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Review

Role of tear location on outcomes of open primary repair of the anterior cruciate ligament: A systematic review of historical studies

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ABSTRACT

Background: The general opinion is that outcomes of open primary repair of the anterior cruciate ligament (ACL) in the historical literature were disappointing. Since good outcomes of primary repair of proximal tears have recently been reported, we aimed to assess the role of tear location on open primary repair outcomes in the historical literature.

Methods: All studies reporting outcomes of open primary ACL repair published between the inception of PubMed, Embase and Cochrane and 2000 were identified. Studies were included if tear location was reported. Outcome scores, return to sports, stability examinations, failures and patient satisfaction were collected and reviewed in the total study cohort and in a subgroup of studies treating only proximal tears. Spearman correlation analysis was performed between the percentage of proximal tears in the studies and all outcomes.

Results: Twenty-nine studies were included reporting outcomes of open primary in 1457 patients of which 72% had proximal and 23% midsubstance tears. Mean age was 30 years, 65% were males, and mean follow-up was 3.6 years. Good outcomes were noted in the total cohort, and excellent outcomes were noted following repair of proximal tears. Positive correlation was found between the percentage proximal tears in the studies and percentage satisfied patients ($p = 0.010$).

Conclusion: Tear location seems to have played a role on the outcomes of open primary ACL repair. Outcomes of open primary repair in patients with proximal tears were excellent, which confirms there may be a potential role for primary repair as treatment for proximal ACL tears.

Contents

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1. Introduction

The first documented treatment of an anterior cruciate ligament (ACL) injury took place in 1895 using primary repair when Mayo Robson repaired both cruciate ligaments in a 41-year-old male using catgut ligatures after they were torn off the femoral wall [1]. Over the following decades, Ivar Palmer [2] and Don O'Donoghue [3] further popularized primary ACL repair as a treatment for ACL injuries. Preservation of the ligament via primary ACL repair was the most common treatment for ACL injuries throughout the early 1990s [4–9].

Open primary repair outcomes were initially good at short-term follow-up [4,5]. Feagin and Curl were the first to notice that outcomes deteriorated at mid-term follow-up with their technique using figure-of-eight absorbable sutures and tying these over the iliotibial band [10]. A few years later, Marshall et al. used multiple looped non-absorbable sutures and tied them directly over the femoral condyle [6,7], but despite these improvements and excellent short-term outcomes [11], their outcomes also deteriorated at mid-term follow-up [12]. They concluded, that, "*although … primary repair of the ACL may work in some patients, it is an unpredictable operative procedure and resulted in a 17% failure rate.*" [12] Several other studies echoed these findings of deterioration at longer follow-up [13,14].

In 1991, Sherman et al. sought to find an explanation for both the unpredictable outcomes and the deterioration at mid-term follow-up by performing an exhaustive subgroup analysis [14]. They noted patients with proximal tears and excellent tissue quality were associated with better outcomes than patients with mid-substance tears and poor tissue quality. This was similar to the observations of others who suggested a role of tear location on the outcomes of primary ACL repair [9,15–17]. Unfortunately, this discovery was made relatively late in the evolution of this procedure and primary ACL repair was already abandoned as ACL reconstruction had become the gold standard for the treatment of ACL injuries.

These observations raise the question if the tear location could indeed be an explanation for both the unpredictable outcomes and the deterioration at mid-term follow-up. This is especially of interest since several studies recently reported excellent outcomes of arthroscopic primary repair of proximal ACL tears [18–21]. To the best of our knowledge, no systematic review or meta-analysis has assessed the role of tear location on outcomes of primary ACL repair. A systematic search of studies reporting outcomes of open primary repair was therefore performed with the goal to assess the role of tear location on the historical outcomes of open primary ACL repair. We hypothesized that better outcomes were reported in studies performing primary ACL repair of proximal tears when compared to studies performing primary repair of all tear types.

2. Methods

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed when performing this study.

2.1. Literature search

A systematic search in the electronic search engines PubMed, Embase and Cochrane Library was performed for historical studies on open primary ACL repair. Following a preliminary search, the search algorithm "(ACL OR anterior cruciate ligament) AND (repair OR reinsertion OR suture)" was used on September 15, 2016. The search was limited for studies published before 2000 since the goal was to assess historical outcomes of open primary repair, and since a recent systematic review showed that no new studies of open primary repair have been performed in the twenty-first century [22]. The search was not limited to English studies since the preliminary search revealed several eligible non-English studies. After removing duplicates, two authors (JPL and GSD) reviewed all studies based on title and abstract. Eligible studies were then scanned for full-text on inclusion and exclusion criteria. References of full-text scanned articles were reviewed for other possibly eligible studies. Agreement was reached on inclusion and exclusion of all studies.

