European Spine Journal (2019) 28:1138–1145
https://doi.org/10.1007/s00586-019-05951-0

ORIGINAL ARTICLE

Spinal injuries in airborne accidents: a demographic overview of 148 patients in a level-1 trauma center

Henrik C. Bäcker[1,2] · J. Turner Vosseller[2] · Lorin Benneker[1] · Markus Noger[3] · Fabian Krause[1] · Sven Hoppe[1] · Moritz C. Deml[1]

Received: 20 November 2018 / Revised: 5 February 2019 / Accepted: 13 March 2019 / Published online: 18 March 2019

Abstract

Purpose The purpose of this study was to investigate the type and severity of spinal injury in airborne sports, as well as patients demographics in this unique set of athletes. Paragliding is one of the most popular airborne sports in Switzerland, which thought to be no less dangerous with a high potential for spinal injury. Few studies on spinal column injuries have been performed in these high-risk athletes with only inconsistent findings.

Methods Patient charts were analyzed for all airborne sports injuries affecting the spine from 2010 to 2017 at a level-1 trauma center in Switzerland. To classify the injuries, we used the newest AOSpine classification, ASIA-grading and the injury severity score (ISS). In total, 235 patients were admitted to the emergency department due to an airborne injury. A total of 148 patients (148/235, 63.0%) which were predominantly male (125/235, 84.5%) at a mean age of 39.4 years suffered 334 spinal fractures and 5 spinal contusions. The mean ISS was 17.3, and the L1 vertebra was most commonly affected (47.6% of cases, 68/148).

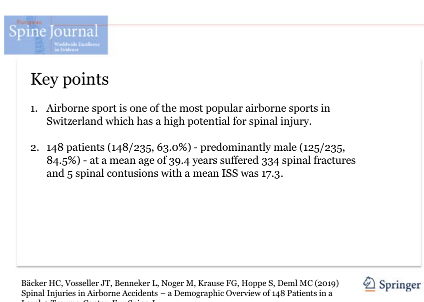
Results A total of 78 patients (54.5% or 78/148) required spine surgery due to instability or neurological deficits (31/148 patients; 20.9%). Concomitant injuries were identified in 64.2% of cases ($n = 95$).

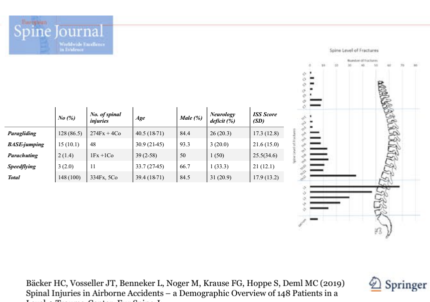
Conclusion Due to the increasing popularity of airborne sports, age of patients and severity of injuries (ISS) increased compared with the literature. The thoracolumbal spine is at especially high risk. To prevent further complications, the treatment procedure has to be sought carefully and algorithm should be introduced in clinics to avoid delay in diagnostics and surgery.

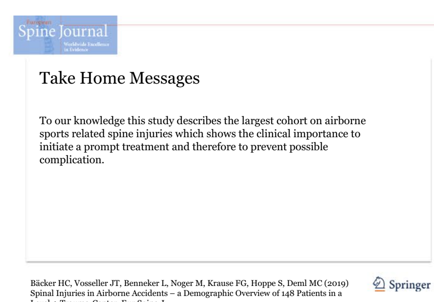
Level of evidence III, retrospective comparative study.

Graphical abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Trauma · Spinal fractures · Paragliding · High traumatic injuries · Sports medicine

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-05951-0) contains supplementary material, which is available to authorized users.

Extended author information available on the last page of the article

Introduction

Spinal fractures in high-energy traumatic injuries are common and contribute significantly to morbidity and mortality [1, 2]. Overall, the mean age in patients with spinal fractures in one report was 45.7 years with a male predominance (65.5%) [3]. In younger patients, the most common causes are accidental falls, (mean age 46.6 years, 58.9%), distinguishable between fall from low (< 2 m) and high heights (≥ 2 m), followed by motor vehicle accidents (mean age 40.1 years, 20.9%) and direct collisions/blunt objects (mean age 39.4 years, 11.3%). In general, spinal trauma in sport occurs only in 5.5% of these injuries and generally in older patients (mean age 68.4 years in the literature) [3].

The most common sports related to spine injuries are winter sports (snowboarding, skiers), mountain biking and contact sports (i.e., American football) [4, 5]. Spine injuries can occur in other extreme sports such as airborne sports (paragliding, speedflying, parachuting, delta flying and BASE jumping), motocross, water sports and mountain sports (climbing) [6, 7].

More recently, airborne sports have become more popular. Due to Switzerland's landscape, airborne sports gained high popularity with paragliding being the most common extreme sport [8]. Only a few publications have examined injuries in airborne sports, and even fewer have assessed the severity and incidence of spine injuries in airborne sports [9, 10].

