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Contralateral ACL tears strongly contribute to high rates of secondary ACL injuries in professional ski racers

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Abstract

Purpose To analyse the effects of graft selection, sex, injury complexity and time to return to competition on the odds to suffer secondary ACL injury (either re-rupture or contralateral ACL tear) in professional alpine skiers.

Methods The database of a specialised joint surgery clinic was screened for professional alpine skiers who had participated in competitions at the FIS race, European Cup and World Cup level prior to having to undergo a primary ACL reconstruction, and who had returned to the same competitional level at least one year prior to the end of the observation period. The rates of secondary ACL injuries were statistically compared between athletes with hamstring and quadriceps tendon autografts, men and women, simple and complex (involvement of menisci or cartilage) primary ACL injuries, and between early (≤ 300 days after primary reconstruction) and late (> 300 days) returners to competition.

Results Fourteen out of the 30 athletes included (46.7%) suffered secondary ACL injuries on average 29.4 ± 22.5 months after primary reconstruction. The secondary injuries comprised five re-ruptures (16.7%) and nine contralateral ACL tears (30.0%). The odds to suffer contralateral ACL tears were non-significantly higher in patients with hamstring tendon autografts (OR 5.69, n.s.) and in those whose primary injuries were classified as simple ACL tears (OR 5.31, n.s.). None of the factors assessed was associated with the odds of graft failure.

Conclusion The odds of ACL-injured professional alpine ski racers to suffer secondary ACL tears are nearly 50%, with subsequent contralateral ACL injuries being more common than graft failures. While statistical significance could not be established due to a lack of power, greater odds of contralateral ACL tears were observed in athletes with hamstring tendon grafts as well as those with simple primary ACL injuries. No factors potentially predisposing athletes for graft failure could be identified.

Level of evidence III.

Keywords ACL · ACL reconstruction · Re-rupture · Contralateral injury · Secondary prevention · Return to sports · Athlete

Abbreviations

ACL	Anterior cruciate ligament
BPTB	Bone patellar tendon bone (autograft)
HT	Hamstring tendon (autograft)
QT	Quadriceps tendon (autograft

Introduction

Tears of the anterior cruciate ligament (ACL) represent one of the most common forms of injury in alpine ski racing [18]. Epidemiological data suggest that in high-level athletes, the injury incidence ranges between 5.4 and 8.5 tears per 100 skier seasons [4, 28]. In terms of time loss from sport, ACL tears have been identified as the most significant injuries in ski racers [36], also because they are frequently accompanied by other ligamentous, meniscal or chondral lesions [19]. Reconstruction of the ACL is considered the only viable approach to restore the joint stability required in ski racing, and most athletes succeed in returning to sports within the first 12 months after primary ACL surgery. Data acquired in members of the French and Austrian national

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skiing teams demonstrate that ACL repair does not preclude a successful career continuation [8, 14].

These encouraging results notwithstanding the odds to suffer either graft ruptures or ACL tears on the contralateral limb, are high, with the reported rates of athletes requiring secondary ACL reconstruction surgeries ranging between 19 and 30% [19, 28, 33]. Thus, ACL re-injury rates are substantially greater in skiers as compared to professional baseball, basketball or hockey players [26] and of similar dimension as those seen in American football [34], making alpine ski racing a high-risk athletic discipline. Considering that the prognosis of reconstruction is substantially poorer in revisions as compared to primary ACL surgery cases [16], further improvement of secondary prevention is of utmost importance. Towards this aim, it is essential to understand the factors predisposing athletes to suffer recurrent ACL injuries.

The aim of the present retrospective cohort study was to analyse the effects of graft selection, sex, injury complexity and time to return to competition on the odds to require secondary ACL surgery (either revision or reconstruction on the contralateral limb) in professional alpine skiers. For this purpose, all professional alpine ski racers, who had undergone primary ACL reconstruction in a specialised joint surgery clinic, were extracted from the clinic's patient database, and the frequencies of secondary ACL injuries were compared between subsets of patients created by the above factors. While the nature of this study was explorative, it was hypothesised that use of hamstring tendon grafts, complex primary injuries and earlier return to competition would be associated with higher rates of secondary ACL injury. This is the first study in professional ski racers testing the potential influences of subject-, injury- and treatment-specific factors on the odds of both revision and contralateral ACL surgeries.

