient distribution, as does the critical mortality rate, which was 0%. Although the patient distribution had no influence on the critical mortality rate; we cannot say whether it had an influence on morbidity.

In the Turkish Airlines crash it was not clear which Emergency Services Centre alerted which hospital or Helicopter Emergency Medical Teams. (14) Six hospitals in 3 safety regions received the request to put their hospital disaster plan into action more than 40 minutes after the crash. This is late, considering it takes time to execute the disaster plan.

Casualties were transported to 14 hospitals, half of which were more than 30 km away from the site of the crash. Four hospitals situated within 25 km by road, did not receive any patients. If all hospitals within 25 km had been considered, 11 hospitals would have been sufficient to cope with all casualties. Two of these hospitals are Level I, four Level II and five Level III, and have a total medical treatment capacity of 162. In this Mass Casualty Incident (MCI) it was not necessary to involve the Major Incident Hospital in Utrecht, because there was enough treatment capacity in the area. Whether the use of a major incident hospital would have been more efficient and practical in terms of costs, patient distribution, casualty identification, etc. has never been studied, to our knowledge.

Four hospitals received more casualties than described in the patient distribution protocol (PDP), exceeding their assigned (3%) medical treatment capacity by 133–223%. Four other hospitals nearby did not receive casualties and 3 hospitals received just 4–11% of their treatment capacity. One hospital, that was officially requested to put its disaster plan into action, received only 1 casualty. Another hospital that put its disaster plan into action without request (but did so because of close proximity to the crash site) received just 6 patients. Activating the hospital disaster plan and receiving only a few casualties resulted in unnecessary financial losses in this MCI.

After the Turkish Airlines crash, the safety region Kennemerland started to revise its patient distribution protocol and has taken into account suggestions made by the MOTAC study group based on this study. Efforts are being made to create a new nationwide rationale in patient distribution.

Conclusions

In this Mass Casualty Incident (MCI) the existing Patient Distribution Plan (PDP) appeared to be unclear and did not account enough for multi-regional medical response for MCIs in the large high risk area of Amsterdam Airport Schiphol. However, the critical mortality rate of 0% and low secondary transfer rate shows that patient distribution worked well in this crash. Lack of communication and a non-functioning PDP led to hospitals being uninformed about the expected casualties and to unnecessary loss of regular treatment capacity in some.

We recommend that PDPs are revised to national standards with specifications for high risk areas like Schiphol Airport. The Emergency Services Centre, the hospitals and Schiphol Airport should cooperate in revising these PDPs.

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Chapter 5

Preparing for mass casualty incidents and disasters Part 1: A proposal on how to determine hospitals' critical treatment capacity

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Introduction

Definition of a Multiple Casualty Incident: A hazardous impact with as many casualties in which the available organizational and medical resources, or their management systems, are severely challenged. (1)

Triage Categories: In case of a Mass Casualty Incident (MCI), casualties are triaged at the scene following the critical/ immediate (P1), serious/urgent (P2), minor/ delayed (P3) triage classification according to the Triage Sieve and Sort system used by the MIMMS (Major Incident Medical Management and Support). (2)

Recent disasters such as the 2004 Madrid and 2005 London bombings, Hurricane Katrina in 2005, or the Japanese earthquake and tsunami in 2011, had a major impact and received worldwide attention. However besides these disasters, large scale accidents with multiple casualties happen more often. In 2013 at least 9 major railway accidents in Europe were reported that resulted in injuries to 6 to as many as 200 people at a time. (3) The World Health Organization's regional office for Europe reported 636 major (man-made) accidents from 1990-2012; either industrial or transport accidents. In these accidents 17,910 people died and they affected 105,865 people. (4) Since 2000, the Netherlands has had an average of 13 major incidents (involving ≥10 injured casualties) a year, with a peak of 19 accidents in 2003 and a peak of 945 people injured and 21 deaths in one incident in 2001. (5) In the Netherlands multiple or mass casualty incidents (MCI's) happen on a monthly basis.

Medical Management of MCI's starts with triage of the injured, and their evacuation to medical facilities. When allocating casualties to the right medical facilities, it is important to know the number of casualties and the grade of injury a specific hospital can accommodate for diagnosis and treatment. Historically, triage and casualty distribution was based on the adage "the greatest good for the greatest number of people". (6) Nowadays, in many MCI's in the developed world, there is an abundance of highly specialised medical care. We may therefore expect the same high level care for MCI casualties as for those in daily medical care.

After the airplane crash near Amsterdam in 2009, the Medical Research Turkish Airlines Crash (MOTAC, Dutch acronym) study group investigated the triage and patient distribution in this MCI. We learned that pre-hospital personnel and commanding emergency service officers were not fully acquainted with the patient distribution protocol (PDP), and found that the foundation of the PDP was inadequate. (7-9) The research into the events of this airplane MCI and the PDP in use (at the time of the crash) identified several questionable aspects. These aspect involved hospitals' treatment capacity for MCI's and the patient distribution principles (box 1).

Box 1: Issues of concern in patient distribution after the February 2009 airplane crash near Amsterdam

1. Different interpretations and definitions are used to indicate hospitals' treatment capacity.
2. The hospitals' capacity number is based on the outdated and irrelevant number of hospital beds.
3. The protocol allows hospitals to be utilized to their maximum capacity before allocating casualties to another hospital.
4. After the 2009 crash patients were distributed to too many different hospitals and over a large area. Some nearby hospitals (several of which had created extra capacity) were hardly or not utilized at all.
5. Pre-hospital personnel (medical officers, coordinators and ambulance personnel) were insufficiently or not acquainted with the patient distribution protocol.

In two chapters, a new concept for a PDP is presented. The concept is written from a medical point a view and is designed to support government and Emergency Services in their task to coordinate patient distribution after an MCI.

In this chapter we propose a model to calculate the capacity of hospitals to receive, diagnose and treat trauma victims in MCI's. This number is called the Critical Care Capacity (CCC). Although many national and international documents can be found on hospitals' preparation for MCI and disasters, we could not find protocols on how Critical Care Capacity is calculated. (10-13)

The next chapter proposes a design of a patient distribution plan for a high risk area, allocating the right number of patients to the right hospitals. Although the location of an MCI or disaster cannot be predicted, some areas can be appointed as high risk. These are for example airports, train stations, business complexes, and chemical industry locations. With pre-designed patient distribution plans for these areas, ad hoc decision making can be reduced.

Principles of patient distribution

These principles are derived from the research literature and experiences from previous MCI's or disasters. (7-9;14-18)

1. The Critical Care Capacity (CCC) of a hospital should be calculated using the same formula in every hospital, considering, among other things, numbers of trained personnel, and the presence of adequate facilities and sufficient equipment.
2. During the patient distribution phase of an MCI, distribution of casualties among several hospitals must be performed from the start.
3. P1 casualties (casualties triaged as critical with first transport/treatment priority) should preferably only be distributed to trauma centres (in the Netherlands, Level I and II hospitals). Only when there is a threat of exceeding the Critical Care Capacity (CCC) in the region and the other trauma centres are too far, can Level III hospitals (basic trauma care) be considered for the resuscitation and stabilization of P1 casualties.
4. Secondary transfers should preferably be minimised by taking the hospital's designated trauma care level (Level I, II, III) and specialisation (e.g. burns, neuro-trauma) into account in the first patient distribution phases.
5. Under-triage among P3 casualties is to be expected. Certain types of incidents can result in such trauma mechanisms that everyone who has been involved is entitled to be screened at the hospital for injury. When the incidence is of such a magnitude that all relatively close hospitals are in danger of being overwhelmed, minimally injured casualties can be screened and treated for their injuries by less specialised and less equipped medical facilities; e.g. a general practitioners' post or a casualty clearing station set up near the accident site.
6. Ambulance personnel are expected to be back at the incident site as soon as possible to pick up the next casualty. However transportation should not be solely to the nearest hospital. It is the task of a (pre-assigned) Patient Distribution co-ordinator (PDC) to manage adequate patient allocation among the appointed hospitals.
7. Recurrent training and drills among all professionals involved in MCI's are necessary to maintain experience and knowledge.

Phases in Mass Casualty Incidents

In MCI trauma care, rapid stabilisation and evacuation of the patient to the right medical facility is seen as essential, but the exact maximum allowed pre-hospital time is subject to debate. (19) Systems and protocols should be designed in order to achieve in hospital treatment of P1 and P2 casualties as soon as possible. In case of a large MCI, hospitals will be asked to create extra treatment capacity, e.g. by activating their MCI/disaster protocol. This 'up-scaling' takes time; with a good protocol and training this may take about an hour. In this first hour some casualties will already arrive at the hospital. Ideally this should mainly be P1 casualties, but will probably involve 'walking wounded' arriving by themselves (not by ambulance). After preparation, most casualties will be arriving in hospital. At the end there is time to treat minor injuries and redistribute casualties if necessary. Based on our principles of trauma care in MCI's we have designed 3 phases of casualty management in MCI's.

Phase 1

Phase 1 starts when the incident is reported to the Emergency Services Centre (ECS) and the level of response is defined. The level of response is based on incident type and an estimated number of casualties. It refers to the number of ambulances and Helicopter Emergency Services (HEMS, Dutch acronym MMT) that need to be sent to the incident side, and the number of hospitals that need to be asked to activate their disaster protocol in order to create extra capacity ("up-scale"). Phase 1 ends after the appointed hospitals have up-scaled their capacity. This will be after approximately 1 hour. If a hospital experiences trouble in activating its hospital disaster protocol this is reported to commanding officer in charge. This will be the patient distribution co-ordinator (PDC).

Phase 2

Most of the P1, and P2 casualties will arrive at the hospitals after the first hour. This is phase 2. The goal is to end phase 2 within a maximum of 6 hours. This is based upon the widespread belief that P1 and P2 casualties benefit the most from treatment as quickly as possible, within a maximum of 1 hour for P1 and 6 hours for P2 casualties. (20-23) After 6 to 8 hours research literature reports that the quality of medical care in hospitals will decrease, since supplies run out and personnel fatigue sets in. (23) There is a maximum time that people can deliver good quality care under extreme pressure of both quantity and high level complexity. The patient distribution coordinator (PDC), will keep track of the reported numbers of P1, P2 and P3 injured casualties that are (still) at the incident site. When the P1 and P2 casualties have been transported from the incident site to the hospital, the PDC will declare the end of phase 2 and the start of phase 3.

Phase 3

At this point there is time to treat the (minor) injuries of the P3 casualties and, if needed, perform secondary transfer of stabilised casualties to other hospitals. Secondary transfers should be minimised by taking hospitals' specialisation into account in the first 2 patient distribution phases. (24) Examples, these specialisations are traumatic brain injury, pelvic and spinal fractures, and extensive burn injuries. P1 casualties should ideally only be transported to trauma centres. (17; 18) Another reason for secondary transfer is to re-distribute the burden of definitive care. The Summary of the phases are presented in Box 2.

Box 2. Phases of patient distribution in MCI's

Phase 1: Start: directly after declaration of an MCI; Duration: 1 hour (from time of declaration of an MCI until the moment hospitals have fully activated their disaster protocol to create extra capacity).
Phase 2: Start: after 1 hour; Duration: maximum 5 hours (from the 2nd hour after declaration of an MCI until all P1 and P2 casualties have arrived for treatment at a hospital).
Phase 3: Start: when P1 and P2 casualties have arrived at hospital. Duration: indeterminate (Until all casualties (P1, 2, 3) have been screened and treated for injuries at the hospitals and are at the right facility for definitive care).

Calculation of Critical Care Capacity

In the preparation for major accidents and disasters it is important that hospitals identify beforehand how many critically and severely injured victims (P1 and P2) they can receive and treat. In this part a method is presented to calculate this capacity. The time needed to perform a primary and secondary survey on 1 casualty is called the Critical Stabilisation Time (CST).

1. During or after office hours.

For phase 1 it is important the make a difference between time during office hours, where most of the personnel is already at work, or after office hours. During phase 2 and 3 the hospital will up-scale and extra personnel will become available. It makes no difference when phase 2 or 3 occurs, since maximum capacity is made available regardless of the time of day.

2. Composition of Critical Care Teams for P1 victims

To be able to calculate the Critical Care Capacity (CCC) it is important to know how many P1 resuscitation beds/ rooms are available at the Emergency Department (ED). After up-scaling, different rooms can be equipped to become P1 resuscitation rooms.

Secondly, medical trauma teams need to be formed to resuscitate critically and severely injured victims. (16; 25) Together this corresponds with the Emergency Department Capacity (EDC_{P1}). Medical personnel must be the best trained and most experienced available.

The composition of a P1 resuscitation team:
* 2 ATLS trained doctors; (at least one trauma surgeon/ anaesthesiologist, or senior resident)
* 2 nurses (ER and/or anaesthesiology nurse)
* 1 radiologist (or resident)
* 1 radiology laboratory assistant/ radiology technician.

One team can perform ATLS work-up (primary and secondary survey) on 1 to 2 P1 casualties in an hour (0,75 hours per casualty, = Critical Stabilisation Time, CST_{P1}), and hand them over to either an operating team or the Intensive care. This time is an estimation based on the Dutch situation and research literature, taking into account that in an MCI setting, only major injuries need to be diagnosed in the resuscitation phase. (25) In a high stress situation, deviation from daily practice can lead to confusion and inferior quality of care. Therefore normal logistics/working routine should be preserved as much as possible, keeping everybody in the environment they are used to working in and where they have the most routine.

Once it is decided how many P1 teams and beds can be created, a cross check is performed for availability of enough equipment and enough secondary facilities available to resuscitate 1 to 2 P1 casualties per team. Examples are: (mobile) x-ray and ultrasound equipment, CT-scanners, ventilation machines, surgical capacity

(50% of all P1 casualties), laboratory capacity, blood bank capacity, splints or casts for extremity fractures, intervention radiologists, etc. (26)

3. Composition of Critical Care Teams for P2 victims

P2 casualties are not vitally threatened. First, the number of P2 resuscitation beds/ rooms need to be assessed, and second, the number of P2 teams. This is the Emergency Department Capacity (EDC_{P2}). Experiences of earlier mass casualty incidents and disasters have taught us to expect more over-triage (P2 casualties being triaged and presented to hospitals as P1) than under-triage. (7)
The composition of a P2 resuscitation team:
* 1 ATLS trained doctor
* 2 nurses (ER or anaesthesiology)
* 1 radiology laboratory assistant/ radiology technician

One team can perform ATLS work-up (primary and secondary survey) at 2 P2 beds (next to each other) at one time (0,5 hours per P2 casualty per team, is Critical Stabilization Time, CST_{P2}). This time is an estimation based on the Dutch situation and research literature taking, into account that in an MCI setting, only major injuries need to be diagnosed in the resuscitation phase. (25) Then another cross-check needs to be performed to confirm there are enough secondary facilities available to give primary treatment to the victims' injuries. There is no need for equipment to support vital organ systems but examples of equipment needed are casts or splints, bandages, laboratory availability, and a radiologist and trauma surgeon for supervision (one each for 6-8 casualties an hour).

4. Total number of P1 and P2 Casualties

Following the method explained below, the total number of P1 and P2 casualties for both phase 1 and 2 (total of 6 hours) must be calculated.

5. P3 casualties

P3 casualties need to be checked and treated for injury. They can receive their primary care either at casualty clearing stations, at a general practitioners' office or at the hospitals once the emergecy there has subsided. After they have been checked at other treatment stations, casualties can be sent to hospital for definitive treatment if needed. The P3 casualties are at risk of a certain type of under-triage. Even though their injuries may not be life threatening, they can sustain injuries that can eventually give (secondary) morbidity. (7) Nevertheless their injuries can be treated at a later stage, sometimes even with a delay of some days. At the end of phase 2 the PDC checks how many P3 casualties are in need of hospital care. Then the PDC checks if the hospitals are still able to receive P3 casualties. It might be necessary to allocate these P3 casualties to hospitals further away.

Formula to calculate Critical Care Capacity (CCC)

Once the number of teams and resuscitation beds (mostly at the Emergency Department) for P1 and P2 casualties (Emergency Department Capacity, EDC) are defined, the exact CCC can be calculated. The estimated rate for P1: P2 casualties is in general 1:3. (27)

Box 3. Formula to calculate Critical Care Capacity (20)

- Critical Care Capacity = Emergency Department Capacity **:** Critical Stabilisation Time.
  CCC = EDC : CST
- Critical Care Capacity of the first hour = CCC_1
  $\text{CCC}_1 = \text{EDC}_1\text{: CST}_1$
- Critical Care Capacity after the hospital is up-scaled = $\text{CCC}_{\text{up-scaled}}$
  $\text{CCC}_{\text{up-scaled}} = \text{EDC}_{\text{up-scaled :}}\ \text{CST}_{\text{up-scaled}}$ (per hour)
- Critical Care Capacity of 1^{st} hour and after up-scaling combined = $\text{CCC}_{\text{total}}$
  $\text{CCC}_{\text{total}} = \text{CCC}_1 + (\text{CCC}_{\text{up-scaled)}}\ \text{x}\ 5$

Example

We provide an example based on a Level I trauma centre in the Netherlands. The numbers provided are the ones calculated for this hospital but have not been tested yet in a real MCI or training. Table 1 presents the Emergency Department Capacity (EDC) for P1 and P2 casualties. Table 2. Shows the formula to calculate Total Critical Care Capacity (Phase 1 and 2, total 6 hours, in a Level I hospital).

P1* CCC**; 5 ÷ 0.75 = ***6 P1/hour.

There will be more P1 teams than beds, so while delivering one casualty to ICU or operating theatre the next team can take care of the next casualty at the same bed.

The fact that it takes some time to clear the room and prepare it again for the next casualty, must also be taken into consideration.
P2 CCC; 9 ÷ 0.5 = 18 P2/hour
One team will be taking care of 2 beds so just 4 to 5 teams are needed.

Table 3 gives an example of how these CCC numbers can be displayed in a PDP. The capacity should never be intended to be used to the maximum and a reserve of about 25% must be calculated in. Table 4 gives an overview of CCC's of Level I-III hospitals.

Table 1. Emergency Department Capacity, EDC

First hour	P1 beds	P1 teams	P2 beds	P2 teams
During office hours	4	4	10	10
After office hours	2	2	4	4
After up-scaling	5	>8	9	>5

Table 2. Total Critical Care Capacity (Phase 1 and 2, total 6 hours, in a Level I hospital)

During office hours	After office hours
P1 CCC_{total}; 4 + 33 = 37 P2 CCC_{total}; 10 + 90 = 100 137 P1/P2 casualties	P1 CCC_{total}; 2 + 33 = 35 P2 CCC_{total}; 6 + 90 = 96 131 P1/P2 casualties
P1 CCC_5; [5 ÷ 0.75] x 5 hours= 33 T1 P2 CCC_5; [9 ÷ 0.5] x 5 hours= 90 T2	

Discussion

To verify our numbers of CCC we compared them to the limited available literature. The ratio of P1 : P2 is 1:3 in the MCI literature. (27) In the example above, the Level I hospital, we calculated the numbers for, has an estimated total bed capacity of 650 (in daily practice); our total CCC is 21% of this total bed capacity and if the 75% maximum is kept, 16%. Literature reports suggest that the CCC should be between 10-20%. (20; 28; 29)
According to the de Boer et al. the CCC per hour should be 0,5-1 casualties per 100 beds before up-scaling, and 2-3 casualties per 100 beds after up-scaling. (30) In our example of a 650 bed hospital, this would add up to 3.25-6.5 casualties in the first hour and 13-19.5 casualties per hour for the next 5 hours. This adds up to

68.25 to 104 casualties in total in 6 hours. De Boer et all consider a total mean MCI time of 8 hours, giving a maximum CCC of a Level I hospital of 94.25 to 143 P1 and P2 casualties in total. Our calculations lie within this range.

Table 3. CCC table like in PDP (for a Level I hospital)

Phase 1 during office hours, 1st hour		Phase 1 Outside office hours, 1st hour		Phase 2 (after up-scaling, regardless of time of day)		Maximum	
P1	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	P2
4	10	2	6	6	18	37	100

Table 4. Example of CCC of Level I, II and III hospitals

Hospital (trauma level)	Phase 1 (day)		Phase 1 (night)		Phase 2		maximum		Maximum 75%	
	P1	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	P2
A (I)	4	10	2	6	6	18	37	100	28	75
B (II)	1	3	0	2	3	10	16	53	12	40
C (III)	0	3	0	2	0	6	0	33		25

Estimation of the number of casualties at the scene of the accident is vital for execution of medical management of an MCI. The number of ambulances, Helicopter Emergency Medical Services and hospitals that need to be (immediately) alerted is dependent on it. Regular updates of the estimation of the number of casualties should therefore be given throughout the entire time of MCI management. The rationale behind a maximum duration of phase 1 and 2 (together) of 6 hours, has already been explained earlier. Taking into account the maximum capacity of a Level I hospital for P1 and P2 casualties calculated above, we believe that exceeding this number is not realistic for the provision of a high level of care. We also think that extending the time frame of phases 1 and 2 beyond 6 hours would put an even higher strain on the daily care, which will be postponed even further. In these cases it will not be possible to provide the high level of care we expect to be able to meet during MCI's, and the incident might become a disaster instead.

If all hospitals calculate their CCC based on the formula proposed here, an accurate view of the capacity needed for the medical management of an MCI can be provided. This should, of course, be checked in an MCI drill. All regional and national PDP's should be based on this same principle, providing clear terminology. An accurate view of CCC limits the chance of inadequate utilisation of care capacity as happened after the 2009 airplane crash.

Specific protocols should be prepared for the management of fire disasters. The trauma teams in the hospital should have a ventilation specialist and the availability of ventilation equipment should be the key point in the preparation of a large number of burn victims.

The new CCC numbers should be checked regularly and updated, and the protocol should be studied and drilled frequently by all professionals involved.

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Checklist

Regional or national government in charge of the preparation and protocol for MCI's and disasters need to ask hospitals for the following numbers:

Phase 1: (1st hour) **during office hours** (08:00-17:00)
1.a How many P1 casualties can be stabilized in this hour?
b How many P2 casualties can be stabilized in this hour?

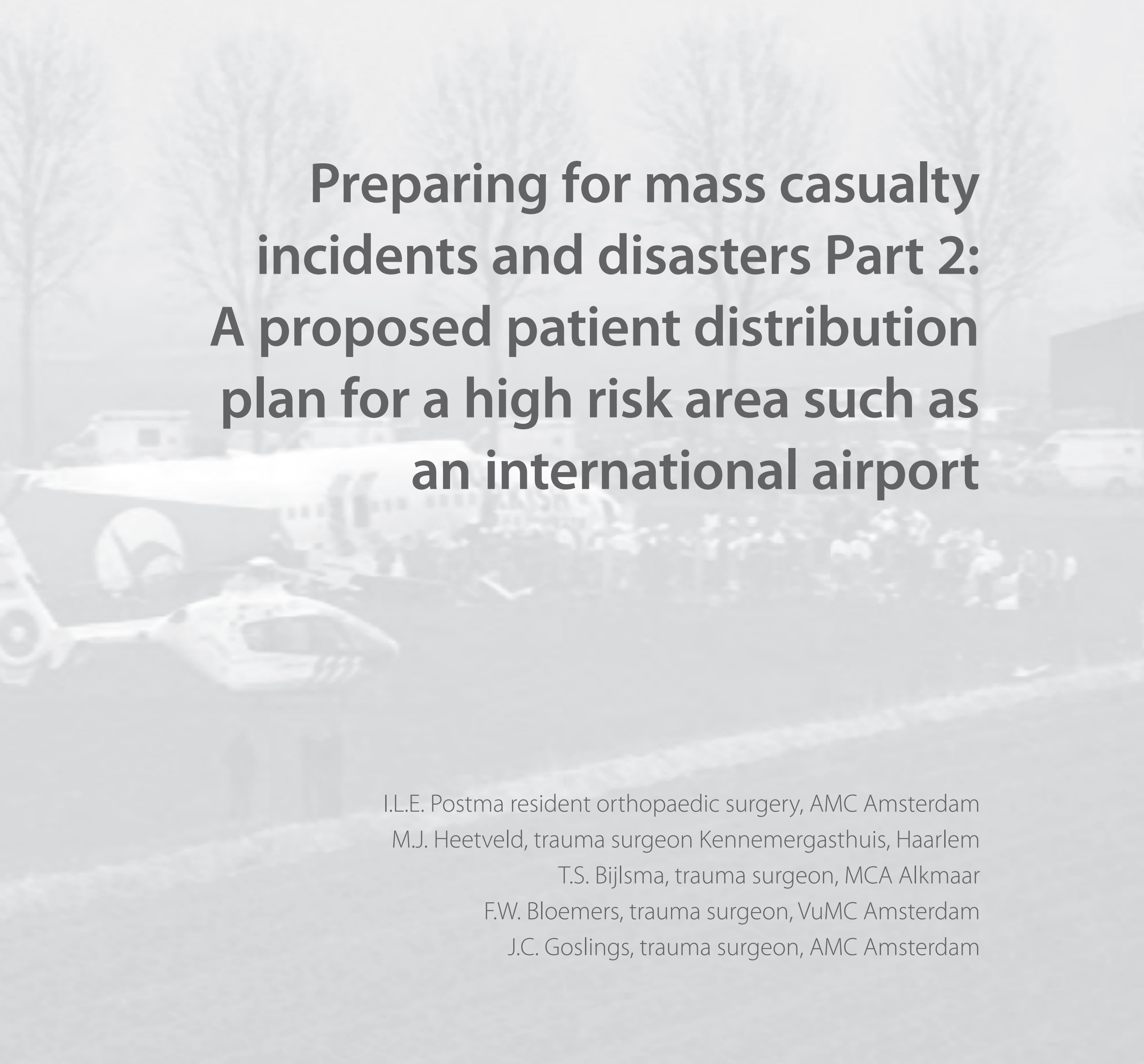
Phase 1: (1st hour) **after office hours** (evening/night weekend)
2.a How many P1 casualties can be stabilized in this hour?
b How many P2 casualties can be stabilized in this hour?

Phase 2. (up-scaled situation 2nd, 3rd hour, etc.)
3.a How many P1 casualties can be stabilized in these hours per hour?
b How many P2 casualties can be stabilized in these hours per hour?

Phase 1 + 2
4.a What is the maximum number of P1 casualties that can be stabilized and receive primary treatment in this hospital?
b What is the maximum number of P2 casualties that can be stabilized and receive primary treatment in this hospital?

Phase 3 (all P1 and P2 casualties are stabilized at the hospitals).
5. How many P3 casualties can you receive and treat?

Phase 4 definitive care (This phase goes beyond the MCI and disaster protocol for local/national government)
6.a What is the ventilation bed capacity?
b What is the high care (no ventilation) bed capacity?
c How many minor to moderate trauma casualties can be admitted?



Chapter 6

Preparing for mass casualty incidents and disasters Part 2: A proposed patient distribution plan for a high risk area such as an international airport

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Introduction

In Mass Casualty Incidents (MCI) and disasters medical personnel and officers work under stressful conditions. It is important that identical protocols are familiar throughout the process. Execution of a patient distribution protocol is mostly performed by local or regional government, or the Emergency Medical Services Centre (ECS). In case of an MCI, and especially if the location of the incident is at a regional border, several regions need to cooperate. Different regions may incorporate the same hospitals in their patient distribution protocol. In our view, the coordination in an MCI should preferably be performed by the region in which the incident takes place. The hospitals most suitable for receiving casualties should be in the MCI proximity even if they are located in another region. In large MCIs or disasters the co-ordination can be up-scaled to a larger regional or even national level.

Although the exact location where an MCI will take place cannot be predicted, there are locations that can be considered a high risk. Examples are chemical industry sites or a busy railway station. These kind of locations should be acknowledged and have a specified MCI protocol. The basis of all MCI protocols should be identical.

In this section a concept PDP with Amsterdam Airport Schiphol as an example of a high risk area is presented. Experience with and analysis of the management

Figure 1. Geographical orientation of the crashsite and hospitals.

after an airplane crash near Schiphol in 2009 led to the design of this protocol. The geographical orientation of the hospitals used in this MCI is presented in Figure 1. In Chapter 4 the patient distribution after the February 2009 airplane crash near Amsterdam is discussed with the actual distribution of casualties displayed in Table 2 of chapter 4. The model proposed in the next part may be adjusted to accommodate specific details for other locations.

