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Biomechanics of Carving Skis

Summary

Carving skis and skiboards have arrived in the Alpine skiing community. The scientific community has great interest in studying both the performance and safety aspects of these new products. To date, several studies have been concluded, and numerous others are in progress. Neither carving skis, which need to be more concisely defined in the future, nor skiboards appear to significantly increase the injury risk to the user. Differences in the biomechanics of skiing using these products do appear to exist compared to traditional skis. Additional research is appropriate to better understand how these kinematic changes relate to factors such as improved ease of use, reduction in fatigue, education and learning how to ski, and injury prevention.

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Introduction

Recent changes in Alpine ski design have led to several new categories of skis, including carving skis and skiboards. Use of these skis with their shorter length and larger sidecut has resulted in modifications to normal skiing technique. As with all new products, questions arise with regard to relative increases in performance, ease of use, and safety compared to existing products. The goal of this paper is to summarize early research quantifying how carving skis and skiboards are used and by whom, differences in the biomechanics of the skier using carving skis and skiboards compared to traditional Alpine skis, and a review of early safety data from the use of carving skis and skiboards.

Carving Skis

Carving skis are generally defined as skis with significant differences in the width between the tip, tail, and waist of the ski. Carving skis are usually used at a length 10–20% shorter than traditional skis. A shorter ski is typically lighter and has less inertia, making it easier to turn. The wider tip and tail allows the skier to lean into the turn. There is no loss of gliding performance with carving skis because the base surface in contact with the snow is the same as a traditional narrow non-sidecut ski.

The effects of large sidecut skis are likely to be different for different experience levels of skiers. Beginners enjoy the new shorter skis because they are lighter and can be more easily turned, making learning how to ski an easier process. The average skier benefits from easier turning with a shorter radius on the edge. Advanced skiers can fully enjoy the benefits of carving skis, leaning their bodies significantly from side to side while generating sharp, short radius turns at high speeds. Competitors are now also using carving skis for several disciplines, but their use in racing is beyond the scope of this paper. The important questions to answer are: 1) Does the use of carving skis significantly alter the biomechanics of the skier?; and 2) Do these biomechanical changes, if they exist, have any impact on the incidence and severity of injuries in skiing?

Epidemiology of Injuries on Carving Skis

There are no studies published specifically addressing injury patterns associated with the rapid proliferation of carving skis on the market. Laporte et al. (2000) found no significant difference in all injuries categories for 1.5 m carving skis versus traditional skis. This study, over seven years and including some 232 571 injuries, is probably the largest ski injury database in the world. From 1992 to 1999, 21 303 ruptures of the anterior cruciate ligament (ACL) in the knee were recorded. The authors found that there was no increase in the incidence of anterior rupture for carving skis compared to traditional skis.

A three-year study of injury patterns with carving skis versus traditional skis in the United States was recently presented at the International Symposium for Skier Safety meeting in Cervinia, Italy, in 1999 (Johnson et al., 2000; Johnson et al., 1998). This study of 1576 skiing injuries found that specific injury categories, including isolated ACL injuries and ankle injuries, were significantly increased by the use of carving skis, but that these differences were significantly related to the skill level of the skier. Skiers of all experience levels were found to have a 40% increase in the likelihood of sustaining an injury (all categories) while skiing on carving skis compared to traditional skis. Yet beginner and intermediate skiers were much more likely to have an injury using traditional skis than carving skis, and this group suffers 30% more injuries than advanced skiers. Advanced skiers were 50% more likely to suffer injuries using carving skis compared to traditional skis. These confounding data demonstrate the care that must be excercised when evaluating the results of longitudinal epidemiology studies. Long-term epidemiology studies in the United States (Johnson et al., 2000) have shown that overall injury rates and injuries to the knee remain relatively stable over the past five years, but these more in-depth reports show that changes in ski equipment usage do indeed have important effects on injury patterns as a function of experience level.

Two additional points about the various epidemiology studies, past and future, on carving skis. 1) There is no clear definition of what makes a ski a carving ski, and 2) Do the skiers using carving skis really carve? The various consumer magazines and manufacturers brochures list numerous types of skis, including race carvers and fun carvers and super sidecut and radical sidecut, each of which is related to the radius of curvature of the ski. At this time, the range of radius' that are called carving skis covers almost every ski on the market. Perhaps a classification system for carving skis is necessary to determine whether particular ranges of curvature are more or less likely to be involved in the various injury groups discussed above. Finally, carving skis were designed for and require somewhat modified skiing technique to fully take advantage of the performance characteristics of the skis. Therefore, it is important to understand how skiers are using carving skis during normal skiing practice.