Materials and methods

Data extraction

The study was approved by the ethical committee of the Medical University of Innsbruck (AN2015-0050346/4.28). Written informed consent was obtained from all participants. The database of a specialised joint surgery clinic was screened for professional alpine skiers who had participated in competitions at the FIS (Fédération International de Ski) race, European Cup and World Cup level prior to having to undergo a primary ACL reconstruction. All available data from professional ski racers meeting these criteria were included, so no a priori sample size calculation was performed. All primary reconstructions were performed by one of two experienced orthopaedic surgeons. To be included, athletes had to return to the same competitional level at least one year prior to the end of the observation period. The data extracted contained information about sex, age and anthropometric characteristics, the leg injured in the first and second injury, the date of the secondary injury and the time (in days) that had passed between the primary ACL reconstruction and the second injury. Moreover, injury- and surgery-specific information concerning the primary reconstruction was noted. This served to classify primary injuries as either simple or complex (involvement of medial or lateral meniscus or cartilage defects) ACL tears, and register the kind of graft used for reconstruction. To evaluate the influence of rehabilitation time, the FIS online database (https://www.fis-ski.com/DB/general/biographies.html) was searched for the dates at which the included athletes participated in their first competition after primary ACL reconstruction to calculate the time to return to competition. In patients who suffered more than two ACL injuries, only the secondary reconstructions were considered for statistical comparisons between groups.

Statistical analyses

For statistical comparisons of proportions of re-injured patients between subgroups created by graft type, sex and injury complexity, Fisher's exact tests were used and odds ratios (ORs) were reported as measure of effect size. To facilitate the calculation of OR in cases where cells of the respective contingency tables contained zero cases, the Haldane–Anscombe correction was applied [37]. To assess the potential influence of the time until return to competition on the odds of subsequent ACL injury, patients were divided into early (return to competition within 300 days or less) and late returners (after more than 300 days) for comparisons between groups. It must be noted that the odds to suffer secondary injuries may be affected by exposure time, i.e., the time between the dates of primary reconstruction and secondary ACL injury (the risk to suffer further injuries accumulates with increasing exposure time). Therefore, this time was calculated for all athletes, tested for normality by the Shapiro–Wilk test and then compared between groups (graft, sex, injury complexity, time to return to competition) using independent samples *t* tests. Since the respective comparison showed significant differences between patients treated with different grafts, comparisons between these groups were restricted to (1) patients with a minimum follow-up time of two years and (2) injuries occurring within two years after primary reconstruction. All statistical analyses were performed, and all graphs created using R version 3.6.1 (https://www.r-project.org).

Results

Primary ACL reconstructions were performed in 33 professional alpine skiers. Three women did not (or not yet) return to professional skiing—two suffered re-injuries prior to returning to competition and one ended her active career after ACL reconstruction. These athletes were excluded from further analyses. The data presented in this study are, therefore, based on a total of 30 pre-injured athletes, consisting of 13 men and 17 women (age and anthropometric characteristics are summarised in Table 1).

Sixteen (53.3%) of the 30 alpine skiers included into this study suffered no further ACL injuries until the end of the observation period, but the remaining 14 athletes (46.7%) required at least one secondary ACL reconstruction on the previously injured limb ($n=5$, 16.7%) or the contralateral leg ($n=9$, 30%). The total number of follow-up ACL surgeries (including tertiary and fourth reconstructions) performed in this sample was 21. In the 14 athletes affected, the secondary ACL injuries occurred on average 29.4 ± 22.5 months (2.5 ± 1.9 years) after primary reconstruction. The occurrence of secondary ACL injuries by kind and time is shown in Fig. 1.