Inclusion criteria consisted of studies that (I) reported outcomes of open primary repair, (II) reported tear location, (III) and were minimum level IV studies. Exclusion criteria consisted of studies that (I) used intra-articular or extra-articular augmentation, (II) did not report tear location, (III) reported bony avulsion tears, and (IV) were review articles, abstracts, or podium presentations.

2.2. Quality of studies

Level of evidence of included studies was determined using the adjusted Oxford Centre for Evidence-Based Medicine 2011 Levels of Evidence. The Methodological Index for NonRandomized Studies (MINORS) criteria were used to assess the methodological quality of studies [23]. Different languages, countries where studies were performed and terms that studies used to define primary repair were assessed.

2.3. Data extraction

Collected baseline characteristics included author names, year of publication, number of knees available at follow-up, length of follow-up, age at surgery and gender. Tear location was in all included studies quantified as upper one-third tears, mid-substance tears and lower one-third tears. Bony avulsions were excluded from analysis. Collected outcome scores included Lysholm scores, percentage of patients with good or excellent Lysholm scores (i.e., >84 points of Lysholm score), mean Tegner scores, return to sport defined as return to previous level, percentage of patients with <3 mm leg difference with the contralateral leg using KT-1000, percentage of patients with negative pivot shift, percentage of patients with grade 0/1 Lachman test and anterior drawer test, percentage of patients that were considered to have a failed primary repair or were revised and percentage of patients that were satisfied with their primary repair or scored good/excellent on patient satisfaction questionnaires. All data was collected in Excel 2011 (Microsoft Corp., Redmond, WA, USA) and weighted percentages were calculated (e.g., total patients return to sports / total patients × 100%). Outcomes were reported in percentages, or mean ± standard deviation (range, minimum–maximum).

Because no studies (statistically) compared outcomes of open primary repair based on the tear locations (as it was generally not known that tear location potentially played a role), the outcomes could not be separately reported in groups of proximal, midsubstance and distal tears. Therefore, no meta-analysis could be performed using Forest plots. Studies were therefore reviewed, and the mean or cumulative outcomes of all studies were reported. In addition, outcomes of studies that treated only proximal tears were separately reviewed to evaluate the hypothesis of better outcomes in studies treating only proximal tears.

2.4. Statistical analysis

Statistical analysis was performed using SPSS Statistics 21.0 (SPSS Inc., Armonk, NY, USA). To describe the outcomes of studies, continuous variables were reported using mean ± standard deviation (range), and categorical data were reported in percentages. Two-sided Spearman correlation analysis was performed to assess correlations between percentage of proximal tears in the individual studies and the percentage of patients fulfilling the categorical data in the individual studies (for example, percentage of negative pivot shift in each of the individual studies). Outcomes of the correlation analysis were reported in correlation coefficient (CC) and p-value (with $p < 0.05$ considered significant). The strength of the correlation was graded according to Evans [24] as "very weak" (0.00–0.19), "weak" (0.20–0.39), "moderate" (0.40–0.59), "strong" (0.60–0.79) or "very strong" (0.80–1.00).

3. Results

3.1. Literature search

A flowchart of the inclusion and exclusion of studies is shown in Figure 1. A total of 932 studies were reviewed on title and abstract. After reviewing these studies on title, abstract and full-text, a total of 29 studies were included [9,11,12,14–17,25–46]. Ten studies treated only proximal tears and one study separately reported the outcomes of proximal tears, and these studies were additionally reviewed separately [9,15,17,39–46].

3.2. Quality of studies

Four studies were level I studies [26,34,35,37], two level II studies [29,33], eight level III studies [15,17,25,32,40,43,45,46], and 15 level IV studies [9,11,12,14,16,27,28,30,31,36,38,39,41,42,44]. The quality of studies is graded according to the MINORS criteria (Table 1). Most studies were lacking blinding, and none of the studies had a control group of different tear location. Eight studies were performed in Scandinavia [16,26,27,34–38], six in the United States [9,11,12,14,25,46], five in Germany [28,32,39,43,44], four in Italy [17,29,30,33], four in Switzerland [15,31,42,45] and two in Austria [40,41]. Most studies were written in the English language [9,11,14,16,25–27,31,34,35,37,38,41,42,46], German [15,28,32,39,40,43,44], Italian [30,33], Norwegian [36], French [45] or both the Italian and English [17,29] language. Terms to describe open primary repair differed between the studies with "primary suture" [16,17,29,32,33,36–40], "primary repair" [9,14,25,29–31,42,46], "reinsertion" [15,40,41] and "primary reconstruction" [44].

