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Identifying candidates for arthroscopic primary repair of the anterior cruciate ligament: A case-control study

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ABSTRACT

Introduction: There has been a recent resurgence of interest in arthroscopic primary repair of proximal anterior cruciate ligament (ACL) tears. Patient selection is critical but not much is currently known on what predicts the possibility of repair. Goal of this study was therefore to assess predictive factors for the possibility of arthroscopic primary ACL repair.
Methods: In this retrospective case–control study, all patients undergoing ACL surgery in a ten-year interval were included. Patients were treated with primary repair if there was a proximal tear and good tissue quality, or otherwise underwent ACL reconstruction. Collected data were age, gender, BMI, injury-to-surgery delay, injury mechanism and concomitant injuries. Receiver operating characteristic curves were used to find cutoff values, and all significant dependent variables were used in multivariate logistic analysis to assess independent predictors for the possibility of primary repair.
Results: Three hundred sixty-one patients were included, of which in 158 patients (44%) primary repair was possible. Multivariate analysis ($R^2 = 0.340$, $p < 0.001$) showed that age > 35 years (Odds ratio [OR] 4.2, 95% CI 2.4–7.5,$p < 0.001$), surgery within 28 days (OR 3.3, 95% CI 1.9–5.7, $p < 0.001$), and BMI <26 (OR 1.9, 95% CI 1.1–3.3,$p = 0.029$) were predictive for the possibility of primary repair, and lateral meniscus injury presence decreased the likelihood of repair (OR 0.5, 95% CI 0.3–0.8, $p = 0.008$).
Conclusion: In this large cohort study, it was noted that 44% of patients had repairable ACL tears. Primary repair was more likely to be possible in older patients, patients with lower BMI and when surgery was performed within four weeks of injury.

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1. Introduction

Over the last decade, there has been a resurgence of interest in arthroscopic primary repair of the anterior cruciate ligament (ACL) [1–6]. The concept of primary repair is not new and this technique was commonly performed in the 1970s and 1980s using an open approach and the short-term outcomes were promising [7–13]. After several authors noticed a deterioration of outcomes at mid-term follow-up [14–19], the technique was abandoned and ACL reconstruction became the gold standard for ACL injuries in younger and active patients, which it still is today [20].

Although the outcomes of ACL reconstruction are nowadays generally good with low graft rupture rates and satisfying functional outcomes in most patients [21–24], ACL reconstruction also has disadvantages. These include significant donor site morbidity [21–24], loss of the native ligament along with its proprioception [25], disappointing return to sports rate [26,27] and not preventing osteoarthritis [28–30]. Furthermore, high failure rates and reoperation rates have been reported in younger patients [31–33] and revision surgery is often complicated and has inferior outcomes [34–36]. These disadvantages have led to the search for other surgical options for ACL tears including primary repair [1,37,38].

Recently, it has been suggested that the primary repair concept may historically have been prematurely abandoned for all patients as there is a subgroup of patients (i.e. with proximal tears) that have good outcomes of repair in both the historical [19,20,39,40] and modern literature [1–6,41]. This can explained by the fact that there is better vascularity in the proximal part of the ligament [42] and thus good healing potential of these proximal tears [43], while the vascularity of midsubstance tears is inferior and healing will not occur in these tear types [44,45]. Potential advantages of primary repair are less invasive surgery with shorter operation time [46] and earlier regain of range of motion (ROM) than reconstruction [46], and experimental studies that have suggested that primary repair may decrease the risk of osteoarthritis when compared to ACL reconstruction [47,48]. Furthermore, no bridges are burned for reconstruction surgery in case primary repair fails. Potential disadvantages of primary repair are failure rates that may be higher than ACL reconstruction – basing on the historical data of all tear types [39] – and subsequent meniscal and chondral injuries that may occur with rerupture.

With this renewed interest, the indications of primary repair have been narrowed when compared to the historical literature: these are proximal tears (that can be reattached to the femoral insertion) and good tissue quality (that is most commonly seen in the (sub)acute phase of weeks after injury). With these new indications, several cohort studies have reported excellent outcomes of arthroscopic primary repair of proximal tears [1–6,49–51]. No studies, however, have yet assessed which patient or injury characteristics are associated with the possibility of primary repair. The goal of this study was therefore to assess which patients and injury characteristics are predictive of a repairable proximal tear. The hypothesis was that older age, skiing injury and early surgery would be predictive for the possibility of performing primary repair.