Table 1 Subjects' age and anthropometric characteristics

	All ($n=30$, 100%)	Men ($n=13$, 43.3%)	Women ($n=17$, 56.7%)
Age (years)	21.6 ± 4.0	22.8 ± 4.6	20.7 ± 3.2
Height (m)	1.73 ± 0.09	1.82 ± 0.03	1.67 ± 0.05
Body mass (kg)	72.9 ± 11.8	85.2 ± 4.3	63.5 ± 4.5
BMI (kg/m^2)	24.1 ± 2.0	25.7 ± 1.0	20.7 ± 3.2

Graft type

Primary ACL reconstruction was performed with hamstring (semitendinosus/gracilis; HT) and quadriceps tendon (QT) autografts in 19 (63.3%) and 11 (36.7%) cases, respectively. However, since the statistical comparison of exposure time (i.e., the time between the dates of primary surgery and secondary ACL injury) showed significant differences between grafts (HT: 66.4 ± 24.6 months vs. QT: 33.8 ± 18.9 months; $t(28) = -3.77$, $p < 0.001$), only the 26 subjects (HT: $n=19$, QT: $n=7$) with a minimum follow-up time of two years were considered for comparison of the numbers of injuries occurring within the first two years after primary reconstruction. A total of three revisions and five ACL reconstructions on the contralateral limb were recorded in the two-year observation period. Although the odds to require ACL reconstruction on the primarily uninjured, contralateral limb was 5.7-fold greater in the HT group, differences between groups were not statistically significant (Table 2).

Sex

Between men ($n=13$) and women ($n=17$), no significant differences in exposure times were found (men: 57.5 ± 28.8 months vs. women: 52.0 ± 27.1 months; $t(28) = 0.53$, n.s.). The rates of revision and contralateral

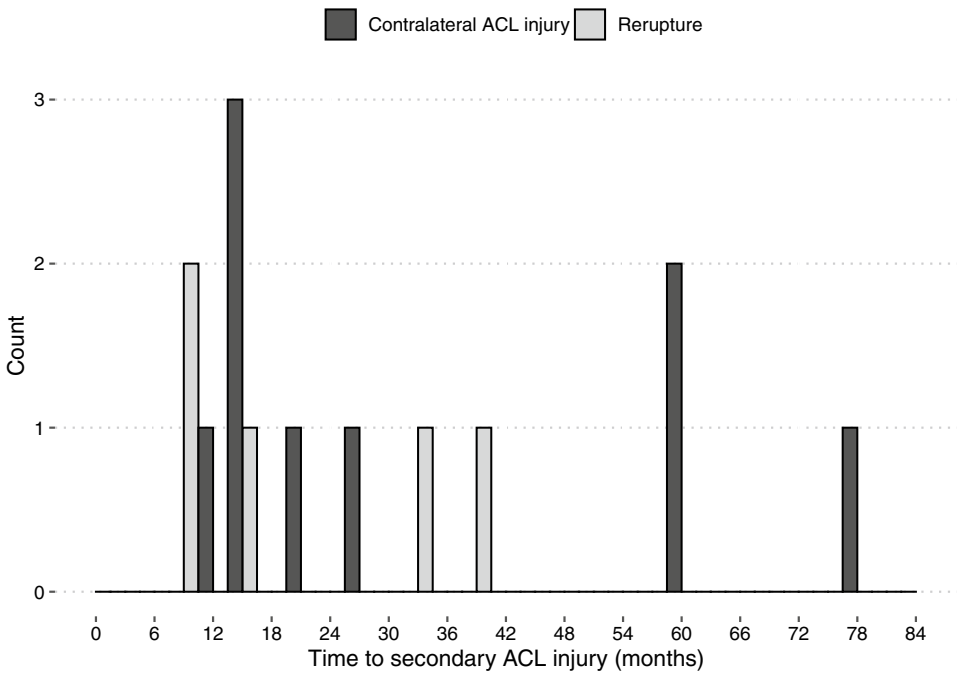

Fig. 1 Occurrence of secondary injuries to the anterior cruciate ligament (ACL) by kind and time after primary reconstruction

ACL surgeries were similar between men and women, which is reflected by non-significant differences between sexes. The counts of secondary ACL reconstructions by sex as well as the results of the respective statistical tests are shown in Table 3.

Injury complexity

No significant differences in exposure times were found between patients whose primary injuries were considered as simple ($n=9$, 58.8 ± 25.6 months) or complex ($n=21$, 52.5 ± 28.6 months; $t(28)=0.57$, n.s.). Similar rates of revision surgeries were observed in both groups of patients, but the odds to require ACL reconstruction on the contralateral limb were 5.3-fold greater in patients whose primary injury was classified as simple. This difference tended towards statistical significance. The rates of secondary ACL injuries by complexity of the primary injury including inferential statistics are summarised in Table 4.