Biomechanical Studies on Carving Skis

The practice of carving – including laying the body out significantly with respect to the skis much like a turn in waterskiing – appears to have had different implementations in Europe and in the United States. Over the past several seasons, many skiers could be seen at European resorts with no poles, very short skis, and practicing the body carving technique. The skiers would, at relatively high speed, initiate a series of turns during which they would extend the outside leg almost to full extension and then rapidly shift their weight in the other direction. This method involves leaning to the inside of the turn with the entire body (Fig. 1a). The more classical carving technique involves a countermovement of the upper body, more a result of former racing technique, with the skis still on the edge (Fig. 1b). This practice appears to have had limited exposure in the United States, although a significant portion of the skiers were now using carving skis of shorter length than previously used. The authors are not aware of how carving technique was implemented and practiced in other areas of the world, including Japan. The effect of these various techniques on skier movement and performance, including fatigue, has not been previously documented.

Several research studies have recently been presented or published that quantify the effect of carving skis on the kinematics of skiing compared to traditional skis (Yoneyama et al., 2000, Greenwald et al., 1999). Yoneyama and colleagues found, for one skier, differences in both joint motions and measured binding reaction forces for both short radius and long radius turns using carving skis compared to traditional skis. Specifically, for carving skis in long radius turns, there was a greater difference in hip flexion angle between the inside and outside legs during a turn, which led to increased body angulation. This allowed a more uniform force to be applied to the outer ski during the turn. There was no need for the hip to be externally rotated to compensate for the turn. Conversely, for traditional skis, the turn was initiated primarily by abduction and adduction of the hips, the forces on the skis were disproportionately applied to the front part of the outer ski, and the hip was forced to externally rotate to complete the turn. For short radius turns, similar changes in body positions were coupled with more consistent ski loading for the carving skis compared to the traditional skis. While these results are from only one skier, they begin to explain some of the anecdotal evidence of why carving skis are «easier» to use, and «easier» to learn. These data demonstrate that carving skis produce a smoother turn, with less rapid changes in body position and loading on the skis during the turn. Less effort in turning is likely to reduce fatigue, which may be a significant factor in injury prevention.

Our research found very little difference in the biomechanics of the lower leg for super sidecut skis compared to traditional skis (Greenwald et al., 1997; Greenwald et al., 1999). Of particular importance was to determine if the leg, and the knee joint in particular, ever approached the extremes of its range of motion during normal skiing. Non-contact injuries to the soft tissues in the knee, such as a rupture of the ACL and other knee ligaments and meniscii, are more likely to occur near the extremes of motion when the knee is in either hyperextension or hyperflexion. Our pilot data, which included only expert skiers, found that use of a carving ski did not cause the skier to significantly change the range of motion of the knee in either flexion/extension, varus/valgus rotation, or internal/external rotation (Fig. 2). There were two significant limitations of these findings. First, only expert skiers were tested – the importance of the difference between carving skis and traditional skis for novices was not studied. Second, the turns performed by the test subjects during the trials did not include the more European style of carving, where the body is much more significantly angulated compared to a conventional ski turn. In order to more completely understand biomechanical differences that exist when using carving skis in this way, additional studies must be undertaken. Research studies are being performed this winter to quantify the effect of carving skis on the biomechanics of turning for novice skiers and for women, for whom ACL injuries occur at a much higher rate than for men, and to quantify physiological parameters, such as energy expenditure, which could help explain whether or not carving skis actually provide an «easier» turning mechanism than traditional skis.

It is important to consider there are numerous interrelated variables that are affected by the change in skiing style now available to most skiers with carving skis. Others have theorized about increased difficulty in being able to recover from «catching an edge» with carving skis or whether carving skis increase the likelihood of catching an edge. Given that none of the injury data supports a rapid increase in injuries using carving skis, it does not appear that these theories are true. Even if skiing practice using carving skis results in biomechanical positions that are more likely to result in injury, it is not clear that a resulting increase in injuries would be seen. Consider that if fatigue were significantly reduced when using carving skis because they were overall easier to maneuver, then this might result in a reduction of injuries. Of course, this is not a scientific argument, but it is made here to caution the reader that there are not clear explanations for what causes injuries in skiing. It is therefore difficult to establish if a change in one component of the equipment independent of other changes to equipment, ski conditions, experience level, gender, and a host of other factors leads to a significant change in injury patterns, particularly without numerous years of epidemiological studies. In the case of carving skis, it appears that there is notable difference in the practice of skiing using carving skis, and that many skiers, and new skiers in particular, find carving skis to be easier to use. Coupled with no overall increase in injury rates recorded in scientific studies of injuries in skiing, carving skis appear to offer new and different fun and excitement to the sport of Alpine skiing.

