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Tibial Plateau Fractures among Alpine Skiers: A Retrospective Case Series

Tyler R. Williamson, Joel N. Smith, Britta L. Swanson, John D. Robinson, Keith R. Swanson and Kyle E. Swanson *

Tahoe Orthopedics and Sports Medicine, Zephyr Cove, NV 89448, USA
* Correspondence: kswanny1989@gmail.com; Tel.: +1-775-589-8950

Abstract: The purpose of this retrospective case series was to review the demographics of alpine skiers who sustain tibial plateau fractures, evaluate the inter-observer reliability of the Schatzker classification for fractures sustained while alpine skiing, and to evaluate patient-reported outcomes. We hypothesized that most tibial plateau fractures would be low-energy fracture patterns (Schatzker I–III) and occur in women and less-experienced skiers. Charts and radiographs of patients treated surgically for tibial plateau fractures caused by alpine skiing were evaluated. Patients treated less than two years prior to review were excluded. Patients who qualified were contacted to complete a questionnaire regarding their skiing experience, their pain levels experienced following their accident, the weather conditions during the accident, and their return to sport. Forty-seven patients met the inclusion criteria. The mean age was 49, and 60% of the participants were male. There were 28 low-energy fracture patterns (Schatzker I–III) and 19 high-energy patterns (Schatzker IV–VI) with a 95.7% inter-observer reliability. Contrary to the hypothesis, tibial plateau fractures sustained while alpine skiing occurred in older, experienced riders. Approximately 40% were high-energy fractures. Although over 75% of patients reported having no pain or occasional pain at their final follow-ups, less than half of the patients returned to alpine skiing.

Keywords: tibial; tibia; plateau; proximal; fracture; alpine; skiing; skiers

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1. Introduction

Alpine skiing is an exhilarating sport enjoyed by participants of all ages. Data from recent years have indicated a continued increase in the number of skiers. As of 2020, estimates indicate that there were over 14 million participants in alpine skiing. Fifty-nine percent of the participants were male, and 61% were older than 25 [1].

Despite its increasing popularity, there is an inherent risk associated with alpine skiing. With newer technology and equipment, the rate of foot and ankle injuries sustained by alpine skiers has decreased over time, but with a concomitant increase in knee injuries [2–4]. Modern boots and bindings cause the force generated by a fall to bypass the ankle and be transferred to the tibial shaft and the knee [5]. In an analysis of Mean Days Between Injuries (MDBI) conducted at a Vermont ski area, the collected data showed a 280 percent increase in ACL injuries and a 485 percent increase in tibial plateau fractures among adults when comparing the 1972–1973 ski season to the 1993–1994 ski season [6].

Tibial plateau fractures were previously thought to be rarely observed injuries in alpine skiing [6,7]. Recent data suggest diaphyseal fractures remain the most common location for tibial fractures; however, the incidence of tibial plateau fractures is nearly three times greater than that of distal tibial fractures among skiers [8]. Tibial plateau fractures are generally a result of axial compressive forces along with varus or valgus forces. These forces cause the proximal end of the tibia to contact the femur, creating either a splitting fracture, a compression fracture, or a combined pattern fracture [9].

There are multiple classification systems for tibial plateau fractures, with the Schatzker classification being the most commonly used in North America [10]. Schatzker types I through

III are generally considered low-energy fracture patterns that occur in osteoporotic bone and create compression fractures. Schatzker types IV through VI are considered high-energy fractures, such as those sustained in motor vehicle accidents or other high-velocity accidents. Younger patients tend to have split fractures of the lateral plateau due to their generally stronger bone; in contrast, older patients tend to sustain more compression fractures [9].

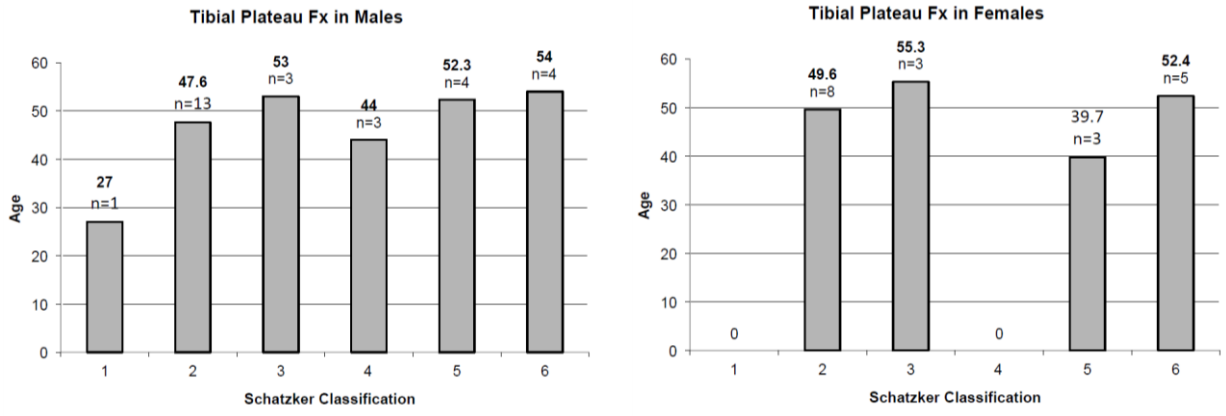
There are many reports stating that skill level, patient age, and gender have a significant effect on injury rates. Injury rates have been observed to be higher in first-day skiers, snowboarders, and skiboarders [11,12]. Female skiers were found to have higher rates of knee injuries in numerous studies [3,5,13–17]. The influence of age on injury rates among skiers is highly variable according to the literature. However, Stenroos et al. reported a significantly higher incidence of tibial plateau fractures and open fractures among adults compared to children [8].