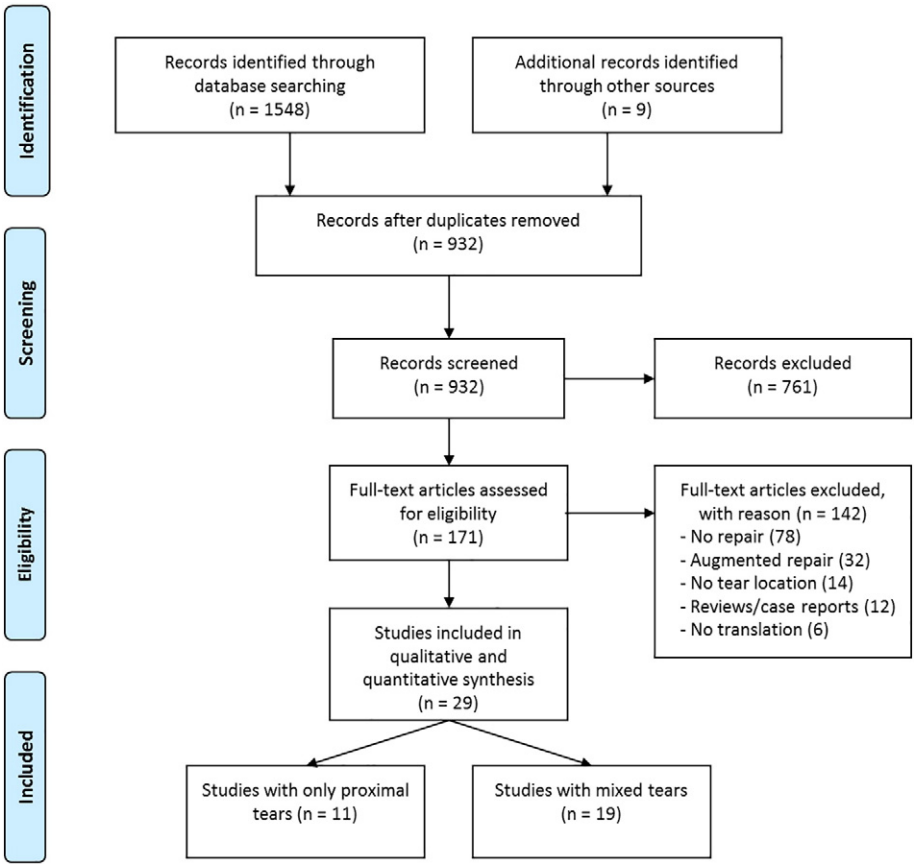

Figure 1. PRISMA flowchart of inclusion and exclusion of this study.

3.3. Baseline characteristics

For all included studies, 29 studies reported primary ACL repair outcomes in 1457 patients, of which 72% were proximal tears, 23% were midsubstance tears and five percent were distal tears. Mean age of these patients was 30 ± 5.4 years (range, 11–72 years) and 65% of these patients were males. Mean length of follow-up was 3.6 ± 1.7 years (range, 0.5–13 years). Eleven studies reported on outcomes of only proximal tears in 539 patients. Mean age in the proximal group was 31 ± 5.8 years (range, 11–71 years), the percentage of males was 63% and mean length of follow-up was 3.9 ± 1.8 years (range, 0.5–13 years) in this subgroup. All baseline characteristics are displayed in Table 2 (studies below the black line are the proximal studies).

3.4. Lysholm scores

Ten studies reported mean Lysholm scores in 489 patients while nine studies reported percentage of good/excellent Lysholm scores in 398 patients. Mean Lysholm score was 87.8 ± 5.0 (range, 77–97) and the percentage of good/excellent Lysholm score was 68.6% ± 16.6% (range, 34%–93%). No significant correlation was noted between the percentage of proximal tears in the studies and the percentage of good/excellent Lysholm scores, but this was not statistically significant (CC 0.233, $p = 0.546$). Three studies treating only proximal tears reported a mean Lysholm score of 86.8 ± 1.7 (range, 85–88) in 184 patients, and good/excellent Lysholm scores in 78.8% ± 2.3% (range, 76%–81%) of 151 patients.

