Pattern of Injury after Rock Climbing Falls is Not Determined by Harness Type

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Running title: Rock climbing falls

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ABSTRACT

Objective: Experimental data suggest that when using a sit harness alone, any major fall during rock climbing may cause life-threatening thoraco-lumbar hyperextension trauma or “head down position” during suspension. To clarify the actual influence of the type of harness on the pattern and severity of injury, accidents involving a major fall in a climbing harness were analyzed retrospectively.

Methods: Individuals with a height of fall equal to or exceeding 5 meters were identified through a search of accident and emergency protocols for the period 2000 - 2004. Data concerning the circumstances of the fall and the pattern of injury were obtained from personal interviews, flight and accident reports, as well as hospital medical records.

Results: Of a total of 113 climbers identified, 73 (64.6%) used a sit harness alone, whereas 40 (35.4%) used a body harness. Fractures and dislocations of the extremities, the shoulder and pelvic region were the most common injuries, while the most severe injuries occurred in the head and neck region. Although most falls were associated with mild or moderate injuries, 13 (11.5%) climbers sustained severe or critical multi-system trauma. Falls on more difficult routes were associated with less severe injury. The type of harness used did not influence the pattern or severity of injury. In particular, no evidence was found for the existence of a thoraco-lumbar hyperextension trauma.

Conclusions: The type of harness does not influence the pattern or severity of injury and the forces transferred via the harness do not cause a specific harness-induced pathology. We did not find any evidence that hyperextension trauma of the thoraco-lumbar region is an important mechanism of injury in climbers using a sit harness alone. Rock contact during the fall, and not the force transferred through the harness, is the major cause of significant injury in climbing accidents.
INTRODUCTION

Improvements in the safety equipment for rock climbers have markedly reduced the risks associated with falls in climbing harnesses. Climbing ropes nowadays absorb a significant portion of the fall energy by elongation. This greatly reduces the forces arising, but may allow a further fall of up to 40% of the rope's length. Furthermore, dynamic belaying techniques, absorbing additional energy by friction, are routinely used. Nevertheless, forces of up to 6.5 kN must be expected after a major fall, and therefore sophisticated harnesses are needed to prevent major injuries when these forces are transferred to the human body.

Basically, three types of harness have been widely used during the last few decades: chest harnesses, sit harnesses and body harnesses. The latter include premade full-body harnesses as well as combinations of sit and chest harnesses tied together. Because of the dramatic hemodynamic and respiratory impairments experienced in free suspension, the use of a chest harness alone is no longer recommended and nowadays rarely used. The use of a sit harness alone is very popular among Anglo-American climbers for sports as well as alpine climbing. By contrast, some European climbers prefer a body harness whenever a greater fall in a climbing harness is possible. This preference is scientifically based on one report from the early nineties, demonstrating a significant risk of hyperextension trauma of the thoraco-lumbar region, as well as of “head down” positions during suspension associated with sole sit harness use. This experimental study suggests that a body harness may be the safest way to deal with the forces associated with a fall in a climbing harness. To further clarify the influence of the type of harness on the pattern and severity of injury in rock climbing accidents, we conducted this retrospective analysis of a significant number of accidents involving a major fall in a climbing harness.
METHODS

Individuals participating in the study were primarily identified through a search of accident and emergency reports for the period 2000-2004. Data were gathered from the flight reports of three physician-staffed emergency medical helicopters operating in the Austrian Alps (Christophorus 1 in Innsbruck, Christophorus 5 in Zams, Christophorus 8 in Feldkirch), from the accident reports of the Austrian Mountain Rescue Service and from the emergency room charts of four hospitals located near busy climbing areas (Innsbruck, Zell am See, St. Johann, Feldkirch). Victims were included only after a fall equal to or exceeding 5 meters in height during outdoor rock climbing. Victims already dead at the arrival of the emergency medical team were not included.

One of the authors contacted each climber meeting the inclusion criteria and asked whether he or she was willing and able to give sufficient information on the circumstances of the accident to be included in the study. During these interviews we learned of further climbing accidents involving other climbers meeting the inclusion criteria, which were also considered for analysis.

