

BIOMECHANICS OF SNOWMOBILE SPINE INJURIES*

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Abstract—A combined experimental and clinical study relative to the production of spinal injuries common to the winter sport of snowmobiling indicates that snowmobile spinal injuries are a repeatable phenomenon with seats of the current design. The number of injuries appears to be growing rapidly with the increased popularity of the sport. However, the redesign of snowmobile and snowmobile suspension systems should allow the elimination of these injuries for most practical conditions.

INTRODUCTION

WITH THE increased popularity of snowmobiling an alarming and ever-increasing number of related injuries have occurred. Investigations have compiled accident reports in an effort to document this problem (McLay *et al.* 1970; Carlson, 1970). The more serious injuries include: multiple extremity fracture, traumatic amputations, skull fractures, facial and eye injuries, spinal injuries and even decapitation. The accident statistics indicate that compression fractures of the spine make up a particularly significant class of snowmobile injuries (Withington, 1970; Chism, 1969).

This study is presented to draw attention to the high risk of spinal injuries in snowmobiling. Illustrative cases of spinal fractures from such injuries, treated or reviewed at The University of Michigan Medical Center are shown.

Full scale experiments to confirm the mechanism of injury were performed, reproducing the forces of vertical fall and impact by dropping an instrumented anthropometric dummy with a snowmobile to which a variety of seats from the ten best-selling snowmobile makes were attached. The seats were also loaded in a materials testing machine to determine their individual load—deflection characteristics.

CASE REPORTS

Case #1

A 28 yr old female, riding behind her husband on their snowmobile, traveling at a high rate of speed across an open field, came upon a graded secondary road obscured by snowbanks. Unable to stop they jumped the snowmobile from one bank to the other clearing the road. She landed hard on the posterior portion of the seat. She experienced the acute onset of severe non-radiating mid-back pain and was unable to stand. Examination revealed a palpable kyphosis, marked tenderness sharply localized over the 1st lumbar vertebra, and an ileus. The remainder of the abdominal examination and the neurological examination were negative. Roentgenograms (Figs. 1A and 1B) demonstrated a 50 per cent compression fracture of the 1st lumbar vertebral body with a 30 per cent kyphosis at the L1 vertebral body apex. She was placed at complete bed rest. The ileus cleared in 36–48 hr. A hyperextension back brace was fitted and progressive ambulation began as her back symptoms subsided. Total hospitalization lasted 9 days. Four months after the accident with only slight residual pain and no progression of the deformity she was weaned from the brace. On our follow-up interview 3 yr after the accident she has only minimal discomfort with light activities and has returned to doing

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routine housework, however, she does experience back pain with more strenuous activities.

Case #2

A 58 yr old man jumped his snowmobile off a 30 in. drop off, experiencing the immediate onset of moderately severe pain in the mid-back region. He was traveling 18–20 m.p.h., with a rider on the vehicle and did not post. To the best of his knowledge the vehicle landed squarely and the forces were verticle. His pain was particularly worse with motion of the spine and standing erect. Examination showed no visable or palpable deformity. There was local tenderness to percussion over the 12th thoracic and 1st lumbar vertebrae with moderate paravertebral muscle spasm. Neurological examination was normal. Roentgenograms (Fig. 2A) demonstrated a moderate compression fracture of the 1st lumbar vertebra. Mild boney demineralization and degenerative changes were present. He was hospitalized and treated at bed rest until the pain subsided, then fitted with a hyperextension back brace. No systemic etiology was found for the osteopenia, which in our opinion was a predisposing factor in his injury. Total hospital stay was 3 weeks. Over the ensuing 4 months roentgenograms (Fig. 2B) demonstrated further collapse of the L1 vertebra body. On follow-up examination 3 yr after the accident he still has residual back pain made worse by lifting or twisting, necessitating occasional bed rest and use of the brace. He has been unable to return to his work as a landscape contractor.

Case #3

A 46 yr old female passenger on a snowmobile was suddenly jolted when the vehicle went over a large bump. She experienced the immediate onset of severe back pain localized to the thoraco-lumbar junction. At no time did she note weakness or sensory change in the extremities. Physical examination revealed an obese female with tenderness

sharply localized over the 12th thoracic vertebra with paravertebral muscle spasm. There were decreased bowel sounds consistent with a mild ileus. The neurological examination was negative. Roentgenograms (Fig. 3) revealed a 50 per cent anterior compression fracture of T12. The patient was kept at bed rest and treated symptomatically for the ileus which cleared in 24 hr, with subsidence of the back symptoms. She was fitted with a hyperextension brace, progressively ambulated and discharged markedly improved on the 14th hospital day. The brace was removed at 4 months. At our follow-up interview 5 months after the accident, mild back pain still limited her activity.

Case #4 and #5

On December 27, 1970, two sisters ages 13 and 18 were following snowmobile tracks up a small hill traveling approximately 45 m.p.h. on their snowmobile. To their surprise the back portion of the hill had been excavated. Their vehicle was propelled off the edge of the excavation dropping roughly 10 ft. The vehicle landed upright with both girls coming down hard on their buttocks on the seat. They both had the immediate onset of severe non-radiating back pain, but were able to stand with difficulty.