The purpose of this study was to review the demographics of alpine skiers who sustain tibial plateau fractures, evaluate the inter-observer reliability of the Schatzker classification for fracture patterns sustained while alpine skiing, and evaluate patient-reported outcomes. Our hypotheses were as follows: most fractures would be lower-energy fractures (Schatzker I–III) and occur in women and less-experienced skiers; inter-observer reliability of the Schatzker classification would be high; patient-reported pain scores would be low; and the rate of returning to sport would be high.

2. Materials and Methods

This retrospective case series was carried out with approval from the institutional IRB. A CPT code search in the electronic medical record system was performed to identify patients treated surgically for a tibial plateau fracture at a community hospital that serves three nearby ski resorts between 1 December 2005 and 31 March 2011. Patients treated less than two years prior to review or whose mechanism of injury was not related to alpine skiing were excluded. A radiographic review was performed, and those without adequate preoperative imaging in the form of orthogonal plain radiographs (XR) or a computed tomography (CT) scan were excluded. The imaging studies were reviewed by a sportsmedicinefellowship-trained orthopedic surgeon and an orthopedic surgery sports medicine fellow for inter-observer reliability. All operative reports were reviewed to identify any concomitant injuries to the knee (i.e., meniscal injuries, ligament injuries, etc.).

Using patient information provided at the time of admission, patients were contacted to complete a questionnaire regarding their functional ability before and after their injury (Figure 1). VAS pain scores and data regarding pain frequency were collected. Information regarding the snow and weather conditions at the time of the injury as well as the contribution of equipment malfunction to the injury was collected. Simple statistical analyses were performed.



(**a**) (**b**)

Figure 1. Mean age (years; n = number of patients) of patients stratified via Schatzker classification. (**a**) Tibial plateau fractures among males; and (**b**) Tibial plateau fracture among females.

3. Results

Forty-seven patients met the inclusion criteria for radiographic analysis. The mean age of the skiers presenting with a tibial plateau fracture was 49 (range 22–70). Sixty percent (28/47) of the patients were male.

There were 28 low-energy fracture patterns (Schatzker I–III), 21 of which were classified as type II. There were 19 high-energy fracture patterns (Schatzker IV–VI), 9 of which were classified as type VI. The distribution of gender and age versus fracture classification is shown in Figure 1. Inter-observer reliability determined using the Schatzker classification was 95.7%, with no significant difference between observers.

Twenty-seven patients completed the questionnaire (Figure 2) at a mean follow-up of 46 months (range 24–85 months). Twenty-one of those patients reported either no pain or occasional pain, with ten reporting no pain at all. Two patients reported frequent pain, and four reported daily pain. Seventy percent (19/27) of patients stated that their knee pain did not limit their activity level. The mean VAS pain level was 2. Seven patients (26%) required at least one additional surgery. There were four hardware removals, one scar release, one hematoma evacuation, and one patient had multiple surgeries and eventually required a total knee arthroplasty. The patient that underwent hematoma evacuation developed the hematoma several weeks after surgery and after he had returned home several hundred miles away. He developed a foot drop from the hematoma, which only partially resolved after evacuation.

