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Mechanisms of snowboarding-related severe head injury: shear strain induced by the opposite-edge phenomenon

HIROSHI NAKAGUCHI, M.D., PH.D., AND KAZUO TSUTSUMI, M.D., PH.D.

Department of Neurosurgery, Suwa Central Hospital, Chino city, Nagano; Department of Neurosurgery, Teraoka Memorial Hospital, Ashina gun, Hiroshima; and Department of Neurosurgery, Aizu Central Hospital, Fukushima, Japan

Object. To date, there has been no published study in which the focus was on the mechanisms of head injuries associated with snowboarding. The purpose of this study was to identify these mechanisms.

Methods. The patient population consisted of 38 consecutive patients with snowboarding-related major head injuries who were treated at two hospitals in Japan, where for years many winter sports injuries have been treated. The skill level of the snowboarder, the cause of the accident, the direction of the fall, the site of impact to the head, and the condition of the ski slope were examined. The injuries were classified as coup, contrecoup, or shear injuries.

The predominant features of snowboarding-related major head injuries included: falling backward (68% of cases), occipital impact (66% of cases), a gentle or moderate ski slope (76% of cases), and inertial injury (76% of cases [shear injury in 68% and contrecoup injury in 8% of the patients]). Acute subdural hematoma frequently occurred after a patient fell on the slope ($p = 0.025$), fell backward ($p = 0.0014$), or received an occipital impact ($p = 0.0064$). Subcortical hemorrhagic contusions frequently occurred after the patient fell during a jump ($p = 0.0488$), received a temporal impact ($p = 0.0404$), or fell on the jump platform ($p = 0.0075$). Shear injury frequently occurred after a fall that occurred during a jump or after simple falls on the ski slope, and contact injury was frequently seen after a collision ($p = 0.0441$).

Conclusions. The majority of severe head injuries associated with snowboarding that occur after a simple fall on the slope are believed to involve the opposite-edge phenomenon, which results from a fall backward on a gentle or moderate slope causing occipital impact. The use of a device to protect the occiput is proposed to reduce head injuries associated with snowboarding.

KEY WORDS • snowboarding • head injury • impact injury • computerized tomography • mechanism of injury

SNOWBOARDS resemble small surfboards with straps to hold the feet in position. The rider stands astride on the board with arms outstretched and shifts his/her weight to turn, slow down, or stop.[1] The popularity of snowboarding has exploded throughout the world, especially among the younger generation. Our prospective study of snowboarding-related head injuries at Suwa Central Hospital in Nagano prefecture in Japan showed that snowboarders (especially beginners) are at higher risk of head injury than skiers and that their injuries, which frequently involve occipital impact, can be more severe than skiing-related injuries.[3,4] These results suggest that head injuries associated with snowboarding arise from mechanisms different from those of other sports and that special protective head gear may be necessary for the prevention of head injury in snowboarders. To date, however, there have been no published studies in which the focus has been on mechanisms of severe head injuries related to snowboarding. Therefore, to identify these mechanisms, we investigated data from cases of snowboarders who were treated at Suwa Central Hospital and Aizu Central Hospital, which for years have managed large numbers of winter sports injuries, and we analyzed the clinical features of snowboarders with severe head injuries.

Clinical Material and Methods

All nine patients who were treated at the Suwa Central Hospital for snowboarding-related injuries between 1995 and 1997, and all 29 patients who were treated at Aizu Central Hospital for similar injuries between 1995 and 2001 were enrolled in the study (a total of 38 patients). These institutions are the primary emergency centers for several ski resorts and receive almost all cases of trauma from those resorts in which care greater than first aid is needed. Major head injury was defined as the detection of findings such as intracranial bleeding or cerebral edema on CT scans.