Examination of the 18 yr old driver demonstrated tenderness localized to the area of the thoraco-lumbar junction, with marked limitation of range of motion of the spine. The neurologic examination was normal. Roentgenograms (Fig. 6) demonstrated a 25 per cent compression fracture of the first lumbar vertebra as well as slight posterior displacement of the vertebral body. She was hospitalized and placed at strict bed rest until symptoms improved at which time she was fitted with a hyperextension back brace and progressively ambulated. She was discharged on the 7th hospital day markedly improved. At the time of our follow-up interview 6 months after the injury, she had returned to

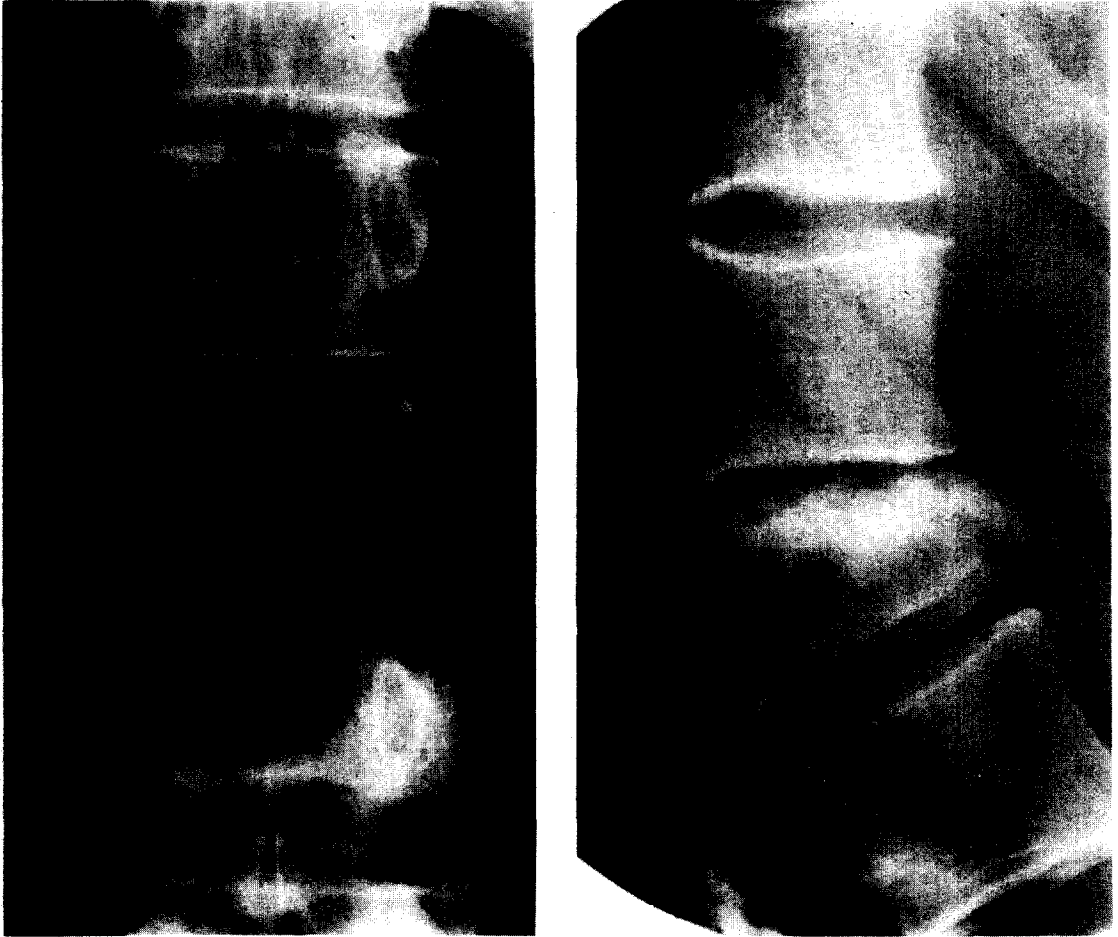


Fig. 1A and 1B. Case #1: Roentgenograms show a 50 per cent anterior wedge compression fracture with comminution of L1 vertebral body. Note fracture of the L1 lamina and kyphosis with posterior displacement of the L1 vertebral body.

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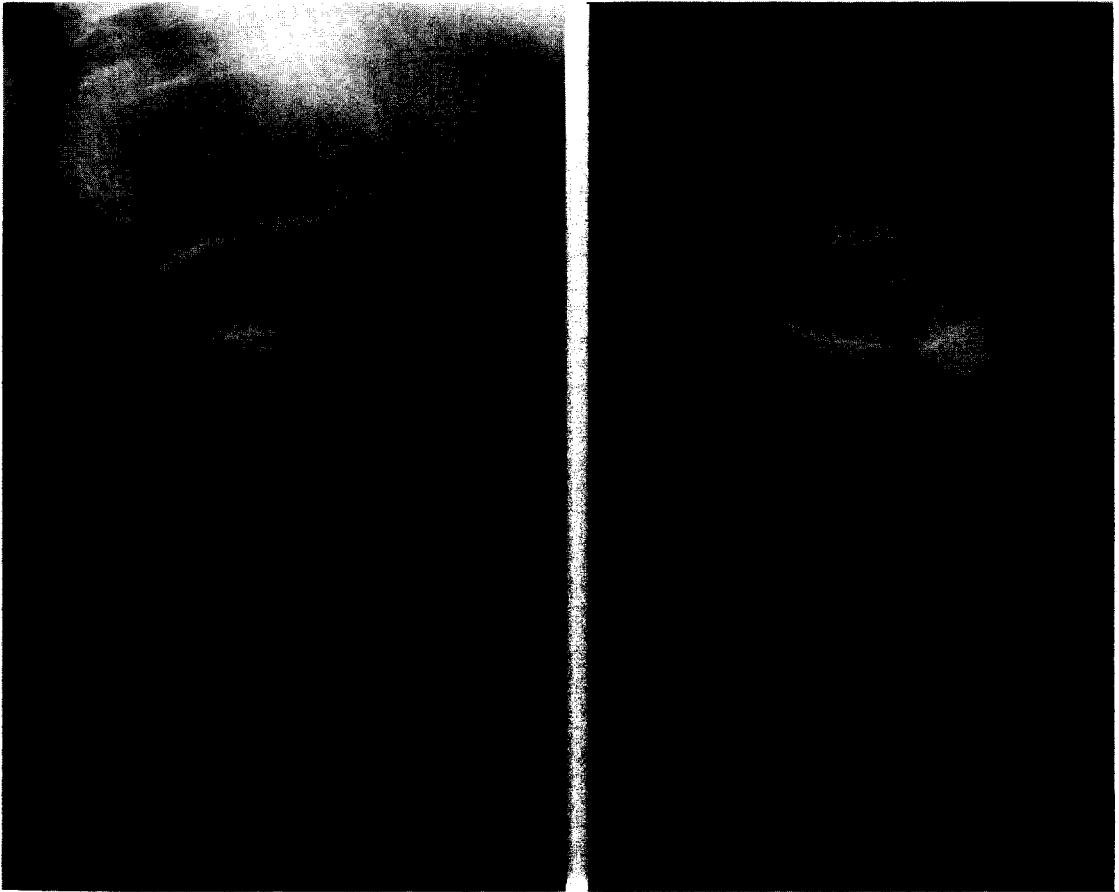


