Brace for impact! A thesis on medical care following an airplane crash
Postma, Ingri

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Chapter 8

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

I.L.E. Postma resident orthopaedic surgery, AMC Amsterdam
F.C. Öner, orthopaedic surgeon, UMC Utrecht
T.S. Bijlsma, trauma surgeon, MCA Alkmaar
M.J. Heetveld, trauma surgeon Kennemer Gasthuis, Haarlem
J.C. Goslings, trauma surgeon, AMC Amsterdam
F.W. Bloemers, trauma surgeon, VuMC Amsterdam

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 from 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 (range 1-66). 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 them 11 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>
<thead>
<tr>
<th>No</th>
<th>Gender, age</th>
<th>Seat</th>
<th>ISS</th>
<th>Level of injury</th>
<th>Burst (Y/N)</th>
<th>Complete burst (Y/N)</th>
<th>AO classification</th>
<th>Treatment</th>
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<tbody>
<tr>
<td>1</td>
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<td>Crew front</td>
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<td>N</td>
<td>T12-L1; C1; A3</td>
<td>surgery</td>
</tr>
<tr>
<td>2</td>
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<td>6D</td>
<td>22</td>
<td>L5</td>
<td>Y</td>
<td>Y</td>
<td>A4</td>
<td>brace</td>
</tr>
<tr>
<td>3</td>
<td>F, 29y</td>
<td>7C</td>
<td>18</td>
<td>C2</td>
<td>N</td>
<td>-</td>
<td>A/A 3; G 3</td>
<td>surgery</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>L1</td>
<td>N</td>
<td>-</td>
<td>A1</td>
<td>brace</td>
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<tr>
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<td>9</td>
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<td>N</td>
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<td>8</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>-</td>
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<td>17</td>
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<td>Y</td>
<td>N</td>
<td>A0-A3</td>
<td>surgery</td>
</tr>
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<td>7</td>
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<td>8A</td>
<td>17</td>
<td>L1</td>
<td>N</td>
<td>-</td>
<td>A1</td>
<td>Brace</td>
</tr>
<tr>
<td>8</td>
<td>F, 38y</td>
<td>25B</td>
<td>21</td>
<td>C7</td>
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<td>-</td>
<td>A2</td>
<td>Miami-J</td>
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<td>10</td>
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<td>-</td>
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<td>4</td>
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<td>T12-L1 B2; L1 A3</td>
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<tr>
<td>11</td>
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<td>A1</td>
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<tr>
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<td>24</td>
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<td>Y</td>
<td>N</td>
<td>-</td>
<td>A3</td>
<td>-</td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td>L3</td>
<td>N</td>
<td>-</td>
<td>A1</td>
<td>-</td>
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<tr>
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<td>T6-7</td>
<td>Y</td>
<td>Y</td>
<td>T6-T7 B2; T7 A4</td>
<td>surgery</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>T12-L1</td>
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<td>Y</td>
<td>T12-L2 C; L1 A4</td>
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<td>9F</td>
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<td>L5</td>
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<td>surgery</td>
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<tr>
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<td>M, 26y</td>
<td>7E</td>
<td>10</td>
<td>T7</td>
<td>N</td>
<td>nv</td>
<td>A1</td>
<td>-</td>
</tr>
<tr>
<td>18</td>
<td>M, 27y</td>
<td>7F</td>
<td>8</td>
<td>C4-5</td>
<td>Y</td>
<td>Y</td>
<td>C4-5 B2; C5 A4</td>
<td>surgery</td>
</tr>
<tr>
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<td>22A</td>
<td>9</td>
<td>T12-L2</td>
<td>N</td>
<td>-</td>
<td>A1 (3x)</td>
<td>surgery</td>
</tr>
<tr>
<td>20</td>
<td>F, 31y</td>
<td>10F</td>
<td>9</td>
<td>T12</td>
<td>N</td>
<td>-</td>
<td>T11/12 C; T12 B2 (A2)</td>
<td>surgery</td>
</tr>
<tr>
<td>21</td>
<td>M, 35y</td>
<td>18C</td>
<td>4</td>
<td>L1</td>
<td>N</td>
<td>-</td>
<td>A1</td>
<td>-</td>
</tr>
<tr>
<td>22</td>
<td>M, 38y</td>
<td>5C</td>
<td>17</td>
<td>T12-L1</td>
<td>Y</td>
<td>Y</td>
<td>T12-L1 B2; L1 A4</td>
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<tr>
<td>23</td>
<td>M, 28y</td>
<td>5E</td>
<td>34</td>
<td>L4</td>
<td>Y</td>
<td>Y</td>
<td>A4</td>
<td>surgery</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Injury Morphology in %</th>
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<tr>
<td>Burst</td>
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<td>Complete Burst</td>
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<tr>
<td>Type B</td>
</tr>
<tr>
<td>Type C</td>
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<table>
<thead>
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<th>CATEGORIE 1</th>
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<tbody>
<tr>
<td>Burst</td>
</tr>
<tr>
<td>Complete</td>
</tr>
<tr>
<td>Type B</td>
</tr>
<tr>
<td>Type C</td>
</tr>
</tbody>
</table>

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
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.
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. 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. 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). 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. 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. 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.
References

Spinal injuries