In addition to appropriate medical treatment, a detailed examination of every patient was performed to determine factors that might potentially be associated with the risks and outcomes of head injury. These factors included the skill level of the patient, the cause of the accident, the direction of the fall, the site of impact to the head, and the con-

Abbreviations used in this paper: CT = computerized tomography; GOS = Glasgow Outcome Scale; ITP = intracranial trauma point; SAH = subarachnoid hemorrhage; SD = standard deviation; SIP = scalp impact point; TI = trauma impact.

dition of the ski slope. With respect to skill levels, patients were assigned to one of three categories: beginner, intermediate, or expert. We defined snowboarders who could not complete consecutive turns even on a gentle slope with an incline of less than 10˚ as beginners, and those who could slalom consecutively on a moderate slope of 10 to 15˚ as intermediate snowboarders. Patients who could slalom consecutively on a steep slope with an incline of greater than 15˚ were classified as experts. The accident was categorized as either a simple fall, a collision, or a fall while jumping. When the patient was not able to provide a medical history, friends, relatives, or other people at the scene were interviewed to obtain the necessary information. In addition to the aforementioned information, we collected questionnaires from 19 patients by mail after they had been discharged to complement our database on snowboarding-related serious head injury. Computerized tomography scanning was performed if a patient presented with a neurological deficit, persistent headache, or any injury suggesting a strong impact to the head.

On the basis of CT scans, the intracranial region suspected to have suffered the most damage (the ITP) and the site of contact on the scalp (the SIP) were determined for each patient and the TI distance was measured. This was defined as the distance between the ITP and the SIP, that is, the extent of separation between the center of the intracranial force and the center of the impact. The ITP was defined as the center of the region of cerebral contusion, intracerebral hematoma, or SAH; as the center of the hematoma or bleeding bridging veins in patients with subdural hematoma and bleeding from the middle meningeal artery; or as the suspected site of a bleeding cranial fracture in patients with epidural hematoma. The SIP was defined as the center of the bruise, contusion, or laceration on the scalp.

Before we initiated this study, we examined the length between the inion and the frontal tip in the heads of 28 healthy adults (17 men and 11 women). The mean distance was 19 cm (SD 1.08 cm). The radius of the occipital planum (the distance between the inion and the root of the mastoid process, the suspected contact area of the head after falling on the occiput) was also measured and the mean was found to be 5.3 cm (SD 0.49 cm). We classified head injuries into three types based on the TI distance. If the TI distance was 5 cm or less and there was moderate-to-severe scalp injury or a cranial fracture under the SIP, this was defined as a coup injury (a contact injury). An inertial injury was defined as an injury in which the TI distance was longer than 5 cm. If the TI distance was 15 cm or longer and the intracranial lesion was located at the frontal tip, temporal tip, or frontal base, this was defined as a contrecoup injury. If the TI distance was between 5 and 15 cm without any lesion at the frontal tip, temporal tip, or frontal base, this was defined as a shear injury.

Results

Skill Level of the Snowboarder

Patients were assigned to the following skill levels: beginner in 34% of cases, intermediate in 16% of cases, and expert in 11% of cases. Excluding those patients in whom the skill level was unknown, beginners accounted for 57% of cases, and this high prevalence of beginners seems to be representative of the demographics of the snowboarding population (Tables 1 and 2).

Cause of Injury

Falling while on the ski slope was the cause of injury in 58% of cases, whereas falling during a jump was responsible in 21% and collisions with other people or obstacles on the ski slope was the cause in 21%. The most frequently identified type of head trauma following a fall on the ski slope was acute subdural hemorrhage (14 [64%] of 22 patients; $p = 0.025$, Fisher exact test); after a fall during jumping the most commonly identified injury was a subcortical hemorrhagic contusion including gliding contusion and intracerebral hemorrhage (four [50%] of eight patients; $p = 0.0488$, chi-square test) (Tables 1–3).

Direction of the Fall and Location of Head Trauma

Sixty-six percent of serious head injuries affected the occipital region, whereas 16% involved the frontal region, 13% involved the temporal region, and only 3% involved the parietal region. When we only considered injuries caused by a fall on the slope and excluded unknown causes, occipital injuries increased to 90% (19 of 21 cases). Mild or no scalp damage was identified in 30 cases (79%), whereas cranial fractures were seen in seven cases (18%).

Sixty-eight percent of injuries were caused by falling backward, 8% by falling forward, and 11% by falling sideways. When we limited the analysis to falls on the ski slope, falling backward accounted for 91% of injuries (20 of 22 patients) (Tables 1, 2, 4, and 5).