1) Overall how does you knee feel?
   a. No pain
   b. Occ Pain (1-2/week)
   c. Frequent Pain (>3 days/week)
   d. Daily Pain
2) Does your knee pain limit your activity level?
   a. Yes
   b. No
3) On a scale of 0 to 10, with 10 being the worst pain, what is your average pain level?
4) Have you had any additional surgeries on the injured knee related to the initial injury?
5) How many years have you been skiing prior to your injury?
6) Prior to your tibial plateau fracture (knee fracture) how often did you ski?
   a. <1x/year
   b. 2-5x/year
   c. 5-10x/year
   d. >10x/year
7) What level of skier or snowboarder are you?
   a. Type 1 – Ski/Board Cautiously – prefers lower speeds on smooth slopes of gentle to moderate pitch, lower than average release/retention settings, prefers an increased risk of inadvertent binding release in order to gain increased releasability in a fall, entry level skier or boarder uncertain of their classification.
   b. Type 2 – Ski/Board Moderately – prefers a variety of speeds, prefers varied terrain, not classified as Type 1 or 3, prefers average release/retention setting appropriate for most recreational skiing.
   c. Type 3 – Ski/Board Aggressively – prefers faster speeds, prefer fast and aggressive skiing/boarding on slopes of moderate to steep pitch, prefer higher than average release/retention settings, and prefer decreased releasability in a fall in a fall in order to gain decreased risk of inadvertent binding release.
8) Have you been able to return to skiing since your injury?
   a. Yes
   b. No
   If No, Why?
   Is it because of your knee injury?
   If Yes, with what frequency?
      i. <1x/year
      ii. 2-5x/year
      iii. 5-10x/year
      iv. >10x/year
9) How were the conditions the day of your injury and how did the accident happen?

Figure 2. Questionnaire administered to patients who sustained a tibial plateau fracture while alpine skiing.

Patients reported a mean of 22 years of experience prior to their tibial plateau fracture (range 0–50 years). Only one patient was a first-time skier. Fifty-two percent (14/27) reported skiing more than five times per year. There were five patients that reported skiing five to ten times per year, and five that reported a frequency of two to five times per year. Only three patients reported skiing less than once per year. According to the skier type

classification used at ski rental stores (Figure 2, question 7), there were 10 type 3 skiers, 16 type 2 skiers, and 1 type 1 skier. Only 13 of the 27 patients (48%) returned to skiing after their tibial plateau fracture. Eight of the fourteen patients (57%) that did not return to skiing reported that "fear" was the reason they were unable to return.

Patients reported the snow and weather conditions on the day of their injury as well as the events they believe contributed to their injury. Twenty-five patients reported the weather conditions on the day of their injury, with eighteen reporting good conditions, which were defined as fresh snow and a clear day with good visibility. Seven patients reported poor conditions, which were defined as the presence of icy and slushy terrain and poor visibility. Nine patients reported that they were skiing when they "caught an edge", causing them to fall. Nine patients reported a binding malfunction as a contributing factor. Six patients were either hit by other riders or injured themselves while trying to avoid an out-of-control rider. One of those six patients was injured while standing in the lift line. Four patients reported that either a marked or unmarked obstacle was the reason they were injured. Three patients reported that their injury occurred at the end of the day.

4. Discussion

The current study represents the largest series of tibial plateau fractures among alpine skiers utilizing the Schatzker classification and evaluating patient-reported outcomes. The inter-observer reliability of the Schatzker classification was high (95.7%), and most fractures were classified as low-energy patterns (Schatzker I–III). Contrary to our hypotheses, most fractures were sustained by experienced, male, adult skiers, and less than half of the patients returned to alpine skiing.

Age and experience level have been implicated as being contributing factors with respect to injuries sustained while alpine skiing. Whereas most snow sport injuries occur in younger, less-experienced populations, the majority of fractures in the current study were sustained by adults (mean age 49), with a mean of 22 years of experience [11,18,19]. Only two patients were less than 25 years of age, and only one was a Type I skier (beginner). This is consistent with prior studies. Shealy et al. found that over the last 35 years, the only major injury pattern among skiers that correlated with increased age was a tibial plateau fracture [20]. The risk of sustaining a TPF among skiers over the age of 55 was 5.7 times greater than that of the general skiing population despite a lower overall rate of injury in this age group. One potential explanation for this is the age-related decline in bone mineral density. Allen et al. demonstrated a reduction in cortical bone volume and increased medullary cavity volume in the proximal tibia in older subjects compared to younger subjects [21].

The majority of knee injuries sustained through skiing occur in women, with soft tissue injuries such as anterior cruciate ligament (ACL) injuries occurring most frequently [19,22]. Several prior studies examining tibial plateau fractures among skiers have reported a higher incidence among females [3,15–17]. In contrast, 60% of the tibial plateau fracture patients in the current study were male, and only 38% (18/47) had concomitant soft tissue injuries. There were 15 lateral meniscus tears (11 male and 4 female), 6 ligamentous injuries, 4 ACL avulsions (2 male and 2 female), 1 patellar tendon avulsion (female), and 1 medial collateral ligament tear (male).