Fig. 2. Case #2: A. Roentgenogram shows a moderate compression fracture of L1 vertebral body. Note in addition to anterior compression, the vertical fracture component through the central portion of the body.
B, Roentgenogram 4 months after injury shows further collapse.

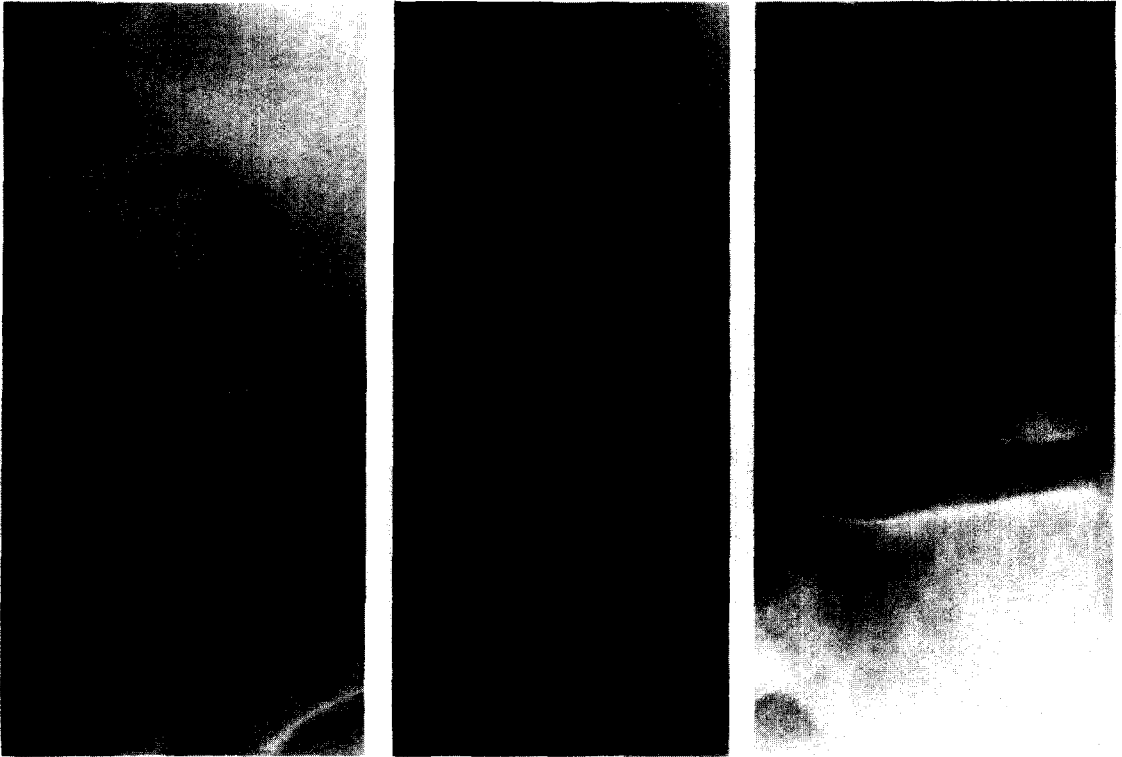


Fig. 3. Case #3: Roentgenogram shows a 50 per cent anterior wedge compression fracture of L1 vertebral body.

Fig. 4. Case #6: Roentgenogram shows a mild anterior compression fracture of L1 vertebral body.

Fig. 5. Case #7: Roentgenogram shows a mild anterior compression fracture involving the inferior portion of D11 vertebral body.