State of the Slope

Nineteen patients (50%) were injured on gentle or moderate slopes, and no patients were injured on steep slopes. Five patients (13%) were injured on jump platforms and one patient (3%) was injured after colliding with a tree at the side of the slope. Among 25 patients for whom data were known, 76% were injured on mild or moderate slopes and 20% were injured on jump platforms; 100% of the 15 injuries known to have been caused by falls on the ski slope occurred on mild or moderate slopes.

Patients who were injured on the jump platform and those who were injured while jumping on the ski slope tended to sustain subcortical hemorrhagic contusions ($p = 0.0075$ and 0.0488, respectively), which may have occurred because a relatively long duration of severe acceleration–deceleration force is thought to induce widespread axonal damage (diffuse axonal injury) at sites other than the brain periphery.[2] When jumping, snowboarders fall from a high position to the snow in a parabolic arc, and the duration of head impact is considered to be relatively prolonged (Tables 1, 2, and 6).

Initial Neurological Findings and Sequelae

Eighty-seven percent of the severely injured snowboarders suffered from loss of consciousness at the accident scene. As sequelae, 26% experienced limb paresis and 21% cognitive disturbance. The final evaluation was based on the GOS: 15 patients were moderately disabled, no patients were severely disabled, one patient was in a vegeta-

TABLE 1

*Clinical characteristics of 38 patients who sustained severe head injuries while snowboarding**