Table 1. The hospitals surrounding Schiphol International Airport

	1st circle Schiphol (>15 km +/-)	2nd circle Schiphol (>25 km+/-)	3rd circle Schiphol (>40 km+/-)
		1st circle +	1st and 2nd circle +
Level I	VU University Medical Centre (VUMC)	Academic Medical Centre (AMC	Leiden University Medical Centre (LUMC)
Level II	Kennemer Gasthuis (KG)		
	Sint Lucas Andreas hospital (SLAZ)	Onze Lieve Vrouwe Gasthuis (OLVG)	Medical Centre Alkmaar (MCA)
	Spaarne hospital (SpZ)	Red Cross hospital (RKZ)	Medical Centre Alkmaar (MCA)
Level III	Slotervaart hospital (SlvZ)	BovenIJ hospital (BovIJ)	Diaconessenhuis Leiden (DiacL)
	Amstelland hospital (AZA, NO ER at night)	Zaans Medical Centre (ZMC)	Rijnland hospital (RLZ)
			Waterland Hospital (WZP)

Basic Features of the design

This protocol is based on some principles that have been derived from research literature and experience from former MCI's. (1-8) Spreading of casualties among different hospitals should be performed from the start. We advise that hospitals should not be utilised to their maximum capacity, before the next hospital is addressed. A reserve of 25% should be calculated in. Critically injured casualties (P1) should only be transported to Level I and Level II hospitals. (7; 8) A more detailed explanation of these principles is given in the previous chapter "Preparing for Mass Casualty incidents and disasters Part 1: How to determine Hospitals' Critical Treatment Capacity". (9) A summary of the principles is given in Box 1.

Box 1. Principles

- *All P1 and P2 casualties should be transported to hospital within 2 hours.*
- *No hospital should receive a casualty surge longer than 6 hours.*
- *The estimated proportion of P1 and P2 casualties is 1: 3.*
- *With an airport as incident location there is no hospital where casualties go to on their own.*
- *No hospital should be filled to its maximum capacity, a reserve of the CCC of about 25 % must be calculated for.*

Table 2. Example of CCC of Level I, 2 and 3 hospitals

Hospital (trauma level)	Phase 1 (day)		Phase 1 (night)		Phase 2		maximum		Maximum 75%	
	P1	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	**P2**	**P1**	P2
A (I)	4	10	2	6	6	18	34	100	26	75
B (II)	1	3	0	2	3	10	16	53	12	40
C (III)	0	3	0	2	0	6	0	33		25

The basic step in the design is a map with the locations of all hospitals around the high risk area. Each hospital has a designated trauma care level (Trauma centre, Level I, Level II, Level III), a specialty (neuro-trauma, burns) and a Critical Care Capacity (CCC). How to calculate the CCC is discussed in the previous chapter. On this map the location of the incident is identified and a circle is drawn around it with a radius depending on the estimated number of casualties, and thus required number of hospitals. The higher the number of casualties, the higher the number of hospitals needed and the larger the area for patient distribution.

It can be useful to pre-design a certain number of circles; for instance a first circle with a 15km radius, a 2nd with 25km radius and a 3rd with a 40km radius from the MCI location. In case of a small scale MCI (< 20 P1/P2 casualties) only hospitals within the 1st circle are used. In case of a moderate-scale MCI (20-40 P1/P2) the hospitals within the 2nd circle (that of course includes the 1st circle) are used, etc.

For high risk areas these circles can be defined in advance. In case the MCI happens in another location, it would be ideal if a computer model can work out a specific and accurate patient distribution scheme, or otherwise the circles can be drawn by hand on a map. The CCC of the hospitals within the circles must be added to see if the total capacity is enough to manage this MCI.

The Amsterdam Airport Schiphol example

Two-thirds (68%) of all airplane accidents happen during take-off or landing. (10) The area of concern is 1 km in front of, 1 km behind and 500 meters to the sides of the runways. (11) Taking this into account the high risk area of Amsterdam Airport Schiphol has a radius of +/- 10km. (12) This is within the gates of the airport grounds. Table 2 shows the hospitals in the direct surroundings of the airport.
The Critical Care Capacity (CCC) of each hospital is determined and noted in the protocol. The CCC is calculated for different time frames; during office hours and after office hours in the first hour, then CCC per hour after up-scaling and a maximum CCC. (9) This only concerns the severely and critically injured (P1 and P2) casualties. The maximum amount of time for evacuation of P1 and P2 casualties should be 1-6 hours. (13; 14; 15; 16) We recommend that all P1 and P2 casualties in need of medical care should be at the appropriate medical facility within 6 hours. After six hours, fatigue might set in amongst the medical personnel and supplies could run short. (16) Accepting more casualties than calculated as the maximum CCC and/or for a longer duration of time might result in a failure to meet the standards of care. When exceeding the maximum capacity an MCI might develop into a disaster. If this seems to become the case, the circle of hospitals must be expanded, to create more capacity. After P1 and P2 casualties have been transported to and assessed at the hospitals, more time is available to treat P3 casualties or perform secondary transfer of P1 and P2 casualties if necessary.

Box 2. Maximum number of casualties per hospital per hour

Level I	VUMC/ AMC/ LUMC	8-24 casualties/hour (max 6 P1/ hour)
Level II	KG/ RKZ/ OLVG/ SLAZ/ MCA	2-13 casualties/hour (max 3 P1/ hour)
Level III*	SpZ/ SlvZ/ BovIJ/ ZMC	2-6 casualties/hour (no P1)

* P1 only for stabilisation if absolutely needed.

Box 3. Circles around Amsterdam Airport Schiphol and the hospitals within

1st **circle** (>15 km):	VUMC, KG, SLAZ, SpZ, SlvZ, (AZA)
2nd **circle** (>25 km):	1st circle + AMC, OLVG, RKZ, BovIJ, ZMC.
3rd **circle** (>40 km):	1st+ 2nd circle + LUMC, MCA, DiacL, RLZ, WZP

Concept of patient distribution for Amsterdam Airport Schiphol

This concept is based on estimated CCC numbers calculated in the previous chapter. (9) The numbers are based on calculations made for an actual Level I Trauma Centre (AMC), but have not yet been tested in an MCI training or real events. Also, professionals and medical staff need to be able to improvise since every disaster is a unique event with different aspects. Table 3 is an example of a patient distribution plan. Patients are distributed between hospitals from the start. Meaning that hospitals that are not up-scaled do receive patients, although not more than acceptable in daily practise (no more than 2 P1 in a level I hospital).

Table 3. Patient distribution plan for an MCI at Amsterdam Airport Schiphol

Small incident: < 20 casualties (<5 P1, <15 P2; max surge of 2 hours*)				
Up-Scale	**Level I**	VuMC	max. P1: 8-10	max. P2: 24-28
	Level II			
	Level III			
Warning	**Level I**	AMC		
	Level II	KG, SLAZ		
	Level III	SZ, SlvZ, (AZA)		
Moderate Incident: 20-40 casualties (5-10 P1, 15-30 P2; max surge of 4 hours*)				
Up-Scale	**Level I**	VUMC, AMC	max. P1: 40-44	max. P2: 120-128
	Level II			
	Level III			
Warning	**Level I**			
	Level II	KG, SLAZ, OLVG		
	Level III	SZ, SlvZ (AZA)		
Large Incident: 40-100 casualties (10-25 P1, 30-75 P2; max surge of 6 hours)				
Up-Scale	**Level I**	VUMC, AMC	max. P1: 56**	max. P2: 150**
	Level II	KG, SLAZ	max. P1: 24	max. P2: 80
	Level III	SZ, SlvZ		max. P2: 50
Warning	**Level I**	LUMC		
	Level II	RKZ, OLVG, MCA		
	Level III	BovIJ, ZMC, WZP, (AZA)		
Major Incident: > 100 casualties (>25 P1, >75 P2)				
Up-Scale	**Level I**	VUMC, AMC, LUMC	max. P1 84**	max. P2: 225**
	Level II	KG, SLAZ, OLVG, RKZ, MCA	max. P1: 60	max. P2: 200
	Level III	SZ, SlvZ, BovIJ, ZMC		Max P2: 100
Warning	**Level I**	UMCU		
	Level II	WFGH, HAGA, TGZ, AZN		
	Level III	WZP, RLZ, (AZA)		

* In small incidents it must be possible to transport all P1 and P2 casualties to hospital within 2 hours. In moderate incidents this should be done within 4 hours.

** Max P1 and P2 are the total of the hospitals combined, with a 75% maximum when the surge is 6 hours. (large and major incidents)

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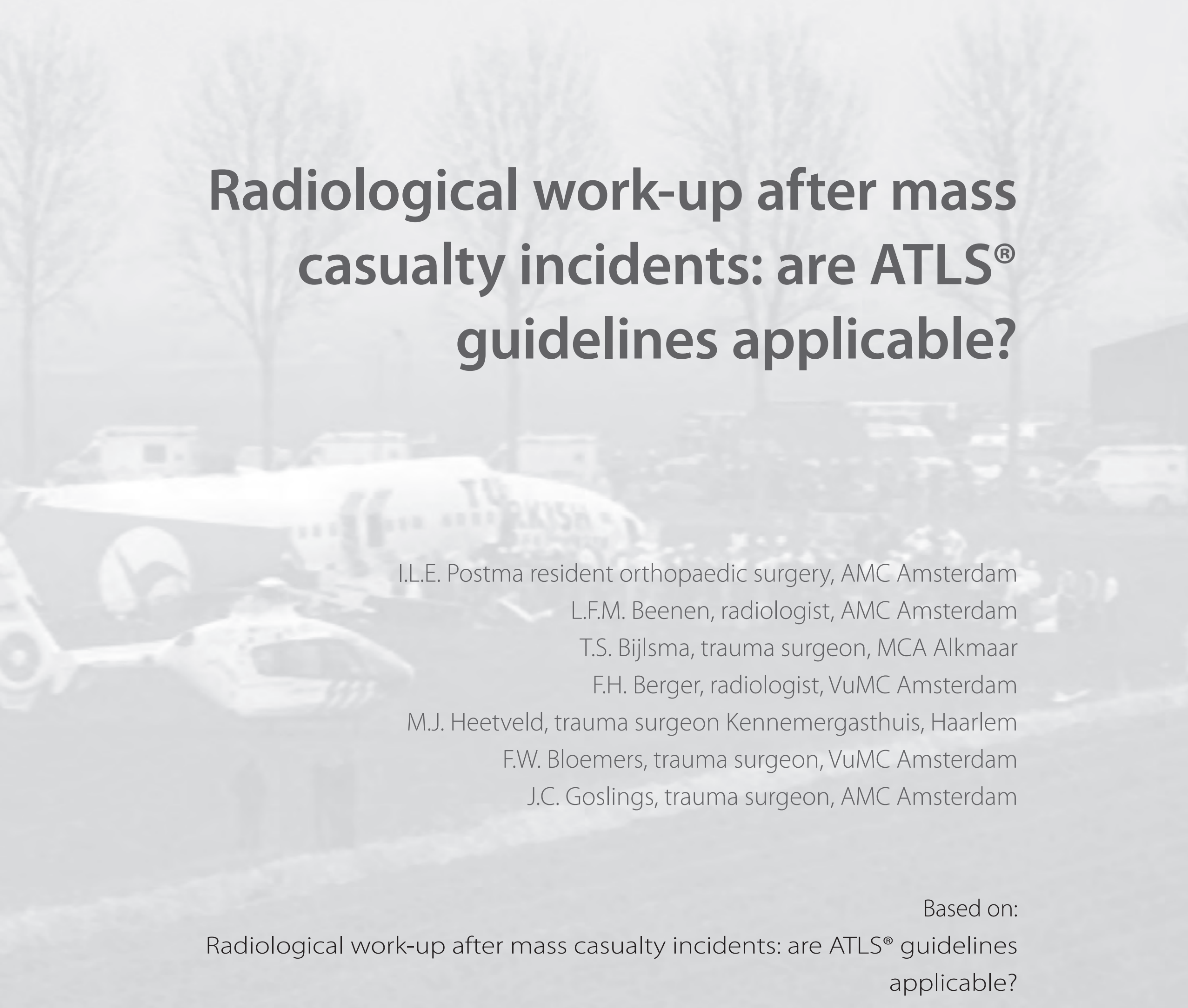
Part 3

In-hospital Phase

Chapter 7



Radiological work-up after mass casualty incidents: are ATLS® guidelines applicable?

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Abstract

Objectives

In Mass Casualty Incidents (MCI) a large number of patients need to be evaluated and treated quickly. Well-designed radiological guidelines can save lives. The purpose of this study is to evaluate Advanced Trauma Life Support (ATLS®) radiological guidelines in the MCI of an airplane crash.

Methods

Medical data of all 126 survivors of an airplane crash were analysed. Data included type and body region of the radiological studies performed on the survivors, AIS and ISS codes and trauma care level of the hospitals.

Results

Ninety patients (72%) underwent one or more imaging studies: in total 297 radiographs, 148 CTs, and 18 ultrasounds were performed. Only 18% received diagnostic imaging of all four body regions as recommended by ATLS®. Compliance with ATLS® was highest (73.3%) in severely injured victims (ISS ≥16); this group underwent two thirds of the (near) total body CTs, all performed in Level I trauma centres.

Conclusion

Overall compliance with ATLS® radiological guidelines was low, although high in severely injured patients. Level I trauma centres, frequently used (near) total body CT. Deviation from ATLS® in radiological work-up in less severely injured patients can be safe and did not result in delayed diagnosis of serious injury.

Introduction

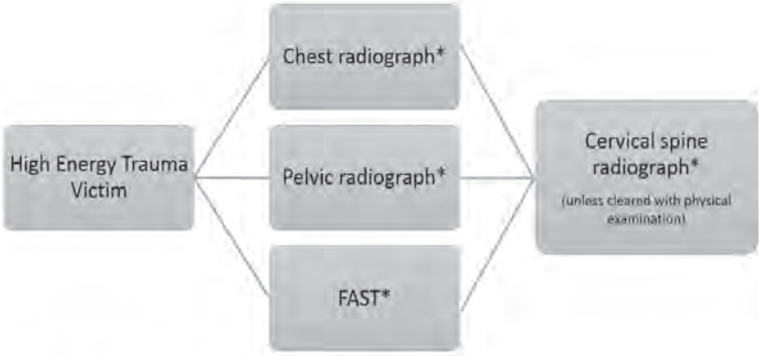
In disasters and Mass Casualty Incidents (MCI) a large number of trauma patients need to be screened for traumatic injuries, and treated within a relatively short time span, in difficult circumstances. Guidelines and protocols have been developed to enhance decision making and stabilisation of patients without wasting time on less critical injuries (1). The radiological work-up in trauma patients is an essential part of the diagnostic process but can be time-consuming. Well-designed radiological imaging guidelines can avoid unnecessary delay and save lives, especially in mass casualty incidents (2-4).

The initial care in trauma patients is based on Advanced Trauma Life Support (ATLS®), a system developed by the American College of Surgeons (1). ATLS® is based on the principle of "treat first what kills first", following an ABCDE list of priorities. This ABCDE list also indicates necessary diagnostic imaging work-up. The ABCDE principle is designed to be applicable to all settings, e.g. no differentiation is made for highly or less developed trauma care systems or a high or low number of patients. No widely accepted protocol for radiological work-up in MCIs exists. The Major Incident Medical Management and Support (MIMMS) provides triage protocols and decision schemes on transport priority, in order to make sure that in MCIs the most severely injured get access to in-hospital diagnostics and treatment as soon as possible (5). But the MIMMS does not hold protocols on radiological work-up in MCIs. Therefore ATLS® may be more appropriate. In the ABCDE of ATLS®, diagnostic priorities are injuries that cause airway, breathing, circulation and neurological disturbances respectively. If a trauma mechanism or clinical evaluation in the primary survey raises suspicion of injury to the chest, abdomen or pelvis, imaging studies are mandated (1; 6). Stabilisation of the cervical spine (C-spine) is mandated until imaging is deemed unnecessary (clinical evaluation) or until imaging is performed and the the C-spine is cleared. With a stabilised C-spine, the imaging of the C-spine can be postponed until, for example, the secondary survey (1).

Radiographs of chest, C-spine and pelvis and a focused assessment with sonography for trauma (FAST) have long been the standard initial screening imaging studies of choice. Nowadays, these imaging studies are frequently replaced or supplemented by computed tomography (CT) in hemodynamically stable (and sometimes even hemodynamically unstable) patients. (Total body) CT is increasingly being used during trauma resuscitation, especially with fast multi-detector CT systems in the emergency department or even in the trauma resuscitation room (7-9). In this way, faster and more accurate diagnosis of injuries can be achieved and morbidity and mortality reduced (10).

Diagnostic pathways and treatment in the case of disasters and MCIs are highly dependent on the capacity of the emergency department and the department of radiology. Hospitals in the Netherlands are designated a trauma care "Level", related to available capacity and resources to provide trauma care, ranging from I to III; Level I hospitals provide the full range of resuscitative and definitive trauma care (11).

Figure 1. Imaging algorithm derived from ATLS principles



* Plain radiograph and utrasound can be replaced with CT

In February 2009, a commercial airplane crashed near Amsterdam, the Netherlands. Nine people did not survive the impact; all 126 survivors were evaluated for injury in several hospitals (12).

ATLS® suggests that the mechanism of injury is essential in determining the index of suspicion of certain types of injury and type of diagnostic imaging required (1; 13). A high energy trauma, such as an airplane crash with large deceleration forces in both horizontal and vertical directions can cause a wide range of injuries, with a high probability of spine, chest, abdominal and pelvic injury. Therefore, according to ATLS® principles, in theory, imaging of the cervical spine, chest, abdomen and pelvis is appropriate in all patients of an airplane crash (1; 14). The algorithm of imaging, as it is widely used in ATLS® care of high energy trauma victims in the Netherlands, is illustrated in Figure 1.

To our knowledge, the appropriateness of ATLS® radiological imaging algorithm has not previously been investigated for an MCI.

In this study the application of ATLS® radiological imaging guidelines in an airplane crash mass casualty incident was evaluated.

The primary questions were:

1. Which types of radiological studies and how many were performed during trauma resuscitation?
2. Was the radiological work-up compliant with ATLS® guidelines?

The secondary aim was to answer the following questions:

3. Was radiological work-up different between centres with different designated trauma care levels?
4. Was there a difference in radiological work-up according to patient injury severity?
5. What were the injuries diagnosed in the radiological imaging of ATLS® body regions of C-spine, chest, abdomen and pelvis?
6. What was the role of CT?

Table 1. Type of imaging per body region

Body region	X	CT	US	No of patients (%)
Head	-	26	-	24 (19.2)
Chest	85	16	-	76 (60.8)
Abdomen	-	14	18	29 (23.2)
Cervical spine	32	30	-	45 (36)
Thoracic Spine	30	21	-	40 (32)
Lumbar Spine	36	22	-	46 (36.8)
Pelvis	34	12	-	37 (29.6)
Extremities	62	6	-	31 (24.8)
Other	18	-	-	13 (10.4)
Total	297	147	18	90 (72)

All (near) total body CTs are counted per body region

US: ultrasound (focused abdominal sonography in trauma/ FAST)

Materials and methods

Medical data of all 126 survivors of the TK 1951 airplane crash were collected and retrospectively analysed. Specific data collected included: baseline characteristics such as gender, age, 1998 Abbreviated Injury Scale (AIS) codes, Injury Severity Score (ISS) (15; 16). The technique and body region of the radiological studies performed on the day of the crash (February 25th 2009), we collected per patient. Compliance with ATLS® was defined as the performance of radiological imaging of all four body regions as suggested by ATLS® guidelines (C-spine, chest, abdomen and pelvis), irrespective of the type of imaging (plain radiography, ultrasound, or CT). To assess compliance of radiological work-up with ATLS® protocol as defined above, we identified casualties in which all four body regions were imaged during radiological work-up and the full compliance group was defined as the percentage of the total group, including casualties in which no imaging was performed.

To research the questions about the differences between hospitals and injury severity of the patient and compliance with the ATLS®, the patients and their radiological work-up were analysed in groups. The first three groups to be compared were patients who were initially treated in Level I, Level II and Level III hospitals respectively, according to the designated trauma care level of the hospitals. The next three groups to be compared were patients classified as minor (ISS 1–8), moderate (ISS 9–16) and severely (ISS≥16) injured.

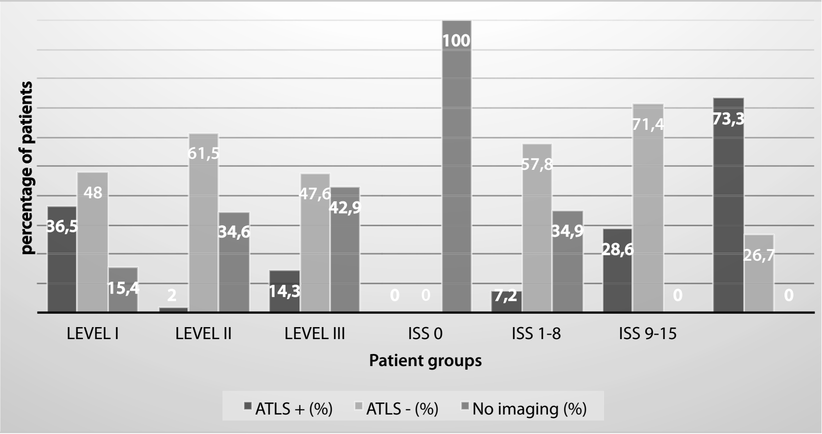
We analysed which injuries were diagnosed in the four ATLS® body regions, by collecting all AIS codes of the injuries of each patient that corresponded with one of the ATLS® body regions. To research the consequences of not imaging the four ATLS® body regions, we looked at the injuries that were missed or diagnosed late in this MCI. The delayed diagnosis of injury in this MCI has been previously reported by this study group (17).

To determine the role of CT in this study group, CTs were first analysed to determine which body regions were completely imaged. The following body regions were defined: head, chest, abdomen, pelvis, C-spine, thoracic spine, lumbar spine and extremities. All different body regions were counted as a separate CT. Also the number of (near) total body CTs was registered. A total body CT included CT imaging of the head and all four ATLS® regions (C-spine, chest, abdomen and pelvis) with multi-planar reformations of the thoracic and lumbar spine. (9) A near total body CT included CT imaging of all except one body region. The collected data about CTs were analysed in groups. The groups to be compared were the same as those used in previous research questions based on the designated trauma level of the hospital (Levels I, II, and III) and ISS classification (minor, moderate and severe). Approval for this study was obtained from the ethics board of the Amsterdam Academic Medical Centre (AMC).

Results

Of the 126 survivors of the airplane crash, 124 were allocated to 14 hospitals for evaluation (4 Level I, 6 Level II and 4 Level III hospitals, responsible for the evaluation of 52, 51 and 21 casualties, respectively), one reported to hospital himself, later that day (Level II) and one the next day (Level III) (12). On the basis of triage in the field (pre-hospital triage) patients were given priority for transport. The most severely injured patients were transported to Level I hospitals, but exact data on pre-hospital triage was scarce (18; 19).

Figure 2. Compliance with the Advanced Trauma Life Support (ATLS) in different patient groups



As we only assessed data from the day of the crash, the survivor who presented himself to a hospital 1 day after the crash was excluded from this study. The remaining study population of 125 comprised 83 men and 42 women, with an average age of 38 (range 11 months to 76 years). The mean ISS was 6.7 with a range from 0 to 66 and median of 4. Six survivors (5%) had no physical injuries. Because of the need for specialised care for spinal injury, secondary transfer to a Level I trauma centre was needed for 2 survivors. They were initially presented at a Level II hospital and a Level III hospital (12; 18).

On the day of the crash 90 of the 125 patients (72%) underwent one or more radiological study: a total of 297 radiographs, 147 CTs of specific body regions and 18 FAST ultrasounds were performed. In 87 patients (70%), at least one radiograph and in 41 (33%), at least one CT was performed. In Table 1 imaging types and imaged body regions are presented. The compliance with the ATLS® guidelines is presented in Figure. 2.

In Table 2 the number of radiological studies performed per group of hospitals with the same designated trauma level and ISS group is presented.

With the imaging of the ATLS® body regions 47 injuries were diagnosed in 28 patients, 20 of these had an AIS ≥ 3. Injury types are presented in Table 3.

Nine patients (7.2%) underwent a total body CT; their mean ISS was 27 (range 9–66). Three patients (2.4%) received a near total body CT in which either the head or pelvis was not (completely) imaged; their mean ISS was 15 (range 9–24). Patients receiving either total or near total body CTs comprised 9.6% of all 125 patients and 13.3% of those underwent diagnostic imaging. Eight of the 15 severely injured patients (53.3%; ISS ≥16) received a (near) total body CT; all were initially admitted to a Level I trauma centre. The remaining 7 patients with an ISS ≥16 underwent at least one CT of the region of their most severe injury (highest AIS). One patient with an ISS ≥16 was at first not admitted to a Level I hospital.

Table 2. Total number of radiological studies performed per trauma level and Injury Severity Score (ISS) group

	X	CT	US (FAST)	Total body CT	Near Total body CT
Level 1 (mean\patient)	146 (2.8)	123 (2.4)	11 (0.2)	9	3
Level 2 (mean\patient)	105 (2.0)	19 (0.4)	2 (0.0)	0	0
Level 3 (mean\patient)	46 (2.2)	5 (0.2)	5 (0.2)	0	0
Total (125)	297 (2.4)	147 (1.2)	18		
ISS 0 (6)					
ISS 1-8 (83)	160	34	11	0	0
ISS 9-15 (21)	70	37	2	2	2
ISS ≥16 (15)	67	76	5	7	1
Total	297	147	18	9	3

Discussion

In this study of 125 airplane crash survivors, 72% underwent some form of diagnostic imaging. An average of 3.6 imaging studies (2.4 radiographs and 1.2 CTs) were performed per patient. According to the available literature on Level I trauma centres, fewer radiographs and a comparable number of CTs were performed in our study. In our study in the Level I trauma centres, the mean ISS in this MCI was 11 (median 9, range 1–66), the mean number of radiographs per patient 2.8 and CTs 2.4. In 2 studies (in regular trauma care) performed at a Level I trauma centre (mean ISS 8.6 and median 14), the mean number of plain radiographs was 6.2–9.5 and CTs 1.8–3 (20; 21). Most literature on radiological imaging in MCIs concerns (terrorist) bombings and reports a wide range of use of radiographs (45–81%) and CTs (7–90%) (22-25).

Table 3. Injuries in ATLS body regions. (28 patients)

Region	Type of Injury	No of patients
Chest	Rib fractures (AIS 1 or 2)	6
	Rib fractures (AIS 3 or 4)	2
	Sternum fracture (AIS 2)	5
	Flail chest (AIS 5)	1
	Pulmonary contusion unilateral (AIS 3)	4
	Pulmonary contusion bilateral (AIS 4)	4
	Myocardium contusion (AIS 3)	2
	Trachea laceration (AIS 4)	1
Cervical Spine	Odontoid fracture (AIS 3)	1
	Cervical spine fracture (AIS 2)	3
Abdomen	Kidney contusion (AIS 2)	12
	Spleen laceration (AIS 4)	1
	Liver laceration (AIS 3)	1
Pelvis	Pelvic fracture (AIS 2)	1
	Pelvic/ Sacrum fracture (AIS 3)	2
	Pelvic fracture (AIS 4)	1
Total		47

Only 18% of all victims received diagnostic imaging studies of all four body regions as recommended by ATLS®. Compliance with ATLS® guidelines was higher in Level I trauma centres than in Level II or III hospitals (36.5% vs. 2% and 14.3% respectively) but can still be considered low. Compliance was highest in the severely injured patients (ISS ≥16; 73.3%), who received two thirds of the (near) total body CTs, all performed in a Level I trauma centre.