3.5. Tegner scores

Six studies reported Tegner scores in 311 patients and Tegner score in this study was 5.3 ± 0.6 (range, 4.4–6.0). No significant correlation was noted between the percentage of proximal tears in the studies and better Tegner scores (CC 0.143, $p = 0.787$). One study treating only proximal tears in 75 patients reported a mean Tegner score of 5.8.

Table 1
Quality assessment of the included studies using the Methodological Index for NonRandomized Studies (MINORS).

Authors	Year	Journal	Study design	1	2	3	4	5	6	7	8	Total
Liljedahl [27]	1965	J Bone Joint Surg Am	Case series	0	2	1	1	0	1	1	0	6
Cabitza [30]	1978	Minerva Ortopedica	Case series	1	2	1	2	0	2	1	0	9
Frank [25]	1982	Can J Surg	Case control	2	2	1	2	0	2	1	1	11
Heim [15]	1982	Helv Chirc Acta	Case control	2	2	1	2	0	2	1	0	10
Marshall [11]	1982	Am J Sports Med	Case series	2	2	1	2	0	2	1	0	10
Gerber [42]	1983	J Bone Joint Surg Br	Case series	2	1	1	1	0	1	1	0	7
Gaudernak [40]	1984	Hefte Unfallheilkd	Cohort study	1	2	1	0	0	0	1	0	5
Simonet [46]	1984	Am J Sports Med	Cohort study	2	2	1	2	0	2	1	0	10
Strand [16]	1984	Acta Orthop Scand	Case series	2	2	1	2	0	2	0	0	9
Marcacci [17]	1985	Ital J Sports Tramatol	Case control	2	2	1	2	0	2	0	0	9
Odensten [26]	1985	Clin Orthop Relat Res	RCT	2	2	2	2	0	1	1	0	10
Weaver [9]	1985	Clin Orthop Relat Res	Case series	2	2	1	1	0	2	1	0	9
Aglietti [29]	1986	Ital J Sports Tramatol	Cohort study	2	2	2	1	0	2	1	0	10
Müller [28]	1986	Unfallchirurg	Case series	2	2	1	1	0	1	1	0	7
Harilainen [37]	1987	Injury	RCT	2	2	2	2	0	1	1	0	10
Costa [33]	1988	Chir Organi Mov	Cohort study	2	2	1	2	0	2	0	0	9
Rosso [45]	1989	Helv Chirc Acta	Cohort study	2	2	1	1	0	2	1	0	9
Sherman [14]	1989	Am J Sports Med	Case series	2	2	1	2	0	2	1	0	10
Ballmer [31]	1990	The Knee and the Cruciate Ligaments	Case series	2	1	0	2	0	2	0	0	7
Engebretsen [34]	1990	Am J Sports Med	RCT	2	2	2	2	0	2	2	2	14
Haaverstad [36]	1990	Tidsskr Nor Laegeforen	Case series	2	2	1	2	0	2	0	0	9
Kaplan [12]	1990	Am J Sports Med	Case series	2	2	1	2	0	2	1	0	10
Kühne [43]	1991	Unfallchirurg	Case control	1	2	1	2	0	2	1	0	9
Raunest [44]	1991	Unfallchirurg	Case series	2	1	1	2	0	2	0	0	8
Fruensgaard [38]	1992	Acta Orthop Scand	Case series	2	2	1	2	0	2	1	0	10
Genelin [41]	1993	Knee Surg Sports Traum Arth	Case series	2	2	1	2	0	2	1	0	10
Seiler [32]	1993	Unfallchirurg	Case control	1	2	1	2	0	2	0	0	8
Bram [39]	1994	Z Unfallchir Versicherungsmed	Case series	1	2	1	1	0	2	1	0	8
Grontvedt [35]	1996	J Bone Joint Surg Am	RCT	2	2	2	2	0	2	2	2	14