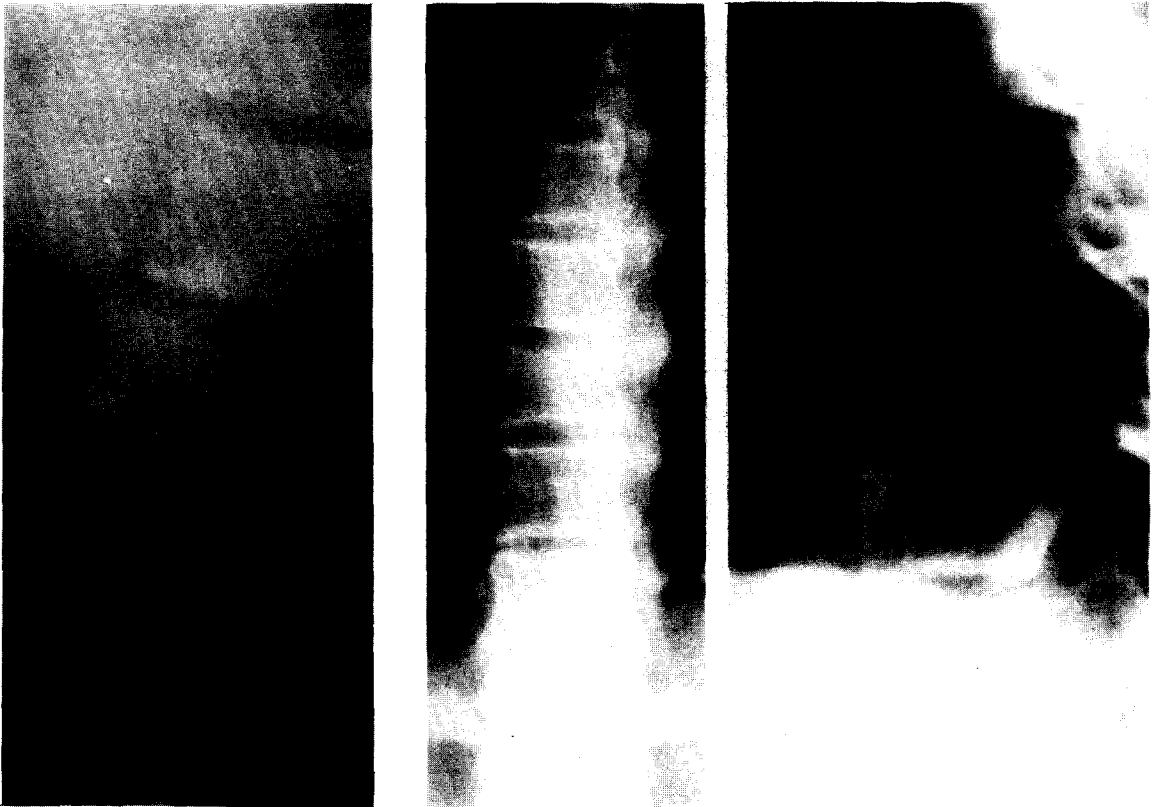


Fig. 6. Case #4: Lateral roentgenogram shows a 25 per cent anterior wedge compression fracture of L1 vertebral body. Note a slight posterior displacement of the vertebral body.

Fig. 7. A, Anteroposterior roentgenogram shows soft tissue outline of a lower dorsal paravertebral hematoma. B, Lateral roentgenograms shows a 15 per cent anterior compression fracture of D8 and D10 vertebral bodies.

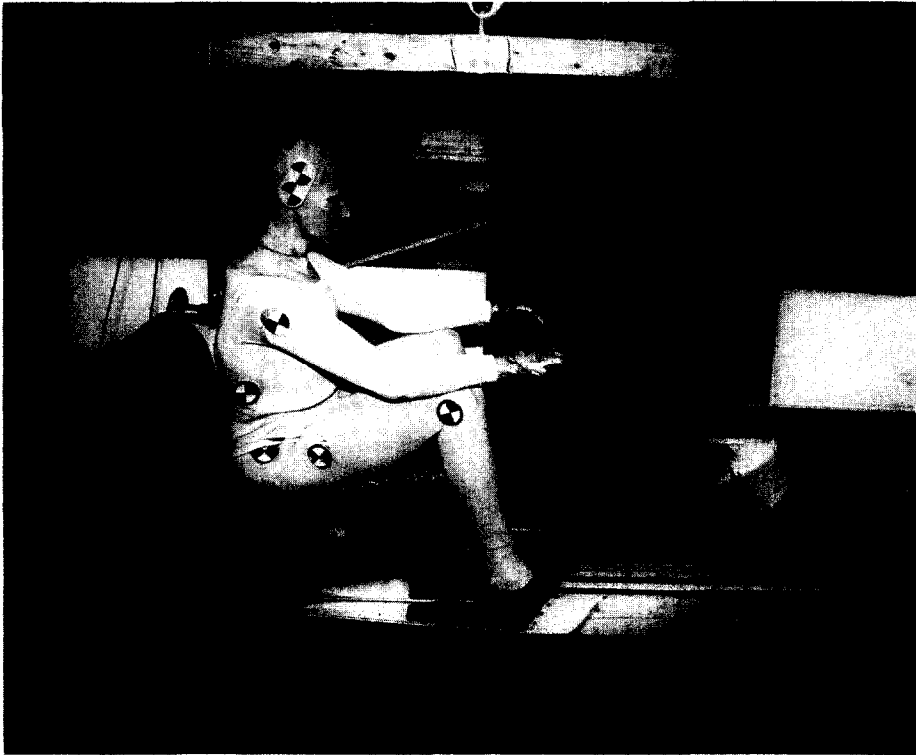


Fig. 8. Snowmobile drop test set-up.