For each accident the following data on the circumstances of the fall were obtained: cause of the fall, height of the fall, difficulty of the climbing route according to UIAA (Union Internationale des Associations d’Alpinisme, International Mountaineering and Climbing Federation, www.uiaa.ch) grading, type of harness used (sit harness alone or body harness), body position during the fall, body position during suspension. All data regarding the circumstances of the fall were obtained in personal interviews, either of the injured climber himself, or of a witness to the accident (typically accompanying climbers or members of the rescue team).
For climbers injured severely enough to require hospital treatment, all injuries diagnosed were obtained from the hospital medical records. Severity of injuries was graded using the Abbreviated Injury Scale (AIS) scoring system and the Injury Severity Score (ISS) system. The AIS is a consensus-derived, anatomically based system, that allocates each injury to one of six body regions (head & neck, face, chest, abdomen, extremity, external) and classifies them on a six-point severity scale ranging from score 1 to 6 (minor, moderate, serious, severe, critical, unsurvivable). In this study only injuries with an AIS severity score equal to 3 or more were considered for further analysis. The ISS takes into account the combined effect of individual injuries in patients with multi-system trauma and is calculated from the AIS scores of the three most severely affected body regions. ISS values between 1 and 7 are classified as minor injury, 8-13 as moderate injury, 14-20 as severe multi-system trauma, and more than 20 as critical multi-system trauma.

In addition, all thoraco-lumbar spine fractures were classified according to the system proposed by Magerl, based on X-ray and CT scan findings. Briefly, this system classifies thoraco-lumbar spine injuries based on the underlying mechanism of injury (type A, compression; type B, distraction; type C, axial torque). This should allow differentiation of spine fractures caused by hyperextension trauma (Magerl class B3) and those caused by compression trauma associated with rock contact during the fall (Magerl class A).

**Statistical analysis**

Means, standard deviations of means and ranges were calculated to describe continuous variables. Qui-square Test, Mann-Whitney-U Test, and one-way-ANOVA were used for statistical analysis. P values below 0.05 were considered significant.
RESULTS

A total of 113 accidents were able to be sufficiently documented and included in the study. Ninety-one percent (103) of the climbers included were male. Seventy-three (64.6%) used a sit harness alone, whereas 40 (35.4%) climbers used a body harness. Mean height of fall was 16.4 meters (±12.2, range 5 to 60 meters) (Table 1A), mean UIAA difficulty of routes climbed was 5.9 (±1.4, range III to VIII) (Table 1B). Among the causes for the fall slipping (39.8%) ranked first, followed by handhold breakage (36.3%) and exhaustion (12.4%).

Injury Severity Score

Most falls were associated with mild or moderate injuries as indicated by a mean ISS of 6.2 (range 1 to 41). Eighty-three (73.5%) climbers were uninjured or had minor injuries, 17 (15.0%) sustained moderate injuries, whereas 13 (11.5%) had severe or critical multi-system trauma. Falls on more difficult routes were associated with less severe injury (Table 2), while the height of the fall did not significantly correlate with the severity of injury. In comparison to climbers with a body harness, those equipped with a sit harness alone fell on more difficult routes (UIAA 5.4 vs. 6.2, p=0.004) and sustained less severe injuries as assessed by their mean ISS (ISS 5.0 versus 8.4, p = 0.039). When considering the difficulty of the route, however, the severity of injury was independent of the type of harness used (Table 2).

Pattern of injury

Apart from a significantly higher rate of head trauma and thoracic injuries in victims using a body harness, the pattern of injury did not differ between the sit harness group and the body harness group (Table 3). Head and thoracic injuries, however, predominantly occurred on routes of low or moderate difficulty (mean UIAA 4.6 and 3.8, respectively), where more climbers used a body harness (60% and 66.7%, respectively). The most common injuries were
fractures and dislocations of the extremities, the shoulder and pelvic region, while the most severe injuries occurred in the head and neck region. Significant abdominal visceral injuries were not seen in the study population.

**Spine fractures**

Eight patients (7.1%) sustained spine fractures, five of them in the thoraco-lumbar region (Table 4). Four of the five thoraco-lumbar fractures were Magerl class A fractures, and one was a twelfth thoracic vertebra spinous process fracture. This patient, using a body harness, fell on a route of low difficulty (UIAA III) and had documented rock contact during the fall. Two displaced cervical spine fractures and a complex thoracic compression fracture with axial torque were associated with transverse spinal cord lesions.

