Injuries in Swedish skydiving

Anton Westman, Ulf Björnstig

Objective: To create a basis for prevention of modern skydiving injuries.

Design: Descriptive epidemiological study.

Setting: National total material.

Patients: Data on all reported injury events (n = 257) in Swedish skydiving 1999–2003 (total 539 885 jumps) were retrieved from the Swedish Parachute Association. Non-fatally injured skydivers were sent a questionnaire asking for event and injury details (response rate 89%), and supplementary hospital records were retrieved for the most serious injuries (n = 85). Human, equipment and environmental factors were assessed for risk.

Main Outcome Measurements: Frequency and severity of injuries.

Results: Incidence of non-fatal injury events was 48 per 100 000 jumps. The lower extremities, spine and shoulders were important regions of injury. The most serious injuries were experienced by licensed skydivers, but students in training had a higher injury rate and more often left the sport because of the injury. Of two student-training systems, one had an incidence less than half that of the other.

Conclusions: A basis for prevention was created, showing a potential for reduction of frequency and severity of injuries with training and technical interventions.
Inclusion and exclusion criteria

All reported skydiving incidents resulting in injuries in Sweden between 1999 and 2003 were included (n = 257). Four fatal incidents were excluded and analysed as part of a separate fatality study. Tandem jumps, military parachuting, skydiving airplane crashes and parachuting incidents in other countries involving Swedish skydivers were also excluded. Sport parachuting from fixed objects (BASE jumping) is not regulated by the SFF, and consequently not a part of this study. Compulsory reporting to the SFF may have missed some minor injuries, but
reporting of cases who sought medical consultation was believed to be satisfactory. The injury and liability insurance coverage granted to SFF members is a reporting incentive. The nationalities of skydivers in the total 257 incidents were 251 Swedish, 4 Norwegian and 2 Danish. Foreign skydivers jumping in Sweden were included in the total jump volume.

**METHODS**

**Total material**

Injury severity was categorised using the Abbreviated Injury Scale (AIS), with every separate injury (n = 311) assigned an AIS value 1–6. Every separate injury (n = 257) was categorised by the maximum AIS (MAIS) value sustained in it. Incidence rates for the whole period (1999–2003) were calculated by experience level and training system. Descriptive statistics were produced on the distribution by gender and experience level of number of incidents, age, number of jumps, severity and phase of jump when the injury occurred. Pearson’s χ² test was used to test for gender differences in the relative frequency of injuries related to landing, as opposed to other phases of the jump, as well as wing loading (ratio of total suspended weight to wing platform area of parachute <1.3 vs ≥1.4 lb/ft²) as determinant of parachute airspeed was related to severity of incident (MAIS 1–2 vs 3). The latter was investigated for landing incidents with licensed skydivers where weight of skydiver and size of parachute were known (n = 61). Statistical analyses were performed using STATA V.9.0.

**Questionnaire**

Skydivers included in the study were sent a questionnaire asking for injury details and permission to read medical records (table 3). Differences in age, gender, number of jumps and injury severity (MAIS category) between respondents and the total sample were tested for using Student’s t test (age and number of jumps) and Pearson’s χ² test (gender and MAIS category). Local ethical committee approval was obtained (04-021 M).

**RESULTS**

**Incidence rates, experience level and gender**

The risk of an injury event of any kind was six times higher per jump for students than for licensed skydivers (table 2). Of the student incidents, 41%(44) occurred during the first two training jumps, and a majority of these (26) were miscalculations during wing parachute flight with fully operational equipment under normal environmental circumstances. AFF student training had an incidence rate less than half of the conventional student training (table 2). Two incidents with student skydivers in free fall were shoulder dislocations in the AFF training system, and in both cases, an instructor deployed

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**Table 1** Demography and reported non-fatal injury events (n = 257) in the Swedish Parachute Association during 1999–2003

<table>
<thead>
<tr>
<th>Year</th>
<th>Licensed (%)</th>
<th>Students (%)</th>
<th>Total (%)</th>
<th>Incidents [rate]*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Female</td>
</tr>
<tr>
<td>1999</td>
<td>1204 (81)</td>
<td>290 (19)</td>
<td>1041 (81)</td>
<td>245 (19)</td>
</tr>
<tr>
<td>2000</td>
<td>1244 (79)</td>
<td>329 (21)</td>
<td>1330 (84)</td>
<td>255 (16)</td>
</tr>
<tr>
<td>2001</td>
<td>1421 (80)</td>
<td>364 (20)</td>
<td>1300 (82)</td>
<td>288 (18)</td>
</tr>
<tr>
<td>2002</td>
<td>1369 (78)</td>
<td>380 (22)</td>
<td>1174 (84)</td>
<td>221 (16)</td>
</tr>
<tr>
<td>2003</td>
<td>1321 (79)</td>
<td>342 (21)</td>
<td>1048 (86)</td>
<td>174 (14)</td>
</tr>
</tbody>
</table>

Tandem skydiving, military parachuting, airplane crashes and parachuting in other countries involving Swedish skydivers are excluded.