The aim of our study was to investigate (1) the incidence of spinal injuries due to airborne sports and the most commonly affected locations in the spine, (2) the severity of spinal injuries in relation to the different airborne sports, (3) the number of associated neurologic deficits, (4) related concomitant injuries and the (5) pre-hospital and emergency center care process.

Patients and methods

After receiving ethical consent, we retrospectively included all patients 18 years or older suffering from spinal injuries due to airborne sports who got admitted to the local level-1 trauma center from February 2010 to June 2017. Patient-specific data were collected in the emergency care database. All patients were admitted and evaluated according to ATLS protocol. Radiologic analyses were performed according to the expected injury patterns and clinical status. Additionally, in those who were admitted to the resuscitation room, an anteroposterior LOw DOse X-ray (LODOX) was performed to exclude pneumothorax or unstable pelvic injuries. Spinal injuries were classified by a senior spine surgeon using the AO spine classification including the modifiers which describe the indeterminate injury to the tension band based on spinal imaging [11–14]. Magnetic resonance imaging (MRI) was not routinely performed.

The AO spine classification was developed to describe the type of the vertebral body injury—minor, nonconstructural fractures, wedge compressions, split, incomplete or complete burst fracture—before indicating the posterior structure involvement and or rotational instability (B- or C-type). The individual types indicate whether there is translational deformity (C), hyperextension (B3), osteoligamentous disruption (B2), pure transosseous disruption (B1), complete or incomplete burst (A4 or A3, respectively), split or pincer fracture (A2), wedge or impaction (A1) or no significant injury to the spine (A0). The neurological deficit was classified using the American Spinal Injury Association (ASIA) impairment scale from A complete to E normal neurological status. Hereby, type A presents a complete neurological impairment in the segments below the injury for sensory and motor function, B, C and D an incomplete impairment with persevered sensory, respectively, motor function with a muscle grade of less than 3 or above 3 (D), and finally E with normal motor and sensory function. To assess the neurological status in an intubated patient, a wake-up trial was performed before surgery, when possible. The severity of injury was classified according to the injury severity score (ISS) between 1 and 75, where 75 indicates unsurvivable [14]. The ISS is calculated by the three most severe injuries, where 1 describes minimal injuries and 6 unsurvivable. It is added up by square of each individual injury, and if any individual value was 6 the score is automatically to 75. Hereby, the body regions are divided into head and neck, face, chest, abdomen or pelvic content, extremities or pelvic girdle and external injuries. For any pre-traumatic neurological deficits, patients were asked as part of the anamnesis. Concomitant injuries were categorized as head, thoracic, abdominal, pelvic and extremity injuries.

If any spine surgery was indicated, we investigated the type of stabilization performed—posterior percutaneous versus open stabilization and/or decompression of the spinal canal, with or without anterior spondylodesis or stand-alone anterior spondylodesis. Additionally, the type of admission—ambulance, self-admission or air rescue—and location of the primary survey performed—resuscitation room or normal emergency room—were noted.

All calculations and graphs were performed with the Microsoft Excel spreadsheet and Origin Lab, using an ANOVA T test for mean and standard deviation.

Results

Between February 2010 and June 2017, 235 patients were admitted to our emergency department due to airborne injuries. A total of 148 patients (63.0%) suffered from spinal injuries at a mean age of 39.4 ± 12.3 years (range from 18 to 71). The cohort was predominately male (84.5% or 125/148). The mean ISS was 17.9 (± 13.2); higher scores were seen in BASE jumping, speedflying and parachuting (significantly higher in comparison with paragliding, $p \leq 0.01$), as shown in Table 1. A total of 77 (52.0%) patients suffered from more than one vertebral body injury, resulting in 334 vertebral body fractures in total, including isolated sacral fractures and 5 contusions (three lumbal and two cervical). Overall, 339 spinal injuries were identified.

Paragliding accounted for the most injuries, which affected 128 patients, followed by BASE jumping, speedflying and two parachuting (one tandem) as indicated in Table 1. Out of the 124 paragliding pilots, 7 performed tandem flights. In our population, there were no injuries correlated to delta flying or other air sports.

The most injured vertebral body was L1 ($n=68/339$; 20.1%), followed by L2 ($n=47/339$; 13.9%), T12 ($n=35/339$; 10.3) and L3 ($n=30/339$; 8.8%), as shown in Fig. 1. Of the 334 vertebral fractures, 272 were classified as type A fractures ($n=272/334$, 81.4%), followed by 46 type B fractures ($n=46/334$, 13.8%) and 6 type C fractures ($n=6/334$, 1.8%) (see Table 2). The remaining 10 patients had fractures of their spinal facets. Six sacral injuries without concomitant pelvic ring fracture ($n=6/334$, 1.8%) were observed. Two of them were isolated without any other spinal injuries. In total, in 14 cases a traumatic dural tear was identified and 24 patients ($n=24/148$) had positive modifiers (M1 or M2). Twenty-three had an indeterminate injury to the tension band on spinal imaging, and one had ankylosing spondylitis. All spinal fractures including pelvic ring injury, such as vertical shear fractures of the pelvis, were not included in this study.