Most of the severely injured patients did receive imaging in compliance with ATLS® guidelines. In the present study, selective compliance with ATLS® guidelines regarding imaging seemed safe, provided that clinical evaluation and trauma mechanism played a vital role in the decision making. Over the years ATLS® guidelines have evolved towards a greater emphasis on the role of clinical evaluation.

The most frequently imaged body region in our study was the chest, which is to be expected according to ATLS® ABC priorities. The next most frequently imaged body region was the lumbar spine and third was the cervical spine. In airplane crashes in particular, a large number of spinal injuries are observed, as in our study population, i.e. 35 injuries in 23 survivors (12; 17; 26). On the basis of a high level of suspicion of spinal injury, given the mechanism of trauma in this MCI, a relatively large number of spinal imaging studies can be expected. Several authors have stated that all victims of a dangerous trauma mechanism should receive at least some C-spine imaging, as is the case in the Canadian C-spine rules (13; 14). The cervical spine is part of the primary survey in the ATLS®, and has some priority in radiological work-up. A third of our crash victims received C-spine imaging with 4 patients positive for C-spine injury (3.2% of total, 10% of the ones with C-spine imaging). This could mean that clinical evaluation played an important role in spinal imaging of the survivors of this MCI. No C-spine injuries were diagnosed late; one day or more after the trauma (17).

A total of 47 injuries were diagnosed in the ATLS® body regions, of which 20 were significant (AIS≥3). In victims admitted to a hospital for longer than 24 hours, 8 injuries were diagnosed with late radiographic imaging (at least 1 day after the crash) (17). Only 2 of the delayed diagnoses were in 1 of the 4 ATLS® body regions. These were both kidney contusions (AIS 2) which are considered to be of little clinical significance in the resuscitation phase.

In our study an average of 1.2 body regions per victim underwent CT. Because all the different body regions were counted as separate CTs, this might have led to a higher number of CTs. For example, in a chest CT the thoracic spine can also be fully represented. Half of the CTs were of the spine and the next most frequently CT imaged body region was the head. These body regions can be considered more difficult to assess with clinical investigation and plain radiographs. All (near) total body CTs were performed in Level I hospitals. A high case load of severely injured patients and high compliance with ATLS® algorithms in Level I trauma centres might have caused the installation of CT systems near the trauma resuscitation rooms before this MCI. This might explain the increased use of (near) total body CT in these

Level I centres. Another reason is the higher index of suspicion of injury in an ATLS® body region in severely injured patients. Of note, 5 of the 7 severely injured patients (ISS ≥ 16) who did not receive a (near) total body CT, were treated in the one Level I trauma centre that has a CT system in the resuscitation room. The placement of this CT equipment in the resuscitation room is the subject of multiple studies, and may lead to more strict indication for the use of CT imaging (7-9). Otherwise, it could have been the character of the MCI, with multiple casualties arriving within a short amount of time that led to strict indications for primarily CT imaging being used only for life-threatening injuries. Nevertheless using total body CT in an MCI as a triage tool as well as a diagnostic tool, can be feasible as well (27; 28). We were unable to retrieve exact time information on the performed diagnostic imaging. Therefore we cannot comment on the effect of CT-scanning on the time till diagnosis. A study on the optimisation of trauma workflow using CT scanning shows a significantly longer work-up time in trauma patients that did receive CT compared to those that did not (7). It was not corrected, though, for ISS. A systematic review on total body CT in trauma patients found 3 studies that registered work-up time. These showed no difference in work-up time or even significantly shorter work-up times in trauma patients receiving total body CT compared to those that received conventional radiological work-up (28). The effect of total body CT on the efficiency of trauma resuscitation in high energy trauma patients is the subject of a current international prospective randomised trial in 5 Level I hospitals, including the 2 Level I hospitals that received most of the critically injured patients in our study. (9)

Conclusion

This study of the radiological work-up of trauma resuscitation of survivors of a very serious airplane crash, showed that the overall compliance with ATLS® guidelines was generally low, although it was high (73%) in severely injured patients. Body regions with the highest priority in the ATLS® guidelines were most frequently imaged. Level I trauma centres, which received the most severely injured patients, frequently used (near) total body CT. With skilled clinical triage it is safe to deviate from the ATLS® guidelines in the radiological work-up of less severely injured patients and in our study this did not result in the delayed diagnosis of serious injury. In Mass Casualty Incidents, an optimised diagnostic imaging strategy is important for maximum survival of the most severely injured.

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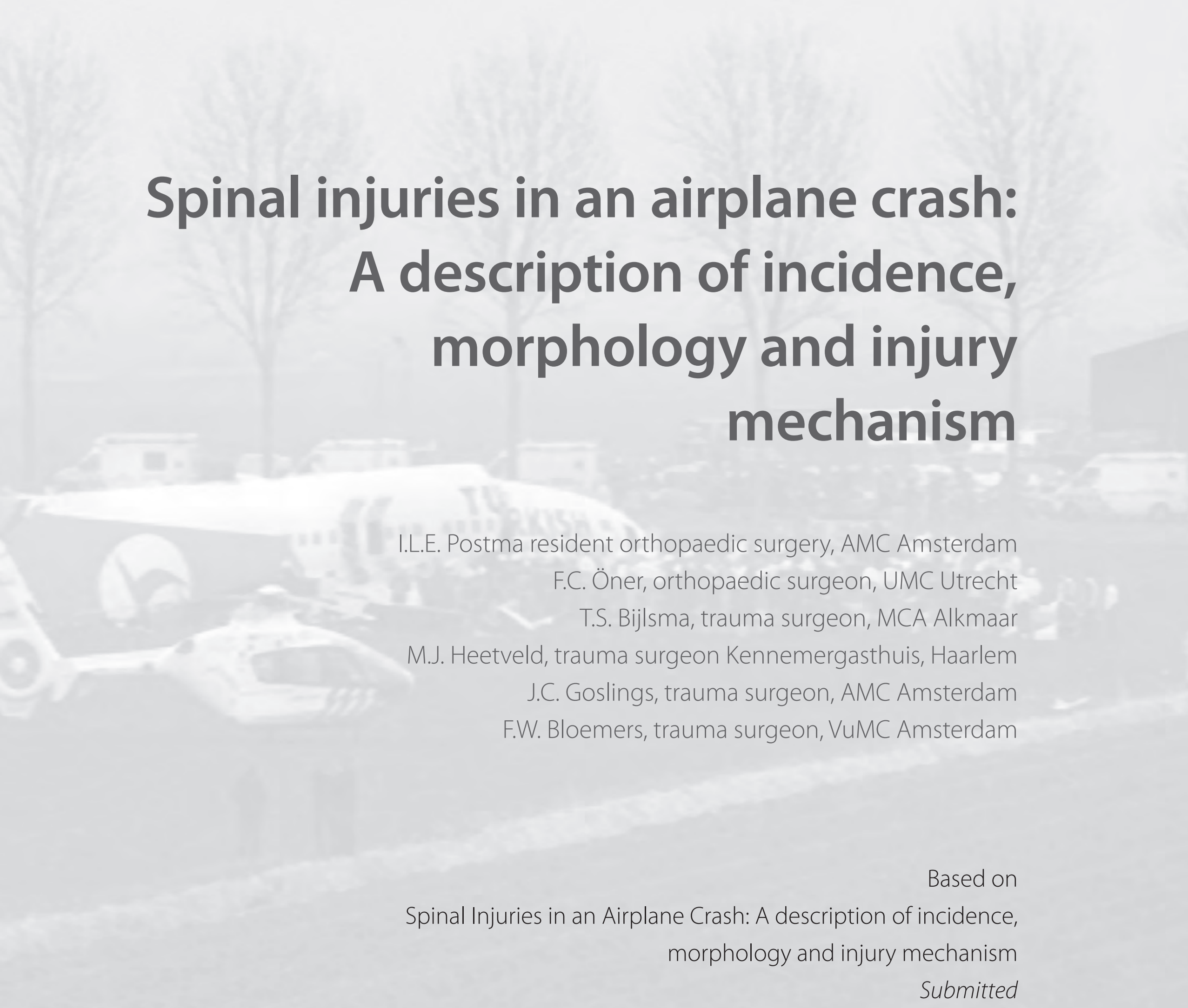

Chapter 8

Spinal injuries in an airplane crash: A description of incidence, morphology and injury mechanism

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Based on
Spinal Injuries in an Airplane Crash: A description of incidence,
morphology and injury mechanism
Submitted

Abstract

Study Design
Retrospective cohort.

Objective
Spinal injuries of the survivors of an airplane crash are described. On the basis of injury morphology and knowledge of the conditions of the accident, injury mechanisms are described and prevention measures are discussed.

Summary of Background Data
The most common causes of spinal fractures are high energy falls, and motor vehicle accidents. Detailed reports, solely on spinal injuries as a result of an airplane crash, are scarce in literature.

Methods
An analysis was performed on the spinal injuries of all 126 survivors of a commercial airplane (Boeing 737) crash near Amsterdam in 2009. Level of injury and fracture classification by morphology, independently performed by four specialists in spinal trauma was documented. An analysis was carried out on the type of injuries and the suggested mechanism of injury, by evaluating the crash characteristics.

Results
Twenty-three (18.3%) of the survivors sustained a total of 27 spinal injuries. Four (17.1% of the patients with spinal injury) suffered a single cervical spine fracture. Eight (29.6%) injuries were at the thoracic spine, 15 (55.6%) at the lumbar spine level. More than half of the injuries included a burst component.

Conclusion
A high number of spinal injuries was found after this airplane crash. The morphology of the injuries consisted of a high rate of burst type fractures, presumably caused by a mainly vertical trauma mechanism, as shown by the accident analysis.

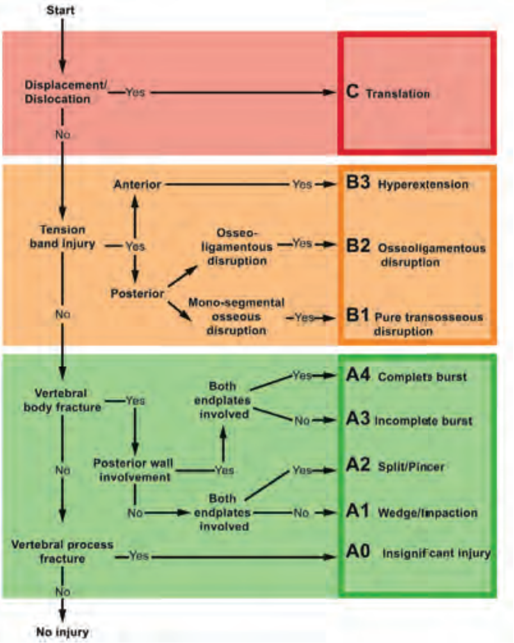
Introduction

Spinal fractures are a relatively rare in the large scale of traumatic injuries, but are an important cause of impairment and diminished function for life. According to the 6th edition of the American Medical Association (AMA) guides', impairment rates can increase from 2% of the whole person for simple thoracic fractures, to 33% of the whole person after severe lumbar fractures with neurological injury. (1) The most common causes of spinal fractures are high energy falls (defined as a fall from at least 2 meters high) with incidence rates of 21.2%- 39%, and motor vehicle accidents (MVA's) with 21.7%- 33.61% incidence rates. (2-4) The subsequent morbidity and mortality rate is therefore high. In MVA's the use of restraints has been shown to reduce the incidence of significant spinal injury (Abbreviated Injury Scale, AIS ≥2) in frontal collision. (5; 6)

Detailed reports, solely on spinal injuries as a result of an airplane crash, are scarce in literature, since most literature is about all types of injuries sustained in aircraft accidents. (7-9)

In this study, the spinal injuries of the survivors of a commercial airplane crash near Amsterdam in 2009 are described. The incidence, morphology and probable injury mechanism are studied.

Figure 1. AO classification (2013) of spinal fractures (13)



Methods

A retrospective analysis was performed on the injuries of all 126 survivors of the Boeing 737-800 airplane crash near Amsterdam on February 25, 2009. Collected data consisted of baseline characteristics such as, age, gender, injuries (by Abbreviated Injury Score – AIS, and Injury Severity Score – ISS), and seating in the airplane. All patients with spinal injuries were identified and analysed. Level of injury, fracture classification and type of treatment were documented.

High cervical injuries (C1,C2; from now on called C1-2 injuries) were classified according to the Anderson and D'Alonzo classification and the modified classification suggested by Grauer et al. (10; 11) Sub-axial cervical injuries (C3-C7) were classified by a description of injury morphology on the basis of the new AO classification scheme. (12; 13) This revised classification about thoracolumbar fractures has just been published, but is also the basis of the sub-axial spinal fractures classification that is still in development. The morphology of the spinal injuries of the thoracic and lumbar spine (TL injuries) was classified according to the new AO classification for spinal injury. (Figure 1.) The AOSpine recently issued a new classification system based on a simplified version of the older Magerl classification, combined with neurological status, and patient specific modifiers. (13; 14) All injuries were independently classified by an orthopaedic trauma resident, 2 trauma surgeons with expertise in spinal fractures, and an orthopaedic spine surgeon. Disagreements in classification were discussed until consensus was reached.

Injuries to contiguous levels of the spine were considered a single injury. When a patient suffered injuries at non-contiguous levels of the spine they were counted as separate injuries.

An analysis was carried out on the type of injuries, seating arrangements, seating and structural damage, and the suggested trauma mechanism, by evaluating the crash characteristics. The Survivability Group, consisting of a team of experts ffrom the Dutch Safety Board, the Federal Aviation Administration (FAA), and Boeing, analysed the crash characteristics to determine the causes of the accident and the structural damage to the aircraft. (15) The detailed documentation of this evaluation, containing measurements and photographs, was made available for this and other studies. It was reviewed together with the injury details by the authors and FAA experts to discuss possible mechanism of several (types of) injuries. (Postma, ILE, DeWeese R. Pelletiere J., et al; Analysis of Biomechanical Aspects of Non-Fatal Injuries in a Major Airplane Crash; Submitted).

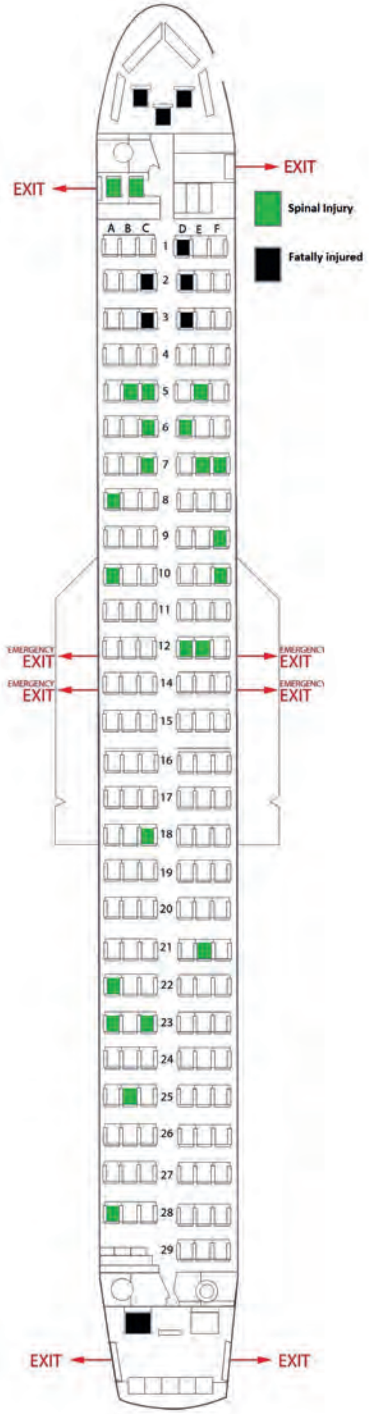
Results

There were 135 persons as passengers and crew on board of the Boeing 737-800 that crashed on February 25th 2009.

The airplane crashed during the landing phase and fractured in three parts: a tail part, a large centre section and a front section containing the cockpit. Most fatalities and serious injuries occurred in the front part. In this particular section the biggest damage to the fuselage and the interior could be observed. The data from the Flight Data Recorder (FDR), consisting of various speeds, roll angle and accelerations are of such a quality that the initial conditions of the aircraft just before first contact with the ground can fairly accurately be reconstructed. With analysis of this FDR data it is estimated that the horizontal (forward) speed of the airplane just before the collision was about 106 miles/hr (170 km/hr) and the vertical speed about 21 miles/hr (33 km/h). FDR data also showed that the first ground contact of the aircraft took place in the rear of the aircraft (tail). Considering the track of the airplane on the ground it can be assumed that the main loading impact on the bodies of the passengers was in a vertical direction. Since the crash occurred during the landing phase, all passengers were sitting in their seats wearing a 2-point lap belt. The surviving crew members were all wearing a shoulder harness during the crash.

Nine occupants did not survive the crash. They died at the scene of the accident. All survivors were taken to hospitals and 120 of them were diagnosed with traumatic injury. There were 84 men and 42 women, with a mean age of 38 (range 11 months-76 years). The mean ISS of these 120 injured survivors was 6.7 (range1-66). Twenty three (18.3%) of these patients suffered a total of 27 spinal injuries (9.1% of 297 injuries). Examples of the injuries are in Figure 3. The mean ISS of the patients with a spinal fracture was 15.8, among them11 poly-trauma patients with an ISS ≥16. The seating arrangement of the occupants in the airplane with a spinal injury is shown in Figure 2. Four patients (17.1 % of all patients with spinal injury) suffered a cervical spine fracture. Eight (29.6%) injuries were at the thoracic spine, 15 (55.6%) at the lumbar spine. Most of the thoracolumbar spinal injuries 14 (60.7%) were at the thoracolumbar junction (T10-L2), 4 at the upper thoracic and 5 at the lower lumbar spine. There were no sacrum fractures. All patients had both plain radiographs and CT imaging of their spinal injuries. Two patients had some neurological dysfunction, both of them sensory and transient. One of those (no. 17) showed a high signal in posterior ligamentous complex (PLC) on MRI but had no bony injury.

Figure 2. Seating arrangement of casualties with spinal injuries



Four patients had spinal injuries at 2 non-contiguous levels. One patient had both a cervical and a thoracic spine fracture, 1 a cervical and lumbar spine fracture, 1 a thoracic and a lumbar spine fracture and one had a fracture in 2 non-contiguous lumbar spinal vertebrae.

Table 1. Spinal injuries

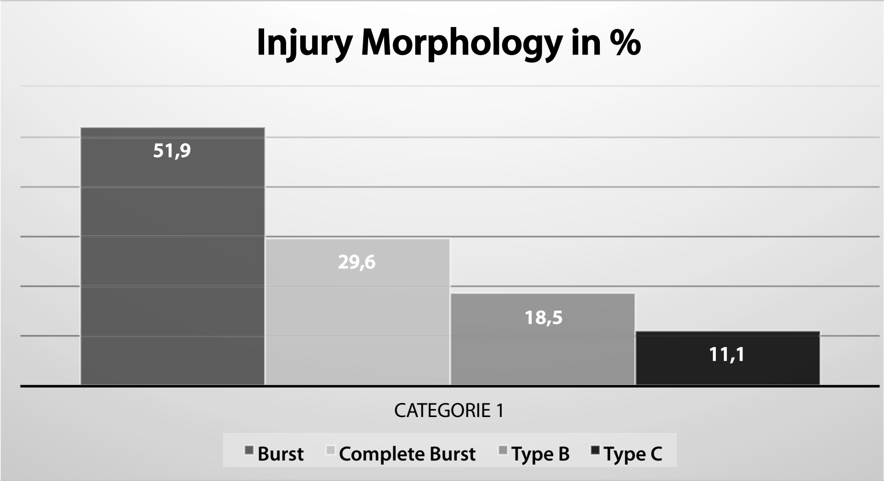
No	Gender, age	Seat	ISS	Level of injury	Burst (Y/N)	Complete burst (Y/N)	AO classification	Treatment
1	F, 36y	Crew front	41	T12-L2	Y	N	T12-L1 C;L1 A3	surgery
2	M, 42y	6D	22	L5	Y	Y	A4	brace
3	F, 29y	7C	18	C2	N	-	A/A 3; G 3	surgery
				L1	N	-	A1	brace
4	F, 52y	12D	9	T11-12	Y	N	T11-T12 B2, T12 A3,T11 A1	surgery
5	F, 27y	23A	8	C7	N	-	A1	Miami-J
				T3	N	-	A1	Brace
6	F, 47y	12E	17	T11-12	Y	N	A0-A3	surgery
7	F, 49y	8A	17	L1	N	-	A1	Brace
8	F, 38y	25B	21	C7	Y	-	A2	Miami-J
9	M, 42y	21E	10	L3	N	-	A1	Brace
10	M, 48y	10A	4	L1	Y	N	T12-L1 B2;L1 A3	-
11	M, 42y	28A	14	T12	N	-	A1	-
12	M, 27y	23C	9	T7	N	-	A1	-
13		6C	24	L1	Y	N	A3	-
				L3	N	-	A1	
14	F, 23y	Crew front	27	T6-7	Y	Y	T6-T7 B2; T7 A4	surgery
				T12-L1	Y	Y	T12-L2 C; L1 A4	
15	M, 29y	9F	14	T12	Y	Y	A4	surgery
16	M, 33y	5B	18	L5	Y	Y	A4	surgery
17	M, 26y	7E	10	T?	N	nvt	A1	-
18	M, 27y	7F	8	C4-5	Y	Y	C4-5 B2, C5 A4	surgery
19	M, 31y	22A	9	T12-L2	N	-	A1 (3x)	surgery
20	F, 31y	10F	9	T12	N	-	T11/12 C, T12 B2 (A2)	surgery
21	M, 35y	18C	4	L1	N	-	A1	-
22	M, 38y	5C	17	T12-L1	Y	Y	T12-L1 B2; L1 A4	surgery
23	M, 28y	5E	34	L4	Y	Y	A4	surgery

Nine injuries involved more than 1 contiguous levels, one patient suffered a compression type fracture (A1) to 3 contiguous vertebral bodies. The spinal injuries per patient, the ISS, seating in the airplane, fracture classification and treatment are presented in table 1.

Six (22.2%) spinal injuries were classified as a flexion distraction injury, of which 1 at the cervical and 4 thoracolumbar level. Two of these were rotational/separation injuries (C type). Beside this one, 1 other C type injury was documented. This adds up to a total of 7 (25.9%) type B and C injuries.

Fourteen of the injuries included a burst type fracture component (51.9%), meaning the vertebral endplate was fractured with involvement of the posterior wall. Eight (29.6%) of these were complete (A4) involving both superior and inferior endplates. The injury morphology is presented in Table 2.

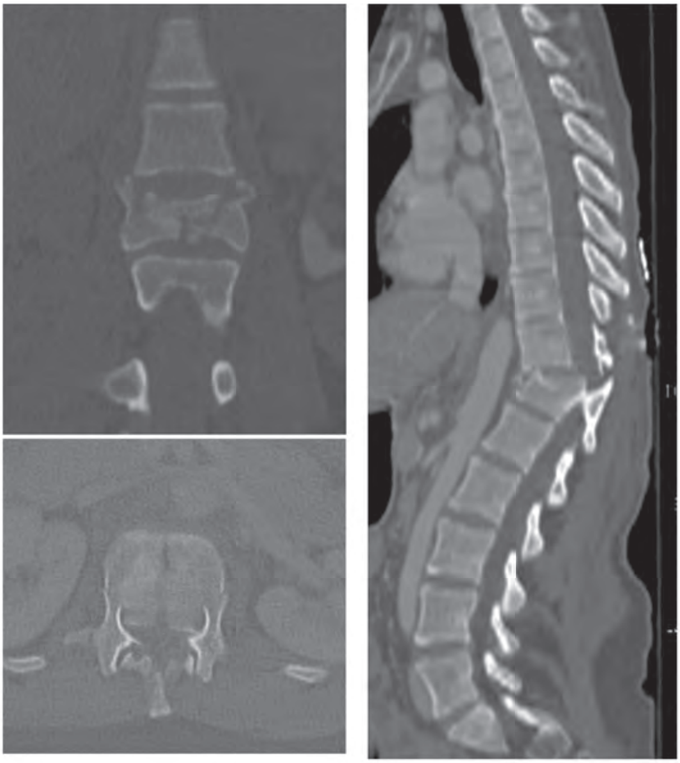
Table 2. Morphology of spinal fractures



Discussion

The incidence of spinal fractures in overall trauma population is 3.84% to 5.8%. (3; 4; 16). In this airplane accident 18.3% suffered spinal injury. High-energy trauma and especially motor vehicle accidents (MVA) are accountable for the majority of spinal injuries. (2-4; 16) The incidence of spinal injury in high energy MVA's is comparable with the results in this study, namely 11.2% to 18.6%. (17; 18) The fuselage of an airplane offers more protection than a car, but the velocity of an airplane crash is mostly higher. An even higher incidence of spinal fractures (34.9%-49.2%) is seen in accidents of airborne sports like paragliding. (19; 20) . Little is known about the incidence of spinal injuries in aircraft accidents but the few case reports describe incidences varying from 7.2% to 32.1 %. (1;8;21-24). Differences are based

Figure 3. Spinal fractures sustained in airplane crash February 2009 near Amsterdam



on whether the percentage of spinal injuries of all injuries are considered, or the patients with spinal injuries as percentage of survivors. Another discrepancy is whether only survivors or fatalities are considered, or whether the aircraft is a fixed wing or rotary wing. Our results lie within this broad range, and it can be concluded that after an aircraft accident the level of suspicion of spinal injury should be high. An earlier study of this 2009 crash showed that 22% of the patients eventually diagnosed with spinal injury were transported without proper spinal immobilisation, and 13% just on a spine board but without collar. (25) Apparently there was no high level of suspicion for spinal injury amongst pre-hospital medical personnel. The mean ISS of the patients with spinal injury was significantly higher than the mean ISS of all injured occupants, namely 15.7 versus 6.7. Three quarters of all multi-trauma patients (ISS ≥16) had a spinal injury. (26) One spinal fracture was missed during primary and secondary survey in hospital and after diagnosis

Figure 4. A seat belt with witness mark showing the belt was worn and loaded during impact.

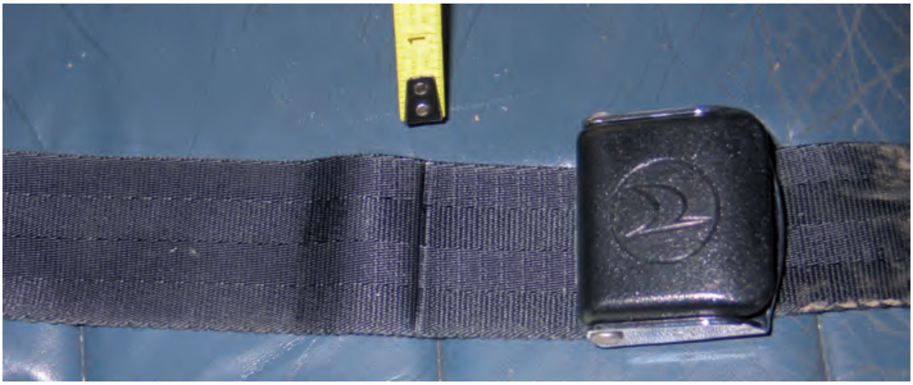


Figure 5. The floor in the front part of the airplane was pushed up.

no surgical treatment was deemed necessary. (27) After a comparable airplane crash in the UK in 1989, 11 significant spinal injuries (excluding minor avulsions, for example of the transverse process) were initially missed in 10 patients. (23) The total number of significant spinal injuries in this crash was 24 in 21 patients, so almost half were initially missed (3% of injuries or 12.6% of the patients). (28) Comparing both crashes, the incidence of missed spinal injuries in our 2009 crash of 0.6 % of all injuries (3.7% of spinal injuries) or 1.5% of patients can be considered low. Apparently the index of suspicion of spinal injury in the hospitals was high. The extensive use of CT scanning in today's day trauma care might explain the decrease in missed spinal injuries. (29)

The segmental distribution of injuries in our study revealed a low number of cervical fractures (14.8% of injuries) compared to general trauma literature (18-21%). (2; 3; 16) In spinal fractures sustained in MVA's the cervical spine comprises about 40% of all spine fractures. (30) This is attributed to the forward flexion of the neck when the rest of the body is restrained with a 3-point shoulder-lap belt. This risk is decreased when seatbelt use is combined with airbag deployment. In this airplane crash, the occupants were unaware of the coming impact and did not brace for it. Since the crash occurred during the landing phase, all occupants were expected to be wearing a 2-point (lap) seatbelt. Considering their upright position just before impact, forward flexion of the torso, neck and head is also to be expected. (7) This could be followed by the head hitting the seat in front, or the wall in the first row. A relative large number of C-spine fractures could be expected within this scenario. Nevertheless only 14.8 % of the spinal fractures were at the cervical level. This might be explained by the fact that in this crash the vertical deceleration component was greater than the horizontal component. In MVA's the main deceleration force is generally horizontal.