Time to return to competition

Early returners ($n=11$) performed their first competition after 8.9 ± 0.7 months, on average. Late returners ($n=19$), by contrast, engaged in the first race 12.0 ± 2.8 months after primary ACL reconstruction. This difference was statistically significant ($t(28)=3.60$, $p=0.001$). The exposure times between primary reconstruction and secondary injury, by contrast, were not significantly different between groups (early returners: 53.5 ± 31.1 months vs. late returners: 55.0 ± 26.0 months; $t(28)=0.15$, n.s.). Neither the rates of revision surgeries nor ACL reconstructions on the contralateral limb were significantly different between early and late returners (Table 5).

Discussion

The main finding of the present study was that nearly 50% of professional alpine skiers with a primary ACL injury must expect a secondary ACL injury upon return to sports. Interestingly, a greater proportion of secondary injuries affected the contralateral limb. Potentially greater odds of secondary ACL injuries on the contralateral limb in patients with HT as compared to QT autografts (OR 5.7, n.s.) and those with simple as compared to complex primary ACL tears (OR 5.3, n.s.) warrant further investigations in larger samples. Sex and time to return to competition were not associated with the rates of secondary ACL injuries.

Table 2 Secondary ACL reconstructions by graft

	HT ($n=19$)	QT ($n=7$)	OR (CI_{95})	p value
All secondary ACL injuries	7 (36.8%)	1 (14.3%)	3.5 (0.4–35.4)	n.s
Revisions	2 (10.5%)	1 (14.3%)	0.7 (0.1–9.3)	n.s
Contralateral ACL surgeries	5 (26.3%)	0 (0.0%)	5.7 (0.3–117.3)	n.s

Only the reconstructions recorded within the first 2 years after primary reconstruction were considered to account for unequal exposure times of patients receiving different grafts. The odds ratios (OR) reflect the odds in patients with hamstring (HT) as compared to quadriceps tendon (QT) autografts

Table 3 Secondary ACL reconstructions by sex

	Men ($n=13$)	Women ($n=17$)	OR (CI_{95})	p value
All secondary ACL injuries	6 (46.2%)	8 (47.0%)	1.0 (0.2–4.1)	n.s
Revisions	2 (15.4%)	3 (17.6%)	0.9 (0.1–6.0)	n.s
Contralateral ACL surgeries	4 (30.8%)	5 (29.4%)	1.1 (0.2–5.1)	n.s

The odds ratios (OR) reflect the odds in men as compared to women

Table 4 Secondary ACL reconstructions by injury complexity

	Simple ($n=9$)	Complex ($n=21$)	OR (CI_{95})	p value
All secondary ACL injuries	6 (66.7%)	8 (38.0%)	3.3 (0.6–16.8)	n.s
Revisions	1 (11.1%)	4 (19.0%)	0.5 (0.1–5.6)	n.s
Contralateral ACL surgeries	5 (55.6%)	4 (19.0%)	5.3 (1.0–29.3)	n.s

Complex injuries were defined as ACL tears with concomitant involvement of menisci or cartilage. The odds ratios (OR) reflect the odds in patients whose primary injuries were considered simple as compared to those with complex ACL injuries

Table 5 Secondary ACL reconstructions by time to return to competition

	Early ($n=11$)	Late ($n=19$)	OR (CI_{95})	p value
All secondary ACL injuries	5 (45.5%)	9 (47.4%)	0.9 (0.2–4.1)	n.s
Revisions	2 (18.2%)	3 (15.8%)	1.2 (0.2–8.5)	n.s
Contralateral ACL surgeries	3 (27.3%)	6 (31.6%)	0.8 (0.2–4.2)	n.s

The odds ratios (OR) reflect the odds in patients who returned to competition early (≤ 300 days) as compared to late returners (> 300 days)