Only the non-comparative part of the MINORS criteria was used (i.e., first eight questions), as no studies compared outcomes between different tear locations (i.e., proximal vs. midsubstance). Some studies compared repair vs. reconstruction but this control group was not considered relevant for this study. RCT indicates randomized clinical trial.
The criteria of MINORS [23] with 0 points when not reported, 1 when reported but not adequate, and 2 when reported and adequate. Maximum score is 24.
1. A clearly stated aim: the question addressed should be precise and relevant in the light of available literature.
2. Inclusion of consecutive patients: all patients potentially fit for inclusion (satisfying the criteria for inclusion) have been included in the study during the study period (no exclusion or details about the reasons for exclusion).
3. Prospective collection of data: data were collected according to a protocol established before the beginning of the study.
4. End points appropriate to the aim of the study: unambiguous explanation of the criteria used to evaluate the main outcome which should be in accordance with the question addressed by the study. In addition, the end points should be assessed on an intention-to-treat basis.
5. Unbiased assessment of the study end point: blind evaluation of objective end points and double-blind evaluation of subjective end points. Otherwise the reasons for not blinding should be stated.
6. Follow-up period appropriate to the aim of the study: the follow-up should be sufficiently long to allow the assessment of the main endpoint and possible adverse events.
7. Loss to follow-up less than five percent: all patients should be included in the follow-up. Otherwise, the proportion lost to follow-up should not exceed the proportion experiencing the major end point.
8. Prospective calculation of the study size: information of the size of detectable difference of interest with a calculation of 95% CI, according to the expected incidence of the outcome event, and information about the level for statistical significance and estimates of power when comparing the outcomes.

3.6. Return to sports

Sixteen studies reported percentage of return to sports level in 788 patients. The percentage of patients that returned to sports was 72.0% ± 13.7% (range, 46%–100%). No significant correlation was noted between the percentage of proximal tears in the studies and the percentage of patients returning to their preinjury level of sports (CC 0.216, $p = 0.421$). Seven studies treating only proximal tears in 360 patients found 80.0% ± 9.3% (range, 67%–89%) of these patients returning to their preinjury level.

3.7. KT-1000 testing

Six studies reported percentage of patients with <3 mm leg difference with KT-1000 testing in 222 patients. The percentage of patients with <3 mm leg difference in this study was 49.5% ± 18.9% (range, 29%–81%). No significant correlation was noted between the percentage of proximal tears in the studies and the percentage of patients with stable KT-1000 testing (CC 0.353, $p = 0.493$). One study treating only proximal tears in 42 patients reported that 81% of patients had stable knees on KT-1000 testing.

Table 2
Outcomes of primary repair of anterior cruciate ligament of studies that reported tear location.

Authors	Year	Knees at FU	FU (years)		Age (years)		Male (%)	Prox. (%)	Lysholm		Tegner	RTS	KT–1000*	Pivot shift test (neg.)	Lachm. test (0/1)	Ant. draw. test (0/1)	Revised (%)	Satisfied (G/E)
			Mn.	Range	Mn.	Range			Mean	G/E								
Frank[25]	1982	42	4.2	1 – 10	32	18 – 72	76%	0%						78%		57%		61%
Odensten[26]	1985	22	1.5	1 – 3	22	13 – 49	72%	0%	88		6						20%	
Weaver[9]	1985	13	3.5	3 – 6	32		31%	0%										23%
Kaplan[12]	1990	56	6.8	5 – 13	27	14 – 49	73%	19%				62%	58%	71%	77%	85%	17%	
Marshall[11]	1982	70	2.4	1 – 8	27	13 – 50	71%	19%				69%		75%	100%	59%	1%	
Liljedahl[27]	1965	27	1.0	0.5 – 2		16 – 55	71%	23%				100%						
Sherman1[4]	1989	50	5.1	4 – 7	23	15 – 56	70%	56%				78%	46%	50%	68%	94%	18%	78%
Müller[28]	1986	94	1.4	0.5 – 6	31	11 – 66	76%	61%										51%
Aglietti[29]	1986	15	3.5	1 – 7	25	16 – 43	69%	67%	97	93%		79%		80%	87%		0%	87%
Cabitza[30]	1978	26	2.4	1 – 4	32	14 – 61	77%	69%										77%
Ballmer[31]	1990	123	5.5	2 – 12	32	16 – 65	61%	71%				57%		49%	88%	85%	6%	89%
Seiler[32]	1993	88	3.7	2 – 6	30	15 – 57	58%	72%	77	34%	4.4			82%	81%			
Costa[33]	1988	27	3.8	3 – 6	27	16 – 46	67%	74%				70%		56%	85%	78%		81%
Engebretsen[34]	1990	50	2.0		29	16 – 50	58%	74%	88	73%			29%	25%	53%		4%	
Grontvedt[35]	1996	41	6.0	5 – 7	29	16 – 50	58%	74%	88	73%	5.0		34%	27%	56%		14%	
Haaverstad[36]	1990	25	3.0	1 – 6	37	17 – 71	64%	76%		76%	5.1		58%	64%	76%	72%	12%	72%
Harilainen[37]	1987	29	1.1	1 – 2	31	15 – 51	53%	77%	92	86%		86%		55%	76%	83%	0%	73%
Fruensgaard[38]	1992	60	5.0	2 – 9	24	15 – 53	69%	85%	88		5.2	46%		66%	56%		20%	
Strand[16]	1984	60	4.0	1 – 6	44	15 – 70	57%	88%						78%	92%	93%		93%
Bram[39]	1994	58	7.0	2 – 13	35	16 – 62	55%	96%	87	79%		76%			91%	94%	7%	88%
Gaudernak[40]	1984	72						100%							96%	94%		
Genelin[41]	1993	42	6.0	5 – 7	27		61%	100%		81%		62%	81%	81%	81%	81%		86%
Gerber[42]	1983	15	1.9	0.5 – 6	43	26 – 62		100%						67%	93%	87%		87%
Heim[15]	1982	86		1 – 6				100%				88%					1%	94%
Kühne[43]	1991	75	3.7	2 – 6	27	11 – 57	62%	100%	85		5.8	89%		88%	87%		0%	
Marcacci[17]	1985	19		1 – 4			66%	100%							74%			79%
Raunest[44]	1991	51	3.5		33	14 – 71	67%	100%	88	76%		71%		84%	73%	84%	0%	75%
Rosso[45]	1989	38	3.3	1 – 7	29		71%	100%				74%					8%	90%
Simonet[46]	1984	17	2.2	2 – 3	24	17 – 40	79%	100%				88%		76%		100%		94%
Weaver[9]	1985	66	3.5	3 – 6	32		50%	100%										79%
All studies		**1457**	**3.6**	**0.5 – 13**	**30**	**11 – 72**	**65%**	**72%**	**88**	**69%**	**5.3**	**72%**	**50%**	**65%**	**81%**	**83%**	**7%**	**80%**
Studies with only proximal tears		539	3.9	0.5 – 13	31	11 – 71	66%	100%	87	79%	5.8	80%	81%	83%	86%	90%	3%	86%