In addition, to the general classification we looked at the age as it related to the type of injury sustained. The younger patients (under 30 years) suffered primarily from thoracic and lumbar fractures, whereas the patients from 30 to 50 and above 60 years sustained more injuries in the lumbar spine. Most cervical fractures occurred in patients from 40 to 60 years of age (18/25, 72%). In terms of ISS, a peak was identified in the patients between 50 and 60 years with a mean ISS of 27.6 (Table 3).

A neurologic deficit was present in 20.9% (31/148 patients) of all patients. According to ASIA guidelines, the distribution of neurologic deficits was as follows: eight patients had a type A deficit, three type B, 7 type C (including cauda equina syndrome) and 13 type D. Eight further patients suffered only from sensory deficits. None of the patients had any pre-traumatic neurologic deficits.

Overall, 78 patients (54.5%) underwent surgery due to instability or neurologic deficits. A total of 53 patients had open posterior spondylodesis (67.9%), and 17 had percutaneous dorsal posterior stabilization (21.8%). Additionally, 50 patients (64.1%) were stabilized by anterior body replacement; in 8 patients (10.3%) a stand-alone anterior spondylodesis with cage and plate was performed. Dural tears were mostly treated using running suture ($n=13/14$), and in one case a fibrin patch was used to cover it. Two patients were transferred to another hospital for surgery close to their hometown.

In 36 cases, emergency surgery was indicated. In 23 patients, the reason was a displaced spinal injury with onset of neurologic deficit or unclear neurologic examination in an intubated or unconscious patient ($n=16/23$). Postoperatively, 7 patients improved in neurologic impairment and the remaining stayed the same during the primary hospital stay. Sixteen patients were thus ASIA C or worse. Other indications for surgery included a concern for impending neurologic deficit or injuries associated with a high degree of instability (C-type fractures and highly comminuted A- and B-type fractures with intraspinal bony fragments) ($n=7/23$). In the other 13 of 36 cases where emergency surgery was required, indications included unstable pelvic fractures ($n=5$), extremity fractures ($n=5$)—(4 femur fractures and one open ankle fracture, including two external fixations). An exploratory laparoscopy, skull fixation and coronary

Table 1 Basic patient data according to the different airborne sports, incidence of neurology deficits and ISS

	No (%)	No. of spinal injuries	Age	Male (%)	Neurology deficit (%)	ISS score (SD)
Paragliding	128 (86.5)	274Fx + 4Co	40.5 (18–71)	84.4	26 (20.3)	17.3 (12.8)
BASE jumping	15 (10.1)	48	30.9 (21–45)	93.3	3 (20.0)	21.6 (15.0)
Parachuting	2 (1.4)	1Fx +1Co	39 (2–58)	50	1 (50)	25.5 (34.6)
Speedflying	3 (2.0)	11	33.7 (27–45)	66.7	1 (33.3)	21 (12.1)
Total	148 (100)	334Fx, 5Co	39.4 (18–71)	84.5	31 (20.9)	17.9 (13.2)