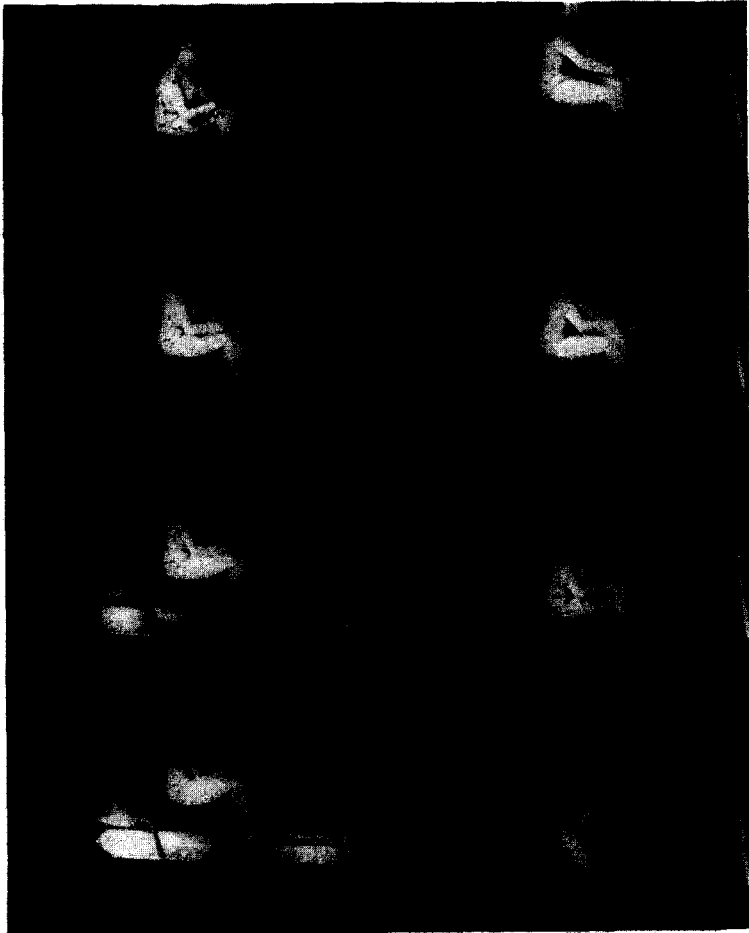


Fig. 10. Typical snowmobile drop test sequence.

SNOWMOBILE DROP TEST
Run Number: 2 018
Seat: Arctic Cat Panther
Drop Height: 4 ft
Chest Vertical Acceleration
Peak: 34 g
Total Duration: 79 msec
Duration Above 20 g: 13 msec

CHEST ACCELERATION
TRANSVERSE 20 g/EA

HEAD ACCELERATION
TRANSVERSE 20 g/EA

CHEST ACCELERATION
VERTICAL 20 g/EA

HEAD ACCELERATION
VERTICAL 20 g/EA

CHEST ACCELERATION
FORE-AFT 20 g/EA

HEAD ACCELERATION
FORE-AFT 20 g/EA

CHIEF ENGINEER
G. H. ...

INSTRUMENT CALIBRATION
VERTICAL

Fig. 11. Snowmobile drop test acceleration-time record with the Arctic Cat Panther seat.

SNOWMOBILE DROP TEST
Run Number: 2019
Seat: Polaris
Drop Height: 4 ft.
Chest Vertical Acceleration
Peak: 20 g
Total Duration: 88 msec.
Duration Above 20 g: 0

CHEST ACCELERATION
TRANSVERSE 20 g/in.

HEAD ACCELERATION
TRANSVERSE 20 g/in.

CHEST ACCELERATION
VERTICAL 20 g/in.

HEAD ACCELERATION
VERTICAL 20 g/in.

CHEST ACCELERATION
FORF-AFT 20 g/in.

HEAD ACCELERATION
FORF-AFT 20 g/in.

TIME SCALE
0-0.25 sec./in.

WAVEFORM ACCELERATION
VERTICAL

Fig. 12. Snowmobile drop test acceleration-time record with the Polaris seat.

limited activity but still required the back brace.

Examination of the 13 yr old passenger demonstrated tenderness in the region of T8 through L1 vertebrae, with paravertebral muscle spasm and marked limitation of motion of the spine. The neurologic exam was normal. Roentgenograms (Figs. 7A and 7B) demonstrated a 15 per cent anterior compression fracture of both the 8th and 10th dorsal vertebral bodies with a formation of a paravertebral hematoma. She was hospitalized and placed at complete bed rest until symptoms improved. She was then fitted with a hyperextension back brace and progressively ambulated. The back brace was removed at 4 months. At the time of our interview 6 months after the accident, she was asymptomatic.

Case #6

A 28 yr old female had the acute onset of low back pain while a passenger on a snowmobile, after going over a moderate bump. They were riding on a marked public trail, however, the terrain was rough. She could not recall the rate of speed but felt it was not excessive for the conditions. After going over the bump she was able to move about with minimal discomfort and thus rode several hours in a car to return home before seeking medical attention. On examination positive findings were limited to local tenderness over the first lumbar vertebra. Neurological examination was normal. Roentgenograms (Fig. 4) demonstrated a compression fracture of the first lumbar vertebra. She was hospitalized, treated with bed rest until comfortable, then fitted with a hyperextension back brace and progressively ambulated. She was discharged on the 9th hospital day. The brace was removed at 3 months. At 6 months she was asymptomatic and roentgenograms showed no progression of the deformity. On our follow-up interview 2 yr after the accident, she was asymptomatic and has returned to normal activities as a wife and teacher.

Case #7

A 60 yr old female was a passenger on a snowmobile which was proceeding along level terrain at approximately 10 m.p.h. when they suddenly dropped into a 2 ft depression which was obscured by snow. She had the immediate onset of mild back pain in the region of the dorsal lumbar junction. The pain was not severe and she did not consult a physician until some 8 weeks after the episode due to continuing pain in this region. Examination demonstrated point tenderness at the dorsal lumbar junction with mild restriction on range of motion. Roentgenograms (Fig. 5) demonstrated a mild anterior compression fracture involving primarily the inferior portion of D11 vertebral body. No other injury was sustained. She was treated with a hyperextension back brace for 3 months with her only complaint of mild pain in this region with strenuous activity.

EXPERIMENTAL METHODS

The experimental program consisted of two series of tests. In the first series, selected snowmobile seats were individually attached to a snowmobile and with an instrumented dummy in the driver's position the snowmobile, seat, and dummy were dropped. This series led to a better understanding of the interaction between rider and machine in a vertical fall. In the second series, the seats were isolated and tested in order to study their performance without interference from the machine or the rider.

The snowmobile drop test simulates a snowmobile jump or fall, thus allowing controlled observation and analysis of the occurrences which lead to back injury. The test is based on the fact that a vertical drop is dynamically equivalent to a jump or fall which occurs at a constant horizontal speed.