FU indicates follow-up; Mn, mean; Prox., % of proximal tears; G/E, good/excellent; RTS, return to previous level of sports; *, <3 mm leg difference with contralateral side; neg., negative; 0/1, grade 0/1.

3.8. Pivot shift test

Nineteen studies reported pivot shift grades in 863 patients. Due to different reporting of outcomes, it was only possible to report percentage of patients with completely negative pivot shift grade. The percentage of patients with a negative pivot shift was 64.9% ± 18.3% (range, 25%–88%). No significant correlation was noted between the percentage of proximal tears in the studies and the percentage of patients with negative pivot examination (CC 0.289, $p = 0.230$). Seven studies treating only proximal tears in 185 patients reported that 82.7% ± 8.3% (range, 67%–88%) of these patients had negative pivot shift examination.

3.9. Lachman test

Twenty studies reported Lachman test outcomes in 993 patients. Due to different reporting of outcomes in the studies, it was only possible to report percentage of patients with grade 0/1 Lachman test. The percentage of patients with grade 0/1 Lachman in all patients was 80.9% ± 13.4% (range, 53%–100%). No significant correlation between the percentage of proximal tears in the studies and the percentage of patients with (nearly) stable Lachman examination was noted (CC 0.090, $p = 0.705$). Seven studies treating only proximal tears in 315 patients reported that 86.0% ± 9.3% (range, 73%–96%) of patients with proximal tears had (nearly) stable Lachman examination.

3.10. Anterior drawer test

Fifteen studies reported anterior drawer test outcomes in 722 patients. Similar to the Lachman tests, it was only possible to assess the percentage of patients with grade 0/1 anterior drawer test. The percentage of patients with grade 0/1 anterior drawer test was 83.4% ± 12.6% (range, 57%–100%). A non-significant trend towards a positive correlation was noted between the percentage of proximal tears in the studies and the percentage of patients with (nearly) stable anterior drawer examination (CC 0.489, $p = 0.064$) (Figure 2). Six studies treating only proximal tears in 251 patients reported that 90.0% ± 7.3% (range, 81%–100%) of patients with proximal tears had (nearly) stable anterior drawer examination.

3.11. Failure rates

Sixteen studies reported failure rates in 885 patients. The percentage of patients that were considered to have a failed repair or were revised was 6.8% ± 7.7% (range, 0%–20%). A non-significant negative trend was noted between the percentage of proximal tears in the studies and the percentage of patients that had failure of the repair (CC −0.406, $p = 0.119$) (Figure 3). Five studies treating only proximal tears in 300 patients reported a failure rate of 2.6% ± 3.9% (range, 0% to eight percent) in proximal repair patients.