2. Materials and methods

2.1. Study design

Institutional review board approval was obtained for this retrospective case–control study. All consecutive patients that underwent surgical treatment for an ACL injury in a 10-year period (between April 1st 2008 and March 31st 2018) by the senior author (GSD) were included in this study (n = 406). Exclusion criteria consisted of true knee dislocations (n = 41), patients with partial ACL tears (n = 1) and with concomitant high tibial osteotomy (n = 2). Patients with knee dislocations were excluded but not patients with other concomitant ligamentous injuries outside the setting of knee dislocations, such as a patient with an ACL-MCL injury. All patients had an MRI confirmed ACL tear and underwent the following surgical treatment algorithm: intraoperatively it was decided that they would undergo arthroscopic primary ACL repair if (I) a proximal tear was present of which the distal portion was long enough for reattachment to the femoral footprint and (II) tissue quality was good enough for passage and withholding of sutures (Figure 1A and B), and if either of these conditions were not present, patients would undergo standard ACL reconstruction using bone-patellar tendon-bone, hamstring or allograft tissue (Figure 1C and D). The case–control study was designed to understand the patient and injury characteristics that were predictive of the ultimate treatment (repair or reconstruction).

2.2. Surgical technique

The patient is placed in supine position and the operative leg is prepped and draped for knee arthroscopy. Standard anteromedial and anterolateral portals are created and a general inspection of the knee joint is performed. Then, a probe is used to assess the location of the tear and, if needed, a grasper is used to tension the distal remnant of the ACL proximally to assess if the remnant is long enough for reattachment to the femoral wall. If the remnant is deemed eligible for primary repair, sutures are passed through the ligament and the distal remnant is reinserted into the femoral wall as previously described [52–54]. If the ligament is not deemed eligible for primary repair, standard anatomic ACL reconstruction is performed. This was performed using an anteromedial portal drilling technique.

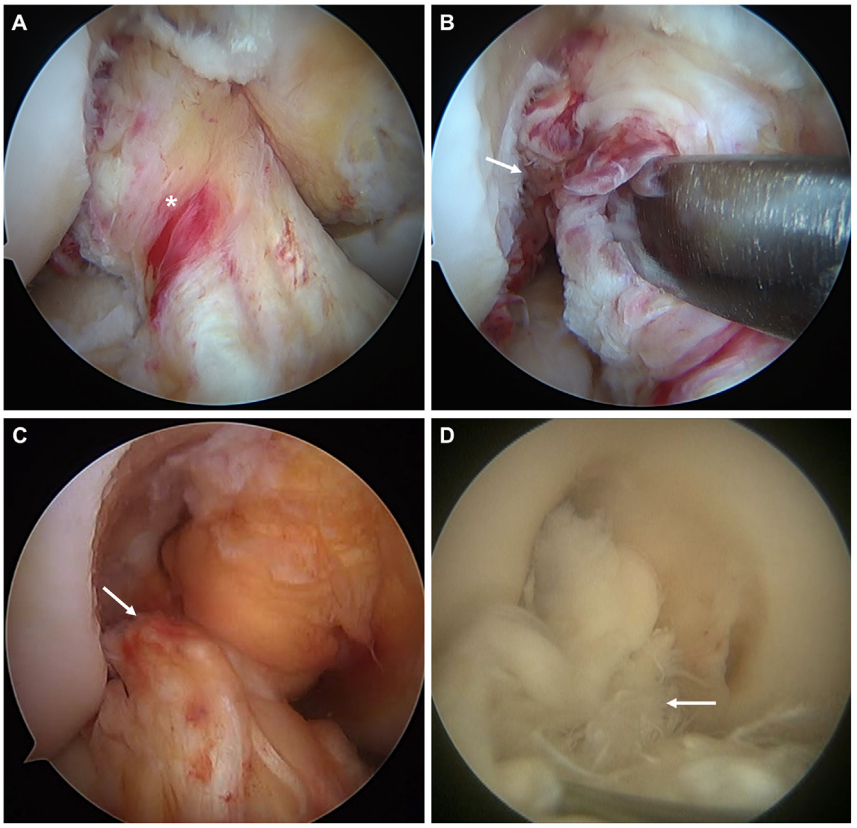

Figure 1. A and B show an ACL tear with excellent tissue quality (asterisk in A) and a proximal avulsion tear that is long enough to reach the femoral wall with reattachment (arrow in B). C shows an ACL tear that is not of sufficient length to reach the femoral wall (arrow). D shows an ACL tear with poor tissue quality that will not withhold sutures (arrow).