Skiboards

Skiboards are defined as skis between 70 and 130 cm in length (Fig. 3). These skis typically have a sidecut that makes them more like carving skis than traditional skis. A distinguishing feature for most skiboards is that they are not typically sold with traditional Alpine ski bindings. Rather, they have fixed bindings which do not release. Skiboards enjoy popularity with young skiers who like to perform maneuvers such as jumps or flips in a snow park or in a half-pipe. The average age of skiboarders is approximately 21 years, which is approximately 10 years younger than the average age of an Alpine skier (Greenwald et al., 2000).

Epidemiology of Injuries on Skiboards

Injury rates and specific injury patterns in skiboarding were analyzed and compared to similar data for Alpine skiing and snowboarding. The hypotheses of our study were that there are no differences in overall injury rates among four winter sports (Alpine skiing, Snowboarding, Skiboarding and Telemarking), and that the incidence of specific injuries would not differ among the sports. The results demonstrated that, for one large mountain resort in the United States, the total number of skiboarding injuries occurred at a rate consistent with injuries in Alpine skiing and snowboarding when normalized for the population at risk (Table 1).

1998–1999	Control Population (n = 1022)		Injured Population (n = 2448)		
	% usage in population	Mean Age	% of all injured	MDBI	Mean Age
Skiing	75	32.7 ± 14.4	65	403	28.1 ± 14.4
Snowboarding	20	21.9 ± 7.3	32	216	20.9 ± 7.8
Skiboard	3	20.8 ± 8.6	1	966	19.7 ± 9.5
Telemark/ Other	2	29.1 ± 6.9	1	2100	28.7 ± 8.0

Table 1: Percentage of injured population(n = 2448) and control population (n = 1022) by sport, including mean age of participants and Mean Days Between Injury (MDBI).

Two other major studies have reported on injury rates and specific injury types for skiboards (Laporte et al., 2000; Shealy et al., 2000) in both France and the United States. These short-term studies of 1–2 years experience with skiboards yielded varying results. Shealy et al. found that skiboard injuries occurred at a rate 3.9x greater than Alpine skiing injuries in a rental population (Shealy et al., 2000). Tibia fractures, which occur very infrequently in the overall Alpine skiing population, were significantly increased in the skiboard population. Yet the two-year studies by Greenwald et al. in Vermont and by Laporte et al. in France found a lower overall incidence of injuries in the skiboard population compared to the Alpine ski population (Table 2). A summary of the mean days between injury (MDBI) for the various sports and for various common injury types shows that knee sprains in Alpine skiing, and wrist and shoulder injuries in snowboarding continue to occur at a much higher rate than tibia fractures in skiboarding (Table 3).

Tibia fractures occur in skiboarding at a rate higher than in Alpine skiing. Any increase in lower leg fractures in skiboarding must be carefully monitored in the future, with statistics that correlate lower leg injury rates for skiboards to age-matched and demographically similar control populations. It may be that the injury mechanisms for skiboarding are quite different than for Alpine skiing, much the way that snowboarding injuries are very different than skiing injuries, and injuries with carving skis are different for various levels of experience. Caution must be exercised, therefore, when comparing injury rates and when drawing conclusions regarding injury mechanisms and possible intervention methods between the two sports.

	Killington 1999	Killington 2000	Médecins de Montagne 2000
Skiers	403	517	381
Boarders	216	277	258
Skiboard	966	404	448
Tele/Other	2100	1600	1194

Table 2: MDBI by sport for the various study locations and years.

1998–2000	Mean Days Between Injury (MDBI)			
	Tibia Fracture	Knee Sprains	Shoulder Injuries	Wrist Injuries
Alpine	10076	1115	4614	15751
Board	28283	3014	1664	965
Skiboard	3653	5479	2989	10958
Tele/Other	26819	6705	8940	13410

Table 3: Mean Days Between Injury (MDBI) for common injuries in the various sports. NOTE: Data for tibia fractures were computed from the ski patrol reports only.