Case No.	Age (yrs), Sex	Skill Level	Cause of Injury	Impact Point	Direction of Fall	CT Scan Findings	Op	Initial GCS Score & Neurological Finding	Final GCS Score & Neurological Sequelae	GOS Score	Snow Condition	Slope	TI (cm)†	Mechanism
1	19, M	UK	coll	forehead	UK	cranial fracture (frontal), intrafrontal sinus hem	no	E3V4M6 (13), amn, HA	E4V5M6 (15), none	GR	UK	UK	0–2	CI
2	21, M	exp	coll	occipital (temporal)	lat backward	AEDH (temporoparietal), cranial frac	no	E3V4M6 (13), NLOC, amn, HA	E4V5M6 (15), mild dysarthria, midmemory disturbance	MD	soft w/ rain	mod	0–4.5	CI
3	23, M	itm	coll	temporal	sideways	AEDH (massive), cranial frac	yes	E1V1M5 (7), anisocoria, hemi	E4V5M6 (15), rt muscle weakness	MD	soft	mod	0	CI
4	24, M	UK	coll	temporal (earlobe contusion, face, tooth fractures)	lat forward	contusion (occipitoparietal)	no	E3V5M6 (14), con	E4V5M6 (15), none	GR	UK	forest	18–20	CCI
5	24, M	UK	coll	forehead	UK	contusion (corpus callosum, internal capsule)	no	E1V1M5 (7), hemi, anisocoria	E4V5M6 (15), lt hemi	MD	UK	UK	5	SI
6	30, M	beg	coll	occiput	backward	ASDH	no	E3V4M6 (13), deterioration in speech	E4V5M6 (15), none	GR	UK	mild	8–10	SI
7	21, F	UK	coll	occipital (temporal)	lat backward	ASDH (temporal depressed frac)	no	E3V4M5 (12), tetra	E4V5M6 (15), lt hearing loss, lt delayed facial palsy	MD	UK	UK	0–2	CI
8	23, F	itm	coll	face (lt)	UK	tSAH (lt parietal)	no	E3V4M6 (13), con, amn, disorientation	E4V5M6 (15), lt face dysesthesia	MD	soft w/ rain	mild	10	SI
9	21, M	beg	FOSS	occiput	backward	contusion (frontal)	no	E4V5M6 (15), con, HA	E4V5M6 (15), none	GR	hard	mild	5–8	SI
10	21, M	beg	FOSS	occiput	backward	ASDH	yes	E1V1M4 (6), rt hemi	E4V4M6 (14), rt hemi, Gerstmann syndrome	MD	hard	mild	5–8	SI
11	21, M	beg	FOSS	occiput	backward	tSAH (parietal)	no	E4V5M6 (15), con, HA	E4V5M6 (15), none	GR	hard	mild	1–3	CI
12	21, M	UK	FOSS	occiput	backward	ASDH	yes	E1V2M5 (8), rt hemi, anisocoria	E4V4M6 (14), rt hemi	MD	UK	UK	7–8	SI
13	22, M	itm	FOSS	occiput	backward	contusion (frontal)	no	E4V5M6 (15), con, HA	E4V5M6 (15), none	GR	hard	mod	5–8	SI
14	22, M	itm	FOSS	temporal	sideways	contusion (bilat frontal), basal cistern SAH	no	E2V3M5 (10), respiration distress, hemi	E4V4M6 (14), disorientation	MD	soft	mod	10–13	SI
15	22, M	exp	FOSS	occiput	backward	ASDH	yes	E1V1M2 (4), comatose, decerebration, mydriasis	D	D	iced	mod	12–14	SI
16	23, M	beg	FOSS	occiput	backward	tSAH (parietal)	no	E4V4M6 (14), con, amn	E4V5M6 (15), none	GR	iced	mild	8.5–10	SI
17	23, M	itm	FOSS	occiput	backward	ASDH (occipital frac)	no	E3V5M6 (14), HA, vomiting, NLOC	E4V5M6 (15), none	GR	hard	mod	5–15	SI
18	23, M	UK	FOSS	occiput (back)	backward	ASDH (midbrain contusion)	yes	E1V1M4 (6), anisocoria, tetra	E4V1M5 (10), rt hemiplegia, vegetative	VS	UK	UK	7–8	SI
19	24, M	beg	FOSS	occiput	backward	AEDH (occipital)	no	E4V5M6 (15), con, HA	E4V5M6 (15), none	GR	hard	mild	0	CI
20	26, M	itm	FOSS	occiput	backward	ASDH	no	E3V5M6 (14), con, HA	E4V5M6 (15), none	GR	hard	mod	8–15	SI
21	26, M	UK	FOSS	occiput	backward	ASDH (frontal contusion)	no	E3V4M5 (12), HA, NLOC	E4V5M6 (15), epilepsy	MD	UK	UK	8–10	SI
22	27, M	UK	FOSS	occiput	backward	ASDH	no	E4V5M6 (15), HA, vomiting, NLOC	E4V5M6 (15), none	GR	UK	UK	18	CCI
23	28, M	UK	FOSS	face (rt eye)	forward	orbital blow-out frac	no	E3V5M6 (14), DV	DV	MD	UK	UK	0	CI
24	29, M	exp	FOSS	occiput	backward	tSAH	no	E3V4M6 (13), con, amn	E4V5M6 (15), none	GR	soft	mod	7–9	SI
25	33, M	beg	FOSS	occiput	backward	ASDH	yes	E1V1M2 (4), comatose, decerebration, mydriasis	E4V4M6 (14), anisocoria, mild tetra	MD	UK	mild	10–15	SI
26	49, M	UK	FOSS	occiput	backward	ASDH	no	E3V5M6 (14), con, HA	E4V5M6 (15), none	GR	UK	UK	13	SI
27	23, F	beg	FOSS	UK	backward	ASDH (frontal)	no	E3V2M5 (10)	E4V5M6 (15), none	GR	UK	mild	UK	UK
28	24, F	beg	FOSS	occiput	backward	ASDH	no	E3V5M6 (14), HA, con	E4V5M6 (15), none	GR	iced	mild	9–14	SI

29	27, F	UK	FOSS	occiput	backward	ASDH	no	E3V5M6 (14), dizziness, HA, NLOC	E4V5M6 (15), none	GR	UK	UK	10–13	SI
30	28, F	beg	FOSS	occiput	backward	ASDH	yes	E1V1M2 (4), bilat mydriasis	E4V4M6 (14), disorientation, ataxic gait	MD	iced	mild	5–8	SI
31	18, M	beg	FDJ	occiput	backward	contusion (frontal)	no	E4V5M6 (15), HA, con	E4V5M6 (15), none	GR	hard	JP	5–8	SI
32	20, M	beg	FDJ	face (temporal)	forward	putaminal hemorrhage	yes	E3V4M6 (13), con, lt hemi	E4V5M6, lt hemi	MD	iced	JP	7–10	SI
33	20, M	beg	FDJ	occiput	backward	tSAH (parietal)	no	E3V5M6 (14), con, HA	E4V5M6 (15), none	GR	hard	JP	0	CI
34	20, M	UK	FDJ	forehead	UK	ASDH (frontal)	no	E3V5M6 (14), con	E4V5M6 (15), none	GR	UK	UK	7–8	SI
35	24, M	UK	FDJ	occiput	backward	ASDH	yes	E2V5M6 (13), hemi	E4V4M6 (14), ataxic gait	MD	UK	UK	8–20	SI
36	31, M	UK	FDJ	temporal	sideways	tSAH (ambient cistern)	no	E3V5M6 (14), epilepsy	E4V5M6 (15), none	GR	UK	UK	7–9	SI
37	20, F	exp	FDJ	parietal (lt)	UK	contusion (frontal, corpus callosum)	no	E3V4M6 (13), con, amn, tetra	E4V5M6 (15), paralytic gait, mild rt hemi	MD	hard	JP	5–8	SI
38	25, F	UK	FDJ	temporal	sideways	contusion (frontal), frontal tSAH, occipital frac	no	E3V5M6 (14), con, HA	E4V5M6 (15), none	GR	UK	JP	17–18	CCI

