

High Traumatic Energy Related Spine Injuries and Spinopelvic dissociations

Short version of Ph.D. thesis

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List of Abbreviations

ANOVA – ANalysis Of VAriance

AO – Arbeitsgemeinschaft für Osteosynthese

ASIA – American Spinal Injury Association

BASE-jumping – Building, Antenna, Span, Earth-jumping

CT – Computed Tomography

DE-CT – Dual-Energy-Computed Tomography

ISS – Injury Severity Score

LODOX – LOw DOse X-Ray

MRI – Magnetic Resonance Imaging

OR – Operating Room

PEA – Pulseless Electrical Activity

RIVA – Ramus InterVentricularis Anterior

List of Figures

Figure 1: Distribution of spinal injuries

Figure 2: Algorithm of aerial sports accidents and subsequent treatment based on the findings in this thesis

1. Introduction

The spine provides stability to resist high forces during bending [1]. Biomechanically, the anterior cortex and caudal bone are thicker than the cranial cortex. The posterior neural arch is protected through the intervertebral discs, vertebral bodies, ligaments and muscles [2]. The discoligamentous complex consists of the posterior and anterior longitudinal ligaments as well as the posterior ligamentous complex which comprises of the flavum-, interspinous, and nuchal ligaments [3], [4]. The main stabilizers are the apophyseal joints, intervertebral ligaments, followed by the spinous processes and especially the lumbar spine is at risk because of the high forces acting on it [5]. The sacrum builds up the spinopelvic joint and enables the comminution between the pelvic ring and vertebral column.

In high energetic spine injuries, the nucleus pulposus concentrates the compressive stress onto the annulus which in combination with spinal flexion can result in crush injuries [6]. Other trauma mechanisms include hyperflexion, shear, bending and torsional forces which have a much wider range of fracture patterns including discoligamentous injuries [7]. All spine injuries are classified according to the AO Spine classification or Magerl classification [8], [9], [10].

On the other hand spinopelvic injuries are rather uncommon and occur in high energetic accidents with multi-directional forces acting on the lumbopelvic junction [11]. The fracture pattern can be classified according to the Denis and Roy-Camille classifications or according to the shape in U-, H-, Lambda-, or T-shape fracture [12]. Hereby, a horizontal fracture in Denis Zone 2 in combination with a transverse fracture at the S1/S2 disc space or S2 vertebral body, extending into bilateral vertical sacral fracture lines are typically present.

The most common complication of the injuries include neurological impairment in up to 94 to 100% of cases [13], [14] which is typically assessed using the ASIA score. Other rather rare complications may include dura tears, soft tissue injuries such as a Morel-Lavallee lesion and further concomitant injuries [15].

The incidence for spine fractures is approximately 6% of all fractures [16] and especially the thoraco-lumbar transition zone is at risk [17]. Main causes of spinal and sacral injuries include osteoporotic fractures in elderly patients as well as high-energy traumatic injuries. In contrast spinopelvic dissociations are rather uncommon and make up 2.9% of all sacral fractures which are associated with U-shaped or H-shaped sacral fractures [18]. In spinal trauma, sports such as mountain biking, contact sports account only a small proportion in approximately 5.5% with a

mean age of 68.4 years [19], [20]. Rather uncommon and likely underreported extreme sports include airborne sports which consists of Paragliding, Speedflying, Parachuting, Delta flying and BASE jumping [21], [22].

The most common aerial sport is Paragliding followed by Parachuting which is especially performed in the Alps' region such as Switzerland. In Paragliding the parachute is of elliptical-shape and persist of multi cells which can be controlled for lateral glide. It is potentially aerodynamically instable and only stable in calm air because of a low centre of gravity. Once a parachute collapses it is difficult to re-inflate it and because of flying in rather low height, pilots are unable to pull an emergency parachute. On the other side, Skydiving pilots typically have two parachutes, which the pilots have to pull and if they become unconscious an emergency parachute is released automatically.

In Switzerland, the university hospital Bern, is the largest trauma center and includes a catchment area of approx. 1.5 million people living in a 10,000 km² area for selected patients such as polytraumatized ones and are initially examined in the resuscitation room [23].

