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ORIGINAL RESEARCH

Pattern of Injury After Rock-Climbing Falls Is Not Determined by Harness Type

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Objective.—Experimental data indicate 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 m were identified through a search of accident and emergency records for the period from 2000 to 2004. Data concerning the circumstances of the fall and the patterns 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 the 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 multisystem 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.

Key words: rock climbing, fall, rope, trauma, mountaineering, harness, accident

Introduction

Improvements in the safety equipment for rock climbers have markedly reduced the risks associated with falls in climbing harnesses.[1] Nowadays climbing ropes 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, which absorb additional energy by friction, are routinely used. Nevertheless, forces of up to 6.5 kiloNewton (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.[2]

Basically, 3 types of harnesses 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

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in free suspension, the use of a chest harness alone is no longer recommended and is nowadays rare.[3] The use of a sit harness alone is very popular among Anglo-American climbers for sport as well as for 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[2] from the early 1990s, which demonstrated 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[2] indicated 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 extending from 2000 to 2004. Data were gathered from the flight reports of 3 physician-staffed emergency medical helicopters operating in the Austrian Alps (Christophorus 1 in Innsbruck, Christophorus 5 in Zams, and Christophorus 8 in Feldkirch), from the accident reports of the Austrian Mountain Rescue Service, and from the emergency room charts of 4 hospitals located near busy climbing areas (Innsbruck, Zell am See, St. Johann, and Feldkirch). Victims were included only after a fall equal to or exceeding 5 m 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, accidents that met the inclusion criteria, and these cases 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 Union Internationale des Associations d'Alpinisme (UIAA, International Mountaineering and Climbing Federation, www.uiaa.ch) grading, type of harness used (sit harness alone or body harness), body position during the fall, and 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[4] and the Injury Severity Score (ISS) system.[5] The AIS is a consensus-derived, anatomically based system that allocates each injury to one of 6 body regions (head and neck, face, chest, abdomen, extremity, and external) and classifies them on a 6-point severity scale ranging from score 1 to 6 (minor, moderate, serious, severe, critical, or 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 multisystem trauma and is calculated from the AIS scores of the 3 most severely affected body regions. Injury Severity Score values between 1 and 7 are classified as minor injury, values between 8 and 13 as moderate injury, values between 14 and 20 as severe multisystem trauma, and values of more than 20 as critical multisystem trauma.[6]

In addition, all thoraco-lumbar spine fractures were classified according to the system proposed by Magerl et al,[7] based on plain radiographic and computed tomographic scan findings. Briefly, this system classifies thoraco-lumbar spine injuries based on the underlying mechanism of injury (type A, compression; type B, distraction; and 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 the mean, and ranges were calculated to describe continuous variables. Chi-square test, Mann-Whitney *U* test, and 1-way analysis of variance were used for statistical analysis. *P* values below .05 were considered significant.

Results

A total of 113 accidents were able to be sufficiently documented to be included in the study. Ninety-one percent (103) of the climbers included were male. Seventy-three (64.6%) climbers used a sit harness alone, whereas 40 (35.4%) climbers used a body harness. Mean height of fall was 16.4 m (±12.2 m; range: 5–60 m) (Table 1), and mean UIAA difficulty of routes climbed was 5.9

Table 1. Characteristics of the 113 climbing accidents analyzed: distribution of falling heights and difficulty of routes climbed

Characteristic	*No. of victims (%)*
Height of fall (m)	
5–10	52 (46.0)
11–20	40 (35.4)
>20	21 (18.6)
Difficulty of route (grade)*	
UIAA III/IV	20 (17.7)
UIAA V/VI	54 (47.8)
UIAA VII/VIII	39 (34.5)

*UIAA indicates Union Internationale des Associations d'Alpinisme; according to UIAA grading: III/IV indicates routes of low and moderate difficulty; V/VI, routes of great difficulty; and VII/VIII, routes of very great and extraordinarily great difficulty.