* AEDH = acute epidural hematoma; amn = amnesia; ASDH = acute subdural hematoma; beg = beginner; CCI = contrecoup injury; CI = coup injury; coll = collision; con = concussion; D = dead; dis = disturbance; DV = double vision; E = eye opening; FDJ = fall during jump; FOSS = fall on ski slope; frac = fracture; GCS = Glasgow Coma Scale; GR = good recovery; HA = headache; hem = hemorrhage; hemi = hemiparesis; itm = intermediate; JP = jump platform; M = best motor score; MD = moderate disability; mod = moderate; NLOC = no loss of consciousness; SI = shear injury; tetra = tetraparesis; tSAH = traumatic SAH; UK = unknown; V = best verbal response; VS = vegetative state.
† Distance between the SIP and ITP.

TABLE 2
*Summary of clinical features in 38 snowboarders with serious head injuries**

Factor	No. of Patients (%)
male/female ratio	30:8 (79:21)
age distribution (yrs)	
mean ± SD	24 ± 5
range	18–49
cause of injury	
fall on slope	22 (58)
fall during jump	8 (21)
collision	8 (21)
impact point on head	
occipital	25 (66)
frontal	6 (16)
temporal	5 (13)
parietal	1 (3)
unknown	1 (3)
skill level	
beginner	13 (34)
intermediate	6 (16)
expert	4 (11)
unknown	15 (39)
direction of fall	
backward	26 (68)
lat	4 (11)
forward	3 (8)
unknown	5 (13)
condition of slope	
mild	11 (29)
moderate	8 (21)
steep	0 (0)
jump platform	5 (13)
forest	1 (3)
unknown	13 (34)
condition of snow	
hard packed or iced	15 (39)
soft	5 (13)
unknown	18 (47)
finding on CT scan	
acute subdural hematoma	18 (47)
brain contusion (including ICH)	9 (24)
traumatic SAH	6 (16)
cranial fracture	2 (5)
acute epidural hematoma	3 (8)
mechanism of injury	
inertial	29 (76)
shear	26 (68)
contrecoup	3 (8)
contact injury: coup	8 (21)
unknown	1 (3)

* ICH = intracerebral hemorrhage.

tive state, and one patient had died (Table 1). Patients in whom a good recovery was attained only accounted for 55% (21 patients). Statistically, there was no relationship between the victim's skill level, direction of the fall, or site of impact to the head and the patient's final GOS score or the need for surgery.

Distance Between the SIP and the ITP

Among the 38 patients with severe head injury, the distance between the SIP and the ITP (the TI distance) could be measured in 37 patients (Table 1 and Fig. 1). The mean TI distance was 7.6 cm (SD 4.8 cm).

TABLE 3

Relationship between cause of injury and findings on the CT scan

Cause of Injury	ASDH	Cerebral Contusion	tSAH	Cranial Fracture	AEDH	Total
collision	2	2	1	1	2	8
fall	14*	3	3	1	1	22
jump	2	4†	2	0	0	8
total	18	9	6	2	3	38

* p = 0.025, Fisher exact test.
† p = 0.0488, chi-square test.