2. Objectives

There is a dearth in literature on airborne sports related injuries such as spine fractures, sacral fractures including spinopelvic dissociation. Aim of the thesis was to investigate the following based on five different publications:

1. Investigation of the logistics of patients' admission and primary examination among all patients.
2. Investigation of the incidence of spine injuries, demographic of patients and spinopelvic dissociation.
3. Recording the different injury patterns and severity of injuries
4. The further procedure after completion of the diagnostics in the emergency room.
5. The current knowledge on spinopelvic dissociation in literature based on a systematic review

6. Since MRI is not available in some cases and too time intensive especially in trauma patients the importance of DE-CT

3. Methods

We reviewed retrospectively our emergency-care database and included all patients who were older than 18 years at the date of hospital admission between February 2010 and June 2017. Inclusion criteria were patients who were initially admitted to the hospital following airborne sports injuries including Paragliding, BASE-jumping, Speedflying, Delta flying and Parachuting accidents. In all patients data on the demographics, type of airborne sports, injury severity score (ISS) [24], neurological impairment, fracture pattern of spine injuries and sacral fractures and subsequent treatment. For classification we used the AO Spine classification respectively the Denis and Roy-Camille classification. All radiographic images including LODOX, CT and if carried out MRI scans were reviewed.

For calculations and graphs we applied the ANOVA T-Test for mean and standard deviation as well as the linear regression model with the standardized coefficient and p-value. For the learning curve, the line of best fit was calculated to present the slope factor, R-squared, standard error and F value we also used Microsoft Excel spreadsheet, Origin Lab and SPSS.

For the systematic reviews the PRISMA guidelines were used searching the Medline, Pubmed, EMBASE and a metaanalysis was conducted using the R software applying the mada[^]package. The random-effects model (DerSimonian-Laird) was used to calculate the τ^2 as well as I^2 to conclude on the heterogeneity.

4. Results

Overview of airborne sports

In total, 235 patients at a mean age of 38.7 years (Min/ Max 18 - 74) with a mean injury severity score 16.5 (SD 14, range from 0 to 75) were admitted suffering from airborne injuries. Paragliding was performed most commonly (n=192; 82.6%; including 13 tandem-Paraglider) followed by BASE-jumping, Skydiving (one tandem-Skydiver), Speedflying and finally Delta

flying. Highest ISS was observed in BASE-jumping however without any significances ($p=0.1$).

Spinal fractures

148 patients (63.0%; 148/235) suffered from spinal injuries at a mean age of 39.4 ± 12.3 years (range from 18 to 71) with predominately male patients (84.5%, or 125/148). The ISS was slightly higher than the overall average with a mean of $17.9 (\pm 13.2)$. A significant distribution of ISS was observed among the airborne sports performed. The ISS in BASE-jumping, Speedflying and Parachuting compared were significantly higher to Paragliding ($p \leq 0.01$). In 77 patients (52.0%) more than one isolated vertebral body injury was observed resulting in 334 vertebral body fractures in total. In a further five patients spinal contusion (three lumbal and two cervical) were identified, resulting in 339 spinal injuries overall. Vertebral body L1 was affected in 20.1% ($n=68/339$), followed by L2 in 13.9% ($n=47/339$), T12 in 10.3% ($n=35/339$), and L3 in 8.8% ($n=30/339$). The distribution of the vertebral bodies is illustrated in figure 1.