An Arctic Cat Panther snowmobile was used for the testing as shown in Fig. 8. The engine and front cowl had been removed, and 50 lb of lead ballast were placed in the engine location to bring the machine weight

up to its normal operating weight of 340 lb. An accelerometer was mounted on the footboard of the snowmobile in line with the middle of the seat. Prior to testing, one of the twelve seats studied in this series was mounted on the snowmobile. The seats were from 1971 models of the ten snowmobile makes which sold best in the 1969–70 season (Butler, 1970). A 95th percentile male Sierra anthropometric dummy weighing 225 lb was positioned on the machine with its hands taped to the handle bars. The dummy head and torso were each instrumented to sense accelerations in the vertical, fore-aft, and transverse directions. In accordance with standard impact test practice, the dummy joints were set to support the limbs against gravity. The snowmobile suspension was adjusted so that a 50 lb load applied to the extreme rear of the snowmobile was necessary to overcome the suspension spring preload. This setting corresponded to 1½ in. and 1 in. of exposed threads on the front and rear suspension setting, respectively.

The snowmobile with the dummy in place was hoisted to the test height and released to fall onto a concrete floor. The data recorded during each test were acceleration–time traces from the instrumented dummy and snowmobile frame, photographs taken with a Graph Chek sequential Polaroid Camera, and, in two cases, high speed motion pictures.

The impact dynamics of a snowmobile with a rider landing on a horizontal surface after a fall or jump involve many factors: (1) attitude and motion of the snowmobile at impact; (2) attitude and motion of the rider at impact; (3) the weight and center of gravity of the snowmobile; (4) the weight of the rider; (5) the energy absorbing mechanism between the snowmobile and the impact surface; and, (6) the energy absorbing material between the rider and the snowmobile. The first five factors have been held constant in the drop testing. The sixth factor, the seat, is critical to the protection of the rider. The results of the drop testing are presented in the following

section but one observation is presented here due to its significance to the role of a snowmobile seat. In all the drop tests, the snowmobile suspension was bottomed or rebounding when the dummy was deforming the seat to the fullest extent. This means that the seats must absorb much of the energy of the falling rider if injury is to be avoided.

Sixteen seats were tested statically in a Universal testing machine to determine their energy absorbing characteristics. The seats were on a large plywood sheet on the movable cross-head of an Instron materials test machine and raised against a 1-ft square piece of plywood which was attached to a rigidly held load cell. The deformation of the seat and the load transmitted through the seat were recorded. Four of the seats tested the Ski-Doo TNT 18 in., TNT 15 in. and Elan seats, and the Arctic Cat Puma, were slanted so that they were thicker at the back than at the front. The slanted Ski-Doo seats were tested in three positions with the load being applied to the front, middle, and rear of the seats. The Arctic Cat Puma seat was shorter and was tested in one position with the edge of the loading surface approximately 1 in. in front of the sharp rise at the rear of the seat. Tests were performed with the seats at temperatures of 70 and 10°F. A typical load–deformation trace is shown in Fig. 9.

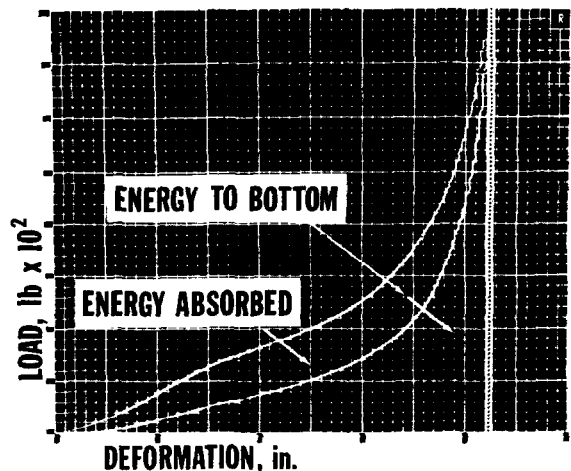


Fig. 9. Typical snowmobile seat load–deformation trace.

As the seat was deformed the load transmitted through the seat first increased non-linearly and then increased very rapidly as the seat bottomed.

RESULTS

A typical drop test is shown in the sequential photograph of test number ZO28 (Fig. 10) in which a Scorpion Stinger seat is attached to the test machine. The sequence starts in the lower left frame and proceeds up the left side to frame 4, then to the lower right frame 5, up the right side, and is completed in the upper right frame 8. In the first three frames the snowmobile is falling with the dummy slightly above the seat. Between frames 3 and 4 the track has contacted the floor, and in frame 4 the suspension has bottomed and the dummy is starting to deform the seat. In frame 5 the dummy has extensively deformed the seat as the machine has already begun to rebound. By frame 6 both dummy and machine are rebounding. In frame 7 the track has left the floor as the dummy rebounds further, and in frame 8 the dummy leaves the seat while the track is still off the floor. Of particular note is the fact that the suspension is bottomed or is just beginning to rebound as the dummy is deforming the seat to the maximum. The action shown in Fig. 3 was repeated without exception in the other tests.

For the determination of back injury, the acceleration-time records from the instrumented dummy are the most important data. Figure 11 is the acceleration-time record for test number ZO18 using the Arctic Cat Panther seat. The significant trace is chest vertical acceleration, third from the top. The time scale runs from right to left and the vertical lines are 10 msec apart. The vertical chest acceleration increased at an average rate of onset of 1200 g/sec to a maximum of 34 g and decreased at approximately the same rate. The acceleration was above 20 g's for 13 msec, and the duration of the total event was 79 msec. When the Polaris seat was used in drop test number ZO19 (Fig. 12), the

vertical chest acceleration increased at a rate 650 g/sec to a peak of 20 g. The total duration of the vertical chest acceleration was 88 msec.

In order that all the snowmobile seats which were drop tested can be evaluated, the test results are listed in Table 1. The drop height for all tests was 4 ft except for the Arctic Cat Panther seat which was tested at additional drop heights of 2 and 3 ft. The seats are listed in approximate order of impact severity to the dummy. The 2 and 3 ft test of the Arctic Cat Panther seat are listed at the top for comparison with the most severe impact which was the Arctic Cat Panther seat dropped from 4 ft. Although the total impact durations are all below 100 msec, the peak vertical chest accelerations and rates of onset are high enough to cause injury.