TABLE 4

Relationship between site of impact on the head and findings on the CT scan

Site of Impact	ASDH	Cerebral Contusion	tSAH	Cranial Fracture	AEDH	Total
occipital	16*	3	4	0	2	25
frontal	1	2	1	2	0	6
temporal	0	3†	1	0	1	5
parietal	0	1	0	0	0	1
unknown	1	0	0	0	0	1
total	18	9	6	2	3	38

* p = 0.0064, Fisher exact test.
† p = 0.0404, chi-square test.

TABLE 5

Relationship between direction of fall and findings on the CT scan

Direction of Fall	ASDH	Cerebral Contusion	tSAH	Cranial Fracture	AEDH	Total
backward	17*	3	4	0	2	26
forward	0	2	0	1	0	3
sideways	0	2	1	0	1	4
unknown	1	2	1	1	0	5
total	18	9	6	2	3	38

* p = 0.0014, Fisher exact test.

TABLE 6

Relationship between the state of the snow slope and findings on the CT scan

State of Snow Slope	ASDH	Cerebral Contusion	tSAH	Cranial Fracture	AEDH	Total
mild	6	1	3	0	1	11
moderate	3	2	1	0	2	8
steep	0	0	0	0	0	0
jump platform	0	4*	1	0	0	5
forest	0	1	0	0	0	1
unknown	9	1	1	2	0	13
total	18	9	6	2	3	38

* p = 0.0075, Fisher exact test.

TABLE 7

Relationship between the cause and mechanism of injury

Cause of Injury	Mechanism of Injury				
	Coup	Contre-coup	Shear	Contre-coup & Shear	Un-known
collision (8 cases)	4*	1	3	4	0
fall (22 cases)	3	1	17	18	1
jump (8 cases)	1	1	6	7	0
total (38 cases)	8	3	26	29	1

* p = 0.0441, Fisher exact test.

According to our criteria for classifying the mechanism of injury, we determined that 26 patients (68%) had sustained a shear injury, eight (21%) a coup injury, and three (8%) a contrecoup injury. Inertial injuries (shear and contrecoup injuries) accounted for 76% of all injuries in this population (Table 2).

Shear injuries consisted of acute subdural hemorrhages in 15 patients, cerebral contusions in six patients, traumatic SAHs in four patients, and putaminal hemorrhage in one patient. If shear stress involves the brain surface and bridging veins, it induces acute subdural hematoma or traumatic SAH; if it affects the brain parenchyma, cerebral contusion or intracerebral hemorrhage occur.

Eighty-one percent of injuries due to simple falls (17 of 21 patients) and 75% of jump injuries (six of eight patients) were caused by inertial forces; among the eight collision injuries, 50% of the injuries were direct injuries (four of eight patients; p = 0.0441, Table 7).

Discussion

Features of Serious Head Injuries Associated With Snowboarding

As demonstrated in the present study, serious head injuries that are associated with snowboarding are predominantly caused by occipital trauma, typically when a snowboarder falls backward on a gentle-to-moderate slope and/or a jump platform. In these patients, inertial force is the main mechanism of serious intracranial injury. In cases in which head injury occurs by falling backward or occipital impact, acute subdural hematoma tends to be the main intracranial complication, whereas in cases in which there is a temporal impact or a jump injury severe cerebral contusion often results.

Eighty-seven percent of patients lose consciousness at the time of initial impact and most snowboarding head injuries cause diffuse brain injury, regardless of whether it is serious.[4] Diffuse brain injury is reported to be caused by rotational or angular acceleration force.[3] Apart from jump-related injuries, head injuries associated with snowboarding often involve angular acceleration at the interface of the snowboard edge and the snow.