Fx fracture, *Co* contusion

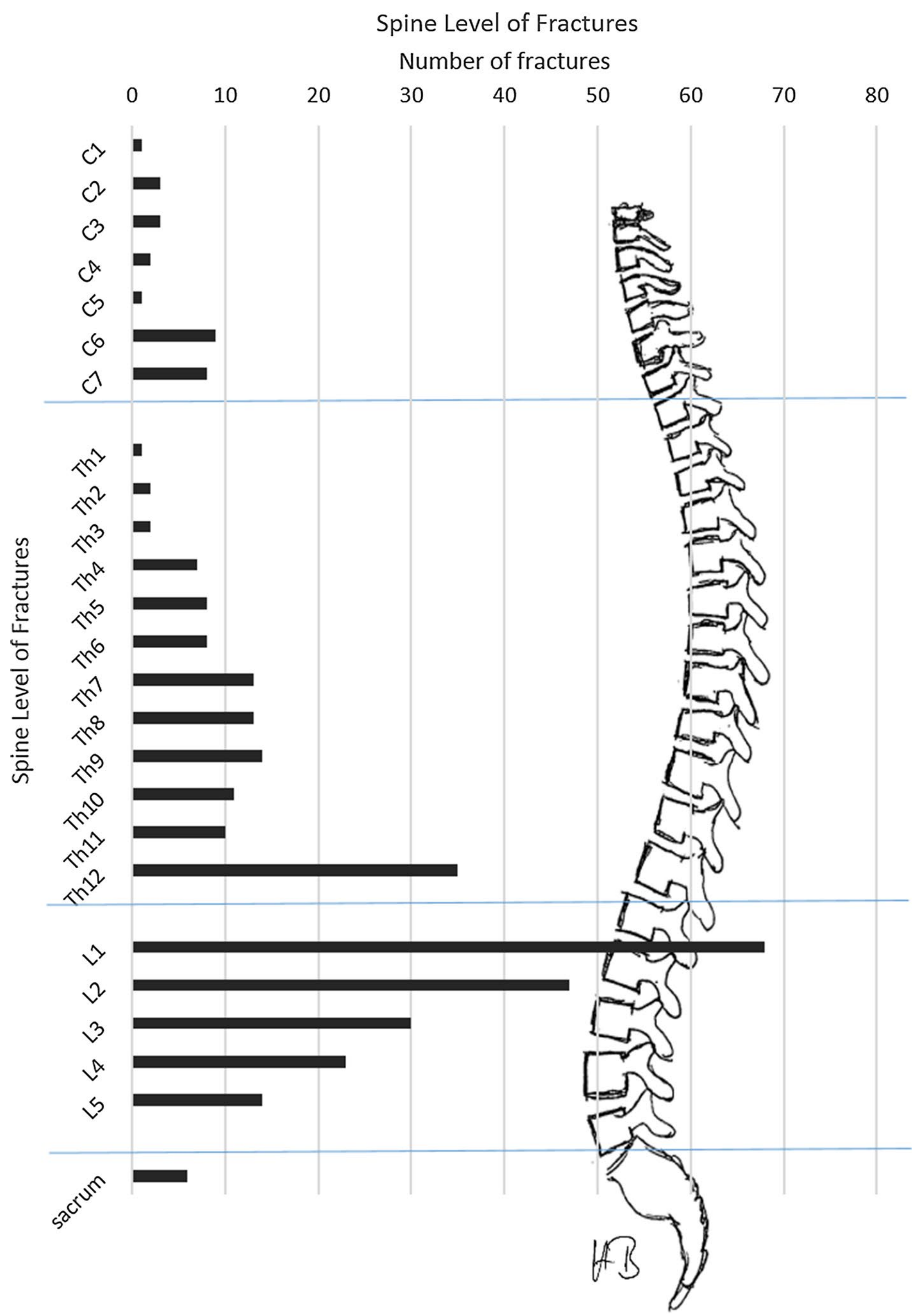


Fig. 1 Fracture distribution in airborne injuries

angiography were performed in the remaining cases (one for each; $n=3$).

Furthermore, 12 patients were transferred to the intensive care unit and 16 patients could be discharged from the emergency department on the same day, as they suffered only from spinal contusion ($n=5$) or a stable type A fracture on standing X-rays and were able to ambulate ($n=11$).

Most patients were primarily admitted to our hospital (129/148 or 87.2%) by air rescue ($n=121$), three by ambulance and five self-admissions. The remaining 17 patients (11.5%) were transferred from a general physician or a smaller hospital to our institution for further treatment, and in two cases, the type of admission was not mentioned. Five patients had to be intubated at the trauma site, and in 111 cases (75.0%), the primary survey was performed in the resuscitation room (see Table 4).

In total, 95 patients (64.2%) had 162 concomitant injuries including one severe burn and one patient was successfully resuscitated after onset of a pulseless electric activity (PEA) after a BASE jump crash. All concomitant injuries are summarized in Table 3.

Table 2 Type of injury according to the AO classification and allocated to the different airborne sports; percentages are given in brackets

Type of injury	Overall $n = 334$	Paragliding $n = 274$	BASE jumping $n = 48$	Parachuting $n = 1$	Speedflying $n = 11$
Facets	10 (3.0)	10 (3.7)	–	–	–
A0	103 (30.8)	74 (27.0)	27 (56.3)	–	2 (18.2)
A1	117 (35.0)	99 (36.1)	13 (27.1)	–	5 (45.5)
A2	9 (2.7)	5 (1.8)	2 (4.2)	–	2 (18.2)
A3	16 (4.8)	15 (5.5)	1 (2.1)	–	–
A4	27 (8.1)	26 (9.5)	1 (2.1)	–	–
B1	20 (6.0)	17 (6.2)	2 (4.2)	–	1 (9.1)
B2	23 (6.9)	21 (7.7)	1 (2.1)	–	1 (9.1)
B3	3 (0.9)	3 (1.1)	–	–	–
C	6 (1.8)	4 (1.5)	1 (2.1)	1 (100)	–