The results for seat testing are summarized in Table 2. The deformations to bottom the seats are listed with the loads applied to the seats when there was 1 in. of deformation remaining before bottoming. For three seats, the energy required to bottom them and the energy absorbed by them are listed in Table 2. For two of these seats the energies were determined for both 70 and 10°F. The energy required to bottom the seat is the area between the loading trace and the horizontal axis in Fig. 9. The energy absorbed by the seat is the area between the loading trace and the unloading trace. There was very little change in the mechanical response of the seats with temperature. This is evident from the energies listed in Table 2 for the Arctic Cat Panther and Ski-Doo Nordic seats at both test temperatures. All other data are given at the 70°F test temperature.

The order of listing for Table 2 is the same as for Table 1; i.e. the seats are listed in decreasing order of impact severity based on the drop tests. The four seats which were not included in the drop tests are listed in Table 2 with the seat from the same manufacturer which they most nearly resemble. Examination of the load at 1 in. from bottoming

Table 1. Snowmobile drop test results

Seat	Drop height (ft)	Peak vert. chest accel. (g's = 32.2 ft/sec ²)	Rate of onset (g's/sec)	Total duration (m sec)	Duration above 20 g (m sec)
Arctic Cat Panther	2	15	320	88	0
Arctic Cat Panther	3	30	960	94	6
Arctic Cat Panther	4	34	1200	79	13
Evinrude	4	31	930	79	8
Sno Jet Starjet	4	33	1060	87	6
Scorpion Stinger	4	32	980	80	6
Ski-Doo Olympic	4	29	800	75	7
Rupp	4	28	830	76	7
Ski-Doo TNT 18"	4	24	520	87	9
Moto Ski	4	24	640	71	8
Coleman Skiroule	4	22	950	81	7
Arctic Cat Puma	4	23	660	82	4
Alloutte	4	22	1700	72	4
Polaris	4	20	650	88	0

indicates that many of the seats were nearly bottomed by the weight of the dummy alone, and that the remaining seats approached bottoming with a force less than twice the dummy weight or an upward vertical acceleration of 1 g in addition to gravity. These low seat stiffnesses might be comfortable under some snowmobile riding conditions but they leave very little margin for vertical impact protection of the rider.

DISCUSSION

The biomechanical study indicated that the

spine of snowmobile drivers, may, under certain conditions, be subjected to forces which exceed human tolerance. In the first series of tests, as the dummy deformed the seat to the maximum extent, the snowmobile suspension was bottomed or rebounding so that the dummy had only the seat to protect it from severe vertical impact. The dummy bottomed the seat and was subjected to 20 g's in the least severe impact and 34 g's in the most severe case. Comparison of drop test results with human tolerance information indicates that the impact severity was suffi-

Table 2. Snowmobile seat test results

Seat	Deformation to bottom (in.)	Load to bottom (lb) 1 in. from bottom	Energy to bottom (in. lb) 70° F	Energy absorbed (in. lb) (10° F)
Arctic Cat Panther	4.5	220	810(895)	353(363)
Evinrude	3.2	280		
Sno Jet Starjet	4.1	340		
Sno Jet SS	3.3	310		
Scorpion Stinger	3.7	300		
Ski-Doo Olympic	4.2	260		
Ski-Doo Nordic	4.6	220	735(814)	168(197)
Rupp	3.2	300		
Ski-Doo TNT 18 in. front	4.0	280		
middle	4.6	360		
rear	4.5	320		
Ski-Doo TNT 15 in. front	3.1	320		
middle	3.5	380		
rear	3.8	370		
Ski-Doo Elan front	3.5	270		
middle	4.2	310		
rear	4.3	340		
Moto Ski	3.5	300		
Coleman Skiroule	3.5	340		
Arctic Cat Puma	4.2	280		
Alloutte	3.6	270		
Polaris	5.2	380	1270	497

cient in all cases to potentially cause compression fractures of the spine (Snyder, 1970).

The values for the upper limit of impact tolerance to the spine are most often calculated assuming the force is applied with the individual seated in an erect position with the spine properly positioned (Snyder, 1970). It has been well documented that asymmetrical loading will produce a concentration of forces in the spine resulting in injuries at a much lower level of impact force (Levy, 1964; Roaf, 1960; Brown *et al.* 1957). In this context such factors as forward head displacement, forward position of the arms, flexed

position of the trunk, and flexion of the hips all tend to produce asymmetrical loading of the spinal column.

One would expect, therefore, the snowmobile rider to be at high risk for spinal injury. On jumping or on uneven ground, his body may be propelled at a forward and upward velocity with little mechanism available to maintain a proper erect body attitude. On landing the rider may come down at various angles and rarely in the erect position. The passenger is probably more prone to injury than the driver in that he is frequently jostled about, unable to use his lower extre-

mities as a spring to relieve forces from the spine and has only side handles to hold on to to maintain an erect body position. At present, no definite pattern of spinal injuries has been reported, although our cases do suggest that the vertebral column of the individuals was flexed and thus predisposed to anterior vertebral body compression fractures.

Compression fractures reported in snowmobilers are not unique. They resemble any other compression fracture resulting from axial loading of the spine. Signs and symptoms of spinal compression fractures include immediate local pain, tenderness, decreased range of motion of the spine, and paravertebral muscle spasm, with ileus and kyphosis in the most severe cases (Howorth, 1959). Fracture of the posterior bony elements, and ligamentous disruption may occur in the more severe cases with resultant instability of the spine (Holdsworth, 1970). Such severe injuries may have concomitant compromise of neurologic function due to spinal cord trauma.