*Incidence rate per 1000 skydivers calculated from the annual total. This incidence in relation to number of participants was affected by the inclusion of six foreign skydivers injured while jumping in Sweden (one woman 2000; two men in 2001; two men and one woman in 2003).**

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**Table 2** Incidence rates of reported non-fatally injuring injury events in Sweden during 1999–2003

<table>
<thead>
<tr>
<th>Jump volume</th>
<th>Reported incidents</th>
<th>Incidents per 100 000 jumps</th>
<th>Jumps per one incident</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>539 885</td>
<td>257</td>
<td>48</td>
</tr>
<tr>
<td>Licensed</td>
<td>481 607</td>
<td>150</td>
<td>31</td>
</tr>
<tr>
<td>Student training*</td>
<td>58 278</td>
<td>107</td>
<td>184</td>
</tr>
<tr>
<td>Conventional</td>
<td>48 450</td>
<td>97</td>
<td>200</td>
</tr>
<tr>
<td>AFF</td>
<td>9828</td>
<td>8</td>
<td>81</td>
</tr>
<tr>
<td>Equipment related†</td>
<td>42</td>
<td>8</td>
<td>12 854</td>
</tr>
<tr>
<td>Serious incidents‡</td>
<td>30</td>
<td>6</td>
<td>17 996</td>
</tr>
</tbody>
</table>

**Table 3** Questionnaire sent to all living people who reported a skydiving incident with personal injury in Sweden during 1999–2003

1. What was the date of your injury?
2. How did your accident occur?
3. What were your injuries?
4. Where did you receive healthcare?
5. Were you admitted as an inpatient? If so, for how many days?
6. How many medical consultations did you have? Where?
7. Do you have any residual disability or discomfort? If so, of what kind?
8. Have you made changes in work or leisure time activities as a result of the injury? If so, of what kind?
9. Have you stopped skydiving as a result of the injury?
10. Do you have any experiences from your injury event that you would like to convey?
11. Will you grant us permission to, if necessary, read your hospital records?

Initial non-responders were sent a second copy of the questionnaire and were also contacted by telephone, but in some cases, neither current address nor telephone number could be obtained. Time from injury to questionnaire response was 1 year, 23%; 2 years, 20%; 3 years, 21%; 4 years, 20%; and 5 years, 16%. Translated from Swedish.
the parachute for the incapacitated student. The other six AFF incidents were landing injuries.

Women were over-represented among injured skydivers, with an annual relative risk (RR) ranging between 1.4 and 2.7 during the years under study (table 1). Women also had a significantly higher proportion of landing injuries than men (RR 1.11 (range 1.01–1.23); table 4).

### Incident mechanisms, club and time of year

Miscalculations during wing parachute flight and turbulence were major risk factors, as were off-drop-zone landings (figs 2 and 3). The three largest clubs combined reported 48% of the total number of jumps during the time period, but their members reported only 27% of the injury events (fig 4). In Stockholm Skydive Club 2001–2003, the risk of injury was

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**Figure 2** Mechanisms in reported non-fatal skydiving injury events in Sweden 1999–2003 (n = 257) in relation to phase of jump and experience level (student (Stud.) vs licensed (Lic.)). Miscalculations during “ordinary flight” included low turns, landings off headwind, and miscalculated horizontal levellings for landing, but excluded intentional low turns aimed at gaining landing airspeed (ie, “hookturns” referred to a separate group).

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**Table 4** Gender and experience level (student–licensed) in reported non-fatal skydiving injury events in Sweden during 1999–2003 (n = 257), in relation to phase of jump when the injury occurred

