Brace for impact! A thesis on medical care following an airplane crash
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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.

<table>
<thead>
<tr>
<th></th>
<th>Initial data</th>
<th>Revised data</th>
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</thead>
<tbody>
<tr>
<td>Total range ISS</td>
<td>0-57</td>
<td>0-66</td>
</tr>
<tr>
<td>ISS 0 (no injury)</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>ISS 1-8</td>
<td>85</td>
<td>84</td>
</tr>
<tr>
<td>ISS 9-15</td>
<td>22</td>
<td>21</td>
</tr>
<tr>
<td>ISS ≥16</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Mean ISS of all occupants (n=126)</td>
<td>6.3</td>
<td>6.4</td>
</tr>
</tbody>
</table>

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 had provided 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 value 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!*