Opposite-Edge Phenomenon

Because of the strong angular acceleration at the inter-

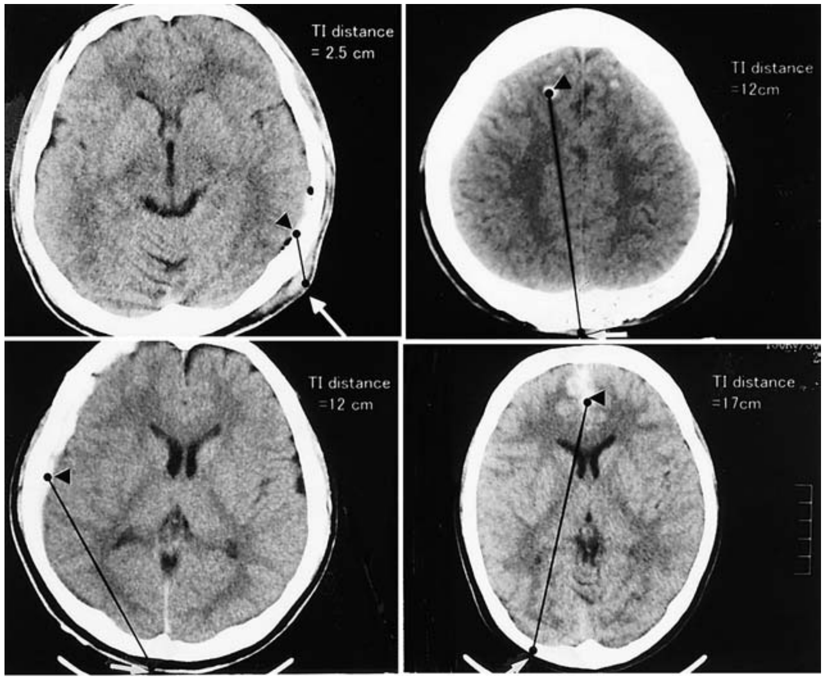

FIG. 1. Computerized tomography scans from four representative cases of severe head injury associated with snowboarding. *Arrowheads* indicate the ITP and *arrows* indicate the SIP point. The distance between the ITP and the SIP (the TI distance) is shown in each case. *Upper Left:* Case 2 (left parietotemporal acute epidural hematoma). Because the TI distance is 2.5 cm and an epidural hematoma is located directly under the SIP, we classified the head injury as a coup injury (contact injury). *Upper Right:* Case 14 (right frontal gliding contusion). Because the TI distance is 12 cm and there is no intracranial lesion beneath the SIP, we classified the head injury as a shear injury (inertial injury). *Lower Left:* Case 35 (right frontoparietal acute subdural hematoma). Because the TI distance is 12 cm and there is no intracranial lesion beneath the SIP, we classified the head injury as a shear injury (inertial injury). *Lower Right:* Case 38 (anterior interhemispherical SAH). Because the TI distance is 17 cm, and there is no intracranial lesion beneath the SIP, and the location of the intracranial lesion is considered to be characteristic of a contrecoup injury, we classified this head injury as a contrecoup injury (inertial injury).

face of the snowboard edge and the snow, there is a characteristic tendency for the snowboarder to fall ventrodorsally, which helps explain the aforementioned features of major snowboarding-related head injuries. In recent years such a tendency has been called the opposite-edge phenomenon among experienced snowboarders.[3,5]

Snowboarders control their direction and speed by altering their centers of gravity to adjust the angle and pressure of the edge of the snowboard relative to the snow (Fig. 2). Compared with skiing, more patterns of turning and sliding are possible during snowboarding by using various edging techniques. Only one edge of the board should be in contact with the snow, however, and if the wrong edge hits the snow, the center of gravity of the snowboarder will deviate violently to the opposite side. This induces angular acceleration at the edge of the board, leading the snowboarder to be thrown down onto the slope resulting in a hard impact on the head (Fig. 3).

If the opposite-edge phenomenon occurs during a backward turn (turning on the heel edge of the board), a snowboarder will be thrown forward and the impact will affect the front of the body and the extremities. On the contrary, if the opposite-edge phenomenon occurs during a forward turn (turning on the toe edge of the board), the snowboarder is thrown so that the occiput or the back takes the impact.

On gentle slopes, the valley side edge of the board can

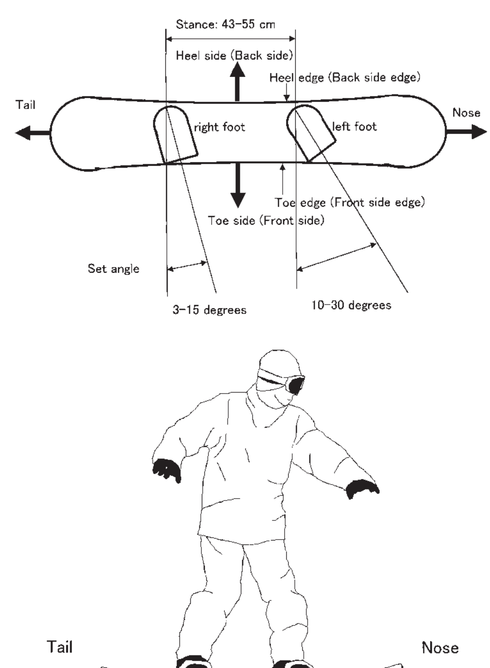

FIG. 2. Drawings showing a freestyle snowboard *(upper)* and snowboarder *(lower)*.