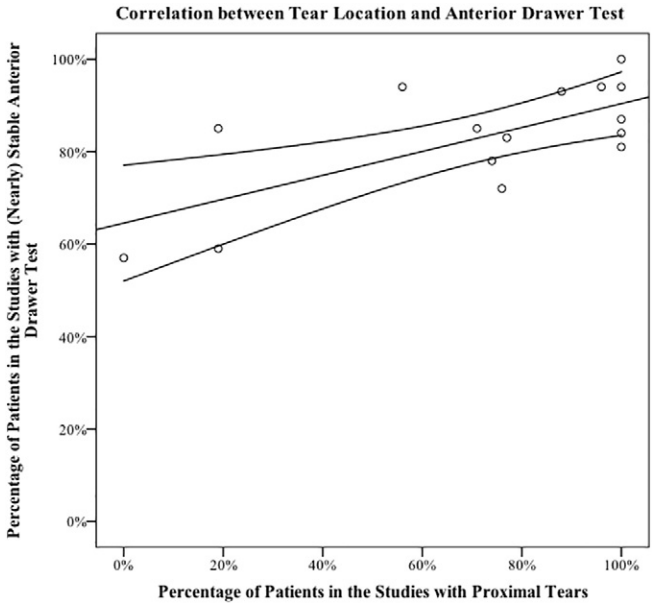

Figure 2. Correlation between the percentage of patients with proximal tears in the studies and the percentage of patients with a negative or 1+ anterior drawer test. Correlation coefficient 0.489, $R^2 = 0.486$, $p = 0.064$.

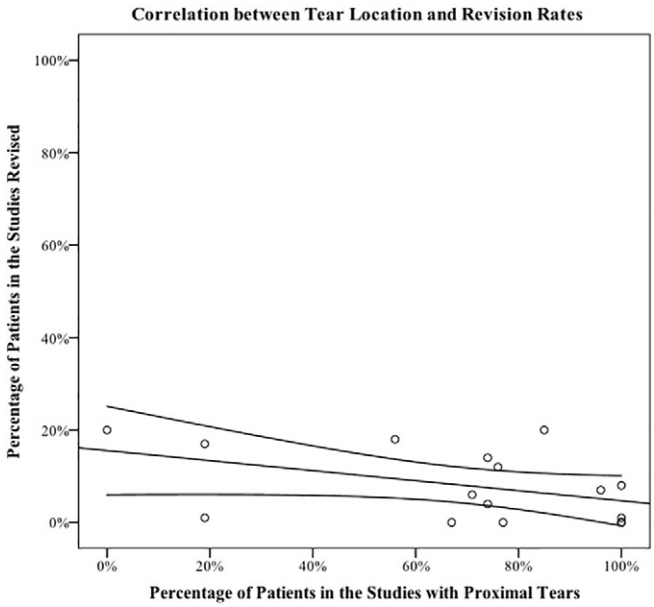

Figure 3. Correlation between the percentage of patients with proximal tears in the studies and the percentage of revisions that were needed for failures. Correlation coefficient −0.406, $R^2 = 0.196$, $p = 0.119$.

3.12. Patient satisfaction

Twenty studies reported the percentage of patients that were satisfied with primary repair in 883 patients. The overall percentage of satisfied patients was 79.7% ± 16.9% (range, 23%–94%). A moderate positive correlation between the percentage of proximal tears in the cohort studies and the percentage of satisfied patients was noted (CC 0.559, $p = 0.010$) (Figure 4). Nine studies treating only proximal tears in 391 patients reported that 85.7% ± 6.9% (range, 75%–94%) of patients with proximal tears were satisfied.

4. Discussion

This study has assessed the role of tear location on historical outcomes of open primary ACL repair. We systematically collected data from all studies reporting ACL tear location of patients undergoing open primary repair. The outcomes of open primary repair were