Table 3 Type and severity of injury related to the age

Fracture type	No.	ISS	Age
Distorsionen	5	1.0	37.4
Facets	10	29.4	49.25
Cervical	27	25.0	47.5
Thorcal	124	20.9	39.46
Lumbal	182	19.0	39.9
Sacral	6	32.7	34.0
Total	339	17.9	39.4

Age	Age	No of pat.	No of injuries	ISS	Dist.		Facet		Cervical		Thoracal		Lumbal		Sacral		A		B		C	
≤ 20	19	7	14	14.1	2	14.3	0	0	0	0	6	42.9	6	42.9	0	0	9	64.3	2	14.3	1	7.1
> 20	26.4	33	88	19.1	0	0	0	0	2	2.3	41	46.6	43	48.9	2	2.3	76	86.4	11	12.5	0	0
> 30	34.8	45	92	17.3	0	0	2	2.2	4	4.3	27	29.3	56	60.9	3	3.2	69	75.0	12	13.0	3	3.3
> 40	46.6	33	84	16.1	2	2.4	5	6.0	10	11.9	22	26.2	44	52.4	1	1.2	62	73.8	10	11.9	0	0
> 50	54.8	23	58	27.6	1	1.7	2	3.4	8	13.8	24	41.4	23	39.7	0	0	41	70.7	9	15.5	2	3.4
> 60	65.1	7	18	18.2	0	0	1	5.6	3	16.7	4	22.	10	55.6	0	0	15	83.3	2	11.1	0	0
Total		148	339	17.9	5		10		27		124		182		6		272		46		6	

Table 4 Concomitant injuries; percentages are given in brackets

	Air rescue (%)	Resuscitation room (%)	Extremity	Pelvis	Abdomen	Thorax	Head/face
Paragliding	106 (82.8)	94 (73.4)	39 (81.3)	19 (73.1)	9 (64.3)	38 (80.9)	21 (77.8)
BASE jumping	13 (86.7)	13 (86.7)	9 (18.8)	5 (19.2)	3 (21.4)	7 (14.9)	5 (18.5)
Parachuting	1 (50)	1 (50)	–	1 (3.8)	1 (7.1)	–	–
Speedflying	3 (100)	3 (100)	–	1 (3.8)	1 (7.1)	2 (4.3)	1 (16.7)
Total	123 (83.1)	111 (75.0)	48 (29.6)	26 (16.0)	14 (8.6)	47 (29.0)	27 (16.7)

Discussion

Airborne sports have become more popular worldwide, although they can be associated with severe injuries. Our study shows that in the spine, L1 is especially at risk and injury to it can cause a neurologic deficit up to 20.9% of the time. Further, 54.5% of patients in our series required surgery for their spinal injury.

Overall, spinal fractures are not very common; the incidence is described to be 64 per 1 million. In terms of sports and associated spine injuries, cycling followed by winter sports (62.7%) are most often associated with injury, whereas airborne sports are ranked as number 25 with an incidence of 16.2% [6, 15]. Between 10 and 30% of traumatic spinal fractures are associated with spinal cord injuries [16]. The incidence of spinal cord injury may also vary upon the country between 39 per million in the USA and 15 per million in Australia [15]. In our institution, the incidence of neurologic impairment was 20.9%, this rate falls within the range described in literature which is between 9.6% and 32% [17, 18].

The overall age for traumatic spine fractures has been noted to be 43.8 years, whereas previous studies described a mean age of 37.0 years in airborne sport pilots [17, 19]. We identified a slightly higher age of pilots at 39.4 years. The ISS was higher in our study than in previous studies (from 8 [17] to 17.9 in our cohort). The reasons for this change are difficult to determine, although it is possible that previous studies have underestimated the severity of injury. There may be some selection bias, as our level-1 trauma center receives preferably polytraumatized patients with suspected higher ISS scores. When looking for the overall ISS in all sports, the mean is 2.2 (2.2) with a mortality rate of 0.03% [20]. In winter sports, where spine trauma is not uncommon, the mean ISS has been reported as 25.9 (SD 8.0) with an incidence of severe injuries of 0.229 per million rides per year [5].

Other dangerous sports include climbing, skating and contact sports. Climbing is an airborne sport of sorts and is associated with a high rate of spine injuries, which vary between 12.5% [21] and 45.7%, whereas head injury is more common in skating and contact sports (i.e., hockey, football and soccer) [22]. In rock climbing, it has to be considered that patients may not only fall straight onto the ground but also hit the rock during fall [23]. An interesting correlation was identified in the gender distribution and ISS group from 12–14, 16–24 to more than 24. As ISS increases, the male: female ratio shifted from 1.69:1 to 1.89:1 and finally 1.95:1 in ISS above than 24 [24].