Prior reports indicate that the rate of ankle injuries is declining, and the rate of knee injuries is increasing [5,14]. According to one report, the overall injury rate in alpine skiing has decreased by 55% since 1972, but tibial plateau fractures have demonstrated a statistically significant negative trend [23]. As the technology of bindings and multi-directional releases improves, the ankle appears to be better protected, and the energy is transferred proximally to the knee, resulting in ligament injuries and fractures. One third of the patients contacted for our survey reported that a binding malfunction was a contributing factor to their injury. It has been demonstrated in multiple studies that properly adjusted bindings decrease injury risk. In a study by Hauser, 50 percent of bindings were at least 20 percent above recommended

release levels [24]. When compared to a control group, the group with improper binding had four times the incidence of binding-related injuries.

Forty percent (19/47) of the tibial plateau fractures in this study were high-energy fractures. These are classified as Schatzker type IV–VI fractures and are often observed in high-speed accidents, such as motor vehicle accidents, and high-velocity sports, such as alpine skiing. Although it cannot be determined whether speed played a factor in the severity of the fracture patterns observed in the current study, the conditions of the injuries indicate that it may have played a role. Ten of the nineteen high-energy fracture patients indicated the cause of their injury: three were involved in a collision, one slipped on ice, three simply lost control on good snow, and three indicated that their skis were caught in heavy, wet snow. Increased downhill speeds or simply a sudden change in the direction of the downhill force may have generated the torque necessary to create the high-energy fracture patterns observed in these patients. In a series of 116 tibial plateau fractures sustained by alpine skiers, Saragaglia et al. reported Schatzker type VI fractures to be the most common type (34%) and stated that the energy of the corresponding impacts was similar to that observed in road traffic accident injury patterns [17].

One alarming finding was that fewer than 50% of patients returned to skiing after sustaining a tibial plateau fracture. Interestingly, 57% of the patients that did not return to skiing reported "fear" as the main reason and stated low impact activities as their preference. In a series of 103 skiers with tibial plateau fractures, Loibl et al. reported that only 53% of the patients returned to downhill skiing, while 88% remained engaged in other sports, with no reported difference in the frequency or duration of engagement in sports per week [3]. Another study reported a 38% drop out rate from skiing despite patients having a high functional status, and the return to sport rate after bicondylar fractures was only 21% [4]. Multiple studies have demonstrated statistically significant decreases in patient-reported outcomes after suffering tibial plateau fractures, although absolute scores remain quite high (just below population norms) [3,4,15]. These findings highlight the psychological impact of ski-related trauma on patients as well as the influence of fracture severity on return to sport.

The reoperation rate in this series was 26%, indicating that it is critical to council patients preoperatively about the potential need for future surgery. Four of the seven reoperations were for implant removal. Prior studies have reported similar reoperation rates for tibial plateau fractures due to any cause, with implant-related discomfort being the most common reason for an unplanned reoperation [25]. Only one patient (4%) in this study required reoperation for conversion to arthroplasty. It is possible that the four-year mean follow-up period was not long enough to capture symptomatic post-traumatic arthritis requiring conversion to arthroplasty. However, a study including 83 patients with a mean age of 50 and ten-year follow-up reported an only 2.3% rate of conversion to arthroplasty [15]. Radiographic progression of arthritis was most significant in the lateral compartment, which was the most common fracture location; however, patient-reported functional outcomes remained high.

There are limitations to this study. The data were collected retrospectively, and not all the patients had the same imaging studies performed preoperatively. Since the patients self-reported the contribution of weather conditions and equipment to their injuries, these data are subject to recall bias. There were few long-term radiographic follow-ups to evaluate whether clinical outcomes correlated with radiographic outcomes. Due to the transient patient population during the winter ski months, sampling bias may have been introduced, as only 27 patients were able to be contacted to complete the patient-reported-outcomes survey. However, of those patients who could be reached, the questionnaire response rate was 100%.

Despite its limitations, the current study has several strengths. Adequate preoperative imaging was available for all patients, and inter-observer reliability for fracture classification was greater than previously reported in the literature [26,27]. This study also included a mean of nearly 4 years of follow up, patient-reported outcomes, and activity levels. The

current study is also the first to correlate patient-reported outcomes in alpine skiers with tibial plateau fractures using the Schatzker classification.

5. Conclusions

Tibial plateau fractures sustained while alpine skiing occurred in older, experienced, male riders, and approximately 40% of the fractures corresponded to high-energy patterns. The inter-observer reliability of the Schatzker classification for the fractures sustained while alpine skiing was 95.7%. The all-cause reoperation rate was 26%, indicating that it is critical to council patients preoperatively about the potential need for future surgery. Although over 75% of the patients reported having no pain or occasional pain at their final follow-up, less than half of the patients returned to alpine skiing.

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Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Conflicts of Interest: The authors declare no conflict of interest.

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