2.3. Data collection

It was registered if patients ultimately underwent primary repair or reconstruction. Patient characteristics collected included age, gender, BMI, time from injury to surgery, and mechanism of injury (type of sport at injury and contact vs. non-contact). Injury characteristics included concomitant injury of the posterior cruciate ligament (PCL), medial collateral ligament (MCL), posteromedial corner (PMC), lateral collateral ligament (LCL), posterolateral corner (PLC), medial meniscus injury, lateral meniscus injury, and chondral injury in the medial tibiofemoral joint (MTFJ), lateral tibiofemoral joint (LTFJ) and patellofemoral joint. Only complete (grade 3) injuries of the ligaments were considered ligament tears for statistical analyses.

2.4. Statistical analysis

Statistical analysis was performed using SPSS version 25.0 (IBM Software, Armonk, NY, USA). For continuous variables, Shapiro–Wilk tests were performed to assess normal distribution and no normal distribution was found for all parameters. Baseline characteristics were therefore reported in median with range for continuous variables and number with percentage for nominal variables. Receiver operating characteristic (ROC) curves were first used to find the cutoff values of the continuous variables (age, BMI and delay from injury to surgery). Then, variables between the two groups (repair and reconstruction) were compared using Mann–Whitney U test and using two-by-two tables with Pearson's Chi-square test (in case all cells were > 5) or Fisher's exact test (in case one of the cells were < 5). All significant dependent variables of these analyses were then used in a multivariate binary logistic regression analysis to assess independent predictors for primary repair, because only a limited number of variables can be used for multivariate analysis and only the potentially relevant (or statistically significant) factors were of interest. The year of surgery was also used as a variable to correct for experience and assess the learning curve effect of primary repair, as this cohort included the first 10 years of experience with arthroscopic primary repair for the senior author. All tests were two-sided and a p-value of <0.05 was considered statistically significant.

Table 1
Baseline characteristics of the entire cohort.

Variables	All patients (n = 361)
Male gender (N (%))	216 (60%)
Age (years) (median; range)	28 (13–64)
BMI (kg/m^2) (median; range))	25 (17–47)
Delay (days) (median; range))	47 (3d– 15y)
Injury mechanism (N (%))	
Basketball	47 (13%)
Football/Rugby	40 (11%)
Skiing	57 (16%)
Soccer	82 (23%)
Other	135 (37%)
Non-contact injury (N (%))	294 (85%)
Any concomitant injuries (N (%))	34 (9%)
PCL injury	0 (0%)
MCL/PMC injury	27 (7%)
LCL/PLC injury	5 (1%)
ALL injury	4 (1%)
Any meniscus injury	205 (57%)
Medial meniscus injury	102 (28%)
Lateral meniscus injury	156 (43%)
Any chondral damage	71 (20%)
Medial TF joint damage	38 (11%)
Lateral TF joint damage	16 (4%)
PF joint damage	29 (8%)

BMI missing in 18 patients; contact/non-contact information missing in 14 patients. N indicates number; SD, standard deviation; BMI, body mass index; PCL, posterior cruciate ligament; MCL/PMC, medial collateral ligament/posteromedial corner; LCL/PLC, lateral collateral ligament/posterolateral corner; ALL, anterolateral ligament; TF, tibiofemoral; PF, patellofemoral.