**Body position**

“Head first” positions during fall occurred in 35 of 102 (34.3%) falls with the position documented during fall, while “head down” positions during suspension were seen in 11 of 113 (9.7%) falls. “Head first” position during fall was found more often on easier routes (Table 5), but was not associated with the type of harness used. By contrast, the harness type significantly influenced body position during suspension as the “head down” position was exclusively seen in climbers without chest harness (n=11, p=0.006). Body position during suspension was documented in six unconscious patients. Two of them using a sit harness alone were found in a “head down” position, while the remaining four using body harnesses were in an upright position after the fall.
DISCUSSION

While stress on a joint is the most important mechanism of injury in sport rock climbing, falling is responsible for the majority of injuries in traditional rock climbing.\textsuperscript{8,9} Based on experimental data Magdefrau\textsuperscript{2} calculated that a fall in a climbing harness is associated with forces of up to 6.5 kN. Transferring these forces to the human body through a harness bears a considerable risk of injury. Magdefrau\textsuperscript{2} concluded that when using a sit harness alone, these forces are sufficient to cause life-threatening spine and abdomino-visceral injuries secondary to a thoraco-lumbar hyperextension trauma. To support his hypothesis, Magdefrau\textsuperscript{2} collected data on a number of climbing accidents, in which climbers using a sit harness alone had sustained thoraco-lumbar spine injuries, often with accompanying paraplegia. Although no detailed information about the type of injury was given, Magdefrau\textsuperscript{2} postulated that these injuries were caused by a hyperextension mechanism. However, factors apart from sit harness use can cause thoraco-lumbar spine injuries. Consequently, it remains to be proven in each case, whether a spine fracture was secondary to hyperextension trauma, or the result of thoraco-lumbar compression trauma associated with rock contact during the fall. In our data the incidence of thoraco-lumbar spine injuries was comparable in climbers using a sit harness alone and those using a body harness. With one exception, all thoraco-lumbar spine injuries were found in climbers injured on routes of low difficulty and in most cases rock contact during the fall was documented. Thoraco-lumbar spine fractures in victims using a sit harness alone were invariably Magerl class A fractures, indicating compression trauma secondary to rock contact, but not hyperextension as the underlying mechanism of injury. Taken together, the postulated problem of thoraco-lumbar hyperextension trauma in climbers without chest harness could not be verified in our analysis of real life climbing accidents. According to our data, rock contact during a fall on routes of lower grades of difficulty is the major cause of spine injuries in climbing accidents.
Due to the limited number of accidents studied, we can not definitely rule out the danger of hyperextension trauma in a few selected situations, for example when the climber carries a backpack. However, nearly two thirds of the climbers in this study belayed themselves with a sole sit harness. This allowed us to study a significant number of large falls involving climbers using only a sit harness. We could not find a single case of thoraco-lumbar hyperextension or abdomino-visceral injury. If the problem of hyperextension trauma in climbers using a sit harness alone actually exists, it is obviously a rare mechanism of injury. In general, we are likely to overestimate the overall severity of injury, because a great majority of the climbers in this study were rescued by professional rescue teams and treated in hospital, whereas in all probability a huge number of non-injured climbers were not available to the authors.

In addition it should be remembered that the use of a body harness does not necessarily ward off the risk of hyperextension trauma. It is reasonable to assume that the use of a body harness only shifts the danger of hyperextension trauma from the thoraco-lumbar to the cervical region. The small number of cervical spine injuries in climbers using a combination of harnesses in our study population does not allow this assumption to be verified. Because this study did not include victims already dead on arrival of the rescue team, one might argue that the most severe cases of hyperextension trauma were missed, because these victims died immediately after the fall. However, common knowledge indicates that lethal free-fall injury (i.e. without impacting fixed terrain objects) is exceptionally rare. This is supported by Bowie WS et al., who reported an overall case fatality rate of 6% in rock climbing accidents, with nearly all victims dying from severe head trauma or hypothermia, whereas spine trauma was described in none of his accidents.
The "head down" position during suspension was exclusively seen in victims without chest harness. This is in accordance with experimental data reported by Magdefrau\textsuperscript{2}, suggesting that only a body harness guarantees an upright position during suspension after the fall. As most of the conscious victims are able to immediately correct their “head down” position, this position is of particular interest in unconscious victims. An upright position during suspension might be preferable for an unconscious patient with cerebral trauma, as it prevents the marked increase in intra-cerebral pressure associated with a “head down” position.\textsuperscript{12} On the other hand, an upright position in an unconscious climber entails the risk of airway obstruction and asphyxia. Without immediate professional help, the prognosis for an unconscious climber with cerebral trauma suspended on a rope is probably extremely poor, no matter what type of harness is used.\textsuperscript{2,3}