(±1.4; range: III to VIII) (Table 1). 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: 1–41). Eighty-three (73.5%) climbers were uninjured or had minor injuries, 17 (15.0%) sustained moderate injuries, and 13 (11.5%) had severe or critical multisystem 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, $P = .004$) and sustained less severe injuries, as assessed by their mean ISS (ISS 5.0 vs 8.4, $P = .039$). 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 values of 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 the 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, 5 of them in the thoraco-lumbar region (Table 4). Four of the 5 thoraco-lumbar fractures were Magerl class A fractures, and one was a 12th 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

Table 2. Severity of injury as assessed by the ISS in relation to the difficulty of the route* climbed and the harness used

Difficulty of route	*ISS (sit harness)*	*ISS (body harness)*	*ISS (total)*	*P value*
UIAA III/IV ($n = 20$)	11.6 ± 11.6	15.6 ± 14.8	13.7 ± 13.2	n.s.d.
UIAA V/VI ($n = 54$)	5.1 ± 6.4	6.0 ± 6.8	5.4 ± 6.6	n.s.d.
UIAA VII/VIII ($n = 39$)	2.9 ± 2.7	4.9 ± 7.7	3.3 ± 4.3	n.s.d.
P value	.002	.024	<.001	

*UIAA indicates Union Internationale des Associations d'Alpinisme; according to UIAA grading: III/IV indicates 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; and 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

Injury	*Sit harness (%) (n = 73)*	*Body harness (%) (n = 40)*	*Total (%) (n = 113)*	*P value**
Head	8.2	22.5	13.3	.034
Upper extremity, shoulder region	13.7	17.5	15.0	n.s.d.
Thoracic trauma	4.1	15.0	8.0	.049
Abdominal trauma	0	0	0	n.s.d.
Spine fractures	5.5	10	7.1	n.s.d.
Lower extremity, pelvic fractures	23.3	20.0	22.1	n.s.d.

*Significance of difference between climbers using a sit harness alone and climbers using a body harness; n.s.d. indicates no significant difference.

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 harnesses ($n = 11$, $P = .006$). Body position during suspension was documented in 6 unconscious patients. Two of them using a sit harness alone were found in a ''head down'' position, while the remaining 4 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.[8,9] Based on experimental data, Magdefrau[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[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[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[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 proved 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 con-

Table 4. Characteristics of patients with spine fractures (fx)

Patient	*Fracture*	*Harness*	*Magerl class*	*Height of fall (m)*	*Difficulty of route**
1	C6/C7 dislocation fx	Sit	···	20	V
2†	C6/C7 dislocation fx	Body	···	10	VII
3	T3/T4/T5 compression fx	Body	C	10	III
4†	T11/T12 compression fx	Sit	A	8	V
5†	T12 spinous process fx	Body	···	6	III
6†	L1 burst fx	Body	A	5	III
7	L1 compression fx	Sit	A	20	III
8†	L2 compression fx	Sit	A	10	III

*According to Union Internationale des Associations d'Alpinisme (UIAA) grading: III/IV indicates routes of low and moderate difficulty; V/VI, routes of great difficulty; and 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*

Difficulty of route	*Climbers, n*	*Head first during fall,† n (%)*
UIAA III/IV	15	9 (60.0)
UIAA V/VI	49	18 (36.7)
UIAA VII/VIII	38	8 (21.1)
Significance		$P = .024$

*According to Union Internationale des Associations d'Alpinisme (UIAA) grading: III/IV indicates routes of low and moderate difficulty; V/VI, routes of great difficulty; and VII/VIII, routes of very great and extraordinarily great difficulty.

†Position during fall documented in 102 victims.

tact, 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.

As a result of the limited number of accidents studied, we cannot 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 were treated in a hospital, whereas in all probability a huge number of noninjured 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 upon 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 (ie, without impacting fixed terrain objects) is exceptionally rare. This is supported by Bowie et al,[10] 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 harnesses. This is in accordance with experimental data reported by Magdefrau,[2] indicating 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 intracerebral pressure associated with a "head down" position.[11] 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.[2,3]

The high incidence of fracture of the extremities, the skull, and the thorax indicates 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 et al,[12] who supposed that the combination of rope and harness attached at the waist most often 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.[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 injury. 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 indicate 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 improves 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 2 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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