Secondary ACL reconstructions were performed in a total of 14 athletes (46.7%), with five (16.7%) and nine (30.0%) subjects requiring revision surgery or contralateral ACL reconstruction, respectively. These results closely match with those reported by Pujol et al. [28] (19.0% revisions and 30.5% contralateral surgeries) and confirm the notion that approximately one out of two ACL-reconstructed alpine ski racers must expect further ACL injuries [19, 28]. While no studies exist to directly compare the prevalence of primary and secondary ACL injuries in alpine ski racers (only older data acquired in recreational skiers are available [25]), these tremendously high re-injury rates suggest that pre-injured athletes are at substantially greater risk of future ACL tears than their non-injured peers. Recurrent ACL injuries are devastating experiences with the potential to end an athlete's career [29]. This is not only because the prognosis of ACL revisions in terms of clinical and patient-reported outcomes is much poorer than that of primary reconstructions [16], but also because of the often severe psychological consequences, which may, in turn, increase the likeliness of further ACL injuries [23]. Therefore, it is of utmost importance to identify the factors that predispose ski racers to secondary ACL injury.

Regarding the choice of graft, current data from the Norwegian Cruciate Ligament Registry compared the survival of HT to bone patellar tendon bone (BPTB) grafts in a cohort of more than 14,000 recreational alpine skiers, soccer and handball players [10]. Hazard ratios suggested that the risk of graft failure was two-fold greater in patients treated with HT grafts, which led the authors to propose that BPTB grafts should be preferred, especially in adolescent athletes younger than 18 years. More recently, a 2-year follow-up investigation of 1,432 level 1 athletes reported that young age (20.3 ± 5.1 years vs. 24.2 ± 7.2 years) and the use of HT tendon autograft (11.9% vs. 1.9% in BPTB, OR: 6.80) were the only two factors associated with an increased risk of ipsilateral ACL re-rupture [20]. Patients treated with a BPTB autograft had an 83% lower risk of re-injury (hazard ratio: 0.17) compared to those treated with an HT autograft. For lesions to the contralateral limb, young age was found to be the only factor related to increased risk of subsequent ACL injury. Concomitant medial or lateral meniscal injuries or cartilage lesions (> grade 3) resulted in significantly lower return-to-play rates [20]. Similar results, with a significantly higher ACL re-rupture rate in patients treated with HT (15%) compared to BPBT grafts (9%), were reported in a systematic review examining 1,239 patients younger than 20 years who returned to high-risk sport activities [2]. As opposed to these findings, a 10-year follow-up examination of 1,661 soccer players from the Swedish National Knee Ligament Registry showed no statistical difference in re-injury risk between BPTB (5.9%) and HT autografts (7.0%) [32].

In recent years, the use of QT has become increasingly popular for primary ACL reconstruction [3], however—in comparison to HT or BPTB grafts—little is known about re-rupture rates and functional outcomes, which particularly holds true in high-level athletes. In a randomised controlled trial of 99 adults, Lind et al. reported no differences between HT and QT in terms of functional outcomes and re-rupture rates [21]. Similar results were reported in non-randomised cohort studies [5, 31] and a recent systematic review comparing all three graft types [1]. When comparing secondary ACL injuries, no statistically significant differences were found between patients treated with QT and BPTB autografts, with rates ranging between 0 and 2.8% for QT and 1.4 and 5.5% for BPTB autografts [12, 13, 15, 22]. Subjective results were similar; however, the consequences of graft harvest were more severe with BPTB. The latter was associated with more kneeling pain and pain around the patellar defect. A large cohort study ($n=875$) performed by our group compared graft failure rates between QT and HT [30]. Our results showed that in highly active patients, the rates of graft failures may be two-fold greater in patients in whom reconstruction was performed with HT grafts, with the reported subjective outcomes of surgery being similar in both groups.