3. Results

3.1. Baseline characteristics

A total of 361 consecutive patients were included in this study with a median age of 28 years (range 13–64 years) and median BMI of 25 kg/m^2 (range 18–35 kg/m^2), of which 59.8% were males. Median delay from injury to surgery was 47 days (range three days–15 years). Most common injury was during soccer (23%), skiing (16%), basketball (13%) and football/rugby (11%), and most injuries were non-contact injuries (85%). Injury to the MCL/PMC was the most common concomitant ligamentous injury (7%). A total of 205 patients (57%) had meniscus injury: 28% had medial meniscus injury and 43% had lateral meniscus injury. Seventy-one patients (20%) had chondral damage. All baseline characteristics are displayed in Table 1. BMI was missing in 18 patients and data on contact vs. non-contact injury was missing in 14 patients.

3.2. Univariate analysis

ROC curves revealed significant thresholds for age (35 years), BMI (26 kg/m^2) and delay from injury to surgery (28 days), as is shown in Table 2. It was noted that a total of 158 patients (44%) had proximal tears that were eligible for primary repair and ultimately underwent arthroscopic primary ACL repair. The other 203 patients underwent ACL reconstruction of which 104 patients (57%) underwent autograft reconstruction (60 patients (30%) hamstring and 54 patients (27%) bone-patellar tendon-bone), 86 patients (42%) soft tissue allograft reconstruction and three patients (one percent) hybrid grafts.

Patients that had repairable tears repair were more often females (47% vs. 35%, $p = 0.023$), older (35 vs. 26 years, $p < 0.001$), lower BMI (24 vs. 26 kg/m^2, $p = 0.029$) and were more often operated within 4 weeks after injury (46% vs. 18%, $p < 0.001$) than patients that did not have repairable tears and ultimately underwent ACL reconstruction. Patients with repairable tears more often

Table 2
ROC curves of determining threshold for eligibility for primary ACL repair.

Variable	Threshold	AUC (95% CI LB – UB)	SE	p-Value	Sensitivity	Specificity
Age	35 years	0.654 (0.596–0.712)	0.030	<0.001	0.665	0.571
BMI	26 kg/m^2	0.569 (0.508–0.629)	0.031	0.029	0.759	0.270
Delay	28 days	0.655 (0.598–0.713)	0.029	<0.001	0.823	0.462

ROC indicates Receiver Operating Curves; BMI, body mass index; AUC, area under the curve; 95% CI LB–UB, 95% confidence interval lower bound–upper bound; SE, standard error.

Table 3
Univariate analysis of variables predicting eligibility for primary ACL repair.

Variables	Primary repair (n = 158)	Reconstruction (n = 203)	p-Value[a]
Male gender	84 (53%)	132 (65%)	**0.023**
Age (years; median (range))	35 (14–60)	26 (13–64)	<**0.001**
≤25 years	64 (41%)	136 (67%)	
25–35 years	16 (10%)	28 (14%)	<**0.001**
≥35 years	78 (49%)	39 (19%)	
BMI (kg/m^2; median (range))	24.4 (18–35)	25.7 (17–47)	**0.029**
≤26 kg/m^2	113 (72%)	104 (56%)	**0.003**
Delay (days; median (range))	32 (3–5499)	66 (4–4865)	<**0.001**
≤28 days	73 (46%)	36 (18%)	<**0.001**
Injury mechanism	30 (19%)	52 (26%)	0.136
Soccer	30 (19%)	52 (26%)	0.136
Skiing	36 (23%)	21 (10%)	**0.001**
Basketball	16 (10%)	31 (15%)	0.150
Football/rugby	10 (6%)	30 (15%)	**0.011**
Injury type (non-contact)	130 (82%)	164 (84%)	0.715
Concomitant injuries	18 (11%)	16 (8%)	0.257
PCL	0 (0%)	0 (0%)	–
MCL/PMC	15 (9%)	12 (6%)	0.864
LCL/PLC	2 (1%)	3 (1%)	>0.999
ALL	3 (2%)	1 (0%)	0.448
Any Meniscus injury	74 (47%)	131 (65%)	**0.001**
Medial Meniscus injury	38 (24%)	64 (32%)	0.118
Lateral Meniscus injury	55 (35%)	101 (50%)	**0.004**
Any Chondral damage	34 (22%)	37 (18%)	0.435
Medial TF joint	18 (11%)	20 (10%)	0.636
Lateral TF joint	6 (4%)	10 (5%)	0.605
PF joint	16 (10%)	13 (6%)	0.197