Our two-year study of skiboard injuries made no attempt to identify the specific cause or mechanism of injury. Loading patterns on the lower leg were not measured, and therefore cannot be compared to lower leg loads typically experienced during Alpine skiing. Differences in specific injuries among the sports, and in particular for knee injuries, may occur as a result of the different ski lengths with the removal of the lever arm that exists with traditional Alpine skis. Anecdotally, several injured skiboarders have reported the situation where the ski becomes caught in a pile of snow and is turned perpendicular to the direction of motion, which might be referred to as «skiboard blocking». In this case, the momentum of the skier might cause a large lateral or medial bending moment on the tibia in the lower leg. In most cases, this leads to a rapid forward or forward twisting fall, which might result in a shoulder injury, lower leg, or knee injury, depending on the specifics of the event.

Limitations of the current study include the fact that only two years of data at one ski mountain were collected. While this is a relatively small sample, taken in conjunction with the French study, a picture of injury patterns in skiboarding begins to emerge. The conclusions following two years of the study are:

1. Injury rates in skiboarding are low, and are representative of the overall participation rate in this sport. The lower overall rate of injury in skiboarding may be a function of the significant reduction in the number of knee injuries in skiboarding compared to Alpine skiing and snowboarding.
2. Skiboarding, like snowboarding in its initial years, is currently most commonly practiced by young males, and injuries in the sport most often occur within this demographic group.
3. Lower leg fracture rates in skiboarding were significantly higher than in the Alpine skiing and snowboarding populations. This increase may be a function of skiboard user demographics or equipment usage. More detailed studies are required to determine if this trend is consistent over several ski seasons, and if there is a mechanism of lower leg fracture in skiboarding that can be identified.

Biomechanical Studies on Skiboards

If injury patterns are different for skiboards compared to traditional length skis, then there must be inherent biomechanical differences between the two sports that lead to different injury mechanisms. As mentioned, there have been anecdotal reports of skiboards becoming blocked by the snow, leading to a forward or forward twisting fall. These types of falls might be associated with increases in tibia fractures and in shoulder injuries. The lack of a release binding on skiboards has been questioned as a possible cause of some injuries.

To begin answering this question, a field study with 64 skier-days was performed with skiboards (called «short carvers» in Senner's reports) fitted with a traditional alpine ski binding set at the appropriate ISO levels for the skier. Whereas twist releases during falls and (occasionally) inadvertent releases at the toe piece of the binding were observed, there were almost no releases in the forward lean direction. From this field study two things were concluded:

1. Cases were observed during which the binding forces at the toe piece exceeded the regular release setting values, therefore a twist release might be useful to prevent injuries in certain situations.
2. As there were almost no heel releases from the skiboard, the vertical forces at the heel part of the binding do not go beyond the ISO release level in normal skiing.

It is not correct to interpret the second conclusion with the statement «a heel release is not necessary», because in the aforementioned study, several forward falls had been observed, one of them resulting in a severe injury of the upper extremity.

Basing on this observation, Senner (2000) developed a computer simulation to further examine the need for heel release bindings in skiboards. They determined differences in loading on an alpine ski binding between traditional length skis and skiboards. For this comparison a typical situation was chosen: an experienced traditional skier is using skiboards for the first time and approaches a mogul. Being experienced he knows how to anticipate such an obstacle and his movements in this maneuver are automated. So the first step was to determine the typical kinematics of a skier using the traditional length ski in the situation of going over a mogul. A 2-D computer simulation was then constructed and run using exactly these kinematics but replacing the traditional long skis with skiboards. The rationale for this simulation was that an experienced skier using skiboards for the first time would not have the experience to modify his technique (i.e. his knee angle).

Figure 4 shows the same instant of the simulated maneuver, on the left when using the conventional ski, on the right when using the skiboard.

For the simulation performed, the ski binding was set to release at 1500 N force at the heelpiece. The simulation demonstrated significant differences in the forces applied to the ski binding for the traditional length ski and the skiboard going over a mogul. For the exact same kinematics that would cause a heel release in a traditional length ski, no heel release would occur on the skiboard. This was explained entirely by the biomechanics of the skier's torso for the two different ski lengths. When the skiboard crosses the mogul, there is no longer the large lever arm in the front of the skier to bend and absorb the energy. Instead, the torso begins to rotate forward rapidly, leading to a forward fall over the tips of the skiboard (Fig. 4b). This is likely to result in an increased risk for upper extremity injury.