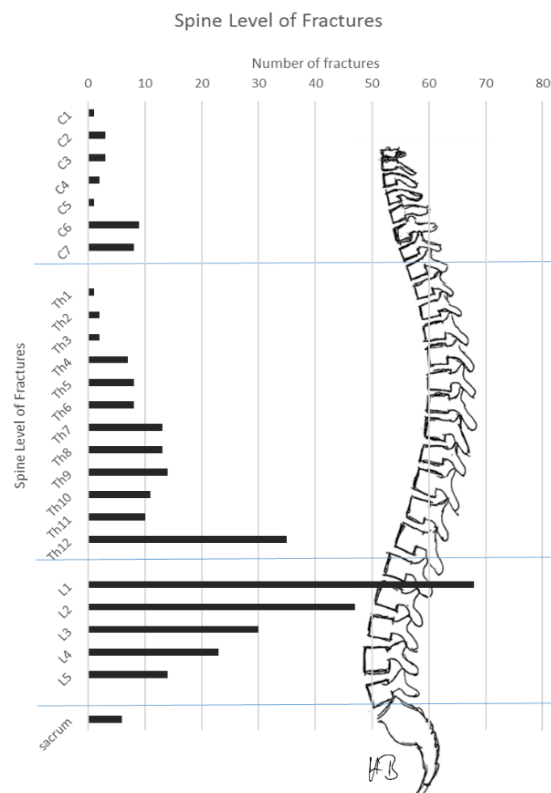


Figure 1: Distribution of spinal injuries [25]

Most fractures were of type A in 272 cases ($n=272/334$, 81.4%), followed by type B fractures in 13.8% ($n=46/334$), type C fractures in 1.8% ($n=6/334$), and in the remaining 10 patients the spinal facets were affected. In six cases ($n=6/334$, 1.8%) sacral injuries with a pelvic ring integrity were diagnosed. Furthermore, of the 148 patients, traumatic dura tear was identified

in 9.5% (n=14/148) and positive modifiers (M1 or M2) were found in 24 patients (n=24/148, 16.2%). Twenty-three of the 24 patients suffered from an indeterminate injury to the tension band on spinal imaging and one had ankylosing spondylitis.

Age-wise, young patients (<30 years of age) suffered primarily from thoracic and lumbar fractures, whereas mid-age people between 30 and 50 years as well as above 60 years were rather diagnosed with fractures in the lumbar spine. The cervical fractures were predominant in 72% of cases in the age range between 40 and 60 years (n=18/25). When looking for the correlation between age and injury severity score, highest ISS with 27.6 was observed between 50 and 60 years of age.

Neurological impairment was present in 20.9% (31/148) of all patients. According to the ASIA guidelines most suffered from type D (n=13/31, 41.9%), followed by type A in 25.8% (n=8/31), type C in 22.6% (n=7/31) and finally three type B ASIA scores (n=3/31, 9.7%). In another eight patients sensory deficit was observed which could not be classified according to the ASIA score. According to the detailed anamnesis no pre-traumatic neurologic deficits were observed.

For surgery, spinal surgery was indicated in 78 patients (54.5%) due to instability or neurological impairment. Hereby, emergency surgery was performed in 23 patients (n=23/78) as a highly instable spine fracture (n=7/23) with onset of neurologic deficit or unclear neurologic exam in an intubated or unconscious patient (n=16/23) was diagnosed. Most commonly open posterior spondylodesis was performed in 67.9% of cases (n=53/78), followed by percutaneous posterior stabilization in 21.8% of cases (n=17/78), and eight stand-alone anterior spondylodesis with cage and plate (n=8/78, 10.3%). Combined anterior body replacement and posterior fixation was performed in 50 cases (n=50/78, 64.1%). As traumatic dura tear was observed in 14 cases a running suture (n=13/14) or a fibrin patch was applied (n=1/14). In another two patients, surgery was indicated however, they wished to be transferred to another hospital close to their hometown. Postoperatively, improvement in neurological deficit was observed in seven patients, where as it remained the same during the hospital stay in 24 patients. Thus, sixteen patients were ASIA C or worse.

For trauma management most patients were primarily admitted to our hospital (129/148, or 87.2%) by helicopter (n=121) and initial diagnostics were performed in the resuscitation room in 111 cases (n=111/148, 75.0%). For concomitant injuries, 95 patients (n=95/148, 64.2%) suffered from 162 injuries including one severe burn and one patient who was successfully resuscitated after onset of a pulseless electric activity (PEA) after a BASE jump crash.

Therefore, another 13 emergency surgeries were indicated for an unstable pelvic fracture in 5 cases, extremity fractures in another 5 patients – (4 femur fractures and one open ankle fracture, including two external fixations) and one exploratory laparoscopy (n=1). In the remaining two cases one skull fixation and one coronary angiography was performed (one for each; n=2).