The number of thoracic spine injuries (29.6 % of injuries) are among the high end of rates reported in literature on traumatic spine injury in general (22.8%-28.8%), as are the lumbar injuries (55.6% of injuries versus 50.4% -56.1% in literature). (2; 4; 16) Fourteen of the injuries included a burst type fracture component (51.9%), meaning the vertebral endplate was fractured with involvement of the posterior wall, 8 (29.6%) of which were complete (both superior and inferior endplates). This is consistent with the trauma mechanism shown by the FDR data. Accident analysis and reconstruction has shown that the vertical load on the airplane during impact was especially high.

Historical literature about spinal injuries in MVA's, reports high incidences of distraction injuries. (31) A probable cause is suggested be the 2-point belt that acted as a fulcrum, also causing abdominal injuries, the so called 'seatbelt syndrome'. (32) Vaccaro et al found that in head-on car accidents, a significantly higher number of burst fractures was found in the victims wearing a 3-point restraint (shoulder-lap belt) (80%) compared to those wearing a 2-point belt (28.6%). (33) Nowadays the 3-point shoulder-lap belt in cars protects occupants from flailing but this in turn results in more compression type injuries. A decrease in the B type (seat-belt, flexion distraction) injuries has been reported since the introduction of the 3-point belt. In an airplane, the passengers are restrained with 2-point lap belts. Only crew and pilots are provided with a 4-point shoulder harness. Therefore, a high incidence of flexion distraction (B type) injuries is to be expected in airplane crashes. In this study only (6 22.2%) spinal injuries were classified as a flexion distraction injury, 1 of which was at the cervical and 5 thoracolumbar level. Two of these were a displacement injury (C type) according to the AO classification. (34) Beside these 2, one other C type injury was documented. This rate of 25.9% type B and C injuries is low compared to the 35.4% reported in literature about spinal fractures in general trauma. (2) Considering the use of lap seatbelt we would expect a higher rate of flexion distraction type B/C injuries. Figure 4 shows a lap seatbelt with a groove as a mark of the belt being worn and loaded during impact. The pull force subjected to the belt leaves this groove at the spot where the buckle was. The two crew members with a spinal fracture both suffered a C type injury, while they were wearing a 4-point shoulder harness. The post-crash analysis showed major destruction of the fuselage mainly in the front part of the airplane, where these two crew members were seated. The most seriously injured survivors and fatalities were seated in the front part of the airplane and two-thirds of the spinal injuries were also found in this section. (Figure 2). (26). The high vertical loading in this part of the airplane was also evident in the extensive floor deformation, described in another study about this crash. (Postma, ILE, DeWeese R. Pelletiere J., et al; Analysis of Biomechanical Aspects of Non-Fatal Injuries in a Major Airplane Crash; Submitted). The bottom was pushed up, resulting in bending and breaking of floor beams and seat assemblies. (Figure 4) Due to the high vertical loading in this crash, we expect the effect of a shoulder-harness, in mitigation of the spinal injuries, to be less than the proven effectiveness of such measures in MVA's. In these specific crash conditions, mitigation of injuries could probably have been effected by seats and bottom of the fuselage with larger energy absorbing properties. This has also been proposed in helicopter accidents where the loading is also mainly vertical, and in biomechanical studies of fixed wing aircraft accidents. (Postma, ILE, DeWeese R. Pelletiere J., et al; Analysis of Biomechanical Aspects of Non-Fatal Injuries in a Major Airplane Crash; Submitted). (22; 35; 36)

Further biomechanical analysis needs to be carried out to study the injury mechanisms of these spinal injuries in airplane accidents in more detail, and produce recommendations to increase crash safety. This could be in the field of structural design of the aircraft and its interior, or the safest brace positions for occupants.

Conclusion

In this study of an airplane crash, an expected high incidence of spinal injuries of 18.3% was found. Nevertheless the morphology of the spinal injuries consisted of an unexpectedly low rate of distraction injuries. More than half of the injuries had a burst component, in line with the vertical load that accounted for the greatest force on impact. Further biomechanical studies might be able to improve crash safety and decrease injury morbidity.

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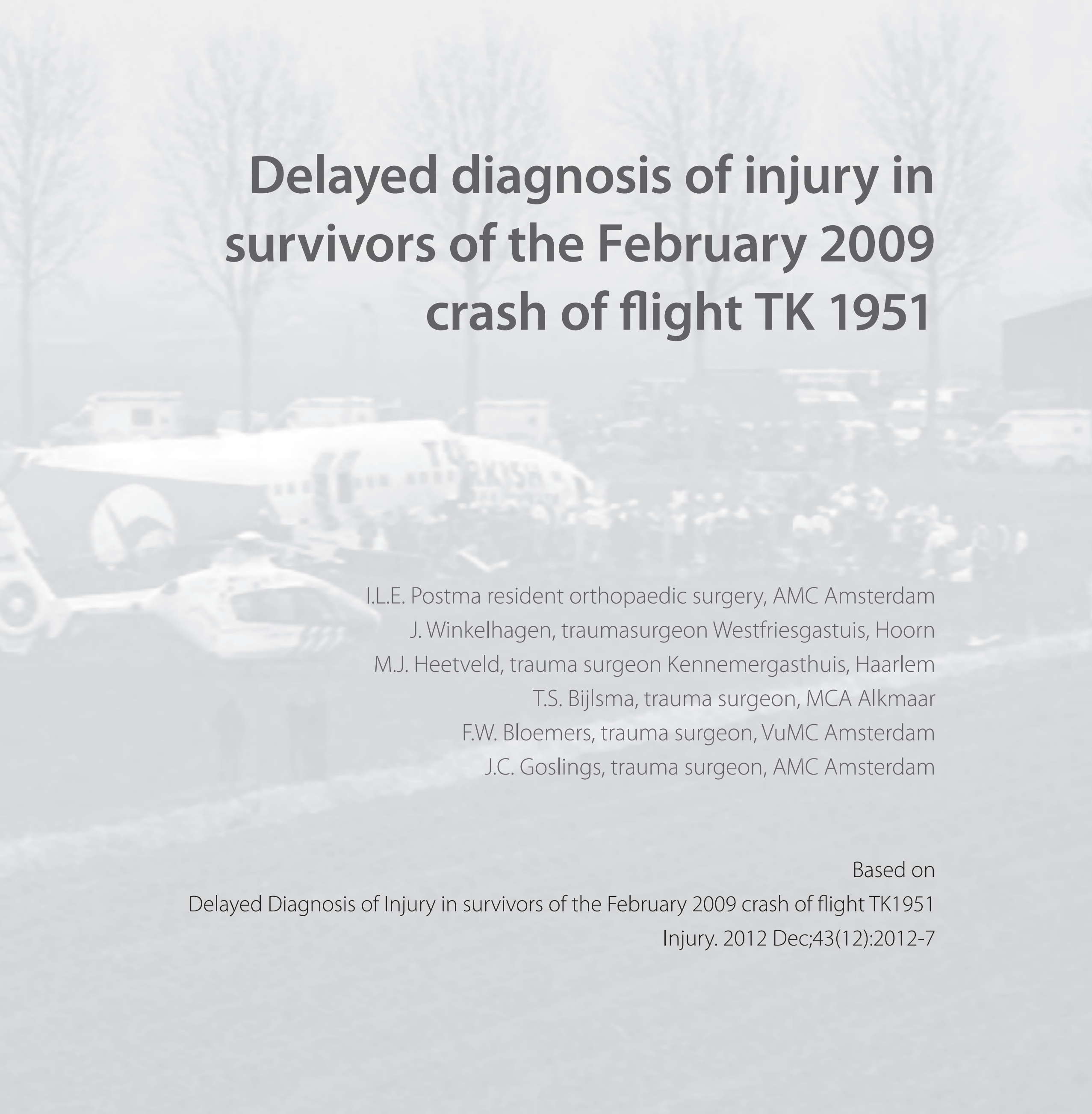

Chapter 9

Delayed diagnosis of injury in survivors of the February 2009 crash of flight TK 1951

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Based on
Delayed Diagnosis of Injury in survivors of the February 2009 crash of flight TK1951
Injury. 2012 Dec;43(12):2012-7

Abstract

Introduction

On 25 February 2009, a Boeing 737 crashed nearby Amsterdam, leaving 126 casualties. Some injuries in trauma patients initially escape detection. The aim of this study was to evaluate both the incidence of Delayed Diagnosis of Injury (DDI) and also the tertiary survey on the casualties of an airplane crash, and to evaluate the effect of ATLS® implementation on DDI incidence.

Patients and methods

Data from all casualties were analysed with respect to hospitalisation, DDI, tertiary survey, ISS, Glasgow Coma Score (GCS), injuries (number and type) and emergency intervention. Clinically significant injuries were separated from non-clinically significant injuries. The data were compared to an airplane crash in the UK (1989), which occurred before ATLS® became widely practiced.

Results

All 126 casualties of the Dutch crash were evaluated in a hospital; 66 were hospitalised, with a total of 171 clinically significant injuries. Twelve (7%) clinically significant DDIs were found in 8 patients (12%). In 65% of all patients, a tertiary survey was documented. The incidence of DDI in patients with an ISS ≥16 (n = 15*) was 27%*, compared to 9% in patients with ISS <16. Patients with >5 injuries had a DDI incidence of 25%, compared to 12% in patients with ≤5 injuries. Head injury patients had a DDI incidence of 19%, patients without a head injury 10%. Fifty percent of patients who needed an emergency intervention (n = 4) had a DDI; 3% of patients did not need emergency intervention. Eighty-one survivors of the UK crash had a total of 332 injuries. DDIs were found in 30.9% of the patients. Of all injuries, 9.6% was a DDI. The incidence of DDI in patients with >5 injuries was 5%, vs. 8% in those with ≤5 injuries.

Conclusion

DDI in trauma still happens. In this study, the incidence was 7% of the injuries in 12% of the population. In one third of the patients no tertiary survey was documented. A high ISS, head injury, more than 5 injuries and an emergency intervention were associated with DDI. The DDI incidence in our study was lower than in casualties of a previous airplane crashes prior to ATLS® implementation.

Introduction

On February 25, 2009, a commercial aircraft crashed nearby Amsterdam Airport Schiphol, in the Netherlands. One hundred and twenty six people survived the crash and nine people died. (1) This Mass Casualty Incident (MCI) warranted evaluation of medical treatment and other procedures.

The diagnosis of all injuries in trauma patients can be a challenge, especially in large-scale accidents, with numerous multi-traumatised patients. Missed or delayed diagnosis of injuries may cause increased morbidity, a longer stay in hospital, higher costs, and can affect the patient–doctor relationship. (2-5)

Since the development of the Advanced Trauma Life Support (ATLS®) course by the American College of Surgeons, trauma resuscitation and care has been based on the principle of "treat first what kills first", with a primary survey in order to detect immediate life-threatening injuries and a secondary survey consisting of a 'head to toe' examination. (6) However, primary and secondary surveys alone are not sufficient for detecting all injuries. In 1991, Enderson et al. reported an increase from 2% to 9% of injuries diagnosed late, when they actively looked for new diagnoses of injury in patients with blunt trauma, after the primary and secondary surveys. As a consequence, they introduced a tertiary survey, comprising a complete repetition of the physical examination performed during the previous surveys. (7; 8) This was later completed with a review of all diagnostic tests that had been carried out at a primary and secondary survey. (3; 5; 9)

The reported incidence of delayed diagnosis of injury (DDI) ranges from 1.3% to 65%. (2-5;7-11) This wide range is attributable to heterogeneous study groups as well as the differences in definitions of DDI. Associated factors in the incidence of DDI are, for example, impaired consciousness, or a high Injury Severity Score (ISS). (3; 7; 9)

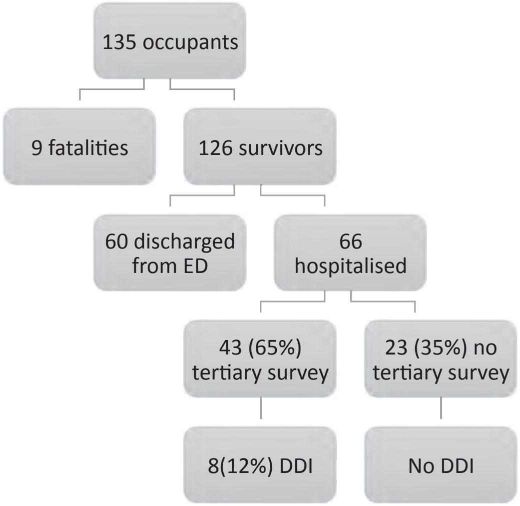
Although DDIs are now often discovered because of the introduction of the tertiary survey, DDIs are still common, even after tertiary survey. The effect of an MCI on the incidence of DDI is not clear.

The aim of this study was to examine the incidence of DDI and a tertiary survey in the casualties of the 2009 Turkish Airlines airplane crash in the Netherlands.

We were interested in associated factors such as ISS, number of injuries, type of injury, GCS and emergency interventions. We were also interested in the effects of 20 years of ATLS® doctrine and evolving trauma care on this incidence rand comparing these to a similar airplane crash in the UK in 1989, that happened shortly before ATLS® became widely practiced.

This study was approved by the Medical Ethical Committee of the Academic Medical Centre, Amsterdam.

Figure 1. Documentation of a tertiary survey in relation to DDI in patients admitted following the Dutch crash.



Patients and methods

Setting Turkish Airlines crash 2009, in the Netherlands

On February 25 2009, at 10:26 a.m., a Turkish Airlines Boeing 737-800 crashed in a field approximately 1.5 km short of the runway of Amsterdam Airport Schiphol. The aircraft broke into 3 sections and both engines ended up dozens of meters away. Amsterdam Airport Schiphol is situated in a densely populated area of the Netherlands, where everybody lives less than 10 minutes from a hospital. (12) Fifteen different hospitals received one or more patients, resulting in all 126 survivors being evaluated in a hospital.

Data collection and outcomes

The demographic and medical data of all patients, at each of the 15 receiving hospitals, were collected retrospectively; using a Microsoft Access® database. The medical charts of the hospitalised patients were reviewed for documentation of a tertiary survey and for DDI, as primary outcomes.

DDI was defined as an injury diagnosed after a primary and secondary survey, meaning this injury could be found at a tertiary survey, or later. Secondary outcomes were possible risk factors for DDI, including a high ISS, number of injuries, head injury, Glasgow Coma Score (GCS) on arrival at the Emergency Department (ED) and an emergency intervention. An emergency intervention was defined as an intervention such as an operation, angiography, or intubation; for any acutely life-threatening injury, within 6 hours after the trauma. A distinction was made between clinically significant injuries and DDIs, and clinically non-significant injuries and DDIs. Clinically significant was defined as an injury that, if unnoticed, would possibly lead to delayed or poor, healing, and could have consequences for a patient's recovery and return to daily activities. Thus, this definition is not based on severity as a threat to life, but more as a chance of disability or impairment. This therefore means, any injury that needs treatment, or at least one check-up after diagnosis. In our results we have only considered clinically significant injuries, unless stated otherwise.

Statistical analysis

Because of the small study population, only descriptive statistics are calculated using SPSS 16® for Windows®.

Comparison with UK crash 1989

Setting

On January 8 1989, at 08:30 p.m., a Boeing 737-400 crashed on the M1 motorway about 900 m short of the threshold of the runway of East Midlands Airport, near Kegworth, Great Britain. The aircraft broke into 3 sections and came to rest on the embankment of the M1 motorway. The nearest hospital was approximately 16 km from the crash site and two other hospitals were approximately 19 km and 32 km from the crash site. (13)

Data collection

The Nottingham, Leicester, Derby, Belfast Study group published the data of this crash in several articles and a book. (13-20) We collected the demographic and medical data from the published articles and compared the relevant data to the outcome measures of the Dutch crash, as described above. The data from the UK crash only consider 'major injuries', the definition of which is comparable to the one we used as 'clinically significant injury'. (19)

Table 1. Patients with and without DDI in Dutch crash.

Admissions	Hospitalised Pt with DDI (n=8, 12%)*	Hospitalised Pt without DDI (n=58, 88%)*	Total Pt hospitalised (n=66)
Mean ISS (range, median)	21.9 (5-66; 13.5)	9 (1-34, 5)	10.5 (1-66, 5)
ISS ≥16	4 (50%)	9 (15.5%)	15
No. of injuries*	39	132	171
Mean no. of injuries (range, median)	4.5* (1-11, 2)	2.3* (0-11, 1)	2.6 (0-11, 2)
>5 injuries	2 (25%)	6 (10%)	8
Mean GCS at admission (median)	14 (15)	15 (15)	14.9 (15)
Head injury (AIS≥2)	3 (19%)	13 (81%)	16
Emergency intervention	2 (25%)	2 (3.4%)	4 (6.1%)
Mean hospital stay (days) (range, median)	29.3 (2-104, 10)	6.9 (1-35 4)	8.9 (2-104, 4.5)

* Only clinically significant injuries.

Results

Demographic data

Nine of the 135 occupants died at the scene of the Dutch crash. There were no later deaths on the way to, or in hospital. Sixty-six percent were male and the mean age was 38 (range 11 months to 76 years). A total of 66 patients (range 1–19) were admitted to 13 hospitals (Figure 1). The Academic Medical Centre (AMC) in Amsterdam and VU Medical Centre (VUMC) in Amsterdam, both major trauma centres, hospitalised most patients, 19 and 18 respectively.

Outcomes

The population and documentation of a tertiary survey is shown in Figure 1. All clinically significant DDIs were found in the 2 trauma centres receiving the largest number of patients and in the most severely injured patients (mean ISS 13.2* compared to 10.5*, of admitted patients). One patient was severely injured, with an ISS of 66*, and in need of several immediate emergency interventions. Non-lifesaving diagnostic studies were deliberately postponed. This patient suffered 5

DDIs and needed operative treatment for 4 of them. The results of patients with and without DDI are in shown Table 1. The types of clinically significant DDIs and their treatment are shown in Table 2.

The results of the associated factors in patients with and without DDI are shown in Figure 2. The mean time to diagnosis of clinically significant DDI was 4.5 days (range 1–10 days, median 5 days). None of the DDIs had been imaged radiographically during the primary and secondary survey (Figure 3).

Table 2. Type of Delayed Diagnosis of Injury

Type of Injury	Number	Treatment
Distal Radius fracture	1	Surgery
Metacarpal fracture	1	Plaster cast
Interphalangeal dislocation	1	Closed reduction and plaster cast
Lumbar vertebral fracture	1	Conservative
Meniscal tear	1	Conservative
Tibial plateau fracture	2	Surgery
Tibial shaft fracture	2	1 surgery, 1 plaster cast
Ankle sprain	1	cast
Kidney contusion	2	expectative
Total	12	

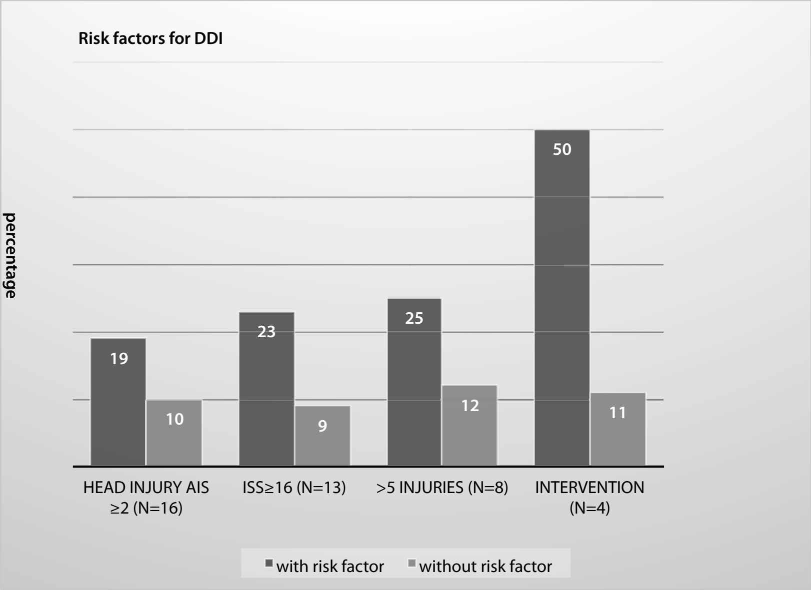
Comparison with UK crash 1989

Demographics

Thirty nine of the 126 occupants of the UK aircraft died at the scene, 4 on their way to hospital, leaving 83 who were transported to 4 different hospitals, which received 37, 24, 20 and 2 patients respectively. One of the 4 hospitals reported not to have hospitalised 2 patients because of minor or no injury. We assume that the other hospitals hospitalised all the casualties that they received, even though 6 of the casualties had an ISS of 1, and 4 had an ISS of 2. A report of the 'Air Accidents Investigation Branch' of the British Department of Transport states there were only 5 casualties with just minor injuries. (21) Of the patients that were hospitalised, another 4 died at 12 hours, and 11, 15 and 22 days after the accident, ultimately leaving 79 surviving casualties.

The demographics were comparable to the Dutch crash.

Figure 2. Patients with DDI, with and without risk factor.



Outcomes

The comparison of DDI in these 2 airplane accidents is shown in Table 3. In the UK crash, all DDIs occurred in the 3 hospitals receiving the most patients. We could not extract data such as ISS, GCS, or number of injuries per patient, patients with or without DDI, from the UK data. The Nottingham, Leicester, Derby, Belfast Study group found no significant difference in the incidence of DDI between patients with ≤5 injuries, or the group with >5 injuries, 8% and 5% respectively. (19) The DDIs consisted of 8 fractures and 1 soft tissue injury of the upper limb, 9 fractures of the lower limb and 14 spinal injuries (13 fractures and 1 prolapsed thoracic vertebral disc). Five DDIs required operative treatment. (19) The cause of DDI in 14 cases was misinterpretations of X-rays, in 8 due to failed clinical investigation and 10 injuries were not radiographed. (19)

Discussion

The incidence of DDI in the Dutch airplane crash was 7% of all injuries and in 12% of the hospitalised patients. This is comparable to DDI incidence in trauma patients in literature. (2; 9; 22-24) All DDIs were found in the 2 hospitals receiving the largest numbers of casualties, with the highest severity of injuries. An unpublished study of delayed diagnosis in 1124 trauma patients in the same two hospitals showed a DDI incidence of 8.2% of the study population. (25) The higher incidence in our study might be due to the large number of casualties presenting in such a short period of time. The fact that all DDIs were found in the major trauma centres could mean that smaller (level 2 and level 3) hospitals could have less complete documentation, i.e. not a standard tertiary survey form.

In 65% of the admitted patients in the Dutch crash, there was documentation of a tertiary survey. This should ideally be 100%. The absence of documentation of a tertiary survey does not necessarily mean that no tertiary survey was performed, and not all DDIs were discovered during a tertiary survey. Nevertheless, all DDIs were found in patients in whom a tertiary survey was documented, so it is possible that, in the remaining 35% (without a tertiary survey), some DDIs were missed.

Table 3. Comparison of Dutch vs. UK data.

	Dutch	UK
Mortality	9 (7%)	43 (34%)
Survivors	126	79
No. of DDIs	12* (7%)	32* (10%)
No. of patients with DDI	8 (12%)	25 (30%)
Mean time to diagnosis of DDI (days) (range, median)	5.3* (1-10, 6)	44* (1-132)
Mean ISS (range, median)	6.3 (1-57, 4)	15.2 (1-50, 11)
ISS≥15	13 (10%)	30 (37%)
Number of injuries	305 (171*)	332 (major injuries)
Head injury (AIS≥2)	21 (17%)	34 (41%)

* Only clinically significant Delayed Diagnosis of Injury

Our definition of clinically significant injury was chosen based on the risk of disability or impairment and not on the basis of AIS score, because injuries with an AIS severity of 1 can have important consequences to a patient if they are missed and left untreated. For example, an interphalangeal dislocation, or rupture of multiple tendons in the hand, has AIS of 1, but if diagnosed late or completely missed, they can be disabling for the patient. In practice, this meant that injuries not accounted for were only minor ones like, superficial lacerations, abrasions and contusion of skin, or joints. These comprised 52 injuries in the hospitalised patients.

A total of four patients needed one, or more, emergency intervention because of acute life-threatening injury. According to the ATLS® principle, the imperative is to "treat first what kills first". (6) In the Dutch crash 2 patients needed immediate surgery because of acute life-threatening injuries. The delay in diagnosing some non-life-threatening injuries caused by this immediate surgery can therefore be seen as functional. Excluding these DDIs, the incidence becomes lower at 3.5% of the injuries in 9% of the patients. It should be noted that all DDIs were non-life-threatening injuries, which is consistent with the application of ATLS® principles. Another debatable DDI is that of a meniscal tear. This DDI was suspected at the end of this patient's hospital stay. The MRI confirming the diagnosis was made a few weeks later. In daily practice a meniscal tear is hard to diagnose through physical examination directly after trauma, because of extensive swelling and pain. An MRI to confirm a meniscal tear is not routinely performed shortly after the trauma.

In the Dutch crash, a high ISS, the number of injuries per patient, a head injury AIS ≥2 and the need for an emergency intervention were associated with a higher chance of a DDI, as shown in Figure 2. Although these factors can be correlated to each other, association with DDI has been shown in previous studies. (3; 7; 9; 26) The Nottingham, Leicester, Derby, Belfast Study group concluded that the incidence of DDI is not related to overall patient condition. Perhaps the difference of 7% compared to 10% (or 12% compared to 31% in population) in DDI incidence between the UK and Dutch findings can also be explained by the fact that more casualties from the UK crash were severely injured than in the Dutch crash (ISS ≥16 of 30.7% compared to 11.9*%). Since we could not correct the data for the severity of the crashes, in terms of the extent of the injuries per patient, statistical analysis of the comparison was not possible.

From the UK data, we could not extract GCS scores per patient with, or without, DDI. However, with the high numbers of significant head injuries and casualties who had no recollection of the crash (55%), it can be presumed that in the UK there was a large number of casualties with a lowered state of consciousness. (18; 27) This could also be a factor related to the higher DDI rate.

Comparison with the UK crash is difficult because the UK crash was more severe, resulting in more initial deaths and more survivors with an ISS≥16. As mentioned earlier this might be an explanation as to why the incidence of DDI was higher in the UK crash. In the Dutch crash only the DDIs found during initial hospital stay were reported. This means that we might have underestimated our DDI incidence in comparison to the UK. On the other hand, according to the published literature, not admitting all patients just because of the high energy trauma mechanism, cannot be presumed to lead to a significantly higher DDI rate. (28)

The UK crash happened before ATLS® was fully adopted in the UK and thus also before a tertiary survey was introduced in daily practice. (7; 8; 20)The first ATLS® courses had only just started in the UK so few doctors were ATLS® certified, and ATLS® principles were not yet protocolled. The Nottingham, Leicester, Derby, Belfast Study group does mention that all patients were carefully re-examined the morning following the crash and every morning thereafter, but a large number of diagnoses were initially missed, due to failure of clinical examination and misinterpretation of X- rays. There was a long delay until some DDIs were found. This might have been (partially) prevented by the structured methods of ATLS® and a tertiary survey.

It is remarkable in the UK crash that so many spinal injuries were initially missed, being 4.2% of all injuries compared to 0.6% of all injuries in the Dutch crash. Tait et al. and the NLDB study group state that this might be explained by an incomplete understanding or realisation of the trauma mechanism, with high G forces (higher than in the Dutch crash) creating a large vertical load. (19) They advised that all casualties of high energy trauma should receive a full spinal radiological examination. In the study of the UK crash, only delayed bony injuries were considered. If this had been done for our study, the DDI incidence would have been 6% of the injuries in 9% of the patients.