<table>
<thead>
<tr>
<th>Phase of jump</th>
<th>Mechanism of incident</th>
<th>Mechanism of injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aircraft exit</td>
<td>Insufficient separation from aircraft</td>
<td>Aircraft collision</td>
</tr>
<tr>
<td>n = 5</td>
<td>Stud. 2</td>
<td>Lic. 3</td>
</tr>
<tr>
<td>Free fall</td>
<td>Arm prone towards airstream forces</td>
<td>Airstream dislocates shoulder</td>
</tr>
<tr>
<td>n = 7</td>
<td>Stud. 2</td>
<td>Lic. 1</td>
</tr>
<tr>
<td>Parachute opening</td>
<td>Miscalculation freefall flight</td>
<td>Human collision</td>
</tr>
<tr>
<td>n = 19</td>
<td>Stud. 0</td>
<td>Lic. 4</td>
</tr>
<tr>
<td>Parachute flight</td>
<td>Turbulence 7 Strong wind 4</td>
<td>Parachute opening deceleration</td>
</tr>
<tr>
<td>n = 216</td>
<td>Stud. 26</td>
<td>Lic. 10</td>
</tr>
<tr>
<td>Landing</td>
<td>Unintentional main opening</td>
<td>Ground impact</td>
</tr>
<tr>
<td>n = 10</td>
<td>Stud. 0</td>
<td>Lic. 125</td>
</tr>
<tr>
<td></td>
<td>Turbulence 11</td>
<td>Sink rate 5</td>
</tr>
<tr>
<td></td>
<td>Stud. 13</td>
<td>Lic. 5</td>
</tr>
<tr>
<td></td>
<td>Unsuitable landing ground 4</td>
<td>Draged behind parachute</td>
</tr>
<tr>
<td></td>
<td>Stud. 1</td>
<td>Lic. 2</td>
</tr>
</tbody>
</table>
increased for the month of May, when skydiving activities resume after a 6-month winter break (fig 5).

Equipment
Equipment-related incidents including reserve activations accounted for 42 of all 257 (16%) cases (table 2). Of the 150 licensed skydiver incidents, 11 involved use of the reserve parachute. Two were a result of hard main parachute openings, when the abrupt deceleration injured both skydiver (neck sprain and rib fractures, respectively) and main parachute, necessitating use of the reserve. The other nine experienced hard reserve landings. Number of jumps with the equipment used was known in 140 incidents for licensed skydivers with a median of 70 (range 1–2000) jumps. There was no significant association between wing loading and severity of landing incidents in this material.

Of the 107 student skydiver incidents, 15 involved use of the reserve parachute. Of these 15 injury events, three occurred during main parachute opening, with two hard openings and one entanglement where the main parachute twisted the knee of the skydiver. The other 12 experienced hard reserve landings. Reasons for student reserve use included four low main parachute activations with subsequent automatic reserve activations and one premature automatic reserve activation.

Anatomical location, severity and most serious incidents
The lower extremities suffered 51% (160) of the total 311 injuries (fig 6). There were no injuries of severity AIS >4. Severities of the total 257 incidents were 105 (41%) MAIS 1, 122 (47%) MAIS 2 and 30 (12%) MAIS 3 (table 5).

The 30 MAIS 3 cases produced a total of 55 injuries (1 AIS 1, 15 AIS 2 and 39 AIS 3), of which 49 (89%) were fractures, mainly located to the lower leg (14), thigh (13), spine (5), pelvis (4) and foot (4). Of the 30 MAIS 3 incidents, six cases had ≥2 injuries of AIS 3 severity. All except one case of a knee injury (complete disruption of the posterior and anterior cruciate ligament) had been admitted to hospital inpatient care (table 6). Of the 30 MAIS 3 incidents, 27 occurred at landing and 3 during parachute opening. Six of these landing incidents were off the drop zone, including three planned demonstration landings.

The MAIS 3 group showed a shift towards higher experience level. The median number of jumps was increased to six times that of the whole group, and 23 (77%) were licensed skydivers. The proportion of D-licensed (expert) skydivers was doubled from overall 67 (26%) to 15 (50%).

Five MAIS 3 incidents were miscalculated hookturns by licensed skydivers. Other MAIS 3 incidents experienced by licensed skydivers included miscalculated standard, straight-approach landings with fully operational parachute under normal environmental circumstances, miscalculated low turns performed without intent of gaining airspeed and turbulent air. Two MAIS 3 incidents with licensed skydivers occurred during parachute opening: one unstable parachute activation with the pilot chute line around the neck and one unintentional opening of the main parachute. Both cases involved relatively
inexperienced skydivers (A-licensed) with few (2 and 12) jumps with the particular equipment used.

Two incidents of MAIS 3 severity were experienced by first-jump students, both sustaining lower leg fractures as a result of hard landings with operational wing (main and reserve, respectively) parachutes. Of the other five MAIS 3 incidents with student skydivers, two were miscalculated standard, straight-approach landings with fully operational parachutes under normal environmental circumstances, one had entangled an arm with the opening parachute and sustained an upper arm fracture, one landed in strong wind on a fence and one landed on grassy, uneven terrain.

Questionnaire responses
A total of 229 questionnaire responses were received, giving a response rate of 89% (table 5). The respondents did not differ significantly from the total group in age, gender, number of jumps and injury severity (MAIS category). Table 6 gives the results from questionnaire responses. On the basis of the Swedish Ministry of Health and Social Affairs assessment...
Questionnaire non-responders

The median number of jumps by non-responders was lowered from 55 to 10 (range 1–1300). The student proportion increased and the proportion of D-licensed (expert) skydivers decreased. Gender and age were the same as for the total group. The proportion of MAIS 2 (moderate) incidents was increased and the proportion of MAIS 3 (serious) incidents decreased. The non-responder group contained five of the total six foreign skydiver cases.