Spinopelvic dissociation and Sacral fractures

For sacral fractures 44 patients were found among all patients (n=44/235, 18.7%). Sacral fractures were observed most commonly without spinopelvic dissociation (n=28/44, 63.6%), followed by spinopelvic dissociation in 16 cases (n=16/44, 36.4%). Likewise the overall demographics, there was a predominance in male with 81.8% (n=32/44). The mean age was 38.8 years old (SD 13.5).

For spinopelvic dissociation the most common fracture pattern was of H-type in four cases, followed by three T-types, two U-types and two Lamda-types. No correlation to one of these patterns was observed in the remaining 5 cases. Especially the right side was affected in nine cases and five patients were injured at both sides. Neurological impairment was identified in four patients - three of them with an incomplete paraplegia or cauda equine syndrome (type B according to ASIA) and one patient with a traumatized lumbar plexus (type C according to ASIA). Fourteen of sixteen patients underwent surgical fixation either percutaneous iliosacral screw stabilization in 43.8% (n=7/16) or triangular stabilization in 37.5% of cases (n=6/16) - either bilateral (n=4) or unilateral (n=2). In the remaining case a dorsal plate osteosynthesis for fixation was used. Retrospectively we identified that the ISS was significantly higher in those patients who underwent triangular spinopelvic stabilization with a mean ISS of 46.3 (SD 14.7).

Concomitant spine injuries were identified in 12 patients (75.0%) of which the lumbar one vertebral body was affected in 15.9% of cases, followed by thoracal injuries in 50.0% of cases including three lacerations of the aortic arch and one traumatic dissection of the RIVA as well as intra-abdominal bleedings in 37.5% (n=6/16), upper extremity traumas in 31.3% (n=5/16), and lower extremity injuries in 25.0% (n=4/16) including one Morell-Lavallee lesion. Furthermore, three patients suffered from head and face injuries in 18.75% (n=3/16). [25]

Among all sacral patients, conservative treatment was recommended in 71.4% (n=20/28) whereas either single anterior pelvic fixation (n=3/28, 10.7%) or iliosacral screw fixation (n=5/28, 17.9%) and one combined anteroposterior stabilization was indicated. Luckily, no neurological impairment was observed. Likewise, for spinopelvic dissociation, the most

common concomitant injuries were spine fractures in 17 patients (n=17/28; 60.7%). Others included pelvic ring injuries (n=19/28), extremity fractures (n=16/28) and thoracic injuries (n=9/28) as illustrated in table 8.

Although demographics including age and gender were equally distributed, the ISS for spinopelvic dissociation was significantly higher with 38.1 compared to 20.0 (standardized coefficient of 0.463, p=0.001). Other than that, spinopelvic dissociations were more commonly associated with vertebral body fractures compared to other sacral fracture group (standardized coefficient of 0.329; p=0.03). In addition, the incidence of neurological impairment was 25.0% in the spinopelvic dissociation group versus 0% in the other sacral fracture group [26].

Systematic review on spinopelvic dissociation

Based on a systematic review on spinopelvic dissociation we found 50 studies reporting 379 patients with spinopelvic dissociation between 1969 and 2018. The mean age of patients was even younger with 31.6 ± 11.6 years compared to our study. In the majority of cases surgical fixation was performed (93.1%; n=353/379). The mean time from injury to surgery was 8.6 ± 9.9 days (range from 0 to 43.5 days). [27], [28] Within the 353 patients where a surgery was performed, 216 patients underwent open reduction (61.2%, n=216/353), and in 95 patients a closed reduction was performed (26.9%, n=95/353). For fixation most commonly, triangular fixation (TF) was performed in 243 cases (68.8%; n=243/353) and especially without iliosacral screw (SI) fixation (n=179; 50.7%). The highest complication rate was >100%, as one study noted 35 complications in 28 patients [29].

Dual-Energy-Computed Tomography systematic review

Since timing is highly important in severely injured polytraumatized patients, MRI is not the best diagnostic tool to identify discoligamentous injuries. Therefore the DE-CT seems to be a good alternative which has been investigated within 13 studies. The pooled sensitivity and specificity was described with 86.2% respectively 91.2% with a PPV of 85.3%, NPV of 91.7% and an overall accuracy was 89.3%. On the other side the overall sensitivity, specificity, PPN, NPV and accuracy for CT was 81.3%, 80.7%, 74.5%, 86.1% respectively 80.9%. Hereby, DE-CT showed significant higher specificity (p<0.001) and accuracy (p=0.023) [30].