This study has several limitations. Studying incidence rates in an isolated event, such as an aircraft crash, carries the disadvantage of a rather small study population. Also, the trauma mechanism and the conditions are unique. Therefore, these data cannot be extrapolated to the general trauma population. The differences between the two airplane crashes described, and the differences in the specification of the data, preclude a direct comparison.

Figure 3. Emergency medical response after Turkish Airlines crash, February 25 2009

Conclusion

DDI incidence in the casualties of the Turkish Airlines crash in Amsterdam was 7% and affected 12% of the study population. This is comparable to the published literature, so it must be concluded that in mass casualty incidents as in any other trauma casualties, some injuries are initially missed.

This study showed a sub-optimal documentation of a tertiary survey in airplane crash casualties. The performance of structured trauma resuscitation with a primary, secondary and tertiary survey is vital in finding DDI. A high ISS, head injury with AIS ≥2, the need for an emergency intervention and >5 injuries/patient should raise the suspicion of a DDI. The implementation of ATLS® may have led to a low number and earlier discovery of DDIs.

*During the process of the several studies, certain calculations of the ISS scores needed to be revised. The injuries and AIS scores were correct but some ISS scores had been miscalculated. This has led to minor revisions of some results, which did not lead to different conclusions. In this chapter the correct results are displayed and therefore there are some numbers that differ from the published article. These numbers are indicated with an *asterisk. The whole dataset of revised results is displayed in a table in chapter 12.

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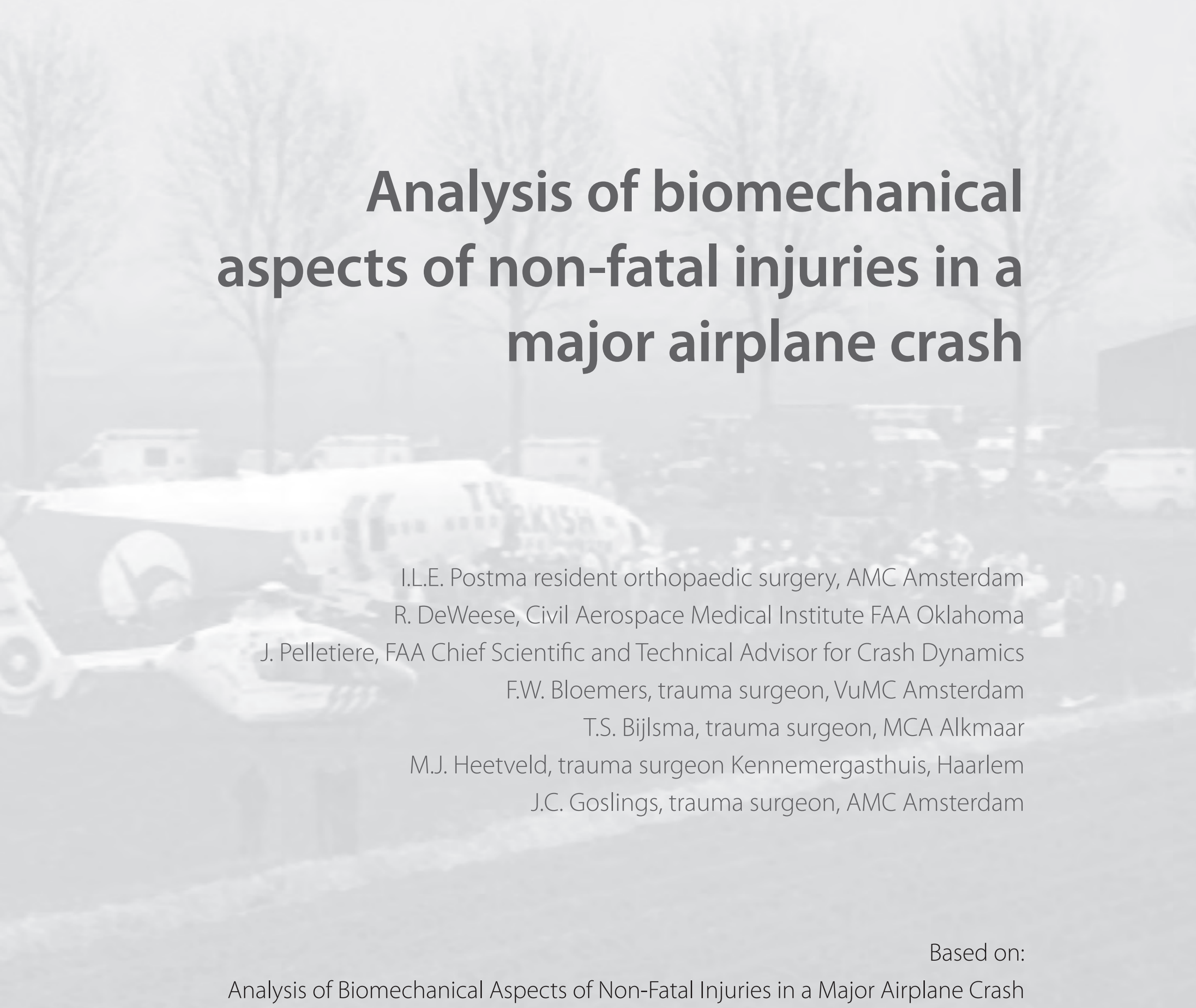
Part 4

The Aftermath

Chapter 10

Analysis of biomechanical aspects of non-fatal injuries in a major airplane crash



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Based on:
Analysis of Biomechanical Aspects of Non-Fatal Injuries in a Major Airplane Crash
Submitted

Abstract

Introduction

Although the number of fatal air accidents has dramatically decreased since the beginning of commercial air travel, they still occur often enough to justify measures intended to reduce the fatality and injury rates. Survivability studies are a means to assess the effectiveness of current occupant safety measures and identify areas where improvements can be made. In this pilot study of the Flight TK-1951 crash on February 25, 2009, near Amsterdam Airport Schiphol, the injuries sustained by the survivors and the documented structural damage of the aircraft were analysed to determine the most likely cause of the injuries.

Methods

All medical data on the injuries of the survivors and the structural damage of the airplane fuselage, seats, and interior were gathered and documented. A team of specialists evaluated the injuries to explain the injury mechanism involved in relation to the damages that occurred. Four cases were chosen to be presented in this pilot study.

Results

Some of the significant injuries found in the 4 cases were: head injuries related to impact from dislodged objects, spinal fracture and chest injuries related to forward flailing, lumbar spine fractures resulting from high vertical loads, facial fractures and pulmonary contusions resulting from impact onto the seat back in front, and leg injuries resulting from vertical load applied by the disrupted floor.

Conclusions

This pilot study identifies 4 areas where improvements could be made to reduce injuries. These are 1. Insufficiently secured equipment can cause head injury; 2. Insufficient vertical energy absorption by the seat can result in lumbar and thoracic spinal compression injuries; 3. Lack of upper torso restraint can permit forward flailing resulting in spine and chest injuries; 4. Floor deformation can cause an increase in severity of the lower leg injuries by applying extra vertical load.

Previous comprehensive studies of relevant accidents have identified many of the same injury causation factors as prevalent in other crashes.

Introduction

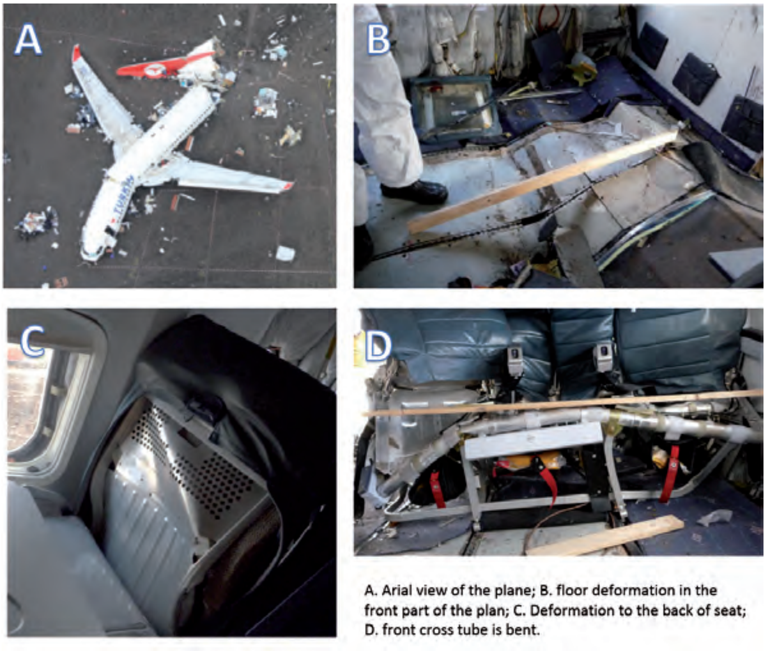
The number of flights and air travellers has increased rapidly since the start of commercial air traffic. Also, the size of the aircraft and therefore the number of passengers on board have increased to meet the growing demand for air travel. After a steady decrease in the rate of fatal air accidents up to the 1970's, the accident rate continues to decline, but at a much slower rate. (1) Fortunately, most (73%) serious airplane accidents are survivable, and in those accidents, 76% of the occupants survived, according to a National Transportation Safety Board (NTSB) study that examined accidents in the period 1983 – 2000 (2) While airliner crashes are relatively rare events (a worldwide average of 2.5 accidents per year in which at least one person is fatally injured during the period from 2002 to 2011), benefit analyses indicate that steps to prevent or mitigate fatalities and serious injuries that could occur, are worthwhile. (3-5)

In 1988, the United States implemented improved safety standards for seats and restraints in aircrafts, with the goal of reducing deaths and injuries. (6) These standards require that seat system strength and occupant protection be evaluated using dynamic testing with Anthropomorphic Test Devices (ATDs), as is done to ensure automotibile safety. This test method provides a realistic loading condition and permits direct evaluation of injury risks. The evaluations consist of two tests, one simulating a crash where the forces are horizontal, and the other where a combined vertical and horizontal load is applied. The seats must accommodate a significant amount of floor distortion without failure, since floor distortion is common in survivable crashes. The seat and restraint system must be designed to limit the load transmitted vertically to the spine, which is usually accomplished by allowing some amount of vertical deflection in the seat. Loads transmitted to the head must also be limited, which can be done by controlling the force required to fold the seat back in front of the passenger, or by use of a shoulder strap or inflatable restraint to prevent or reduce the velocity of head impact. These standards were initially applicable to newly designed aircrafts, but this implementation approach resulted in a smaller percentage of the fleet having the improved seats than desired (64% in 2004). In 2009, the standards were applied to all newly produced airliners, to accelerate implementation. (7) Similar requirements have been adopted by the European Union.

Recently, there has been a series of accidents with Boeing 737 aircraft incorporating seats meeting the new safety standards. These are Continental Flight 1404 in

Denver, Turkish Airlines flight TK-1951 in Amsterdam, American Airlines Flight 331 in Jamaica, and Aires Flight 820 in San Andres. (8) Although the impact scenarios differed somewhat, they were similar in that the fuselage broke into sections but maintained a survivable volume in the majority of those sections. The outcome of these accidents was also remarkably similar, in that most, if not all of the passengers survived. An analysis of these accidents could provide insight into the effectiveness of the new safety standards and identify areas where further improvements to crash safety could be developed. Therefore, in this pilot study the injuries sustained by the surviving victims of Turkish Airlines flight TK-1951 that crashed on February 25 2009 near Amsterdam Airport Schiphol were analysed. This study focuses on the causation of the injuries that occurred, such as inertial loading and contact with the interior. Based on these analyses, recommendations will be provided for improving the protection of aircraft occupants during an impact.

Figure 1. Arial view of wreckage and structural damages



A. Arial view of the plane; B. floor deformation in the front part of the plan; C. Deformation to the back of seat; D. front cross tube is bent.

Methods

Figure 2. Injury severity distributions throughout cabin

Data Collection

Of the 135 passengers and crew members on board the aircraft, 9 died. The 126 surviving occupants were all evaluated in hospital. Their medical data, consisting of type of injury, diagnostic imaging, and treatment methods, were gathered for this study. The injuries were coded using a standardised injury coding system, the Abbreviated Injury Scale (AIS; update 1998). The AIS is an anatomically based, consensus derived, global severity scoring system that classifies each injury by body region according to its relative importance on a 6-point ordinal scale. The AIS characterizes the severity of injury as 1 Minor, 2 Moderate, 3 Serious, 4 Severe, 5 Critical, and 6 Maximal. (9) The overall injury level of each occupant was determined by calculating the Injury Severity Score (ISS). (10) This score is the sum of the squares of the maximum AIS values for the 3 body areas where the most serious injuries have occurred. Autopsies were only conducted on the fatally injured cockpit crew, but the results were not available for this study.

After the crash, an international team of experts, called the Survivability Group, led by the Dutch Safety Board (DSB), carried out detailed measurements of the damage that occurred in the interior of the aircraft. Specialists from NTSB, Boeing, the U.S. Federal Aviation Administration (FAA), and the Dutch Cabin Crew Union (VNC) were team members. The team noted the general condition of interior components such as the seats, overhead baggage compartments (overhead bins), walls, and emergency exits. Measurements were taken to determine the amount of deformation that had occurred in the seat frames and aircraft floor. The condition and length of all seat belts was also documented. The belts were also inspected for evidence of loading indicated by "witness marks," which is a crease across the webbing made as the webbing adjuster bar was forced into the fabric by the belt tension. For such measurements, no standard protocols were available; the methods used were developed and specified at the scene by the Survivability Group. The measurements were documented in tables and photographs which were made available for our analyses. The DSB also collected the seating arrangements by checking the passenger list from the airline and by asking the passengers about their seat and the people seated around them. These data were made available for the purpose of this study. It should be noted that the medical records consulted for this study are not publically available. Also, the Survivability Group data and the seating arrangement information consulted for this study have not been publically released by the DSB. This study's protocol was approved by the ethical review board of the Academic Medical Centre, Amsterdam, the Netherlands.

Data Analysis

A team consisting of medical doctors with a special interest in trauma, trauma surgeons, engineers in injury biomechanics, and engineers in aircraft design reviewed the data of structural damage and injuries to the occupants. These data were then compared with each other to explain possible injury mechanisms. The confidence in the determinations were ranked using the National Highway Traffic Safety Administration (NHTSA) terms for confidence: Certain, Probable, and Possible. (11) After reviewing a substantial number of the cases, 4 cases were selected that were considered illustrative for this crash. The facts concerning these 4 cases and the consensus of the reviewers with regard to injury causation are presented in the results section.

Since no fire occurred during or after the crash, it can be assumed that all injuries were a result of the forces applied to the occupant by the impact of the crash or occurred during evacuation. If the cabin crew are aware that an impact is imminent, passengers are instructed to "brace," an action that includes placing the head and upper torso against the interior feature just forward of the occupant (typically a seat back). This action can reduce the relative impact velocity with the interior and therefore reduce the impact-related injuries. None of the occupants were aware that the airplane was about to crash, so it can be assumed that no one in the airplane had adopted a "brace position".

Results

Setting and Conditions of the Accident

This crash involved a Boeing 737-800 that impacted a ploughed farm field during its final approach to Amsterdam Airport Schiphol. The plane was severely damaged but did not catch fire. The airplane fractured in three parts: an rear section including the tail, a large centre section, and a forward section containing the cockpit. The front fracture was between rows 7 and 8, just forward of the wing, and the rear section fractured at row 29, the last seat row. Figure 1A gives an overall view of the aircraft damage. The forward section sustained the most extensive damage to the interior.

The data from the Flight Data Recorder (FDR) consisted of various speeds, roll angle and accelerations, and were of such quality that the initial conditions of the aircraft just before first contact with the ground were fairly accurately known; however, horizontal and vertical velocity at impact were not cited in the DSB final report (8). It is likely that these parameters could be derived from an analysis of the entire FDR data set. Available FDR data do show that the plane was pitched up 22 degrees and rolled 10 degrees to the left when it contacted the ground. Examination of the ground contact scars and aircraft wreckage indicates that the rear of the aircraft contacted the ground first. FDR data, ground contact scars and the final position of the wreckage provided sufficient information for the DSB to create an animation of the likely sequence of events that occurred during the crash. This animation shows that the initial contact transmitted enough force to the tail of the aircraft to cause the horizontal stabiliser to separate immediately and for the entire fuselage section after row 29 to separate at some point in the crash. The animation also shows the aircraft pitch forward rapidly after the tail touched the ground, causing the nose to hit with sufficient vertical force to break the fuselage just ahead of the wing. The floor of this section deformed significantly, exhibiting an accordion pattern of failure, shown in Figure 1B, indicative of significant forward loading.

Summary of Injuries

Of the 135 passengers and crew, 9 suffered fatal injuries, and 120 had injuries ranging from minor to critical; 15 with an injury severity score (ISS) greater than 15, 21 with an ISS between 8 and 15, and 84 with an ISS of 8 or less. (12) The severity of the injuries sustained as a function of the seat location is provided in Figure 2. Most fatalities and seriously injured occupants were seated in the front section of the aircraft. Most passengers with minor injuries were seated in the middle section (main cabin). It should be noted that under the category of minor injuries there were some occupants who had been unconscious for a short duration. These minor injuries could have resulted in fatalities if there had been a post-crash fire because these occupants may not have been able to evacuate in time. (13)

Cases

Because of privacy issues, no exact seat location, gender or age is provided. The location of the occupant is noted as forward, centre, or rear section, of the plane since the impact environment differed significantly in each of these sections. A summary of the mechanism of every injury is presented in Table 1.

Case 1: forward section; ISS 29

Main injuries: Nose fracture, (AIS 1); Orbital fracture left (AIS 2); Pulmonary contusion, bilateral (AIS 4); Humeral fracture, left (AIS 2); Forearm fracture, open right (AIS 3); Femur fracture, proximal right (AIS 3); Tibia fracture, distal left (AIS 3). Figure 3.

Discussion: The seat remained attached to the seat track, but the aircraft side wall showed significant intrusion, contacting the end of the seat. The cross tubes that support the seat pan were only supported at one end. These tubes were bent down 4.5 inches at the unsupported end, indicating significant vertical loading at this location. The lack of spinal injuries may be explained by the energy absorbed during the seat frame deformation. During dynamic tests run to qualify new seat designs, flexion of cross tubes has been observed to significantly reduce force transmitted to the lumbar spine. However, the amount of permanent deformation at this seat location implies that loading was beyond the load (14 g) applied during dynamic qualification tests.

Overhead bins in this area were dislodged and then later removed by rescue workers. The back of this seat and the one beside it were buckled at about 12 inches up from the hinge, indicating significant loading from above (potentially from the dislodged overhead bin). Figure 1C.

The row in front was completely dislodged during the crash. The seat back in front of this occupant was broken and was bent forward, but did not have blood or other prominent marks. The right seatbelt anchor bolt was pulled out of the seat frame. The seatbelt was still latched and had an obvious witness mark, showing that the seatbelt was worn and loaded during the crash. This failure is consistent with the significant forward loading apparent in this section of the aircraft. It is likely that the attachment failure resulted in ejection of the occupant from the seat, allowing excursion of the whole body forward and to the left, likely hitting the side wall and pushing the seatback in front, forward. The orbital fracture appears as a blowout caused by high intra-orbital pressure; it is likely that was caused by a high velocity impact with the seat in front. The seat is a more likely cause than the side wall, because its softer surface provides an increased contact area associated with this type of injury. The nose fracture is likely to have occurred during this same contact. The pulmonary contusion is most likely due to the impact from the side (wall) and seat in front.

The complex spiral fracture of the humeral shaft on the left is the result of a high energy, direct impact and suggests impact with the side wall and seat frame in front, which probably occurred when the occupant was ejected. Contact with the frame of the seat in front was also the likely mechanism for the transverse forearm fracture on the right.

The complex spiral wedge fracture of the proximal femur on the right side is the result of a high-energy bending load. The most likely fulcrum point was the front cross tube of the occupant's seat, since forward flailing of the occupant tends to force the femur downward against this tube as would vertical loading if the lower leg was extended forward. Figure 1D shows that the cross tube is bent down more on the left side of the occupant than the right, which may be why there is not a similar injury on the left side.

The left tibia and fibula fracture were the result of a high energy impact, with loss of occupant space, consistent with the downward bending of the seat frame, causing an axial load. This was probably combined with a direct impact caused by contact of the lower leg against the seat in front, when the occupant was ejected.

Table 1. Injury, causation and confidence level

	Injury	Injury Cause	Confidence
Case 1	Nose fracture	Impact with seat in front	Probable
	Orbit fracture	Impact with seat in front	Probable
	Bilateral pulmonary contusion	Being thrown forward, against row in front	Probable
	Humeral fracture left	Side wall intrusion, direct impact of side wall	Probable
	Femur fracture, proximal right	Bending load, front cross tube of seat as lever	Probable
	Tibia fracture left	Axial load from floor, and direct impact by leg flail	Probable
Case 2	Spinal fracture L5	Axial loading by vertical impact	Certain
	Humeral fracture right	Direct impact (certain)against seat in front (probable)	Probable
	Kidney contusion	Direct impact (certain) with armrest (possible)	Possible
	Tibia fracture, distal bilatera	Axial compression loading	Certain
Case 3	Cerebrum contusion, right	Impact from loose object (probable), like PSU or oxygen generator (possible)	Possible
	Retinal laceration, left	Direct impact to head by heavy object.	Possible
Case 4	Sternum fracture	Direct impact (certain) with knee (possible)	Possible
	Spinal fracture T11/T12	Forward flail resulting in anterior compression and posterior distraction injury.	Certain

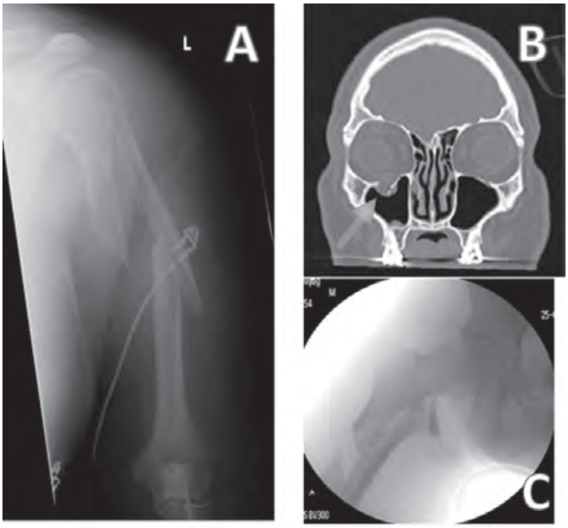
Case 2: forward section. ISS 18

Main injuries: Kidney contusion, right (AIS2); Humeral fracture, right (AIS 2); Tibia fracture, distal left (AIS 3); Tibia fracture, distal right (AIS 3, Figure 4A); Spinal fracture, L5 (AIS 3, Figure 4B).

Discussion: The seat assembly was severely damaged and canted forward with the front cross tube nearly at floor level. The floor track under this seat sheared just in front of and behind the seat leg attachments, allowing the entire seat assembly to rotate forward. Occupants in this row were probably thrown forward in their seats as the seat was pitched forward. The downward motion of the front of the seat relative to the remaining floor would have applied significant axial loading to the occupant's lower legs and forced the ankles into dorsiflexion. Both lower legs exhibited an almost pure axial loading injury, resulting in a comminuted intra-articular distal tibia (pilon) fracture. A flailing component against the seat in front was less prominent. The left roll of the aircraft could have caused the occupant to be thrown forward in a skew manner forcing the right side against the front row first, causing the greater tuberosity fracture of the right humerus. The seat in front was pushed forward even though it was unoccupied, indicating significant loading by the occupants behind it. The 5th lumbar vertebral fracture shows again an almost pure axial load through all 3 columns. A posterior distraction caused by flailing over the seat belt was not present. The cross tubes under this seat place remained relatively straight, while those on either side were somewhat bent down. This caused the axial load to be almost completely transferred through the lumbar spine, causing the compression burst fracture with great loss of the height of the spinal corpus.

The kidney contusion could have been the result of a direct impact, possibly the armrest.

Figure 3. Injuries in Case 1: A. humeral shaft spiral fracture, B. blow out orbit fracture, C. proximal femur fracture



Case 3: centre section ISS 10
Main injuries: Cerebral contusion, right (AIS 3); Retinal laceration left (AIS 1)
Discussion: The overhead panel above this seat was missing. This panel may have contained an oxygen generator or video monitor, both of which are relatively heavy objects. The Passenger Service Unit (PSU) door was open and the oxygen masks were hanging down in this row. There was limited damage to the seatback in front and no damage to the tray table. An AIS 3 cerebrum contusion indicates a high velocity impact that would typically produce high head accelerations. An impact with the seatback producing that level of acceleration would have resulted in significant break-over of the seatback in front, which was not observed here. Therefore, this head injury was probably not caused by contact with the seatback, but more likely from impact of a large object falling from above. This same impact could have also caused the retinal injury.

Case 4: centre section. ISS 9
Main Injuries: Spinal fracture T11 (AIS 2); Spinal fracture T12 (AIS 3, Figure 4C); Sternum fracture (AIS 2, Figure 4D).
Discussion: This row had extra leg room which provided more space for the occupant to flail forward. The seat frame under this occupant was intact, but the overall condition of the seat just after the impact is hard to determine since it was one of several in this area removed by rescue workers. This means that the documented condition of the seat could include damage that occurred as it was extracted. The occupant suffered spinal injury of the flexion/ distraction type, with a compression fracture at the anterior corpus and continuation into the posterior column resulting in distraction. This was probably caused by the occupant flailing forward with the seat belt acting as a fulcrum.
The sternum fracture was a direct impact injury and could be inflicted by contact with the knees from forward flailing, consistent with T11/T12 vertebrae injuries. The distance to the seat in front makes it unlikely that the sternum could have struck a rigid structure on the back of the seat.

Discussion

In this pilot study we focused on mechanical injuries, which in crashes can be from inertial loading causing indirect acceleration/deceleration injuries, or the result of direct loading of various body parts against objects in the environment during impact. Contact injuries can be prevented by restraining the occupant and restraining potentially harmful objects. Acceleration injuries can be prevented through energy absorption in crush zones and energy absorbing seats. This discussion elaborates on the injury biomechanics of the illustrative cases in comparison to literature. Several safety items are identified.

Figure 4: Injuries Case 2 and 4.

A. Pilon fracture;
B. Lumbar spine fracture;
C. Thoracic spine fracture;
D. Sternal fracture

Loose objects

In case number 3, it is likely that a loose object struck the occupant's head causing an injury. The cerebrum contusion (AIS 3) indicates that a high-velocity impact of significant energy occurred. A blow like this to the seat in front would have left evident marks, which were not present. So, a loose object from above is more likely to have caused this injury. We found that in several places in the airplane the PSU or sometimes even heavier objects such as oxygen generators and video monitors came loose from the bottom of the overhead bins above the occupants and could have swung down with quite some force. Head injury causes a major safety issue in airplane crashes. When a head injury is severe enough to knock an occupant unconscious, they would be unable to evacuate the airplane. In a post-crash fire, this is often fatal. Improving the attachment of overhead objects could greatly improve survivability. In this crash, 60 (48%) of the survivors suffered a head, or face injury. (12)

Upper-Torso Restraints

The sternum fracture in case 4 is surmised to have been inflicted from contact with the knees by the occupant flailing forward, consistent with T11/T12 vertebral injuries. Sternal fractures in Motor Vehicle Crashes (MVA) often occur in combination with spinal injuries. (14) We found that 14 occupants in this crash suffered significant (AIS 3-5) chest injury. A shoulder harness or inflatable restraint system (airbag) that keeps the torso upright during a forward impact might have prevented this injury. Flexion distraction type spinal injuries, as first described by Chance and seen in case 4, were often observed in car crashes before the introduction of the 3 point shoulder restraint. (15) The seat belt allows the occupant to flail with the belt acting as a fulcrum, resulting in a flexion at the anterior and distraction at the posterior column (16). In this accident 23 (18%) of the 126 survivors suffered a spinal injury. (12) Six of these injuries were fractures with a flexion and distraction pattern. (Ref: Unpublished data: Spinal Injuries in an Airplane Crash; I.L.E. Postma, et al.) For many seat designs, the introduction of conventional shoulder harnesses may not be possible, as the seats may not have the structural strength to support the restraint, and they are designed to break over to limit head injuries to the passengers rear of the seat. Forces applied by a shoulder strap to the seat back would defeat this function. Inflatable restraint systems are available that can significantly reduce forward flailing without interfering with the seatback's load-limiting function. (17) However, implementation of technologies to mitigate one injury risk could have the unintended consequence of raising the risk of other injuries. For instance, retinal injuries are described in MVA as a result of a forward flail of the head against the deploying airbag. (18) With a pressure rise, compression and distraction of tissue can cause several types of injury, like orbital blowout fracture or retinal laceration. Studies of MVA show that the use of a shoulder restraint does not seem to decrease the incidence of pulmonary contusion and could even increase thoracic injury by rib fractures along the seatbelt line. (19; 20) Moreover, restraint systems that keep the occupant upright could increase the risk of head impact injuries from loose objects. (21) Studies also show that airbags and upper torso restraint systems are not effective in preventing upper- and lower-extremity injuries. (22)

Insufficient Vertical Energy Absorption

The femur fracture in case 1 resulted from a bending load. After an airplane crash in England, Brownson et al identified the front cross tube of the seat to be a fulcrum on which the femur breaks when the leg is forced down during forward flailing. (23-25) In our study population there were two additional femur fractures that could have been caused by the same trauma mechanism.