Paragliding, which is a potentially aerodynamically unstable system, is mostly associated with pilot errors while launching and landing, and the mortality rate is stated to be 45/100,000 [10, 25–27]. This agrees with our data, where the severity of injuries in paragliding is worse than BASE jumping, parachuting and speedflying. This may be due to higher speeds during flying and potential higher risk-taking characters in these subcategories (Table 4).

According to the literature, more than 60% of all spine fractures independent of the cause are located in the thoracolumbar region; this remains true in airborne sports [6, 22, 28]. In airborne sports, type A fractures occur most commonly, and L1 is affected mostly [3, 17, 18] (type A fracture 79.9%, L1 47.6%). No difference regarding fracture classification or affected vertebral body in between the different airborne sports was identified, even though the pilots are in different positions when flying. In contrast to airborne sports, in non-airborne spine injuries another peak can be identified at C5/6 such as in cycling or in motocross in which the most often accident mechanism (falling to front over the handlebar) is prone to hyperextension injuries of the cervical spine [7, 29]. The most common complications are spinal cord injuries related to the trauma which are present in 44.3% [3]. Further, no age pattern was identified, although the highest ISS was observed in patients aged 50 and 60 years. Lumbar fractures were most commonly observed in all age groups, even though in the age group between 50 and 60 thoracic fractures were slightly more common.

The decision on surgical procedure depended on the fracture pattern. In unstable fractures without spinal stenosis, single posterior stabilization was performed. Most commonly, patients underwent stabilization with posterior spondylodesis and percutaneous posterior stabilization, followed by anterior surgery in 78 cases. It is recommended that in highly comminuted or unstable fractures a combined anteroposterior stabilization with a cage should be performed. This type of stabilization shows better maintenance of thoracic kyphosis than only a posterior stabilization in highly comminuted fractures, especially in the thoracolumbar area [30]. In traumatic spinal stenosis, an additional decompression should be the method of choice [31].

Concomitant injuries were identified in 95 patients (64.2%) with 162 different injuries including a variety of other fractures, abdominal or thoracic injuries including aortic rupture. To achieve the highest survival rate, a quick admission to the hospital and primary diagnosis is essential such as by air rescue [32, 33]. In our center, 83.1% of patients were admitted by air rescue as life-threatening injuries were assumed and 5 patients had to be intubated at the site of accident. One patient needed resuscitation, which was successful; thus, the overall survival of those surviving the pre-hospital phase was 100% in our setting. To simplify and fast-track the diagnostics, LODOX can replace conventional thoracic and pelvic X-rays to exclude pneumothorax and major pelvic and extremity injuries even though in most cases no lateral LODOX is performed to save time. For detailed diagnostics, computed tomography was performed in every patient in which severe injuries were suspected (146/148, 98.6% in our cohort).

To prevent injuries, new devices have been developed and introduced such as rescue parachutes, saver harnesses and replaceable PVC as a protector, even though we identified an increase in the injury severity (ISS of 17.9) in comparison with the literature. The efficacy of these devices is thus in some question. It is possible that they give a false feeling of security, leading to a higher risk-taking mentality, or lead to some restricted movement that may reduce a pilots' ability to react in emergency situations.

This study has some limitations. The AO classification is a good and reliable tool although it has a low inter-observer reliability. Fractures in the thoracolumbar transition zone showed a reliability of 0.77 with a range between 0.69 and 0.90 [34]. The injury severity score has limitations as well; a new ISS was established which does not take into account the different body parts but only three major injuries [35]. For ASIA score assessment, we did not perform MRIs; however, a comprehensive review with the patient was performed as soon as they were awake and responsive. Furthermore, as we investigated the spine fractures at a level-1 trauma center, the more severe fractures may be directly admitted or transferred from smaller hospitals to our center, and so some minor injuries may be missed.

Over the last several years, the severity and age of patients suffering from spinal injuries due to airborne sports have increased. The thoracolumbar region is mostly affected, and A0 fractures were most common. A total of 54.5% of patients required surgery as a result of their spinal injury and 20.9% due to neurologic impairment. To minimize risk of future injury, further prevention courses should be offered and athletes must be aware and informed about how to act in case of an emergency.

Compliance with ethical standards

Conflict of interest Henrik C. Bäcker, J. Turner Vosseller, Lorin Benneker, Markus Noger, Fabian Krause, Sven Hoppe and Moritz C. Deml have no conflict of interest directly related to this work.

Ethical approval IRB: IRB Approval was obtained from the Swiss ethical committee.