BMI indicates body mass index; MCL/PMC, medial collateral ligament/posteromedial corner; LCL/PLC, lateral collateral ligament/posterolateral corner; ALL, anterolateral ligament; MTFJ, medial tibiofemoral joint; LTFJ, lateral tibiofemoral joint; PF, patellofemoral, LB–UB 95% CI, lower bound–upper bound 95% confidence interval.
Signficant differences are displayed in bold.
[a] For continuous variables, Mann–Whitney U test is performed, while for nominal variables Chi-square tests of Fishers's exact tests were used.

suffered skiing injuries (23% vs. 10%, p = 0.001), less often football/rugby injuries (six percent vs. 15%, p = 0.011) than patients that underwent reconstruction, while no difference in non-contact injury was seen (p = 0.715). Patients with repairable tears had less often meniscus injuries (47% vs. 65%, p = 0.001) and lateral meniscus tears (35% vs. 50%, p = 0.004). No differences in

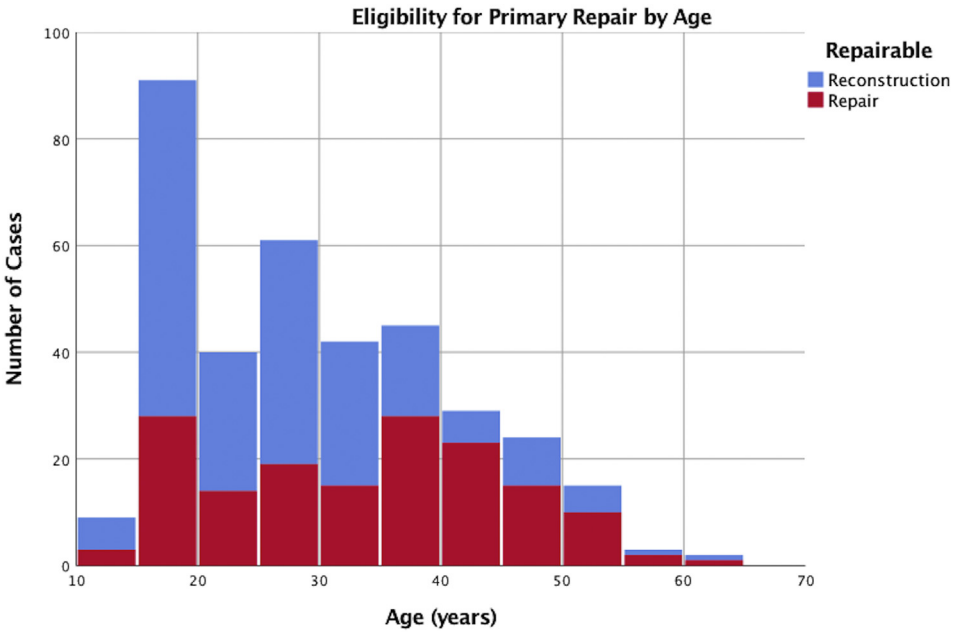

Figure 2. Histogram showing the number of primary repair and reconstruction cases per age.

Table 4
Multivariate binary logistic analysis of variables predicting eligibility for primary ACL repair.

Variables	Variables (0 vs. 1)	OR (LB – UB 95% CI)	p-Value
Age (years)	<35 vs. ≥35	**4.2 (2.4–7.5)**	<**0.001**
Delay (days)	>28 vs. ≤28	**3.3 (1.9–5.7)**	<**0.001**
Lateral meniscus injury	No vs. yes	**0.5 (0.3–0.8)**	**0.008**
BMI (kg/m^2)	>26 vs. ≤26	**1.9 (1.1–3.3)**	**0.029**
Learning curve	Per year experience	**1.4 (1.2–1.6)**	<**0.001**
Gender	Male vs. female	0.8 (0.4–1.3)	0.340
Skiing	No vs. yes	1.3 (0.6–2.7)	0.491
Football/rugby	No vs. yes	1.2 (0.5–2.8)	0.734

BMI indicates body mass index; OR, odds ratio; LB–UB 95% CI, lower bound–upper bound 95% confidence interval.
$R^2 = 0.340$, $p < 0.001$.
Signficant differences are displayed in bold.

chondral damage between both cohorts were found. All univariate analyses are shown in Table 3. A distribution of the repair and reconstruction cases per age are displayed in Figure 2.