The lumbar spine fracture (L5) in Case 2 occurred in a seat place that had little to no vertical energy-absorbing capability. The centre place of a typical triple place seat is well supported by structure, whereas the end places are free to deflect downward as vertical loading increases. This downward deflection is likely to be the reason that Case 1 did not have a spinal fracture, even though that seat place received the same or greater vertical loading as the Case 2 seat place (based on the amount of vertical deformation observed). For the centre place, the only features available to absorb or control energy are the seat pan and seat cushion. Conventional seat cushions tend to amplify loads rather that absorb them, which leaves the energy absorbing function to the seat pan. (26) The deformation observed in the cantilevered seat places in the front of the aircraft were indicative of vertical loading in excess of the 14 CFR Part 25.562 Emergency Landing Conditions, so the frequency of spine injuries in this area of the aircraft is not unexpected. However, in other areas where seat deformation indicated vertical loading was less than in the forward section, there were also many occupants with spinal injuries. Among the 23 thoracolumbar spinal injuries throughout the cabin, 14 had a burst fracture pattern consistent with axial loading of the spine. (Ref: Unpublished data: Spinal Injuries in an Airplane Crash; I.L.E. Postma, et al.) Some of these injuries may have been prevented if the seats had provided more vertical energy absorption.

Floor and Seat Deformation

Floor deformation and disruption often occur in aircraft crashes and can cause seats spanning the distorted sections to become detached. This occurrence is prevalent enough that current aircraft seat safety standards (the 16-g seat rule) require that seats accommodate some distortion without failure. A benefit analysis of the 16-g seat rule by the U.S. Federal Aviation Administration and the UK Civil Aviation

Authority determined that in some accidents the use of dynamically qualified seats offer no benefit in terms of decreasing injury or fatality if there is extensive floor deformation. (4) In this crash, most seats remained attached, even in cabin areas where the distortion was beyond the level applied in seat qualification tests. However, in addition to creating a seat structural integrity risk, the significant amount of floor distortion and disruption that occurred in the front portion of the cabin also caused a direct injury risk by applying a vertical load to the occupants' legs. Studies show that pure axial loading on the foot/ankle complex is more likely to result in calcaneal fractures, but with added Achilles tendon tension, distal tibia fractures result. (27; 23) In MVA, Achilles tendon tension is thought to be the result of bracing for impact and braking with the foot pedal. In the case of airplane crash victims, extensive floor deformation could have caused the same injury mechanism. Intra-articular distal tibia fractures, like in cases 1 and 2, can cause significant impairment. Eighteen (14%) surviving occupants of the crash suffered in total 30 lower extremity fractures or ligamentous injuries. A major injury to a lower extremity could prevent an occupant from evacuating the airplane, which in a post-crash fire, could become fatal. In our study population, we found 6 patients with 8 tibia fractures that could have resulted from an axial load, and 3 patients with 4 tarsal fractures (talus, calcaneus and navicular) that were consistent with an axial load. These findings indicate that aircraft floor designs that limit the amount of floor distortion not only reduce the risk that seats will be detached, but can also reduce the risk of leg injuries.

Comparison with Previous Crash Investigation Findings

In 1995 and again in 2009, R.G.W. Cherry & Associates Limited, a consultancy company formed from widely experienced aeronautical engineers carried out a study, on behalf of the European Aviation Safety Agency, on the potential benefits of structural design changes that could improve passenger safety in aircraft accidents. (28) Some of the "Cabin Safety Threats" cited in that report that could lead to injuries are: 1) detached overhead bins and cabin equipment, 2) seat detachment, 3) floor deformation, 4) seatbelt failure, and 5) leg contact with structure resulting in lower-limb injuries. These threats coincide with some of the injury causation mechanisms we identified in this study. Findings from our study and from previous studies of similar accidents (absence of fire and toxic fumes, lack of brace position before impact) suggest that these identified injury risks may be typical for survivable aircraft crashes and are not unique to this specific crash.

Limitations

Although seat and aircraft damage information was available for all locations, lack of autopsy data for the fatally injured did not permit determination of the possible causes of those injuries. The injuries were coded using the 1998 version of the AIS. The injury codes and severity levels of some injuries have changed slightly in the latest (2008) version. Use of the older version does not allow direct comparison of this data set with the latest accident data that utilize the 2008 version. The injury causation findings in this study were deduced from the likely occupant motion induced by the apparent major impact vector and the seat/aircraft damage observed. Advanced computer modelling techniques could be used to analyse the entire crash sequence, and to estimate the acceleration time history for each seat place. This information could be used as an input to detailed aircraft seat/interior/occupant models designed to directly evaluate injury potential. Once calibrated using the documented injuries and damage, these models could show the most likely occupant/aircraft interior interactions that took place throughout the impact sequence and estimate the contact forces. This additional knowledge would increase the confidence level for many of the injury causation determinations.

Conclusions

This pilot study focused on the causes of the injuries sustained during a severe but survivable aircraft crash. While the study focused on some of the most seriously injured passengers, it should be noted that, considering the overall severity of the crash, a significant number of passengers (70%) had only minor to moderate injuries (ISS 0-8). While anecdotal, this statistic is an indication of the level of safety afforded by the current aircraft and seat system designs. In examining the causes of the injuries, four areas were identified where improvements could be made to reduce the risk of some of the observed injures. These areas are: 1) preventing or reducing the severity of head injuries by improving the security of objects above the head; 2) preventing some spine and chest injuries caused by forward flailing by incorporation of upper torso restraint, such as a shoulder harness, or inflatable restraint; 3) preventing or reducing the severity of lumbar and thoracic spine injuries by increasing the amount of vertical energy absorption provided by each seat; 4) preventing or reducing the severity of some leg injuries by limiting the amount of floor distortion that occurs during a crash. Previous comprehensive studies of relevant accidents have identified many of the same injury causation factors as prevalent in other crashes. Incorporation of improvements in these areas are likely to require further research to implement and to ensure that they do not introduce any new injury mechanisms.

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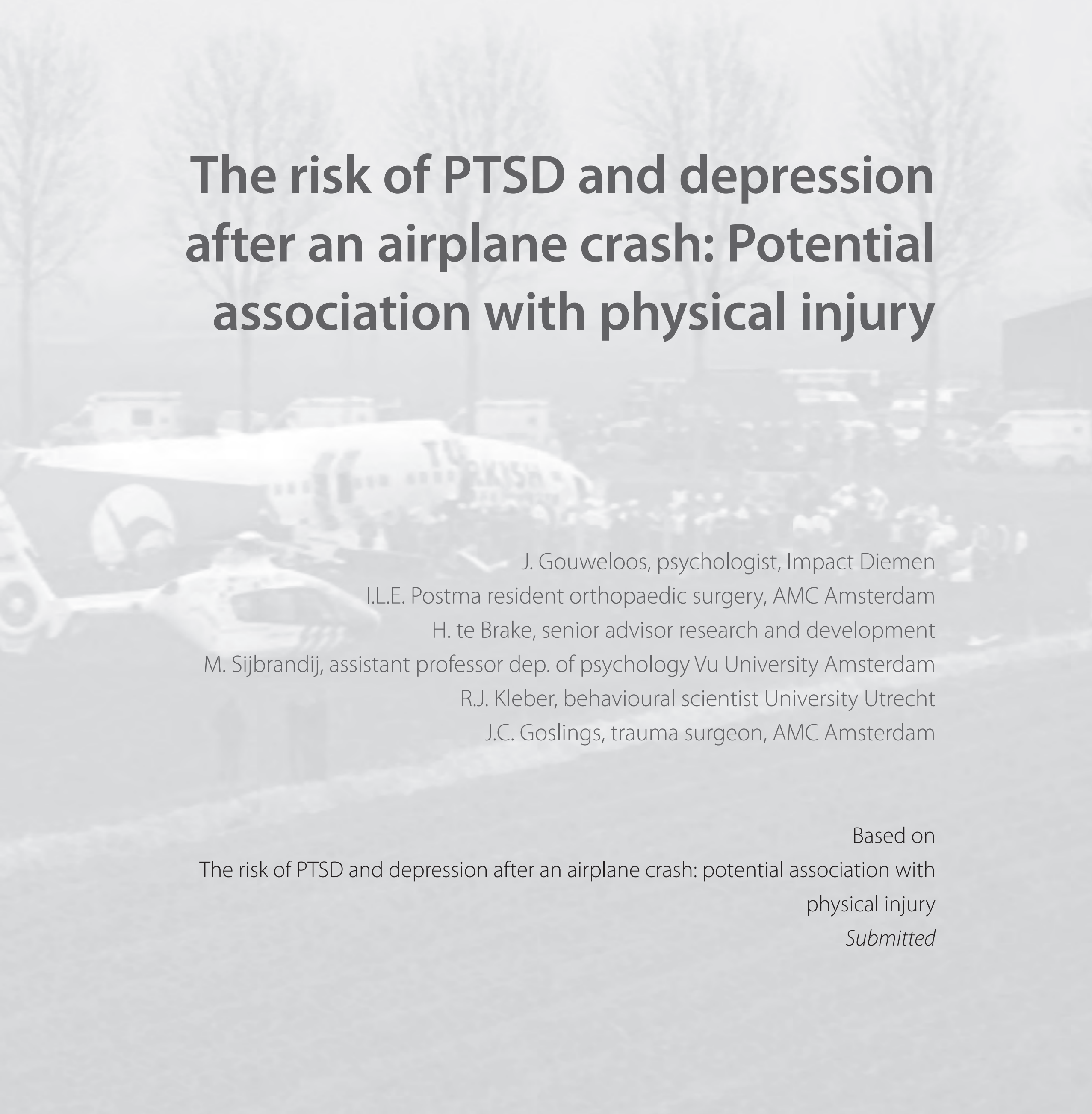

Chapter 11

The risk of PTSD and depression after an airplane crash: Potential association with physical injury

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Based on
The risk of PTSD and depression after an airplane crash: potential association with physical injury
Submitted

Abstract

Background

After experiencing a potentially traumatic event, a small percentage of people develop post-traumatic stress disorder (PTSD) and/or depression. This study aims to investigate 1. the risk of PTSD and depression after an airplane crash, and 2. whether this risk is predicted by trauma characteristics. Identifying these risk factors is crucial for early detection and treatment.

Methods

Of the 126 survivors of a commercial airplane crash near Amsterdam in 2009, 82 adults were included in this study. Risk for PTSD and depression was measured with the self-report instruments Trauma Screening Questionnaire and Patient Health Questionnaire-2, 2 and 9 months after the crash. Trauma characteristics assessed were Injury Severity Score (ISS), number of days in hospital and seating position in the airplane. Descriptive statistics and mixed design ANOVAs were computed to measure risk for PTSD and depression and its association with physical injury.

Results

Forty seven percent of participants showed an increased risk of PTSD, at both 2 and 9 months after the crash. The risk of depression was 34% at 2 months and 32% at 9 months. There was a small but significant correlation between length of stay in hospital and symptoms of PTSD and depression 9 months after the crash (r=.27 and r=.34 respectively). Mixed design ANOVAs showed no association between the course of symptoms of PTSD and depression 2 and 9 months after the crash and ISS or hospitalisation.

Conclusion

Survivors of an airplane crash are at risk frfPTSD and depression, but physical injuries and hospitalisation have no effect on the course of these symptoms; health care providers need to be aware that survivors may be at risk of PTSD or depression, regardless of the objective severity of their physical injuries.

Background

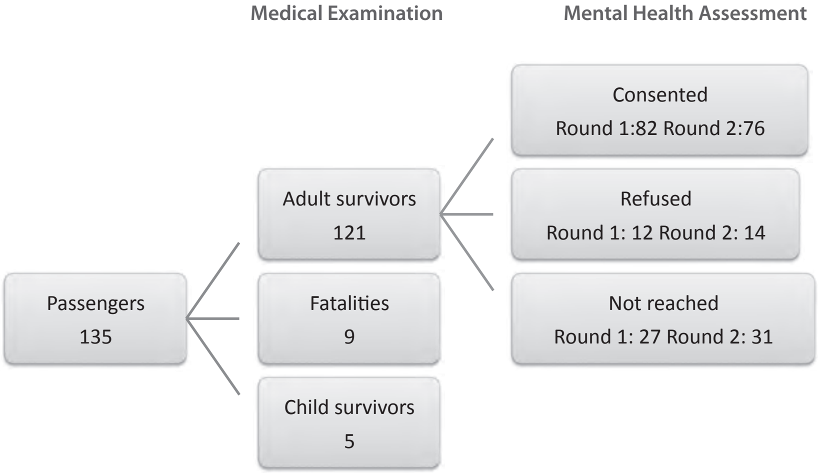
On 25 February 2009, a Boeing 737-800 crashed near Amsterdam Airport Schiphol. Most occupants (93%) survived the crash. Ninety five percent of survivors were injured. (1) Following such an event, survivors are at risk of developing mental disorders that may cause significant suffering and functional impairment, particularly Posttraumatic Stress Disorder (PTSD), major depression and other anxiety disorders. (2; 3)PTSD is characterised by involuntary intrusive thoughts of the event, avoidance, negative alterations in cognition and mood and heightened arousal. (4) Acute PTSD may be diagnosed one month after the traumatic event; chronic PTSD is diagnosed when symptoms persist for over 3 months. Depression may be diagnosed when symptoms of depressed mood and/or loss of interest in life activities last longer than 2 weeks. (4) Studies on PTSD and depression among airplane crash survivors are rare. In 1995, Gregg et al. found PTSD prevalence rates of 40% and depression rates of 33%. (5)

Early identification of symptoms of PTSD and depression is important to prevent a chronic course of PTSD; acute PTSD may be treated effectively with brief psychotherapy. (6) Identifying the risk factors in the acute phase following trauma that predict PTSD and depression is crucial for facilitating early treatment. First of all, characteristics of the traumatic event may affect the development of symptoms of PTSD and depression following trauma. (7; 8) For instance, proximity to the stressor is associated with an increased risk of symptoms. (8) Physical injury is also often considered a possible risk factor. (7) However, research studying the relationship between physical injury and mental health problems following a trauma, has yielded conflicting results. Most studies carried out on injured trauma patients, investigated survivors of motor vehicle accidents (MVA) and the majority of these studies report no significant relationship between injury severity and incidence of PTSD and/or depression. (9; 10; 11) However, since most of these studies were conducted in severely injured trauma patients, it remains possible that patients with severe injuries may be at higher risk of PTSD than patients with no or very mild injuries.

This study examined the risk of PTSD and depression in survivors of the February 2009 airplane crash and its relationship to characteristics of the event. The study population offered several advantages for research into this relationship. Firstly, it was homogeneous with respect to the type of event, as all participants were occupants of the airplane during the crash; secondly, the survivors varied in terms of severity of injury, from not injured to severely injured, and length of stay in a hospital after the crash. By combining data from two unrelated studies, we were able to include medical and psychological data of victims.

The study addressed two research questions: 1) what was the risk of PTSD and depression in survivors of the February 2009 airplane crash? and 2) to what extent were symptoms of PTSD and depression associated with trauma characteristics (injury severity, length of stay in hospital and event characteristics such as seating position) in survivors of this airplane crash?

Figure 1: Flow diagram of survivors and participants



Methods

Study population

On 25 February 2009, a commercial airplane crashed near Amsterdam in the Netherlands. Of the 135 occupants (passengers and crew) from 12 different nationalities, 9 were fatally wounded. (1) All 126 survivors (including 5 children) were screened and treated for injuries at the emergency departments of several hospitals. Demographic data (age, gender and nationality) and extensive medical data on all survivors were gathered. The regional Community Health Service (CHS) conducted a survey to identify symptoms of PTSD and depression 2 and 9 months after the crash using self-report instruments, administered by telephone. Survivors were invited to participate by letter or phone call. All interviewers received

appropriate training and interviews were conducted in Turkish, Dutch or English.
Figure 1 provides a flow diagram showing survivors of the crash and the participants of this study. Response rates were 68% at time point 1 (at 2 months; n = 82, total adult survivors N = 121) and 63% at time point 2 (at 9 months; n = 76). The main reason given for refusal to participate was that the individual had moved on with his or her life. Some had already received psychological treatment and some did not want to talk about their complaints.
The Regional Medical Ethical Committee and the Medical Ethical Board of the Academic Medical Centre Amsterdam gave approval for this study. Anonymised medical records were made available for this study, and the requirement to obtain consent for the use of these data was waived by the Medical Ethical board. All participants gave oral informed consent for participation in the CHS study; the parents of adolescents (15-18 years at time of the crash) also gave consent for their participation. The inclusion criterion was age above 14 years.

Outcome measures

To address our first research question, symptoms of PTSD and depression were measured. Symptoms of PTSD were measured using the Trauma Screening Questionnaire (TSQ), a ten item questionnaire developed to enable early identification of individuals at risk of PTSD. (12; 13) The TSQ uses a yes/no response format and asks about symptoms during the past week. It consists of five items about re-experiencing and five items about arousal taken from the DSM IV (Diagnostic and Statistical Manual of Mental Disorders, 4th ed.) PTSD criteria; scores range from 0 (asymptomatic) to 10 (14) A score ≥6 was considered to indicate that the individual was at risk of PTSD. (15) The TSQ is considered to accurately identify individuals at risk of a PTSD diagnosis using this threshold, when compared with a "gold standard", clinician-administered interview; sensitivities of 0.76-0.86 and specificities of 0.93-0.97 have been reported. (12)
Symptoms of depression were measured by the Patient Health Questionnaire 2 (PHQ-2), a two item measure that inquires about the frequency of depressed mood and anhedonia over the past two weeks. (16; 17) The PHQ-2 uses a four option response format (not at all; several days; more than half the days; nearly every day). Total score ranges from 0 to 6. A cut-off score of 3 was used to identify those at risk of depression. (16) The PHQ-2 score ≥3 has been found to correspond well with formal diagnosis; sensitivities of 0.83-0.87 and specificities of 0.78-0.92 have been reported. (16; 18)
To address our second research question, Injury Severity Score (ISS) length of stay

in hospital (LOS) and seating position in the airplane were measured. (17) Sixty four victims were admitted to a hospital for 1 or more days. Information about seating position in the airplane was provided by the Dutch Safety Board. We used seating position as a proxy for the difficulty of victims to get to safety after the crash, as measured by the distance to the nearest escape. Number of seats and rows, survivors had to pass before reaching the nearest exit were counted. Scores ranged from 0 (next to exit) to 10.

Table 1. Demographics and physical injury of the participants

	Adult Survivors (N=121)		Round 1 (N=82)			Round 2 (N=76)		
	N (%)	M (SD)	N (%)	M (SD)	Sig	N	M (SD)	Sig
Male	85 (70)		55 (67)			49 (65)		
Female	36 (30)		27 (33)		0.66	27 (35)		0.42
Dutch	60 (50)		47 (57)			45 (59)		
Turkish	46 (38)		28 (34)		0.41***	26 (34)		0.37***
Other**	15 (12)		7 (9)			5 (7)		
Age*		40.2 (13.2)		40.4 (13.7)	0.91		41.7 (14.1)	0.46
ISS		6.6 (9.3)		5.4 (6.5)	0.32		6.1 (7.0)	0.69
ISS 0-8	85 (70)		60 (73)			53 (70)		
ISS >8	36 (30)		22 (27)		0.65	23 (30)		0.94
LOS		5.2 (12.4)		4.2 (8.1)	0.49		4.5 (8.3)	0.65
Days at hospital	64 (53)		42 (50)		0.81	41 (54)		0.88

*In 2009. **Other nationalities were mostly Iranian, American, English and Syrian. ***We tested whether the deviation of Turkish and Dutch survivors differed from the participants at round 1 and round 2. For other nationalities, groups were too small for Chi Square analysis.

Analysis

To examine the characteristics of the participants and investigate our first research question, descriptive statistics, independent t-tests and chi-square tests were conducted. To test our second research question, bivariate correlations (Pearson), mixed design ANOVAs and independent t-tests were conducted. Bivariate correlations were used to examine the association between demographic variables (age, gender), trauma characteristics (ISS, LOS as continuous variables) and symptoms of PTSD and depression at 2 and 9 months after the crash. Mixed design ANOVAs were conducted to examine if ISS and hospitalisation (as dichotomous variables) were related to the course of PTSD symptoms and depressive symptoms between 2 and 9 months after the crash. We used an ISS threshold of 8, and compared survivors with no or minor injuries (ISS = 0-8) and moderate to severe injuries (ISS ≥ 9). (18) Participants who were admitted to hospital for 1 or more days were compared with participants who were not hospitalised. With independent t-tests we examined whether the number of seats and rows survivors had to pass before reaching the nearest exit differed between participants at high risk of PTSD or depression compared participants at low risk.

Statistics were computed in SPSS® Statistics 20, with p-levels of < 0.05 taken to indicate statistical significance.

Results

Characteristics of participants

Table 1 presents demographic data (gender, age, nationality) for adult survivors and participants who completed the TSQ and/or PHQ-2 at both time points. There were no significant differences in the distribution of gender, age and nationality between the total population of survivors of the crash and participants who completed the study protocol.

After the crash 3 were not injured (ISS = 0) and 118 survivors were injured (ISS > 0). Many of the survivors (45%, n = 54) had an ISS score of 1 (e.g. bruises, lacerations). Thirty percent (n = 36) were moderately to severely injured e.g. fractures, multiple trauma (ISS score > 8). Fifty-three percent of survivors (n = 64) were admitted to a hospital after being treated in the emergency department. Of those hospitalized, 33% (n = 21) stayed in hospital for longer than 1 week and 3 participants were hospitalized for more than 1 month.

Table 1 includes the ISS and LOS for the population of adult survivors and the samples at time points 1 and 2. There was no difference between the study sample and the population of adult survivors in terms of mean scores on the ISS and LOS. Table 1 also shows that the group distribution of the survivor population and the study sample did not differ with respect to injury severity and hospitalisation.

Research question 1: High-risk groups of PTSD and depression

At time points 1 and 2, 47% of the participants (n = 33 and n = 35 respectively) were considered to be at risk of PTSD (a score of ≥ 6). Mean TSQ scores were 5.23 at time point 1 (SD = 3.45, N = 70) and 4.79 at time point 2 (SD = 3.47, N = 75). Furthermore, 34% (n = 27) of participants at time point 1 and 32% (n = 24) of participants at time point 2 were at risk of depression (a score of ≥ 3). Mean PHQ-2 scores were 2.09 at time point 1 (SD = 1.99, N = 80) and 1.84 at time point 2 (SD = 1.84, N = 76).

Table 2. Mean TSQ score related to ISS and hospitalisation.

		TSQ Round 1	TSQ Round 2
	N (64)	M (SD)	M (SD)
ISS 0-8	46	5.0 (3.4)	4.3 (3.5)
ISS≥9	18	5.7 (3.7)	5.8 (3.5)
Not hospitalised	30	5.0 (3.3)	3.7 (3.5)
Hospitalised	34	5.4 (3.6)	4.7 (3.5)

Table 3. Mean PHQ-2 score related to ISS and hospitalisation

		PHQ-2 Round 1	PHQ-2 Round 2
	N (66)	M (SD)	M (SD)
ISS 0-8	47	1.8 (2.0)	1.6 (1.8)
ISS≥9	19	2.1 (1.6)	2.2 (2.0)
Not hospitalised	31	1.7 (2.0)	1.3 (1.6)
Hospitalised	35	2.1 (1.8)	2.1 (2.0)

Research question 2: Relation between symptoms of PTSD, depression and physical injury

At time point 2, longer LOS correlated with a higher TSQ score (r = 0.27, p < 0.05) and PHQ-2 score (r = 0.34, p < 0.05). At time point 1 there was no such correlation. ISS was not associated with TSQ or PHQ-2 score at either time point. Age and gender were not associated with TSQ and PHQ-2 scores.

Tables 2 and 3 show mean TSQ and PHQ-2 scores for participants grouped by injury severity and hospitalisation. There was no interaction between TSQ score and ISS (p =0 .29) or between PHQ-2 score and ISS (p = 0.50), indicating that the course of PTSD symptoms and depressive symptoms did not differ significantly between high and low ISS participants. In addition no main effect of time on the course of PTSD symptoms (p =0.43) or depressive symptoms (p =0.76) were found, indicating that there was no significant decrease in TSQ and PHQ-2 scores between 2 and 9 months after the crash.

There was also no significant interaction between hospitalization and TSQ score (p = 0.055) and between hospitalisation and PHQ-2 score (p = 0.65), indicating that the course of PTSD symptoms and depressive symptoms was not different for hospitalized participants and non-hospitalized participants. In addition, there was no significant main effect of time on the course of PTSD symptoms (p = 0.12) and depressive symptoms (p =0.50), indicating that there was no significant decrease in TSQ and PHQ-2 scores between 2 and 9 months after the crash.

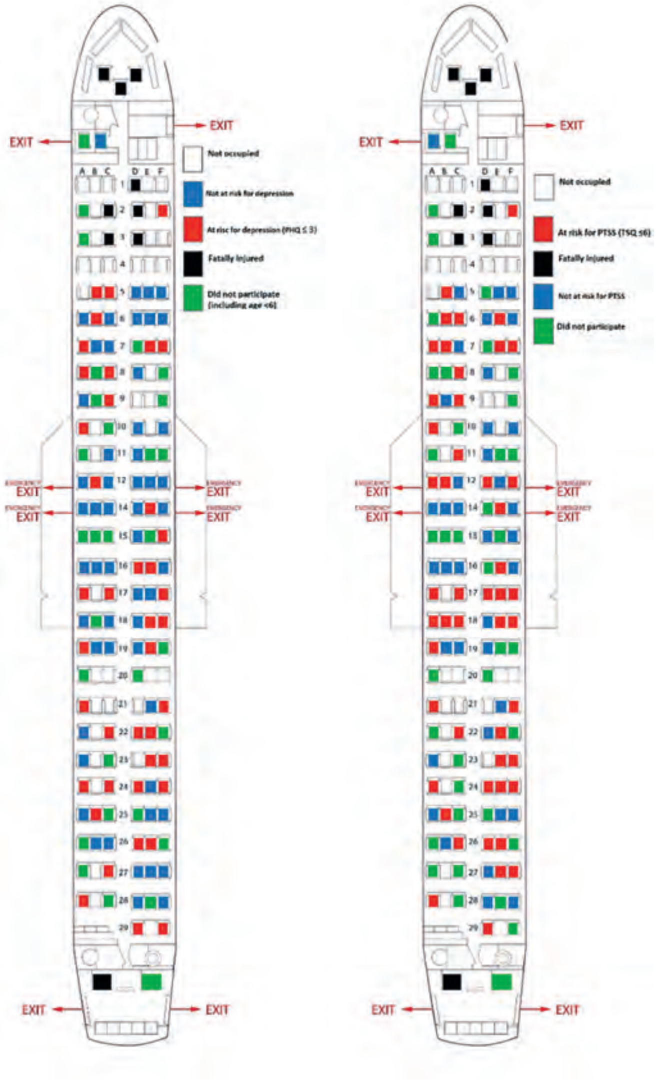
The seating distribution of participants at risk of PTSD or depression at time point 1 and/or 2 in the airplane is shown in Figure 2. Visual inspection of this figure suggests no relationship between seating position and later being at risk of PTSD or depression. It shows that survivors later assessed as at risk were spread throughout the airplane. Independent t-tests showed no difference between participants at high risk compared to participants at low risk of PTSD or depression at time points 1 and 2 with respect to the number of seats and rows survivors had to pass before reaching the nearest exit.