The high incidence of fracture of the extremities, the skull and the thorax suggests that direct impact-associated injuries caused by rock contact during the fall are the leading cause of major injury in climbing accidents. This is also supported by the fact that more difficult routes in steeper terrain and consequently less risk of rock contact during the fall were associated with less severe injuries. By contrast, the height of fall was not closely associated with the severity of injury. The large number of fractures of the lower extremities implies that the force of impact is often absorbed by the lower limbs. This was already described by Locker T et al.\textsuperscript{13}, who supposed that the combination of rope and harness attached at the waist mostly maintains the falling climber in a vertical position. A preponderance of lower extremity injuries has also been documented among injured climbers in Yosemite National Park.\textsuperscript{11} As head injuries were rare there, the authors believed this could further support the assumption that body position was upright during the fall.
However, "head first" positions during a fall do indeed occur and carry a particularly high risk of severe head and neck injuries. These falls occur significantly more often on easier, less steep climbing routes. We assume that rock contact during the fall is the mechanism that changes the climber from a “feet first” to a “head first” position. This mechanism is obviously more frequent in less steep terrain. Taken together, our data suggest that it is primarily the number of correctly placed belaying pins and bolts used to reduce the incidence and impact of rock contact during a fall that improve the safety of rock climbing and reduces the risk of major injury. This is obviously neglected above all on climbing routes of low or moderate difficulty.

We found a significantly higher mean ISS in climbers equipped with a body harness. But these climbers fell on less difficult routes, where the risk of injury was significantly greater. Taking route difficulty into consideration, a comparison of the two harness-type groups showed no significant difference in mean ISS. Furthermore, the higher rate of head and thoracic injuries in victims with body harnesses, is also seen from the fact that those with a body harness fell on less difficult routes, where a “head first” position and rock contact during the fall were more common. Therefore, it is very likely that it was not the type of harness used but the terrain in which the accident occurred that caused the observed difference in the pattern of injury.

**Conclusion**

In summary, we did not find any evidence to show that the type of harness used significantly influences the pattern or severity of injury in climbing accidents. Hyperextension trauma of the thoraco-lumbar region is not an important mechanism of injury in climbers using a sit harness alone. Our data indicate that direct rock contact during a fall is the leading mechanism of injury, especially on routes of lesser difficulty. The forces transferred via the harness did
not cause a specific harness-induced pathology. During suspension only a body harness guarantees upright position, particularly in unconscious victims.
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Table 1: Characteristics of the 113 climbing accidents analyzed

A. Distribution of falling heights

<table>
<thead>
<tr>
<th>Height of fall</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10 m</td>
<td>52 (46.0%)</td>
</tr>
<tr>
<td>11-20 m</td>
<td>40 (35.4%)</td>
</tr>
<tr>
<td>&gt; 20 m</td>
<td>21 (18.6%)</td>
</tr>
</tbody>
</table>

B. Difficulty of routes climbed

<table>
<thead>
<tr>
<th>Difficulty of route</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIAA III/IV</td>
<td>20 (17.7%)</td>
</tr>
<tr>
<td>UIAA V/VI</td>
<td>54 (47.8%)</td>
</tr>
<tr>
<td>UIAA VII/VIII</td>
<td>39 (34.5%)</td>
</tr>
<tr>
<td>Difficulty of route</td>
<td>ISS (sit harness)</td>
</tr>
<tr>
<td>---------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>UIAA III/IV (n=20)</td>
<td>11.6 ± 11.6</td>
</tr>
<tr>
<td>UIAA V/VI (n=54)</td>
<td>5.1 ± 6.4</td>
</tr>
<tr>
<td>UIAA VII/VIII (n=39)</td>
<td>2.9 ± 2.7</td>
</tr>
</tbody>
</table>