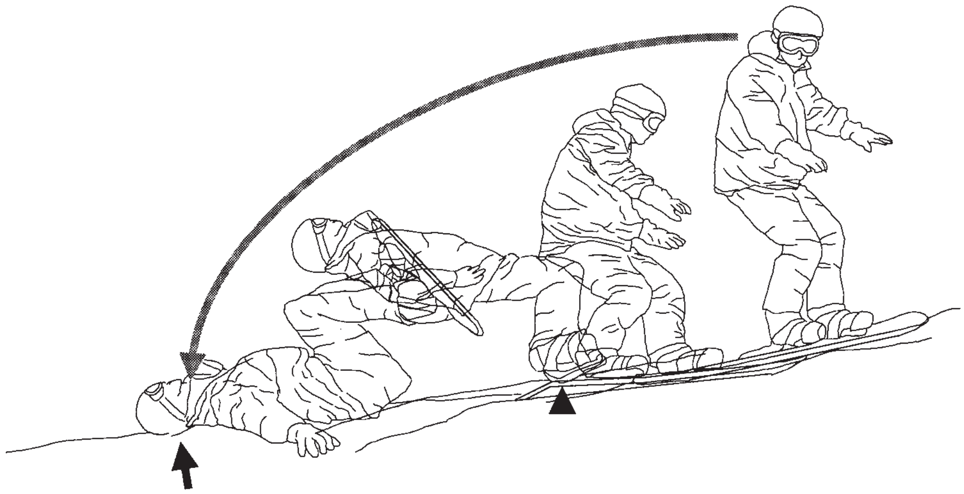

FIG. 3. Drawing demonstrating the mechanism of the opposite-edge phenomenon. When turning the toe edge of the board *(arrowhead)* on a gentle or moderate slope, a snowboarder tends to fall backward on the slope as a result of the opposite-edge phenomenon, resulting in injury to the occiput *(short arrow)*. *Long arrow* follows the movement of the turn and fall.

more easily come into contact with the slope and, thus, the opposite-edge phenomenon is considered to occur more frequently on gentle slopes than on steep slopes.

Prevention of Snowboarding-Related Serious Head Injury

The special features of snowboarding-related head injuries that we have demonstrated in this study suggest an approach to the prevention of such injuries. The use of a device to protect the occiput from inertial injury after an occipital impact would be the most direct and potentially the most effective measure to reduce snowboarding-related head injuries. Because current protective devices do not guard against such an injury, head gear designed to protect the occiput needs to be developed. In addition, to reduce the incidence of severe head injury, snowboarders must be educated to avoid the risks associated with the opposite-edge phenomenon and be properly trained in alternative safer techniques. If a fall should occur, they must learn to tuck in the chin instantly to avoid an occipital impact. To reduce jump injuries, jumping maneuvers that carry a higher risk of head injuries should be well publicized and a certification program should be introduced that would only allow experienced snowboarders to perform acrobatic jumping.

Conclusions

The predominant features of snowboarding-related head injuries included occipital impact (66% of all injuries and 90% of falls on a slope), backward falls (68% of all injuries and 91% of falls on a slope), gentle or moderate slope (100% of falls on a slope), mild scalp injury (79% of all injuries), and inertial injury (76% of all injuries).

The majority of snowboarding-related severe head injuries involving a simple fall on the ski slope were considered to be caused by the opposite-edge phenomenon in which the victim fell backward and sustained an occipital impact on a gentle slope. The use of a device to protect the occiput is proposed to reduce snowboarding-related head injuries.

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Address reprint requests to: Hiroshi Nakaguchi, M.D., Ph.D., Department of Neurosurgery, Teraoka Memorial Hospital, 37 Ooaza Shinichi, Shinichi town, Ashina gun, Hiroshima prefecture, 729-3103, Japan. email: hnakaguchi@hi-ho.ne.jp.