To the best of our knowledge, the present study is the first to compare HT and QT in a sample of professional athletes. Contradicting our hypothesis, comparable revision rates were found with both grafts (HT: 10.5% vs. QT: 14.3%). Interestingly, however, the odds of subsequent ACL surgery on the contralateral limb were nearly six-fold greater in the HT group, although our study was underpowered to establish statistical significance. The aetiology of contralateral ACL injuries in athletes is poorly understood [20, 35, 38] and the reasons for the possibly greater susceptibility in athletes with HT autografts are unclear. It may be speculated that altered neuromuscular control might play a role. To assess this, we

performed a study comparing the isokinetic knee extensor and flexor muscle strength between patients with HT and QT autografts [11]. This study showed that approximately six months after ACL reconstruction, the hamstring-to-quadriceps strength ratio was significantly higher in patients with QT autografts. More recently, a follow-up study in a sample of physically highly active patients was performed, in which the outcomes of a series of functional return-to-sports tests was also reported [9]. In confirmation of our earlier results, this study showed that, in comparison to healthy control subjects, maximal knee extensor strength deficits were greater in patients with QT, but knee flexor strength deficits greater in patients with HT grafts. Interestingly, however, no differences in the performance in more complex jump, speed or agility tasks included into our return-to-sports test series were found [9]. Further biomechanical and psychological studies investigating potential differences in movement quality and kinesiophobia between athletes with different ACL grafts are required.

Another interesting observation made in the present study was that patients whose primary ACL injuries were considered as complex, due to the involvement of menisci and/or cartilage, tended to be less rather than more susceptible to contralateral ACL injury. One possible explanation for this apparently counterintuitive finding is that patients with more complex primary injuries might take longer to return to sports. A later return might provide athletes with the time needed for the graft ligamentisation process to complete [7], and to fully restore muscular strength and neuromuscular control. This hypothesis, however, is challenged by our observation that the time to return to competition was not associated with the odds to suffer secondary ACL injuries, which conflicts with the notion that return to sport should be delayed until two years after primary reconstruction [24, 27]. It may be speculated that the severity of primary ACL injuries would affect the athletes' fear of re-injury [17], which in turn might impact their risk-taking behaviour [6] even after successful return to competition, but this notion warrants further research.

This study is subject to several limitations that warrant disclosure. First and foremost, the small sample size ($n = 30$) needs to be mentioned. Given the lack of statistically significant between-group differences in the ratios of re-injured athletes, the proposed influences of graft and injury complexity are speculative until confirmed by larger scale (prospective) studies. The limited sample size also precluded us from performing multi-factorial analyses (such as binary logistic regressions) that would allow for the joint analysis of potential risk factors. However, we would like to emphasise the specificity of the sample studied in this investigation. Scant data on the ACL re-injury risk in professional alpine skiers are available, and the fact that all primary reconstructions were performed in a single clinic by just two experienced surgeons ensures consistency of surgical procedures. Another potentially biasing factor may lie in different rehabilitation routines. While the immediate post-operative physiotherapy was performed in a single, specialised rehabilitation centre in most cases, the following strength and conditioning measures and skiing-specific training were decided on by the responsible coaches of the Austrian Skiing Federation and not controlled for in this study. Finally, the odds to suffer secondary ACL injuries naturally increase over time due to the accumulation of situations in which injuries may occur. While differences in exposure time between patients with HT and QT autografts were accounted for by considering only patients with a minimum follow-up time of two years and injuries occurring within this period, no significant differences in exposure time were found for the other subsets of athletes compared. For this reason, it was decided to include all secondary ACL injuries, irrespective of the time at which they occurred, into the respective statistical comparisons.

Conclusion

The results of this study in a sample of 30 professional alpine ski racers with primary ACL reconstruction showed that the overall odds to suffer secondary ACL tears are nearly 50%, with subsequent contralateral ACL injuries being more common than graft failures. This information must be clearly communicated to injured athletes and their trainers to facilitate well-informed decisions about the return to sports after primary ACL tear. While the statistical power was too low to establish statistically significant differences between groups, the results indicate that patients with simple primary ACL injuries and those in whom ACL reconstruction was performed with HT grafts may be at increased risk of re-injury as compared to patients with complex primary injuries and those with QT grafts. None of the factors assessed was associated with the odds of graft failure.

Author contributions RC analysed the data and drafted the manuscript. AR, CH and CF revised the manuscript. All authors approved the final version of the manuscript.

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Compliance with ethical standards

Conflict of interest All authors have no conflicts of interest to disclose.

Ethical approval The study was approved by the ethical committee of the Medical University of Innsbruck (AN2015-0050346/4.28).

Informed consent Written informed consent was obtained from all participants.

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