To avoid this situation, a heel release should occur as early as possible. But further analysis with the computer simulation showed, that this would only be achievable if the release level of the binding were set to much lower levels as defined by the ISO standard. And lowering the setting values would certainly dramatically increase the risk of inadvertent releases.

From these simulation results, it has to be concluded, that it is not relevant to simply place a traditional ski binding on a skiboard, set it at existing ISO levels, and expect it to perform the same as it would on a traditional length ski. The solution to this problem probably needs the development of a new type of binding (one possible technical solution has been proposed in the aforementioned research).

Summarizing the study, an experienced skier but novice skiboarder who is likely to ski with the same type of mechanics used with his conventional skis is exposed to different risks. As the simulation showed, this might lead to falls on skiboards that would not have likely occurred with a traditional length ski. Studies such as these are critical to our understanding of how modifications to ski shape and length can have significant impact on the biomechanics of skiing, on the role and utility of release systems designed specifically for traditional skis, and on the potential for different patterns of injuries.

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Figure 1a

Figure 1b

Differences in carving styles: a) body carving, and b) traditional countermovement carving.

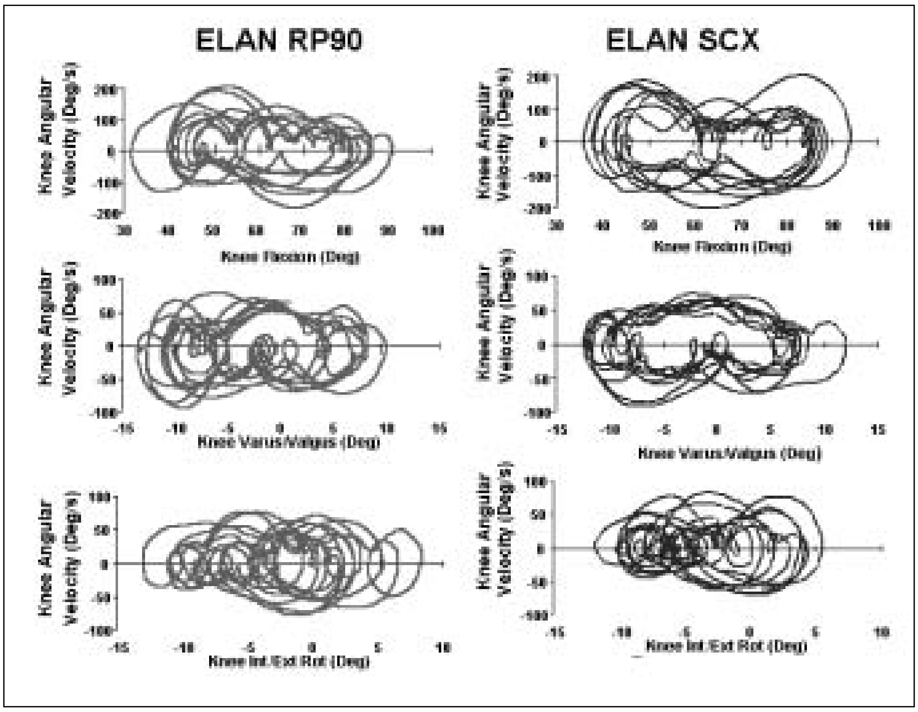

Figure 2:

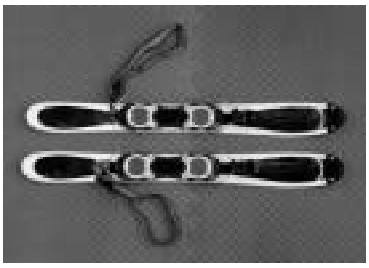

Figure 3: Typical Skiboard (<130 cm) with nonreleasable binding.

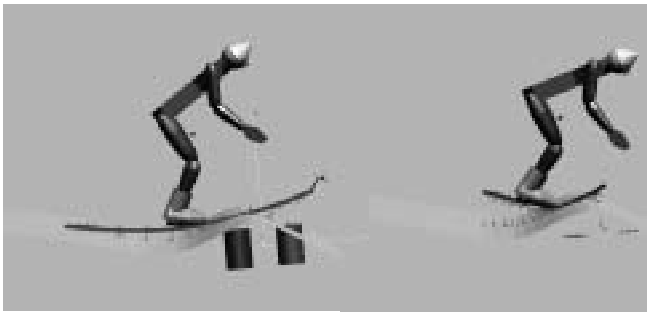

Figure 4: Simulation of skier traveling over a mogul with a) traditional length skis; and b) skiboards.