DISCUSSION

Most injuries were caused by wing parachute pilot errors. A parachute (aerodynamic decelerator) slows down motion against air, whereas a wing slices through it with the ability to, given speed, deflect airstreams powerful enough to generate lift against gravity. When these two contrasting principles were
shoulder stability in skydiving must be considered by medical practitioners to maintain a stable body position in free fall. The importance of functional arm and leg strength can render an inexperienced skydiver unable to control his or her body position and falling velocity during the free fall. In acute danger, as reserve parachute emergency deployment is possible, but it requires adequate training and preparation.

Both students who dislocated their shoulders in free fall were alongside to assist, the AFF advantage may lie in better training of wing parachute piloting. Free-fall tumbling leading to head trauma, which was initiated by one skydiver hookturning into another, was saved by a skydiving friend. High-speed landing approaches that produce a high-speed glide path into the ground were observed in Swedish skydiving. High-speed landing approaches may reduce the number and severity of injuries. Such a landing technique exists; the parachute landing fall, distributing the forces of a hard landing through rolling. It has been part of parachuting for decades, but presently seems neglected.

It may be speculated whether some of the spinal injuries sustained during landing might have been prevented or moderated by use of protective equipment. Several spinal injuries were also sustained directly during parachute opening. Although the skydiver has some influence on opening shock with packing, body position and slowing down in free fall before deploying, part of the problem with injuries sustained during this phase of the jump seems technical. The relatively few head injuries may be an encouraging outcome of helmet requirements.

If miscalculated, the steeply diving hookturn manoeuvre will produce a high-speed glide path into the ground. This was a common mechanism for licensed skydivers and the cause of death of one Swedish skydiver in 2005. High-speed landing approaches can also create traffic disturbances. The chain of events that led to the most severe incident (pelvis fracture, bilateral femur and tibia fractures) was initiated by one skydiver hookturning into another before landing. High-speed landing approaches should receive recognition as advanced manoeuvres, and be separated from other parachute traffic. Definitions of the experience levels required to fly fast wing parachute models should include the ability to perform advanced manoeuvres with slower wing parachutes before upgrading. Work in this area has started in the SFF, and existing regulations regarding experience level and the use of fast-flying wing parachutes for licensed skydivers may have contributed to the present injury rate being the lowest described for skydiving.

The lower injury incidence for the AFF student training system seems favourable, but present data could not give any indications as to how AFF students fare as new license holders. As most students were injured at landing, when no AFF instructors were alongside to assist, the AFF advantage may lie in better teaching of wing parachute piloting. Free-fall tumbling leading to unstable parachute activation with subsequent line entanglement is a risk factor for a student’s death where AFF may offer protection. Both students who dislocated their shoulders in free fall were in acute danger, as reserve parachute emergency procedures require bilateral hand and arm function, and a non-functional arm can render an inexperienced skydiver unable to maintain a stable body position in free fall. The importance of shoulder stability in skydiving must be considered by medical doctors performing precourse examinations.

Efforts should be undertaken to minimise the risk for off-drop-zone landings. Half the total Swedish area is forest, and unintentional water landings have been a mechanism in skydiving deaths. It has been claimed that the wing parachute has eliminated the risk of future drownings, but the numerous present student off-drop-zone landing incidents do not support that view. Many Swedish clubs abandoned ground-to-student radio instruction during the 1990s, mainly because of poor technical quality. A radio reconsideration may be called for. Turbulent air collapsing or deforming the textile wing can be avoided by parachutists who are aware of this invisible enemy, and parachutes can be designed to minimise susceptibility to it.

During 2002, the Swedish urban centre of Umeå (population 138 313) had 22% MAIS 2 and 2% MAIS 3 vehicle-related incidents, whereas Swedish skydiving during 1999–2003 had 47% MAIS 2 and 12% MAIS 3 incidents (including cases who never sought medical consultation). With a proportion of non-minor injuries more than double that of road traffic, it is imperative that injured skydivers receive fast and adequate care. One of the present cases had an obstructed airway and was saved by a skydiving friend.

A general instruction for students to activate the reserve on any uncertainty about main parachute integrity may have exaggerated the equipment-related incidence. In future studies on skydiving, it would be desirable to obtain license-level and gender-specific jump volumes. The larger landing injury proportion within the female group is intriguing. Some skydiving equipment in the early 1970s was unsuitable for women. Is there a modern gender pattern for skydiving injuries?

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REFERENCES

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