3.3. Multivariate analysis

All significant factors from univariate analysis were used for multivariate binary logistic regression analysis to find predictors for the possibility of primary ACL repair ($R^2 = 0.340$, $p < 0.001$). Patients were more likely to undergo primary repair if surgery was performed within four weeks of injury (OR 3.3, $p < 0.001$), if they were older than 35 years compared to younger than 35 years (OR 4.2, $p < 0.001$) and if BMI was under 26 kg/m^2 (OR 1.9, $p = 0.029$). Patients were less likely to undergo primary repair if a lateral meniscus tear was present (OR 0.5, $p = 0.008$). Furthermore, per year of surgical experience patients were 1.4 times more likely to undergo primary repair. Finally, skiing injury, football injury and gender were no predictors for the possibility of primary repair (Table 4).

4. Discussion

The goal of this retrospective case–control study was to assess predictive factors of the eligibility of arthroscopic primary repair of proximal ACL tears. In this cohort, 43.8% of all tears were found to have proximal tears with sufficient tissue quality that were eligible for primary ACL repair and were repaired. Multivariate regression analysis showed that patients older than 35 years and patients with a BMI under 26 had a higher chance of undergoing repair, and that operation within four weeks of injury was independently correlated with a higher likelihood of repair.

In this cohort of patients with a mean age of 28 years, it was noted that 44% of patients had tears that were eligible for primary repair (i.e. they had a proximal tear with sufficient length for reattachment and sufficient tissue quality to withhold sutures). This percentage seems high when comparing these findings with studies reporting the incidence of repairable proximal ACL tears ranging from 7.6 to 11.4% [1,2,4,51]. However, these studies have all reported the incidence of repairable tears at the start of their surgical treatment. Similar to the current cohort of the senior author, there has been a significant learning curve (OR 1.4 per year of experience, equivalent to an OR of 28.9 over 10 years of experience) which can explain these differences. In the early years of this current cohort, approximately 8% of ACL tears were repaired by the senior author while this was approximately 40–50% in the latest years. Recent studies have shown that approximately 43% of all acute ACL tears are located in the proximal quarter on MRI [55,56] and that most of these tears are ultimately repairable intraoperatively [57], but it is likely that the surgical experience of the senior author has resulted in a higher percentage of repairable tears at the end of the study period.

One of the significant predictors for eligibility for primary repair was older age, and specifically above 35 years of age. When reviewing the literature, similar findings can be noted in various studies on this topic. In their aforementioned ACL tear location study, Van der List et al. similarly noted that patients above 35 years of age had a significant higher incidence of proximal avulsion type tears on MRI (23%) when compared to patients under 35 years of age (eight percent) [55]. Furthermore, several clinical studies reported mean age of primary repair patients to be ranging from 32 to 43 years of age [2–4], which is higher than the average age in ACL reconstruction patients [26]. These studies show that there is a higher likelihood of proximal tears in older patients, and that there is also a higher likelihood of primary repair of these proximal tears in older patients. This can be valuable information, as ACL reconstruction can be an invasive procedure in these (often) lower demand patients and has a high risk of osteoarthritis in these older patients [28,29,58].

Data in this study also showed a significantly higher likelihood of primary repair if surgery was performed within four weeks of injury (OR 3.3). Historical studies have shown that long delay between injury and surgery can cause retraction and scarring of the ligament, which can lead to suboptimal tissue quality and insufficient tissue length for reattachment to the femoral wall [59–62]. Although several studies have advocated for early repair and have given general recommendations, such as performing repair within a few weeks of surgery, this is (to our knowledge) the first study assessing a cutoff value for the likelihood for primary repair. Generally, it is believed that performed ACL surgery within few weeks would increase the risk of arthrofibrosis, but recent studies have shown that the risk of arthrofibrosis is low in acute surgery if patients have good range of motion

preoperatively [63–65], and some studies have even suggested that the outcomes of acute reconstruction are better than delayed reconstruction [64]. Based on these findings, we recommend performed ACL surgery within one and four weeks following injury in order to have the highest likelihood of primary repair while decreasing the risk of stiffness (by not performing surgery in the first week and only when full ROM is present) in case primary repair was not possible.