Discussion

The first research question focused on the risk of developing PTSD and depression in 82 survivors of a commercial airplane crash near Amsterdam, in the Netherlands. We found that 47% of survivors were at risk of PTSD 2 months after the crash, the same percentage were at risk for PTSD 9 months after the crash. The prevalence of risk of depression was 34% 2 months after the crash and 32% 9 months after the crash. These rates are relatively high, compared to previously reported prevalence of 10%. (2; 19) There are a number of possible reasons for this. First, all survivors were in close proximity to the event and were unable to escape; proximity is an important risk factor for mental health problems. (7; 20) Proximity varies between events, but is generally high in accidents. This explanation is supported by the findings from two previous studies on PTSD and depression after an airplane crash. In 1988 Sloan assesed 32 survivors of a non-fatal charter flight crash and found initially intense stress that subsided over the following months. (21) In line with our results, Gregg at al. found that 40% of survivors of an airplane crash in England in which 47 people died and most of the 79 survivors were injured had a PTSD diagnosis and 33% had a diagnosis of major depression in the year after the crash. (5) There is also a high risk of mental health problems after motor vehicle accidents, although some studies have produced contradictory results. (22-25) (26; 27) A second explanation for the rather high PTSD and depression rates relates to the use of self-report screening instruments. These are known to over-estimate mental health problems compared to structured clinical interviews. (28) This explanation alone cannot in itself explain the higher prevalence, as many studies of mental health problems in disaster survivors have used self-report questionnaires and reported lower prevalence. (3; 29; 30) It is important to note that the TSQ and PHQ-2 questionnaires are considered accurate for the early identification of PTSD and depression. A third explanation for the high rates relates to cultural differences. Drogendijk et al. found that Turkish migrant victims of a disaster scored considerably higher than native Dutch victims on instruments assessing mental health problems and posttraumatic stress. (31; 32) To test this explanation we compared Turkish and Dutch participants in our sample, but found no group differences in either TSQ or PHQ-2 score. A fourth explanation relates to the mental health care survivors received after the incident. Some survivors may not have received the mental health care they needed, and this is more than likely, given that occupants of the airplane originated from several countries. Survivors can be dissatisfied with the support provided after an airplane crash, however in this case the CHS actively sought to identify all survivors with mental health problems and to help them find appropriate, local psycho-social care. (33) Nonetheless this explanation cannot be ruled out.

The second research question focused on whether symptoms of PTSD and depression were associated with trauma characteristics. Injury severity, hospitalisation and distance to an exit were not associated with the course of symptoms of PTSD and depression. Those at risk of PTSD or depression were also not overly represented at the front of the airplane, where the severe and critical injuries occurred. This result is in line with previous studies that did not find any relationship between physical injuries and mental problems. (9-11) It also confirms previous findings that subjective experience of the severity of an event may be more important than objective indicators of trauma severity (such as ISS, hospitalization or seating position). (9; 25; 34) Although stringent ANOVA analyses found no association, length of stay in a hospital has a significant correlation with symptoms of PTSD and symptoms of depression 9 months after the crash. This is consistent with the findings of Sijbrandij et al. who reported that injury tends to be associated with late onset symptoms rather than early symptoms. (9) This may be because survivors focus on physical recovery first and become aware of psychological distress later. In the long term, survivors may become functionally impaired and have work or relationship difficulties that may contribute to symptoms of depression and PTSD. (35)

Figure 2 Seating arrangement for those at risk of PTSD and depression



Limitations

This study has a number of limitations. Obviously sample size was limited, which reduced the statistical power of the study. The TSQ does not measure the whole spectrum of PTSD symptoms; specifically it does not address avoidance symptoms. This could have resulted in misclassification of individuals in our sample with undetected symptoms of PTSD. Finally, because this study started measuring symptoms at 2 months after the crash, we could not identify survivors who suffered from symptoms within the first 2 months but recovered naturally before the study started.

Given these limitations, we strongly recommend future research to confirm our findings, using different and larger samples with varying severity of physical injury. This would improve the understanding of differences in the relationship between proximity to a stressor and subjective and objective injury.

Conclusions

Almost half the survivors of the airplane crash are at risk of PTSD and a third of depression. Objectively measured physical injuries and hospitalisation had no association with the course of the symptoms of either PTSD or depression. Raising awareness of these results among health care providers is important. Victims' need for mental health care cannot be related to their often much more visible physical needs, so monitoring mental health needs is particularly important, not only during the first days after an incident, but also over the following weeks and months. Survivors without severe physical injuries may nevertheless suffer from mental health problems; communication and cooperation between the medical health care system and community health services is therefore essential to deliver optimal long term care.

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Chapter 12

Summary, general conclusions and future perspectives

Samenvatting, conclusies en vooruitzichten

Dankwoord en CV

Mass casualty incidents (MCIs) pose a great challenge to manage. In this thesis a thorough analysis of the medical management and outcomes of an airplane crash, of February 2009, is described. In retrospect this incident involved many casualties, but seemed a relatively manageable incident. If circumstances had been different, such as a larger airplane, or a crash site in a built-up area, organising the medical relief could have been much more challenging. It is important to be prepared for these events. Studying incidents meticulously can help to prepare for future incidents.

*During the process of the several studies, certain calculations of the ISS scores needed to be revised. The injuries and AIS scores were correct but some ISS scores had been miscalculated. This has led to minor revisions of some results, which did not lead to different conclusions. In all chapters the correct results are displayed. In chapter 2 and 9 some numbers differ from the published article. These numbers are indicated with an *asterisk. The whole dataset of revised results is given here in table.

	Initial data	Revised data
Total range ISS	0-57	0-66
ISS 0 (no injury)	6	6
ISS 1-8	85	84
ISS9-15	22	21
ISS ≥16	13	15
Mean ISS of all occupants (n=126)	6.3	6.4

Part 1

In part 1 of this thesis the general events and outcomes of the accident are described. An overview is given and the aims of the further research are identified. The available early data collected here, gave insight into the magnitude of the accident, the difficulties faced in managing the medical needs, and possible bottlenecks that were worthwhile addressing.

In ***Chapter 2*** the overall description of the event is presented. In the February 2009 Turkish Airlines aircraft crash near Amsterdam Airport Schiphol, the Netherlands, 9 people died and 120 were wounded. There was no in-hospital mortality. Fifteen casualties were multi-trauma patients with an ISS of ≥16. The mean ISS was 6.4 with a range of 0-66. The analysis has shown that, even though the crash occurred in the most densely populated area of the Netherlands, with numerous hospitals nearby, a considerable period of time elapsed between the crash occurring and the arrival of the victims at the hospitals. There were hardly any records found of the pre-hospital triage and there appears to have been discrepancies in the definition of critically injured (triage category P1) patients. Finally, evaluation of the types of injury has revealed a remarkable number of head/ facial injuries and spinal injuries. The MOTAC ('Medical Research Turkish Airlines Crash') study group identified several areas of further study. These areas were the pre-hospital management with triage, patient distribution and the accompanying protocols; the in-hospital management with the radiological work-up and the possibility and impact of delayed diagnosis of injury in this MCI; Detailed injury studies including the injury mechanism must provide further insight into the safety of air travel; Finally the importance of studying the long term mental effects of the crash on the survivors was recognised.

Part 2

This part deals with the pre-hospital phase of the MCI and ***Chapter 3*** reveals that in only 12% of casualties was pre-hospital data recovered. Triage tags were hardly used even though 'only' 126 casualties needed evaluation. In larger incidents, with greater numbers of casualties, practical sorting methods of triaged casualties are indispensable. However, all casualties in this MCI were eventually evaluated in a hospital and no under-triage was present. We also evaluated the under-triage to standards of daily practice, not MCIs, which determines whether critically injured casualties (triage category P1) are transported to the highest level of care in the region. In this sense, the 12% under-triage in our study can be considered low for an MCI. Over-triage rates were high (80-89%) when considering the Baxt criteria of casualties in need of acute life-saving measures. When using the ISS as a measure, the rates were lower (35-63%). However, an ISS ≥16 can involve non (acute) life-threatening injuries and ISS should not be used as the only means to define critically injured casualties as in the P1 triage classification. Our data show that walking casualties from an airplane crash and/or triaged as P3 can still have major injuries, including spinal fractures. Repeated evaluation of casualties (re-triage), is therefore necessary. In this crash, 75% of the casualties had no spinal immobilisation during transport to hospital, and 22% of the casualties eventually diagnosed with spinal injury were not transported with immobilisation. If the trauma mechanism had been considered at an earlier stage, emergency medical personnel at the scene would probably have immobilised more casualties. The decision that all casualties should be evaluated in-hospital on the basis of the high energy trauma criteria, was correct.

In the study of the distribution of the patients in ***Chapter 4***, we found that without formally using a Patient Distribution Protocol (PDP), a critical mortality rate of 0% was accomplished in this particular Mass Casualty Incident (MCI) involving 126 casualties. However, the existing PDP appeared to be unclear and did not account properly for multi-regional medical response for MCIs in this large high risk area. Personnel managing patient distribution were not acquainted with the actual protocol.

The existing regional PDP defined a hospital's medical treatment capacity (MCT) in MCIs as 3% of total bed capacity. This does not reflect the true treatment capacity of hospitals' emergency department. Four hospitals received more casualties than described in the PDP, and exceeded their assigned (3%) medical treatment capacity by 133- 223 %. Three hospitals received 4-11% of their assigned treatment capacity. One hospital was officially requested to put its disaster plan into action, but received 1 casualty. Only 4 (11%) of the critically injured (P1) casualties and 1 multi-trauma casualty (ISS ≥16,) were not primarily transported to a Level I trauma centre. Three secondary transfers were needed which demonstrates good patient distribution.

Casualties were distributed to too many hospitals in an unnecessarily large area. If all hospitals within a 25 km radius had been considered, this would have been sufficient to cope with all the casualties.

In ***Chapter 5 and 6*** a proposal is laid down for a new patient distribution protocol (PDP). Casualty surge in disasters and MCIs involve 3 distinct phases. These phases should form the basis of the management of patient distribution and transport prioritisation.

Chapter 5 deals with the calculation of the Critical Care Capacity (CCC), which consists of Emergency Department Capacity (EDC) based on the number of resuscitation beds and the availability of adequately trained medical personnel, divided by the time needed to stabilise a P1 and P2 casualty (Critical Stabilisation Time, CST). Using the right formula, an accurate CCC can be calculated per hour, and a maximum for every hospital. These numbers will provide the basis of a well-designed patient distribution protocol.

Chapter 6 gives an example of how to use the calculated CCC numbers to design a specified PDP for a high risk area like Amsterdam Airport Schiphol. It is based on the number of expected casualties and distance of the hospitals. Hospitals should not be driven to maximum capacity. A capacity reserve of about 25% must be taken into account. The maximum amount of time for scene evacuation of P1 and P2 casualties should be 1-6 hours. All disciplines involved in the management of an MCI should be involved in the process of developing MCI protocols, recognising their expertise in their appropriate field on a daily basis. The new concepts presented here should be tested in a drill. MCI protocols should be trained on a regular basis.

Part 3

In this part an in depth analysis is provided of the in-hospital management of the crash casualties.

In ***Chapter 7***, concerning the radiological work-up of trauma resuscitation, it is mentioned that 72% of the casualties underwent some form of diagnostic imaging. Only 18% of all victims received diagnostic imaging studies of all four body regions as recommended by ATLS®. Compliance with ATLS® guidelines was higher in Level I hospitals than in Level II or III hospitals (36.5% compared to 2% and 14.3% respectively) but can still be considered low. Compliance was highest in the severely injured victims (ISS ≥16; 73.3%). Body regions with the highest priority in the ATLS® guidelines were most frequently imaged, with the chest being imaged most frequently. The next most frequently imaged body region was the lumbar spine and third was the cervical spine. This could have been expected considering a high level of suspicion of spinal injury, given the mechanism of trauma in this airplane crash. A total of 47 injuries were diagnosed within the ATLS® body regions of which 20 were significant (Abbreviated Injury Scale, AIS of ≥3). Only 2 injuries in ATLS® body region were diagnosed late, but were considered to be of little clinical significance. All (near) total body CTs were performed in Level I hospitals. Nevertheless using total body CT in an MCI as a triage tool as well as being a diagnostic tool can be feasible as well. With skilled clinical triage it is safe to deviate from the ATLS® guidelines in the radiological work-up of less severely injured patients, and in our study did not result in the delayed diagnosis of any serious injury. In MCIs, an optimised diagnostic imaging strategy is important for maximum survival of the most severely injured.

Airplane crashes have high incidences of spinal injuries, as was found in ***Chapter 8*** of this study, namely 18.3%. The incidence of spinal injury in high energy motor vehicle accidents (MVA) is comparable with the results in this study, namely 11.2% to 18.6%. Little is known about the incidence of spinal injuries in airplane accidents but the few case reports describe incidences varying from 7.2% to 32.1 %. The mean ISS of the patients with spinal injury was significantly higher than the mean ISS of all injured occupants, namely 15.7 versus 6.7. Three quarters of all multi-trauma patients (ISS ≥16) had a spinal injury. One spinal fracture was missed during primary and secondary survey in hospital, and after diagnosis, no surgical treatment was deemed necessary. Apparently the index of suspicion of spinal injury in the hospitals was high, in contrast to the pre-hospital index of suspicion. The extensive use of CT scan in today's trauma care might explain the decrease in missed spinal injuries.
The segmental distribution of spinal injuries in our study revealed a low number of cervical fractures (14.8% of injuries) compared to general trauma literature (18-21%). This might be explained by the fact that the vertical deceleration component was greater than the horizontal component in this crash. This also explains the unexpected low rate of distraction (25.9% type B and C) injuries and high rate of burst fractures. More than half (51.9%) of the injuries had a burst component, meaning the vertebral end-plate was fractured with involvement of the posterior wall. Considering the use of the lap seatbelt, we would expect a higher rate of flexion distraction type B/C injuries. Due to the high vertical loading in this crash we presume that the effect of a shoulder-harness in mitigation of the spinal injuries to be less than the proven effectiveness of such measures in MVA's. Further biomechanical studies might be able to improve crash safety and decrease injury morbidity.

Diagnosing all injuries in trauma patients can be challenging, especially when numerous patients are presented to a hospital within a short amount of time. ***Chapter 9*** is about the delayed diagnosis of injury (DDI) in the casualties of this MCI. DDI incidence in the victims of this airplane crash was 7% and affected 12% of the hospitalised casualties. This is comparable to the published literature in trauma. All DDIs were found in the 2 hospitals receiving the largest numbers of casualties, with the highest severity of injuries. A tertiary survey was documented for all patients that had DDI. The total of documented tertiary surveys was only 65%. This means that it is possible that, in the remaining 35% (without documentation of a tertiary survey), some DDIs were missed. The documentation of a tertiary survey in our study population was sub-optimal. A high ISS, head injury with AIS ≥2, the need for

an emergency intervention and >5 injuries/patient were associated with a higher chance of a DDI.
A comparison was made with an airplane crash in the UK in 1989. The Nottingham, Leicester, Derby, Belfast (NLDB) Study Group concluded that the incidence of DDI is not related to overall patient condition. Perhaps the difference of 7% in the Dutch crash versus 10% in the UK crash (or 12% compared 30% in population) in DDI incidence can also be explained by the fact that more casualties from the UK crash were severely injured than in the Dutch crash (ISS ≥16 of 30.7% compared 11.9%). We found some correlation factors for the risk of DDI, but the associations are in accordance with literature. The UK crash happened before ATLS® was fully adopted in the UK and thus also probably before a structured tertiary survey was routine in daily practice. Over the last decades the implementation of ATLS® may have led to a low number and earlier discovery of DDIs.

Part 4

The aftermath of the accident concerns the study into improvements to be made to mitigate injury in the future, and long term effects on the survivors. The pilot study in ***Chapter 10***, focused on the causes of the injuries that occurred during a severe but survivable airplane crash. It should be noted that, considering the overall severity of the crash, a significant number of passengers 70% had only minor to moderate injuries (ISS 0-8). While anecdotal, this statistic is an indication of the level of safety afforded by the current aircraft and seat system designs. In examining the causes of the injuries, four areas were identified where improvements could be made to reduce the risk of some of the injuries observed. These areas are: 1) Prevention of head injury and decreasing head injury severity by improving the security of objects above the head. In many places overhead objects had come down during the crash, and 60 (48%) of the surviving occupants suffered a head or facial injury. 2) Prevention of chest injuries caused by forward flailing by incorporation of upper torso restraint, such as a shoulder harness, or inflatable restraint. We found that 14 occupants in this crash suffered significant (AIS 3-5) chest injury. 3) Reduction of lumbar and thoracic spine injuries by increasing the amount of vertical energy absorption provided by each seat; As reported in ***Chapter 9***, more than half (51.9%) of the spinal injuries had a burst component, consistent with high vertical loading. Some of these injuries may have been prevented if the seats hadprovided more

vertical energy absorption. 4) Preventing or reducing the severity of some leg injuries by limiting the amount of floor distortion that occurs during a crash. In our study population we found 12 fractures of the lower leg that are consistent with an axial load. The significant amount of floor distortion and disruption that occurred in the front portion of the cabin, caused a direct injury risk by applying a vertical load to the occupant's legs. These findings indicate that aircraft floor designs that limit the amount of floor distortion not only reduce the risk that seats will be detached, but can also reduce the risk of leg injuries.
Previous comprehensive studies of relevant accidents have identified many of the same injury causation factors as prevalent in other crashes. Incorporation of improvements in these areas will require further research before implementation; They also need to ensure that they do not introduce any new injury mechanisms.

Chapter 11 studies mental health risks of the survivors of the crash on the basis of 2- consecutive rounds of telephone interviews. Forty seven percent of participants showed an increased risk of PTSD, both at 2 months and 9 months after the crash. The risk of depression was 34% at 2 months and 32% at 9 months. ISS and hospital stay were not associated with symptoms of PTSD and depression. The correlation between length of hospital stay following the airplane crash and symptoms of PTSD and depression 9 months after the crash was small but significant (respectively r=0.27 and r=0.34). Our results show that mental health issues are very common among the survivors. Therefore the aftercare should also be aimed at prevention and early recognition of symptoms of mental health issues.

General Conclusions

Triage and patient distribution according to triage priority is indispensable in the management of mass casualty incidents.

After an airplane crash, the injuries of less severely injured casualties can be underestimated, probably due to suboptimal recognition of the high energy trauma mechanism involved.

MCI protocols need to be simple, clear and have an identical basic order to provide practical guidance.

In an MCI, hospitals should receive a number of casualties based on an accurate calculation of their (critical care) capacity.

The ATLS® protocol provides adequate guidance in the radiological work-up of casualties of the MCI of an airplane crash. In less severely injured casualties, deviation from protocol is safe after a good clinical evaluation.

A routine performance of a tertiary survey, as designed by ATLS®, leads to the diagnosis of significant injuries days after the accident.

Spinal injuries are common in an airplane crash. Understanding the trauma mechanism can lead to a high index of suspicion of certain types of injuries.

Biomechanical analysis of injuries sustained in an airplane crash identifies safety issues in airplane construction that warrant further study.

Survivors of an airplane crash are at a high risk of developing post-traumatic stress disorder and depression. Early recognition is needed to be able to provide adequate aftercare.

Future perspective

When mass casualty incidents and disasters occur, evaluation is warranted. In this thesis several issues were identified in the 3 phases of this MCI:
In the pre-hospital management, it is important that simple and clear protocols are used, which are identical in each geographical region and for all disciplines involved. MCI work-process should reflect daily practise. We did not identify the ideal format for triage tags. A triage tag needs to be fast, simple, open for re-triage and feasible in all weather and terrain. Digital triage tags could transmit information. In daily practice ambulance personnel is already used to transmitting a digital announcement to the receiving hospital, with information about the patient. These features need to be combined so that the daily practice for ambulance personnel becomes feasible in the management of MCIs.
Considering patient distribution in MCIs, there are many different protocols in the Netherlands. These protocols sometimes overlap in responsibilities and are

contradictory, sometimes even within themselves. The evaluation of the crash was discussed at several meetings, with multiple institutes or individuals concerned with MCI management. This has led to proposals for improvements that were more widely recognised. However, we have recently received an updated proposal of a patient distribution protocol that still contains several errors. There is a need to involve different kinds of disciplines and industries in developing protocols. When the consensus format is developed and validated it should be implemented nationally. This thesis provides a first draft of such a protocol.

All personnel involved in the management of an MCI should be properly trained for their individual task and this training should be repeated in MCI drills every few years.

Doctors who are concerned with the care of trauma casualties may learn from the experiences provided in this thesis. In addition to the extensive education and training, this experience can be of vulue when dealing with many complex injuries in a high stress environment.

The biomechanical analysis of the injuries sustained in this airplane crash has provided some new questions on how to mitigate injury severity and prevent mortality. Detailed aircraft seat/interior/occupant models designed to directly evaluate injury potential can be used in the future to show the most likely occupant/aircraft interior interactions that take place throughout the impact sequence and estimate the contact forces. This additional knowledge would increase the confidence level for many of the injury causation determinations.

In the future a more active approach is required in an MCI or disaster when identifying those at risk of mental health issues. This should be commenced directly after the event.

In preparing for MCI's and disasters, it is important to anticipate risks and bottlenecks. At the time of the actual event, the need for ad hoc decisions should to be limited. History provides the knowledge to cope with future events.

Brace for the impact you can expect!

Samenvatting, conclusies en vooruitzichten

Management van grootschalige incidenten en rampen is een lastige opgave. In dit proefschrift wordt, naar aanleiding van de vliegtuigcrash in februari 2009 nabij Schiphol, aangegeven hoe belangrijk het is om de gebeurtenissen van een grootschalig incident of ramp objectief en in detail te bestuderen. Achteraf bekeken waren er veel slachtoffers bij dit incident, maar bleek de hulpverlening redelijk goed te organiseren. Er zijn omstandigheden denkbaar waarin dat veel moelijker zou zijn geweest. Bijvoorbeeld wanneer er een groter vliegtuig zou zijn neergestort of het vliegtuig zou zijn neergestort op een bebouwd gebied. Het is belangrijk om voorbereid te zijn op dergelijke situaties. Het gedetailleerd onderzoeken van ongevallen kan helpen om in de toekomst beter om te gaan met dergelijke incidenten.*Tijdens het proces van de verschillende studies, is het nodig geweest om voor een aantal slachtoffers de scores van de ernst van het totaal aan letsels, de ISS (Injury Severity Score), aan te passen. De codering van de gedocumenteerde letsels, de AIS scores (Abbreviated Injury Scale), was correct. In een paar gevallen waren echter, vanuit deze AIS scores, de ISS score onjuist berekend. Dit heeft geleid tot kleine aanpassingen in de data maar niet tot andere conclusies. In hoofdstuk 2 en 9 verschillen enkele data van het gepubliceerde artikel. Deze data zijn aangegeven met een *asterisk. De data met de verschillen zijn hieronder aangegeven in een tabel.

	oude data	nieuwe data
Totaal bereik ISS	*0-57*	*0-66*
ISS 0 (niet gewond)	*6*	*6*
ISS 1-8	*85*	*84*
ISS9-15	*22*	*21*
ISS ≥16	*13*	*15*
Gemiddelde ISS van alle inzittenden (n=126)	*6,3*	*6,4*

Deel 1

In Deel 1 van dit proefschrift worden de algemene gebeurtenissen en gegevens van het vliegtuigongeval beschreven. Er wordt een overzicht gegeven en de doelstellingen van toekomstig onderzoek worden benoemd. Met de gegevens die in dit deel verzameld zijn kwam er zicht op de omvang van het ongeval en de moeilijkheden tijdens het hulpverleningsproces die de onderzocht dienden te worden. In ***Hoofdstuk 2*** worden de gebeurtenissen van 25 februari 2009 omschreven. Op die dag crashte vlucht TK1951, een Boeing 737-800 van Turkish Airlines, vlak voor de landingsbaan van de internationale luchthaven Schiphol. Negen mensen overleefden de crash niet en 120 mensen raakten gewond. Er is niemand in het ziekenhuis of op weg naar het ziekenhuis overleden. Vijftien slachtoffers waren poly-traumatisé, met een ISS ≥16 (ISS= Injury Severity Score, een maat voor hoe ernstig gewond iemand is; de maximale score is 75). Dit betekent dat ze meerdere ernstige letsels hadden opgelopen. De gemiddelde ISS was 6.4 en het totale bereik 0-66. Ondanks dat de crash in een dichtbevolkte regio plaats vond, duurde het lang voordat de slachtoffers het ziekenhuis hadden bereikt. Na 3,5 uur was de helft nog niet in een ziekenhuis. Pas na 6 uur was iedereen naar een ziekenhuis gebracht. Er was weinig documentatie over de triage van de slachtoffers vanuit "het veld" (pre-hospitaal), en er zijn ook maar zeer weinig (11) triage kaarten terug gevonden. Er leek veel onduidelijkheid te zijn over de definitie van *kritisch gewonde* slachtoffers (triage categorie T1). Bij de evaluatie van de letsels bleken er opmerkelijk veel mensen letsel van het hoofd en gezicht te hebben opgelopen, alsmede wervelletsels. Er werden verschillende gebieden aangewezen die nader diende te worden onderzocht. Dit waren:

- de pre-hospitale zorg met triage en gewondenspreiding plus de bijhorende protocollen;
- de in-hospitale zorg met de radiologische werkprocessen en de invloed van een grootschalig ongeval met veel slachtoffers op het diagnosticeren van alle letsels, en de kans op gemiste diagnosen;
- gedetailleerde onderzoeken naar de mechanismen waardoor de letsels zijn ontstaan, om een beter inzicht te krijgen in de "vliegveiligheid";
- de lange termijn effecten op de mentale gezondheid van de slachtoffers van de crash.

Deel 2

In dit deel wordt de pre-hospitale zorgfase na dit grootschalige ongeval onderzocht. In Nederland hebben alle ziekenhuizen een accreditering toegewezen gekregen voor de opvang en behandeling van ongevalsslachtoffers op een schaal van I tot III op basis van hun faciliteiten. Een Level I traumacentrum heeft alle specialisaties en volledige capaciteit voor opvang en behandeling van ongeval slachtoffers; een

Level II ziekenhuis heeft beperkte faciliteiten; en een Level III ziekenhuis heeft minimale faciliteiten met betrekking tot de traumazorg.

Hoofdstuk 3 beschrijft de pre-hospitale triage. Van slechts 12% van de slachtoffers documentatie is terug gevonden van de pre-hospitale triage classificatie. Er zijn ook nauwelijks triage kaarten gebruikt, ook al betrof het een relatief klein aantal van 126 slachtoffers. Bij grootschalige ongevallen en rampen is het essentieel om een praktische methode te handhaven om ernstig en minder ernstig gewonde slachtoffers te onderscheiden. Dit vormt de leidraad bij het prioriteren van slachtoffers met betrekking tot het geven van medische hulp en vervoer naar het ziekenhuis. Uiteindelijk zijn alle slachtoffers voor een medische beoordeling en, indien nodig, behandeling naar het ziekenhuis vervoerd. Vanuit dat oogpunt was er geen onder-triage. Onder-triage kan ook berekend worden naar de ratio van het aantal kritische gewonde slachtoffers (triage categorie T1) dat niet direct naar een Level 1 traumacentrum is gebracht, t.o.v. het totale aantal kritische gewonde slachtoffers. Dit is meer conform de dagelijkse praktijk. Volgens deze berekening heeft er 12% onder-triage plaatsgevonden. Dit kan als weinig worden beschouwd in een grootschalig ongeval. Er was wel een hoog over-triage getal. Dit was namelijk 80-89% beoordeeld naar het aantal slachtoffers dat een levensreddende spoed interventie nodig had (*Baxt criteria*), ten opzichte van het aantal slachtoffers dat als kritiek gewond (T1) was getrieerd. Wanneer de ISS score van de slachtoffers wordt genomen om de mate van over-triage te beoordelen, was dat met 35-65% een stuk lager. Het is echter wel van belang om te realiseren dat een ISS hoger dan 16 kan bestaan uit een optelsom van niet levensbedreigende letsels. Maar een ISS $\geq$16 kan ook uit één of meer letsels bestaan die wel meteen een medische handeling vereisen, vanwege een hoge kans op overlijden wanneer dit niet geschiedt.