References

1. Leucht P, Fischer K, Muhr G, Mueller EJ (2009) Epidemiology of traumatic spine fractures. Injury 40:166–172. https://doi.org/10.1016/j.injury.2008.06.040
2. Wang H, Xiang Q, Li C, Zhou Y (2013) Epidemiology of traumatic cervical spinal fractures and risk factors for traumatic cervical spinal cord injury in China. J Spinal Disord Tech 26:E306–E313. https://doi.org/10.1097/BSD.0b013e3182886db9
3. Wang H, Zhang Y, Xiang Q, Wang X, Li C, Xiong H, Zhou Y (2012) Epidemiology of traumatic spinal fractures: experience from medical university-affiliated hospitals in Chongqing, China, 2001–2010. J Neurosurg Spine 17:459–468. https://doi.org/10.3171/2012.8.SPINE111003
4. Boden BP, Breit I, Beachler JA, Williams A, Mueller FO (2013) Fatalities in high school and college football players. Am J Sports Med 41:1108–1116. https://doi.org/10.1177/0363546513478572
5. Corra S, Girardi P, de Giorgi F, Braggion M (2012) Severe and polytraumatic injuries among recreational skiers and snowboarders: incidence, demographics and injury patterns in South Tyrol. Eur J Emerg Med 19:69–72. https://doi.org/10.1097/MEJ.0b013e328347c1e9
6. Gosteli G, Yersin B, Mabire C, Pasquier M, Albrecht R, Carron PN (2016) Retrospective analysis of 616 air-rescue trauma cases related to the practice of extreme sports. Injury 47:1414–1420. https://doi.org/10.1016/j.injury.2016.03.025
7. Silva L, Fernanda Bellolio M, Smith EM, Daniels DJ, Lohse CM, Campbell RL (2017) Motocross-associated head and spine injuries in adult patients evaluated in an emergency department. Am J Emerg Med 35:1485–1489. https://doi.org/10.1016/j.ajem.2017.04.058
8. Schulze W, Richter J, Schulze B, Esenwein SA, Buttner-Janz K (2002) Injury prophylaxis in paragliding. Br J Sports Med 36:365–369
9. Cevik AA, Kaya FB, Acar N, Sahin A, Ozakin E (2017) Injury, hospitalization, and operation rates are low in aerial sports. Turk J Emerg Med 17:81–84. https://doi.org/10.1016/j.tjem.2016.11.004
10. Feletti F, Goin J (2014) Accidents and injuries related to powered paragliding: a cross-sectional study. BMJ Open 4:e005508. https://doi.org/10.1136/bmjopen-2014-005508
11. Vaccaro AR, Oner C, Kepler CK, Dvorak M, Schnake K, Bellabarba C, Reinhold M, Aarabi B, Kandziora F, Chapman J, Shanmuganathan R, Fehlings M, Vialle L, Injury AOSC, Trauma Knowledge F (2013) AOSpine thoracolumbar spine injury classification system: fracture description, neurological status, and key modifiers. Spine (Phila Pa 1976) 38:2028–2037. https://doi.org/10.1097/brs.0b013e3182a8a381
12. Vaccaro AR, Koerner JD, Radcliff KE, Oner FC, Reinhold M, Schnake KJ, Kandziora F, Fehlings MG, Dvorak MF, Aarabi B, Rajasekaran S, Schroeder GD, Kepler CK, Vialle LR (2016) AOSpine subaxial cervical spine injury classification system. Eur Spine J 25:2173–2184. https://doi.org/10.1007/s00586-015-3831-3
13. Kepler CK, Vaccaro AR, Koerner JD, Dvorak MF, Kandziora F, Rajasekaran S, Aarabi B, Vialle LR, Fehlings MG, Schroeder GD, Reinhold M, Schnake KJ, Bellabarba C, Cumhur Oner F (2016) Reliability analysis of the AOSpine thoracolumbar spine injury classification system by a worldwide group of naive spinal surgeons. Eur Spine J 25:1082–1086. https://doi.org/10.1007/s00586-015-3765-9
14. Ebrahimi M, Pirazghandi H, Reihani HR (2015) How is the injury severity scored? a brief review of scoring systems. Clin Med 2:125–128. https://doi.org/10.17463/RCM.2015.03.004
15. Chen Y, Tang Y, Vogel LC, Devivo MJ (2013) Causes of spinal cord injury. Top Spinal Cord Inj Rehabil 19:1–8. https://doi.org/10.1310/sci1901-1
16. Tomlinson J, Athanassacopoulos M (2015) Adult vertebral fractures. Surgery 33:264–276. https://doi.org/10.1016/j.mpsur.2015.03.005
17. Hasler RM, Huttner HE, Keel MJ, Durrer B, Zimmermann H, Exadaktylos AK, Benneker LM (2012) Spinal and pelvic injuries in airborne sports: a retrospective analysis from a major Swiss