It was noted in this study that there was an increased likelihood of primary repair in patients with BMI <26 when compared to patients with higher BMI. It is currently unclear why patients with lower BMI had more proximal tears in this study, and when reviewing the literature on primary repair and repair with dynamic intraligamentary stabilization, nothing is mentioned on the role of BMI on the eligibility of primary repair. Future prospective will be needed to clarify why patients with lower BMI have more proximal tears and/or better tissue quality.

It should also be mentioned that the range of delay in the repair group was three days to 15 years, which is interesting at it is generally recommended to perform primary early to prevent retraction and scarring of the ligament. Some authors have reported that 14–73% of patients with chronic tears (>3–6 months delay) had a reattachment of the ACL to the PCL [66–69]. With this reattachment, the length and tissue quality of the ACL are preserved, and in these chronic cases, the ACL can be dissected off the PCL and can be repaired [70]. Although these chronic cases were rare (median delay of repair from injury to surgery was 1 month), this shows that primary repair is possible in these chronic cases.

It was hypothesized that a higher likelihood of primary repair would be noted in patients with skiing injury when compared to high-energy football or rugby injuries. This was based on the many historical studies reporting on proximal tears in skiing injury mechanism [19,71–74], and one study showing that the incidence of proximal tears in skiing population was 80% [75] while the estimated incidence of proximal tears is 42% in the general population in a recent MRI study [55]. The multivariate analyses in this current study did not find any role of sports injury mechanism on the likelihood of repairable proximal tears. Furthermore, no significant correlation between contact vs. non-contact injury and the possibility for primary repair were noted in this study, and therefore this hypothesis was rejected. It might be possible that the observation of higher likelihood of primary repair in skiers was confounded by the fact that these patients often have a higher age (and perhaps lower BMI) when compared to football/rugby patients, which was indeed shown in the multivariate regression analysis. No data could be collected on the mechanism of injury (e.g. hyperextension injury, valgus injury etc.) and it would be interesting to assess the role of the mechanism of injury on the tear location and eligibility of primary repair in future studies. A different injury mechanism might perhaps also explain the lower incidence of lateral meniscus tears in the repair group.

Limitations were present in this study. First of all, this is a single surgeon case series who is experienced in ACL preservation surgery and future studies are needed to assess the external validation of these findings. Secondly, this is a retrospective study and the exact cause of delay from injury to surgery was not known, and a potential selection bias could therefore be present in this cohort with patients with proximal tears potentially undergoing surgery earlier than reconstruction surgery. However, since the senior author always attempted to repair the ligament regardless of delay, patient age or suggested tear location on MRI, the regression analysis is in our opinion still representative. Thirdly, there is a risk for selection bias in this study as some patients come to the clinic of the senior author for primary ACL repair, and it is possible that people with proximal tears are more often referred to the clinic than patients with midsubstance tears, and this might have influenced the incidence of repairable tears. Fourthly, and perhaps most importantly, only the eligibility for repair and no correlation with outcomes were assessed in this study, and no correlation has been made with failure rates or functional outcomes. Future studies are needed to assess the correlation between age, BMI, delay and other variables with the failure rates and functional outcomes of primary repair.

5. Conclusion

This retrospective case–control study of 361 patients showed that 44% of all patients were intra-operatively deemed eligible for and underwent arthroscopic primary ACL repair. Independent predictors for the possibility of primary ACL repair were age above 35 years, BMI under 26, while presence of a lateral meniscus tear decreased the likelihood of repair. Furthermore, patients had a higher likelihood of primary repair if surgery was performed within four weeks of injury, and a significant learning curve for the eligibility of primary repair was noted. Future studies are needed to correlate these predictors with the outcomes of arthroscopic primary repair of proximal ACL tears.

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Conflict of interest

Jelle P. van der List and Gregory S. DiFelice declare that they are a paid consultant for Arthrex (Naples, FL, USA), and Gregory S. DiFelice declares that he receives research grants from Arthrex (Naples, FL, USA).

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