Uit de gegevens van deze crash is gebleken dat slachtoffers die als licht gewond werden geclassificeerd (triage categorie T3) of die op eigen kracht lopend uit het wrak zijn gekomen toch nog ernstig letsel konden hebben, zoals gebroken rugwervels. Het is daarom belangrijk om slachtoffers herhaaldelijk medisch te beoordelen. Tijdens het transport naar het ziekenhuis is 75% van de slachtoffers niet met wervelimmobilisatie (wervelplank en/of harde nekkraag) vervoerd. Uiteindelijk zijn er bij een groot aantal slachtoffers wervel fracturen (botbreuken) gediagnosticeerd (zie ***hoofdstuk 8***). Van deze slachtoffers had 22% geen wervelimmobilisatie tijdens transport naar het ziekenhuis. Gezien het hoog energetisch karakter van het ongeval, had bij meer slachtoffers de wervelkolom moeten worden beschermd tijdens transport. Erkenning van dit hoog energetische karakter heeft er wel toe geleid dat werd besloten alle slachtoffers voor een medische beoordeling naar het ziekenhuis te brengen. Dit was een correct besluit.

In ***hoofdstuk 4*** wordt de gewondenspreiding van de slachtoffers over de ziekenhuizen bestudeerd. Het bestaande gewondenspreidingsprotocol is niet goed nageleefd, maar er is niemand op weg naar of in het ziekenhuis overleden. Hiermee komt de "critical mortality rate" op 0%. Met dit getal wordt het deel van het aantal kritische slachtoffers (triage categorie T1) dat op weg naar of in het ziekenhuis is overleden bedoeld, ten opzichte van het totale aantal T1 slachtoffers. Het bestaande gewondenspreidingsprotocol was onduidelijk en niet geschikt voor een bovenregionale opvang, zoals snel is nodig bij een grootschalig ongeval in en hoog risico gebied als een internationale luchthaven. Verschillende hulpverleners die de taak van gewondenspreiding op zich hadden waren niet of onvoldoende bekend met het protocol. In het protocol wordt de "medische behandel capaciteit" van ziekenhuizen benoemd als 1% of 3% van hun totale bedden aantal. Tevens staat er een onduidelijke norm in van 1-2 T1/T2 slachtoffers per behandelteam per uur. Deze cijfers geven geen duidelijk beeld van capaciteit van ziekenhuizen voor de opvang, stabilisatie en behandeling van grote aantallen ongevalsslachtoffers. De slachtoffers van de crash zijn verspreid over 14 ziekenhuizen. Vier ziekenhuizen zijn daarbij, volgens het protocol, overbelast met een aantal slachtoffers corresponderend met 133-223% van hun "Medische Behandel Capaciteit". Drie andere ziekenhuizen ontvingen slechts 4-11% van hun "Medische Behandel Capaciteit". Een van deze ziekenhuizen was zelfs na een officieel verzoek opgeschaald, door het in werking stellen van hun "Ziekenhuis Rampen Opvang Plan" (ZiROP), maar kreeg slechts 1 slachtoffer. Slechts 4 (11%) van de kritisch gewonde slachtoffers (T1) en 1 poly-traumatisé (ISS ≥16) zijn niet direct naar een Level 1 trauma centrum gebracht; 3 slachtoffers zijn secundair overgeplaatst naar een ander ziekenhuis. Vanuit dit oogpunt is de gewondenspreiding goed verlopen. De slachtoffers zijn verspreid in een groot geografisch gebied (grootste afstand van crash tot ziekenhuis 53.5 km). Terwijl de opvangcapaciteit van de 11 ziekenhuizen die binnen een straal van 25 km van het ongeval liggen meer dan genoeg was voor de opvang van alle slachtoffers.

De ***Hoofdstukken 5 en 6*** bestaan uit een voorstel voor een nieuw gewondenspreidingsplan. In dit plan worden 3 fasen onderscheiden in de hulpverlening na een grootschalig ongeval. Deze fasen vormen de basis voor de tijdsindeling bij de hulpverlening, en voor de prioritering van het transport van de slachtoffers.

In ***Hoofdstuk 5*** wordt de nieuwe term "Kritische Opvang Capaciteit" van ziekenhuizen gedefinieerd. De "Kritische Opvang Capaciteit" van een ziekenhuis wordt berekend aan de hand van de capaciteit van de afdeling Spoed Eisende Hulp (SEH) (voor en na opschaling) op basis van het aantal bedden/ opvang plekken voor kritisch en ernstig gewonde slachtoffers (T1 en T2). Tevens moet het aantal medisch opvang teams dat kan worden geformeerd berekend worden. Dit SEH capaciteitsgetal moet gedeeld worden door de tijd die nodig is om T1 en T2 slachtoffers te stabiliseren (primaire en secundaire survey volgens ATLS®). Aan de hand van deze formule kan een accurate berekening worden gemaakt van de "Kritische Opvang Capaciteit" van een ziekenhuis. Deze ratio en deze getallen vormen de basis is van een goed gewondenspreidingsplan.

In ***Hoofdstuk 6*** word een voorstel gedaan een nieuw gewondenspreidingsplan voor een hoog risico gebied voor grootschalige ongevallen en rampen. Hierbij wordt de internationale luchthaven Schiphol als voorbeeld genomen. Op basis van de in ***Hoofdstuk 5*** beschreven formule kan de "Kritisch Opvang Capaciteit" van alle ziekenhuizen in Nederland worden bepaald. Ziekenhuizen mogen niet tot hun maximum beladen worden, dus moet er een reserve van 25% worden ingebouwd. Op basis van het geschatte aantal slachtoffers wordt er een verdeling gemaakt van de slachtoffers over de ziekenhuizen. Hierbij wordt rekening gehouden met de specialistische capaciteiten van de ziekenhuizen (Level, I, II en II) en hun "Kritische Opvang Capaciteit". Alle slachtoffers moeten in het tijdsbestek van 1 tot 6 uur geëvacueerd kunnen worden van de plaats van ongeval. Voor hoog risico gebieden zoals Schiphol kan het protocol met de precieze verdeling van slachtoffers van te voren worden opgesteld. (zie ***Hoofdstuk 6*** *tabel 4*). Het hier beschreven format moet nog worden gevalideerd in rampenoefeningen. Het zal ook daarna regelmatig moeten worden geëvalueerd en getraind. Bij de ontwikkeling van protocollen voor grootschalige ongevallen en rampen moeten de verschillende disciplines die onderdeel zijn van de hulpverlening allemaal betrokken worden.

Deel 3

In dit Deel worden in-hospitale processen van de hulpverlening na de vliegtuig crash geëvalueerd.

Hoofdstuk 7 gaat over de radiologische work-up in de opvang van de ongeval slachtoffers. Na de crash heeft 72% van de slachtoffers een vorm van radiologische beeldvorming ondergaan (röntgenfoto, echo, CT of MRI scan). Bij slechts 18% van de slachtoffers was er beeldvorming verricht van alle 4 de lichaamsregio's die in de ATLS® richtlijn worden aanbevolen. ATLS® ("Advanced Trauma Life Support") is de wereldwijde gouden standaard voor de opvang van trauma patiënten, ontwikkeld door "the American College of Surgeons". In Level I ziekenhuizen werden de aanbeveling van ATLS® beter nageleefd dan in Level II en III ziekenhuizen (respectief bij 36.5%, 2% en 14.3% van de slachtoffers). Dit kan als een lage naleving worden beschouwd. Bij de meest ernstig gewonde slachtoffers was de naleving het hoogst, namelijk 73.3% bij slachtoffers met een ISS≥16. Van de lichaamsregios's die in de ATLS® richtlijn de hoogste prioritiet hebben was ook de meeste beeldvorming verricht, met als nummer 1 de thorax (beeldvorming van de borstkast ten behoeve het opsporen van schade aan o.a. de longen). Als 2e is de meeste beeldvorming verricht van de lumbale wervelkolom (lendenwervels) en de cervicale wervelkolom (halswervels). Dit kan worden verklaard door de verwachting van een groot aantal slachtoffers met letsel in deze regio's op basis van het ongeval mechanisme, en omdat deze lichaamsregio's lastiger te boordelen kunnen zijn bij lichamelijk onderzoek. In totaal zijn er bij de slachtoffers 47 letsels gediagnosticeerd in de "4 ATLS lichaamsregios's". Hiervan waren er 20 klinisch significant, met een (AIS) letsel score van 3 of hoger. Dit is op een schaal van 1 tot 5, waarbij 1 een lichte verwonïng betreft (bijvoorbeeld een kneuzing) en 5 een direct levensbedreigend letsel (bijvoorbeeld een scheur in de grote lichaamsslagader, de aorta). Er waren slechts 2 diagnosen in 1 van de ATLS® lichaamsregio's laat gediagnosticeerd (zogeheten 'gemiste diagnosen', zie ***Hoofdstuk 9***). De type letsels waren van weinig belang in de primaire opvang en stabilisatie van deze slachtoffers.

Bij 9 slachtoffers was er een CT scan van het hele lichaam (total body CT) gemaakt. Dit was in alle gevallen in een Level I ziekenhuis. Deze slachtoffers waren bijna allemaal zeer ernstig gewond met een gemiddelde ISS van 27 (bereik 9-66). In een grootschalig ongeval kan het gebruik van de CT scan voor beeldvorming van het gehele lichaam van nut dienen voor zowel triage als diagnostische doeleinden. Na een goede klinische beoordeling van minder ernstig gewonde slachtoffers kan het veilig worden geacht om af te wijken van de ATLS® richtlijnen voor de radiologische beeldvorming. Bij de opvang van grote aantallen slachtoffers van een grootschalig ongeval is een goed radiologisch beeldvormingsprotocol is van groot belang. dit het meest bij aan de overlevingskansen van de ernstig gewonde slachtoffers.

Bij auto- en vliegtuigongevallen komen vaak wervelletsels voor. In ***Hoofdstuk 8*** worden de wervelletsels van de slachtoffers van deze vliegtuigcrash geëvalueerd. Ruim 1% van de slachtoffers had één of meerdere wervel letsels. Op één patiënt na betroffen dit allemaal fracturen (botbreuken). Dit voorkomen (de incidentie) is vergelijkbaar met die van auto ongevallen (11,2%-18,6%). Er is weinig bekend over de incidentie van wervelfracturen na vliegtuigongevallen, maar in de spaarzame literatuur worden cijfers genoemd van 7,2%-32,1%. De slachtoffers met wervelletsel waren beduidend ernstiger gewond dan de gehele geroep van slachtoffers, met een gemiddelde ISS score van 15,7 versus 6,7. Driekwart van de poly-traumatisé (ISS≥16) had dan ook een wervelletsel. Bij één slachtoffer was er een wervelfractuur gemist tijdens de primaire opvang. Nadat de diagnose was gesteld, bleek een operatie niet nodig. Blijkbaar was men tijdens de opvang in het ziekenhuis bedacht op de grote kans op wervelletsels. Dit was in de pre-hospitale opvang niet het geval, wat bleek uit het lage percentage slachtoffers dat op een wervelplank (en/of met nekkraag) naar het ziekenhuis was vervoerd. In een vergelijkbaar vliegtuigongeval in 1989 in Engeland waren er initieel veel wervelletsels gemist. Tegenwoordig wordt er veel meer gebruikt gemaakt van CT scans wat de diagnose van wervelfracturen makkelijker heeft gemaakt.

Er waren relatief weinig fracturen van de hals wervels (14,8%) in vergelijking met de algemene literatuur over ongeval patiënten (18-21%). Dit kan wellicht worden verklaard door het feit dat er in dit ongeval een relatief grote verticale/axiale kracht op het lichaam van de slachtoffers is gekomen omdat het vliegtuig, nagenoeg “uit de lucht kwam vallen”. Bij de meeste vliegtuigongevallen en natuurlijk bij auto-ongevallen is de horizontale kracht overheersend. Dit verklaart ook het relatief lage aantal “flexie-distractie” letsels van de wervelkolom. Bij dit type letsel wordt de wervelkolom met kracht gebogen, zodat er aan de voorzijde de wervels in elkaar worden gedrukt (compressie) en aan de achterzijde de wervels uit elkaar worden getrokken. Dit type letsel past goed bij het dragen van een 2-punt gordel over het bekken, zoals vroeger veel in auto-ongevallen werd gezien. Bij dit vliegtuigongeval had het dragen van een 3-punts gordel de slachtoffers waarschijnlijk nauwelijks kunnen behoeden voor de wervelletsels omdat de grootse component van de kracht dus in verticale/ axiale richting was. Er zijn verdere biomechanische studies nodig om de mogelijkheid om wervelletsels te voorkomen (of in ernst te verminderen) beter te onderzoeken.

Bij alle ongeval slachtoffers, bestaat er een kans dat letsels initieel worden gemist. Deze kans is vooral groot wanneer er veel slachtoffers tegelijk zijn en deze allemaal in een korte tijdsbestek medisch moeten worden beoordeeld en behandeld. In ***Hoofstuk 9*** wordt ingegaan op deze zogenaamde "gemiste diagnosen" onder de slachtoffers van deze crash. De incidentie van gemiste diagnosen was 7% van het aantal letsels en betrof 12% van de slachtoffers die uiteindelijk voor één of meerdere dagen in het ziekenhuis waren opgenomen. Deze incidentie is vergelijkbaar met de literatuur over ongevalsslachtoffers. Alle gemiste diagnosen kwamen voor in de twee ziekenhuizen die het grootste aantal slachtoffers van de crash hadden opgenomen, waarvan een grootdeel ernstig gewond was. Bij ongevalsslachtoffers is het gebruikelijk om tijdens opname in het ziekenhuis het slachtoffer nog minimaal 1x van top tot teen te onderzoeken om te controleren over er nog letsels onopgemerkt zijn gebleven. Dit heet de *tertiaire survey*. Bij 65% van alle slachtoffers was er een dergelijke tertiaire survey gedocumenteerd in hun medische status; dit is niet optimaal. Alle gemiste diagnosen zijn gevonden bij de slachtoffers waar er wel een tertiaire survey was gedocumenteerd. Het zou dus kunnen dat er in de overige 35% nog meer letsels onopgemerkt waren gebleven.

Slachtoffers met een hoog ISS of een hoofdletsel met een minimale graad van ernst (AIS) van 2 hadden een verhoogde kans op een gemiste diagnose. Ook het moeten ondergaan van een spoedinterventie, en het hebben van meer dan 5 letsels toonde een relatie met gemiste diagnosen. Een aantal van deze associaties worden ook beschreven in de literatuur.

Er is vergeleken met de uitkomsten van een vliegtuigongeval in Engeland in 1989. Hier werd geconcludeerd dat de kans op een gemiste diagnose niet samenhing met de ernst van het letsel van de slachtoffers. Er werd hier een hoge incidentie van gemiste diagnose gerapporteerd van 10% van de letsels bij 30% van de slachtoffers. Hier moet bij vermeld worden dat dit een ernstiger ongeval betrof, waarbij 30,7 % van de slachtoffers een ISS van 16 of meer had (poly-traumatisé), en 39 van de totaal 126 inzittenden van het vliegtuig zijn overleden. Dit ongeval in Engeland gebeurde voordat de ATLS® methode volledig zijn intrede had gedaan in Europa. Deze werkmethode was dus ook nog niet standaard in Engeland. De introductie van de ATLS® methode met de daarbij behorende tertiaire survey kan hebben bijgedragen aan de daling van het aantal gemiste diagnoses in de laatste paar decennia.

Deel 4

In het onderzoek betreffende de nasleep van de vliegtuig crash is er gekeken naar de mogelijkheid om in de toekomst letsel te voorkomen, en naar de lange termijn effecten op de psychische gezondheid van de slachtoffers.

Hoofdstuk 10 is een pilot studie naar het ontstaansmechanisme van de letsels die zijn opgelopen in deze ernstige, maar overleefbare vliegtuigcrash. Het is belangrijk op te merken dat 70% van de slachtoffers slechts licht tot matig ernstig gewond was (ISS 0-8). Dit zegt iets over de bescherming die de vliegtuigconstructie tijdens de crash heeft geboden. Na het bestuderen van de letsels en hun ontstaansmechanisme zijn er 4 gebieden geïdentificeerd waar verbeteringen in de constructie van het vliegtuig mogelijk zijn om letsels te voorkomen of de ernst ervan te verminderen. Deze gebieden zijn: 1) Voorkomen van hoofdletsel en het verminderen van de ernst van hoofdletsel door het beter zekeren van objecten boven het hoofd van de inzittenden. Op veel plekken waren er bagagebakken en andere objecten boven de inzittende losgekomen. Zestig slachtoffers (48%) hadden een letsel aan het hoofd of gezicht. Een hersenschudding met (tijdelijk) bewustzijnsverlies kan fataal zijn wanneer een slachtoffer daardoor niet kan ontkomen als er brand uitbreekt. 2) Het dragen van een 3-punts gordel of een opblaasbare barrière (zoals een airbag) kan voorkomen dat een inzittende met een grote kracht naar voren wordt geworpen, tegen de stoel of wand voor hem. Dit kan (ernstig) letsel aan de borstkast en longen voorkomen. Onder de slachtoffers van deze crash waren er 14 met een significant thorax (romp) letsel (AIS 3-5). 3) Het vergrote van de energie absorptie kwaliteiten van de stoelen kan (ernstige) fracturen (botbreuken) van de borstwervels en lendenwervels voorkomen. Zoals al in ***Hoofdstuk 9*** werd gerapporteerd, waren er 23 slachtoffers met wervelkolom letsel waarvan meer dan de helft veroorzaakt door een grote verticale/axiale kracht. 4) Het aantal letsels, en/of de ernst van letsels, aan de onderbenen kan mogelijk gereduceerd worden door het verminderen van de vervorming van de vloer in het vliegtuig. In dit onderzoek zijn er 12 fracturen van de onderbenen gevonden die veroorzaakt waren door een axiale/verticale kracht (zoals je bijvoorbeeld ziet als iemand van een hoogte valt en op zijn voeten landt). Vooral in het voorste gedeelte van het vliegtuig werd een grote mate van vervorming van de vloer gevonden. Een versterkt vloerontwerp zou niet alleen de kunnen voorkomen dat stoelen loskomen, maar kan ook letsel aan de benen voorkomen.

Bij eerdere uitgebreide onderzoeken naar relevante vliegtuigongevallen zijn dezelfde oorzaken van letsels vastgesteld. Er is meer onderzoek nodig om de voorgestelde verbeteringen te testen en te controleren of deze niet juist weer ander letsel veroorzaken.

Hoofstuk 11 gaat over de lange termijn effecten van het vliegtuig ongeval op de psychische gezondheid van de slachtoffers. Er zijn 2 opeenvolgende telefonische enquêtes met gevalideerde vragenlijsten afgenomen onder de slachtoffers van de vliegtuigcrash. Hieruit bleek dat na 2 en na 9 maanden 47% van de ondervraagden een verhoogd risico had op post-traumatisch stress syndroom (PTSS). Na 2 maanden had 34% een verhoogd risico op depressie en na 9 maanden 32%. Er was geen relatie met letsel ernst of opname in het ziekenhuis. Het is duidelijk dat de psychische gevolgen van dergelijk ongeval niet onderschat moeten worden. Het is daarom belangrijk om de slachtoffers, op zowel korte als lange termijn, na het ongeval te evalueren, om zo vroegtijdig symptomen van PTSS en depressie te onderkennen, en behandeling aan te bieden.

Conclusies

Triage en gewondenspreiding naar (medische) prioriteit is onmisbaar bij de hulpverlening na grootschalige ongevallen en rampen.

Na een vliegtuigcrash worden de letsels van de minder ernstig gewonde slachtoffers snel onderschat. Dit kan worden veroorzaakt door onvoldoende begrip of kennis van het hoog energetische karakter van het ongeval.

Protocollen voor grootschalige ongevallen en rampen moeten simpel en eenduidig zijn en moeten allemaal gebaseerd zijn op dezelfde principes, willen ze op een werkbare manier richting kunnen geven aan hulpverleners.

Bij grootschalige ongevallen moet het aantal slachtoffers dat een ziekenhuis kan opvangen gebaseerd zijn op een correcte berekening van de “Kritische Opvang Capaciteit”.

Het ATLS® protocol is goed bruikbaar als richtlijn voor de radiologische work-up van slachtoffers van een grootschalig incident als een vliegtuigcrash. Bij minder ernstige gewonde slachtoffers kan er, na een goede klinische evaluatie, op een vellige manier worden afgeweken van deze richtlijn.

Routinematige verrichting van een tertiaire survey volgens ATLS® protocol kan leiden tot vermindering van klinisch significante gemiste diagnosen.

Wervelletsels komen vaak voor als gevolg van een vliegtuigongeval. Begrip en kennis van het ongevalsmechanisme is belangrijk voor het onderkennen van het risico op bepaalde type letsels.

Door middel van biomechanische analyses van de letsels die zijn ontstaan door de crash zijn er veiligheidsissues geïdentificeerd met betrekking tot de constructie van het vliegtuig.

Overlevenden van een vliegtuigcrash hebben een verhoogd risico op post-traumatisch stress syndroom en depressie. Een vroege herkenning kan bijdragen aan het reduceren van lange termijn effecten.

Vooruitzichten

Zolang er grootschalige ongevallen en rampen gebeuren is het van belang om ze te bestuderen. In dit proefschrift zijn verschillende lessen in de 3 fasen van dit ongeval geïdentificeerd. Voor de pre-hospitale hulpverlening is het van belang dat er duidelijke protocollen zijn die allemaal gebaseerd zijn op dezelfde principes ongeacht geografische oriëntatie of uitvoerende discipline. We hebben geen ideale triage kaart geïdentificeerd, maar een goede triage kaart moet, simpel en snel zijn, de mogelijkheid bevatten om een her-triage uit te voeren en bruikbaar zijn in alle weer- en terreincondities. Het zou ideaal en conform deze tijd zijn, wanneer triage kaarten digitaal zijn zodat de informatie die ze bevatten verzonden en verzameld kan worden. In de dagelijks praktijk is het al gebruikelijk dat ambulance personeel een vooraankondiging verstuurt naar het ziekenhuis met informatie over de patiënt. Het is belangrijk dat deze eigenschappen gecombineerd worden zodat de dagelijkse werkwijze van ambulance personeel ook bruikbaar wordt bij grootschalige ongevallen en rampen.
In Nederland zijn er zeer veel protocollen en draaiboeken voor grootschalige ongevallen en rampen. Veel van deze protocollen overlappen elkaar in verantwoordelijkheid, maar zijn tegelijkertijd niet compatibel en spreken elkaar tegen. De gebeurtenissen van de crash op 25 februari 2009 en het hulpverleningsproces daarna zijn uitgebreid en meermaals geanalyseerd en bediscussieerd in verschillende

conferenties en vergaderingen. Dit heeft geleid tot voorstellen ter verbetering van o.a. het gewondenspreidingsprotocol, welke breed werden gedragen. Toch kwam ons recent een voorstel van een gewondenspreidingsprotocol onder ogen waarin nog steeds dezelfde fouten werden gemaakt. Het is belangrijk om bij de ontwikkeling van protocollen voor grootschalige ongevallen en rampen, alle disciplines te betrekken die onderdeel zijn van de hulpverlening. Wanneer het juiste format is gevonden moet dit getest en gevalideerd worden in rampenoefeningen. Daarna kan het uniform worden geïmplementeerd in heel Nederland. In dit proefschrift is een begin gemaakt met een dergelijk format.

Iedereen die onderdeel is (of kan zijn) van de hulpverlening bij grootschalige ongevallen en rampen moet hierin herhaaldelijk getraind worden. Zowel de individuele taken als het teamproces dienen elke paar jaar geoefend te worden in rampenoefeningen.

We hopen dat artsen die betrokken zijn bij de opvang en behandeling van ongevalsslachtoffers kunnen leren uit dit proefschrift. Wanneer het gaat om het behandelen van complexe letsels in een stressvolle omgeving is ervaring van onschatbare waarde.

De biomechanische analyse van de letsels die zijn opgelopen in dit vliegtuigongeval hebben veel nieuwe vragen opgeworpen over de mogelijkheden morbiditeit en mortaliteit te voorkomen. Het zou mooi zijn als we in de toekomst met behulp van experts op het gebied van letsel biomechanica en vliegtuigconstructie de voorlopige bevindingen van dit proefschrift verder kunnen onderzoeken.

In de toekomst is het van belang om slachtoffers van een ongeval of ramp actief te benaderen en te evalueren op symptomen van PTSS en depressie, om door vroegtijdige herkenning lange termijn schade te voorkomen.

Wanneer je je voorbereidt op grootschalige ongevallen en rampen is het van belang om vooraf te anticiperen op mogelijke moeilijkheden en beperkingen. Dit voorkomt ad hoc beslissingen tijdens het daadwerkelijke proces van hulpverlening. De geschiedenis biedt veel informatie en kennis noodzakelijk om toekomstige rampen het hoofd te bieden.
Brace for the impact you can expect!

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Lieve Derk, jij had geen idee waar je aan begon toen we elkaar leerden kennen. Nou, je hebt het geweten! ;-) Ook al had ik zo weinig tijd, het ging allemaal opeens een stuk makkelijker, dankzij jouw geduld en liefde. Ik heb zo ongelooflijk veel zin in Sicilië, en alle komende avonturen samen.

Curriculum Vitae

Ingri Postma was born in Rotterdam on October 19, 1980. She spent her childhood in Utrecht, and graduated from high school (Utrechts Stedelijk Gymnasium) in 1998. Ingri studied medicine at the University of Maastricht. In these years she explored healthcare in a broad spectrum. She attended several courses of Dutch law and did a scientific internship at the World Health Organization in Geneva, Switzerland. During her clinical internships she went to Willemstad, Curacao and Cape Town, South Africa. Here, her interest in trauma care became visible for the first time when she did an extra-curricular internship with the Ambulance/ Paramedic Services. Her final clinical internship brought her to the Trauma Unit at the Academic Medical Centre (AMC) in Amsterdam, under the supervision of prof. J. C. Goslings. After obtaining her medical degree in 2006 she started to work at the department of surgery at the Diaconessenhuis in Utrecht (dr. G.J. Clevers). In 2008 she started her orthopaedic residency at the department of Surgery of the Spaarne Ziekenhuis in Hoofddorp (dr. G.J.M. Akkersdijk) and 3 months at the Kennemergasthuis (dr. H.L.F. Brom). During her training at the Spaarne Ziekenhuis in Hoofddorp, she was involved in the trauma resuscitation of casualties of the crash with flight TK 1951 at the 25th of February 2009. This was the beginning of the extensive research in to the medical care after this airplane crash. The next few years she performed several in depth studies, under the supervision of prof. J.C. Goslings, while continuing her orthopaedic residency. In 2011 Ingri worked at the department of orthopaedics at the AMC Amsterdam (prof. C.N. van Dijk), 2012 at Tergooi ziekenhuizen Hilversum (dr. A.M.J.S Vervest), and in 2013 at the Amphia Ziekenhuis Breda Hospital (dr. D. Eygendaal). Now she is in her final year of her residency and back at the AMC.
In the future as an orthopaedic surgeon, Ingri would like to specialise in trauma surgery and continue to contribute to the optimal medical care after mass casualty incidents and disasters.