Treatment of mild compression fractures with no additional complications usually involves bed rest until acute symptoms subside, followed by immobilization in a hyperextension back brace and progressive ambulation. Return to normal activity is possible within a few months to 1 yr (Howorth, 1959; Baab and Howorth, 1951; Nicoll, 1949) and is often related to the magnitude of the original injury.

Long term sequelae of vertebral compression fractures may be significant. Nicoll (1949) reported that up to 20 per cent of patients in his extended study could not return to heavy work. Baab (1951) reporting a 10 yr follow-up study of spinal fractures, found that 35 per cent of his patients with compression fractures still had residual back pain. The obvious vertebral compression fractures are, however, only part of the problem. Brown (1951) and Roaf (1960) through the use of special X-ray techniques, have shown that when the spine is axially loaded the nucleus pulposus will herniate

fracturing the end plate of the vertebral body before roentgenographic evidence of compression occurs. Fracture of the vertebral end plate occurs at lower force impact levels of up to 50 per cent of the force required to produce compression fractures (Perey, 1957; Henzel, 1967). The significance of this phenomena, often not detectable on routine roentgenograms, has been suggested as the cause of initial back pain (Brown *et al.* 1957), as well as leading to later degenerative disk disease (Beadle, 1931).

It is beyond the scope of this paper to provide a complete analysis of the causes of vertebral fractures during snowmobile use or to supply exact design recommendations to remedy the problems raised. It is our opinion, however, that the snowmobile rider is subjected to a risk of serious bodily injury as a result of multiple factors. We have been concerned with the high number of extremity injuries in that the extremities are not protected and serious fractures and amputations have occurred due to the absence of any protective restraint mechanism.

We have drawn attention to the high impact forces to which the spine may be subjected. A correct spine posture in the snowmobile rider will decrease asymmetrical loading. Further studies of snowmobile design are required so that modifications in design would allow better positioning of the occupants.

A second modification would be construction of a seat which would allow better dampening and absorption of the forces involved. In the second test series, when the seats were deformed by a force equal to the weight of the dummy, they were nearly bottomed, leaving little margin for rider protection to vertical impact. As they were deformed further, the loads increased sharply until the seats become virtually rigid. The seats tested were capable of absorbing only a small part of the rider's energy at impact. The remaining energy must be dissipated within the rider which increases the injury potential. Using presently available tech-

nology, snowmobile seats could be designed with little expense or inconvenience, which would sharply reduce the potential of spinal fracture.

Another factor is the bottoming out of the snowmobile, which imparts an acceleration to the rider and increases the forces upon the spine. An adequate suspension system would solve this problem. We have also alluded to the poor location of the passenger safety handles and inability of the passenger to maintain a proper position. We have not mentioned the high risk of the upper torso and head and neck region which may present unsurmountable problems.

Individual factors such as good judgement, caution, driver instruction, and familiarity with the snowmobile are obvious factors involved in safely operating any moving vehicle. The driver and passenger should understand and be educated to the high risk of bodily injury in snowmobiling. With attention to the multiple factors raised, it is the authors' opinion that the risks of bodily injury could be significantly reduced.

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REFERENCES

- Baab, O. D. and Howorth, M. B. (1951) Fractures of the dorsal and lumbar vertebrae. *J. Am. med. Ass.* **146**, 97–100.
- Beadle, O. A. (1931) The intervertebral discs, observations on their normal and morbid anatomy in relation to certain spinal deformities. Great Britain Privy Council, Medical Research Council, Special Report Series, No. 161.
- Brown, T., Hansen, R. J. and Yorra, A. J. (1957) Some mechanical tests on the lumbo-sacral spine with particular reference to the intervertebral disc. *J. Bone Jt. Surg.* **39A**, 1135–1164.
- Butler, J. (1970) Snowmobile sales up-swing defies slowing economy. *Michigan Snowmobiler*, April.
- Carlson, W. L. (1970) Snowmobile accidents in Michigan during the 1968–1969 and 1969–1970 seasons. Preliminary report internal to the Highway Safety Research Institute, University of Michigan.
- Chism, S. E. and Soule, B. A. (1969) Snowmobile injuries: hazards from a popular new winter sport. *J. Am. med. Ass.* **209**, 1672–1674.
- Henzel, J. H. (1967) The human spinal column and upward ejection acceleration: an appraisal of biodynamic implications. Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio, Report AMRL-TR-66-233, Sept.
- Holdsworth, F. (1970) Fractures, dislocations and fracture-dislocations of the spine. *J. Bone Jt. Surg.* **52A**, 1534–1551.
- Howorth, M. B. (1959) *A Textbook of Orthopaedics*, pp. 577–585. Saunders, Philadelphia.
- Levy, P. M. (1964) Ejection seat design and vertebral fractures. *Aerospace Med.* **35**, 545–549.
- McLay, R. W., Chism, S. E. and Soule, A. B. (1970) Snowmobile accidents: causes and prevention. University of Vermont Report for National Safety Council and ERG, 90131-01, Aug.
- McLay, R. W., Chism, S. E. and Soule, A. B. (1970) Snowmobile accidents: causes and prevention. University of Vermont Report for National Safety Council and ERG, 90131-01, Aug.
- Nicoll, E. A. (1949) Fractures of the dorso-lumbar spine. *J. Bone Jt. Surg.* **31B**, 376–394.
- Perey, Olof (1957) Fracture of the vertebral end plate in the lumbar spine. *Acta orthop. scand., Suppl.* 25.
- Roaf, R. (1960) A study of the mechanics of spinal injuries. *J. Bone Jt. Surg.* **42B**, 810–823.
- Snyder, R. G. (1970) Human impact tolerance. SAE Paper No. 700398, 1970 International Automobile Safety Conference Compendium, pp. 713–796.
- Withington, R. L. and Hall, L. W. (1970) Snowmobile accidents: a review of injuries sustained in the use of snowmobiles in northern New England during the 1968–1969 Season. *J. Trauma* **10**, 760–763.