Based on our findings presented in this thesis we developed an algorithm in the diagnostics and treatment for airborne sports related injuries (Figure 2).

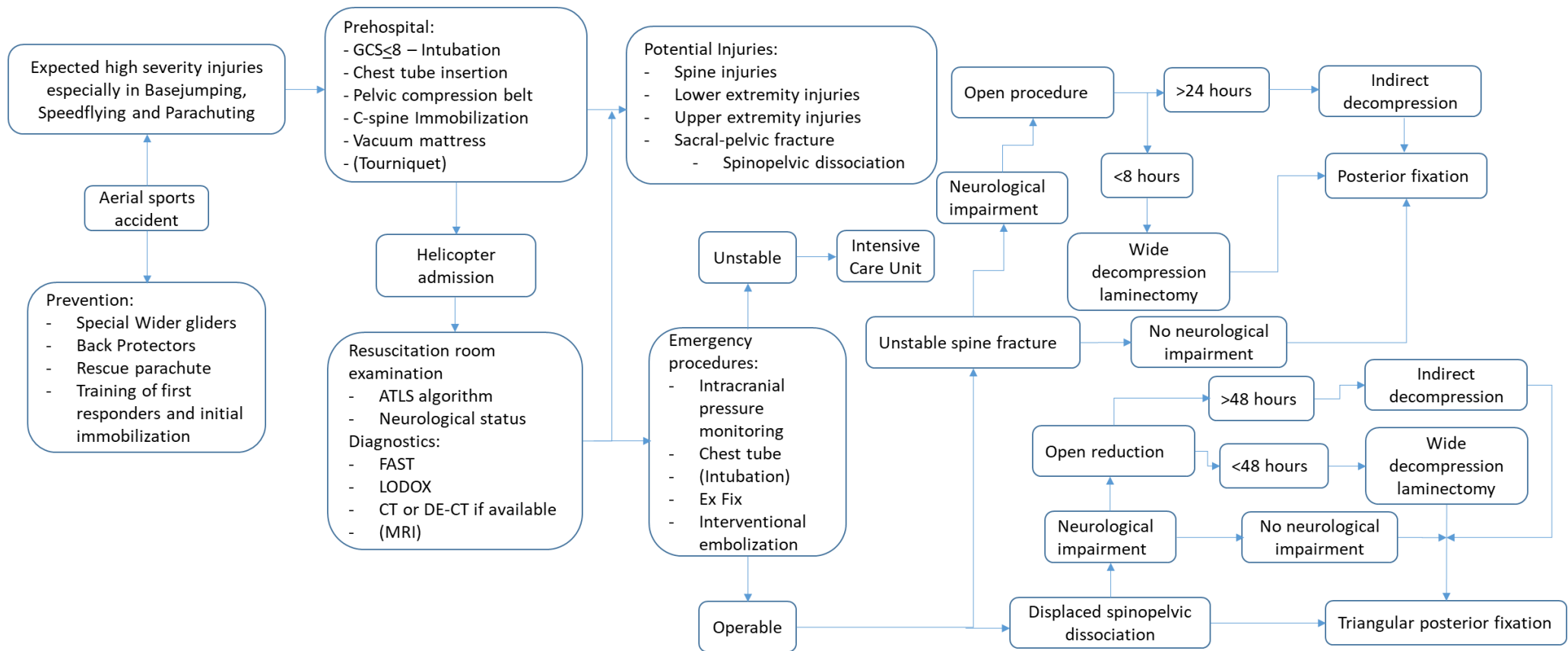


Figure 2: Algorithm of aerial sports accidents and subsequent treatment based on the findings in this thesis

5. Conclusion

Due to increasing popularity in the last years, this thesis provide evidences of the logistical difficulties, variety of injury pattern, severity related to the aerial sports as well as related concomitant injuries and therefore subsequent surveillance and treatment.