* according to UIAA grading: III/IV = routes of low and moderate difficulty, V/VI = routes of great difficulty, VII/VIII = routes of very great and extraordinarily great difficulty; ISS = Injury Severity Score, n.s.d. = no significant difference between climbers using a sit harness and climbers using a body harness when considering climbing routes of comparable difficulty
Table 3: Pattern of injury in relation to the type of harness

<table>
<thead>
<tr>
<th>Injury</th>
<th>Sit harness (n=73)</th>
<th>Body harness (n=40)</th>
<th>Total (n=113)</th>
<th>p value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>head</td>
<td>8.2%</td>
<td>22.5%</td>
<td>13.3%</td>
<td>p=0.034</td>
</tr>
<tr>
<td>upper extremity, shoulder region</td>
<td>13.7%</td>
<td>17.5%</td>
<td>15.0%</td>
<td>n.s.d.</td>
</tr>
<tr>
<td>thoracic trauma</td>
<td>4.1%</td>
<td>15.0%</td>
<td>8.0%</td>
<td>p=0.049</td>
</tr>
<tr>
<td>abdominal trauma</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>n.s.d.</td>
</tr>
<tr>
<td>spine fractures</td>
<td>5.5%</td>
<td>10%</td>
<td>7.1%</td>
<td>n.s.d.</td>
</tr>
<tr>
<td>lower extremity, pelvic fracture</td>
<td>23.3%</td>
<td>20.0%</td>
<td>22.1%</td>
<td>n.s.d.</td>
</tr>
</tbody>
</table>

* Significance of difference between climbers using a sit harness alone and climbers using a body harness; n.s.d. = no significant difference
### Table 4: Characteristics of patients with spine fractures (fx)

<table>
<thead>
<tr>
<th>Pat.</th>
<th>Fracture</th>
<th>Harness</th>
<th>Magerl class</th>
<th>Height of fall</th>
<th>Difficulty of route*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C6/C7 dislocation fx</td>
<td>sit</td>
<td>-</td>
<td>20 m</td>
<td>V</td>
</tr>
<tr>
<td>2*</td>
<td>C6/C7 dislocation fx</td>
<td>body</td>
<td>-</td>
<td>10 m</td>
<td>VII</td>
</tr>
<tr>
<td>3</td>
<td>T3/T4/T5 compression fx</td>
<td>body</td>
<td>C</td>
<td>10 m</td>
<td>III</td>
</tr>
<tr>
<td>4*</td>
<td>T11/T12 compression fx</td>
<td>sit</td>
<td>A</td>
<td>8 m</td>
<td>V</td>
</tr>
<tr>
<td>5*</td>
<td>T12 spinous process fx</td>
<td>body</td>
<td>-</td>
<td>6 m</td>
<td>III</td>
</tr>
<tr>
<td>6*</td>
<td>L1 burst fx</td>
<td>body</td>
<td>A</td>
<td>5 m</td>
<td>III</td>
</tr>
<tr>
<td>7</td>
<td>L1 compression fx</td>
<td>sit</td>
<td>A</td>
<td>20 m</td>
<td>III</td>
</tr>
<tr>
<td>8*</td>
<td>L2 compression fx</td>
<td>sit</td>
<td>A</td>
<td>10 m</td>
<td>III</td>
</tr>
</tbody>
</table>

* according to UIAA grading: III/IV = routes of low and moderate difficulty, V/VI = routes of great difficulty, VII/VIII = routes of very great and extraordinarily great difficulty;  
# documented rock contact during the fall
Table 5: Head position during fall in relation to route difficulty*

<table>
<thead>
<tr>
<th>Difficulty of route</th>
<th>Climbers</th>
<th>Head first during fall*</th>
</tr>
</thead>
<tbody>
<tr>
<td>UIAA III/IV</td>
<td>n = 15</td>
<td>n = 9 (60.0%)</td>
</tr>
<tr>
<td>UIAA V/VI</td>
<td>n = 49</td>
<td>n = 18 (36.7%)</td>
</tr>
<tr>
<td>UIAA VII/VIII</td>
<td>n = 38</td>
<td>n = 8 (21.1%)</td>
</tr>
</tbody>
</table>

Significance: \( p = 0.024 \)

* according to UIAA grading: III/IV = routes of low and moderate difficulty, V/VI = routes of great difficulty, VII/VIII = routes of very great and extraordinarily great difficulty;

+ position during fall documented in 102 victims