trauma centre. Injury 43:440–445. https://doi.org/10.1016/j.injury.2011.06.193
18. Gauler R, Moulin P, Koch HG, Wick L, Sauter B, Michel D, Knecht H (2006) Paragliding accidents with spinal cord injury: 10 years' experience at a single institution. Spine (Phila Pa 1976) 31:1125–1130. https://doi.org/10.1097/01.brs.0000216502.39386.70
19. Canbek U, Imerci A, Akgun U, Yesil M, Aydin A, Balci Y (2015) Characteristics of injuries caused by paragliding accidents: a cross-sectional study. World J Emerg Med 6:221–224. https://doi.org/10.5847/wjem.j.1920-8642.2015.03.011
20. Dekker R, Kingma J, Groothoff JW, Eisma WH, Ten Duis HJ (2000) Measurement of severity of sports injuries: an epidemiological study. Clin Rehabil 14:651–656. https://doi.org/10.1191/0269215500cr374oa
21. Lack DA, Sheets AL, Entin JM, Christenson DC (2012) Rock climbing rescues: causes, injuries, and trends in Boulder County, Colorado. Wilderness Environ Med 23:223–230. https://doi.org/10.1016/j.wem.2012.04.002
22. Weber CD, Horst K, Nguyen AR, Lefering R, Pape HC, Hildebrand F, TraumaRegister DGU (2018) Evaluation of severe and fatal injuries in extreme and contact sports: an international multicenter analysis. Arch Orthop Trauma Surg 138:963–970. https://doi.org/10.1007/s00402-018-2935-8
23. Hohlrieder M, Lutz M, Schubert H, Eschertzhuber S, Mair P (2007) Pattern of injury after rock-climbing falls is not determined by harness type. Wilderness Environ Med 18:30–35
24. Palmer C (2007) Major trauma and the injury severity score–where should we set the bar? Annu Proc Assoc Adv Automot Med 51:13–29
25. Fasching G, Schippinger G, Pretscher R (1997) Paragliding accidents in remote areas. Wilderness Environ Med 8:129–133
26. Rekand T (2012) The epidemiology of injury in hang-gliding and paragliding. Med Sport Sci 58:44–56. https://doi.org/10.1159/000338581
27. Zeller T, Billing A, Lob G (1992) Injuries in paragliding. Int Orthop 16:255–259
28. Bakhsheshian J, Dahdaleh NS, Fakurnejad S, Scheer JK, Smith ZA (2014) Evidence-based management of traumatic thoracolumbar burst fractures: a systematic review of nonoperative management. Neurosurg Focus 37:E1. https://doi.org/10.3171/2014.4.FOCUS14159
29. McGoldrick NP, Green C, Burke N, Synnott K (2012) Acute traumatic spinal injury following bicycle accidents: a report of three cases. Acta Orthop Belg 78:409–413
30. Smits AJ, Polack M, Deunk J, Bloemers FW (2017) Combined anteroposterior fixation using a titanium cage versus solely posterior fixation for traumatic thoracolumbar fractures: a systematic review and meta-analysis. J Craniovertebr Junction Spine 8:168–178. https://doi.org/10.4103/jcvjs.JCVJS_8_17
31. Reinhold M, Knop C, Beisse R, Audige L, Kandziora F, Pizanis A, Pranzl R, Gercek E, Schultheiss M, Weckbach A, Buhren V, Blauth M (2009) Operative treatment of traumatic fractures of the thoracic and lumbar spinal column: part III: follow up data. Unfallchirurg 112:294–316. https://doi.org/10.1007/s00113-008-1539-0
32. Soreide K, Ellingsen CL, Knutson V (2007) How dangerous is BASE jumping? An analysis of adverse events in 20,850 jumps from the Kjerag Massif, Norway. J Trauma 62:1113–1117. https://doi.org/10.1097/01.ta.0000239815.73858.88
33. Feletti F (2017) Extreme sports medicine. Springer, Cham
34. Reinhold M, Audige L, Schnake KJ, Bellabarba C, Dai LY, Oner FC (2013) AO spine injury classification system: a revision proposal for the thoracic and lumbar spine. Eur Spine J 22:2184–2201. https://doi.org/10.1007/s00586-013-2738-0
35. Stevenson M, Segui-Gomez M, Lescohier I, Di Scala C, McDonald-Smith G (2001) An overview of the injury severity score and the new injury severity score. Inj Prev 7:10–13

Affiliations

Henrik C. Bäcker[1,2] · J. Turner Vosseller[2] · Lorin Benneker[1] · Markus Noger[3] · Fabian Krause[1] · Sven Hoppe[1] · Moritz C. Deml[1]

✉ Henrik C. Bäcker
Henrik.baecker@sports-med.org

1 Department of Orthopaedic Surgery and Traumatology, University Hospital of Bern (Inselspital), Bern, Switzerland

2 Department of Orthopaedic Surgery, Columbia University Medical Center/Presbyterian Hospital, New York, USA

3 Department of Orthopaedic Surgery and Traumatology, Cantonal Hospital of Lucerne, Berne, Switzerland