1. Most patients were primarily admitted to our hospital (155/235, or 67.0%) by helicopter, followed by ambulance and self-admission and initial diagnostics was primarily performed in the resuscitation room in 162 cases (n=162/235, 68.9%).

2. In total, 235 met inclusion criteria at a mean age of 38.7 years (min/ Max 18 -74) and predominantly male were affected in 84.3% (194/235). Three of the patients had to be resuscitated after onset of a PEA of which one patient deceased. The most common aerial sport performed was Paragliding (n=192; 82.6%, including 13 tandem Paraglider), followed by BASE-jumping, Skydiving (one tandem-Skydiver), Speedflying and Delta flying. Especially the spine was affected in 63.0% of cases (148/235) suffering from 334 spine injuries whereas sacral injuries occurred in 18.7% (n=44/235) of patients. Of the 44 sacral fractures only 16 patients suffered from spinopelvic dissociation (n=16/44, 36.4%). 162 concomitant injuries were observed within 95 spine patients including extremities in 32.4% (n=48/148), thoracal injuries in 31.8% (n=47/148), head/face injuries in 18.2% (n=27/148) and pelvic lesions (17.6%; n=26/148). In those patients suffering from spinopelvic dissociation especially pelvis and spine injuries were observed in 87.5% (n=14/16), respectively 75.0% (n=12/16), followed by extremity injuries in 68.8% (n=11/16), thoracal injuries in 50.0% and intra-abdominal bleedings in 37.5%.

3. Overall the ISS was 16.5 compared to the spine group with 17.9. For the spinopelvic dissociation group a mean ISS of 38.1 was observed. Furthermore, highest ISS was observed at age between 50 and 60 with 27.6. In the spine group 20.9% suffered from neurological impairment (31/148) whereas in the spinopelvic dissociation group this was 25.0% (n=4/16).

4. Among all patients 15 thoracic drainages and three invasive intracranial sensors were inserted. In 55 patients (23.4%; n=55/235) an immediate emergency surgery was required and in another 61 patients surgery was scheduled within the next few days (26.0%; n=61/235). For the spine group, surgery was performed in 54.5% and especially open posterior spondylodesis was performed in 67.9%, followed by percutaneous posterior stabilization in 21.8% of cases (n=17/78), and eight stand-alone anterior spondylodesis with cage and plate (n=8/78, 10.3%).

For spinopelvic dissociation, 14 of 16 patients underwent surgical stabilization and especially percutaneous iliosacral screw stabilization in 43.8% (n=7/16) and 37.5% of cases underwent a triangular stabilization (n=6/16) either bilateral (n=4) or unilateral in two cases (n=2).

5. Patients suffering from spinopelvic dissociation are typically young at a mean age of 31.6 ± 11.6 years and gender is equally distributed with 49.3% being male. Because of a high rate of neurological impairment in 68.1% (n=258/353) an open reduction was performed in 61.2% (n=216/353) and especially triangular fixation (TF) was used in 68.8% (n=243/353). However, despite the surgical fixation technique the overall union rate was 100% (n=307/307). Based on the findings in the literature we recommend open reduction including wide decompression laminectomy and triangular fixation within 48 hours if neurological impairment is present and patient is stable enough.

6. To identify potentially discoligamentous injuries DE-CT is a good alternative to MRI especially in cardio-pulmonary unstable patients. Hereby, we found an overall sensitivity and specificity of 86.2% respectively 91.2% compared to 81.3% (p=0.119) and 74.5% (p<0.005) for conventional CT. Likewise the sensitivity the accuracy was significant higher for DE-CT with 89.3% compared to 80.9% (p=0.023).

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7. Bibliography of the candidate's publications

1. Related to the thesis

1. Backer HC, Vosseller JT, Deml MC, Perka C, Putzier M. (2021) Spinopelvic Dissociation: A Systematic Review and Meta-analysis. *J Am Acad Orthop Surg*, 29: e198-e207.
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1. Backer HC, Wu CH, Kienzle A, Perka C, Gwinner C. (2022) Mechanical failure of total hip arthroplasties and associated risk factors. *Arch Orthop Trauma Surg*.
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