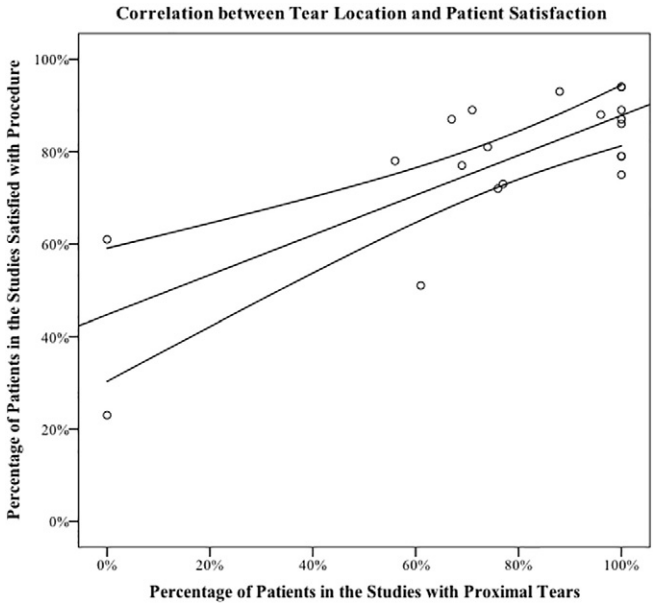

Figure 4. Correlation between the percentage of patients with proximal tears in the studies and the percentage of satisfied patients in the studies is shown. Correlation coefficient 0.559, $R^2 = 0.598$, $p = 0.010$.

reviewed in the total cohort and in studies treating only proximal tears. Data in this study suggest that open repair of ACL injuries resulted in good outcomes in the total cohort and excellent outcomes in proximal tears at short- and mid-term follow-up. Trends were also noted towards better anterior drawer examination, failure rates and satisfaction rates in studies with more proximal tears in their cohort.

Limitations are present in this study. First of all, it was not possible to statistically compare the different studies as no direct comparative studies of proximal versus midsubstance repair were identified. Therefore, we could only describe the different outcomes of open repair in all patients and in the subgroup of proximal tears. Secondly, we could not correct for potential confounders, such as surgical technique and concomitant injuries (meniscal injures, chondral injuries, etc.) in this study, which could have influenced the trends that were noted. Other known confounders (age, gender and, more importantly, follow-up length) were not different between the total study cohort and the studies treating only proximal tears. Thirdly, despite recognizing a trend of better outcomes in the proximal tears, it is difficult to draw strong conclusions regarding the exact outcomes of both groups as the quality of studies was low. This can be explained by the fact that these studies were performed in the period of 1965–1996. Despite these limitations, we feel that, when reviewing the mean outcomes, correlation analyses and the ranges of the groups, this study shows better outcomes in studies with more proximal tears, which confirms and also justifies the current increased interest in primary repair of proximal tears [18–21,47,48].

An often-reported problem with open primary ACL repair was the deterioration of outcomes at mid-term follow-up [10,12–14]. When reviewing all studies that had mean follow-up of 5.0 years or longer, significant similar differences were noted between the proximal and mixed groups. Genelin et al. and Bram et al. treated patients with proximal tears and reported excellent outcomes [39,41]. Genelin et al. [41] reported that 81% of patients had a negative pivot shift, grade 0/1 Lachman and anterior drawer test, while Bram et al. [39] reported a 91% grade 0/1 Lachman test, 94% grade 0/1 anterior drawer test, 76% return to sports and seven percent failure rate at seven-year follow-up (one percent per year) [39]. In the mixed group, however, five studies reported mid-term outcomes with very high failure rates [12,14,31,35,38]. Kaplan et al. [12] reported at 6.8-years of follow-up a 62% return to sports and 17% failure rate. Sherman et al. [14] reported their outcomes in the mixed group in their landmark study with a negative pivot shift in only 50% of patients and an 18% failure rate. Ballmer et al. reported a 46% return to sports, 49% negative pivot shift and six percent failure rate at a 5.5-year follow-up, Grontvedt et al. [35] reported at a 6.0-year follow-up that only 27% had a negative pivot shift, 56% a stable or nearly stable Lachman test and a 14% failure rate while Fruensgaard et al. [38] reported a 46% return to previous level of sports, 66% negative pivot shift and 56% stable or nearly stable Lachman test and a 20% failure rate. Most of these mixed studies reported revision rates of 2.5% to four percent per year. It not only seems that tear location played a role in the overall outcomes of open primary ACL repair but that also the mid-term results were better in studies that treated only proximal tears compared to studies that treated all types of tears.

Kaplan et al. performed open primary repair in patients with midsubstance tears and reported deterioration of their outcomes at mid-term follow-up with a 17% failure rate and 62% return to previous level of sports [12]. They concluded that open primary repair in these patients was an unpredictable procedure. Reviewing the results in our study, it was noted that the outcomes in the mixed group indeed had a greater variation, a larger range in outcomes than the proximal group and that the standard deviation was approximately twice the standard deviation of the proximal group. It therefore not only seems that outcomes of open primary repair in the proximal group were better than the mixed group, but that these outcomes were also more reliable when compared to midsubstance tears, as was already noted by Kaplan et al. [12].

The observations of better outcomes in proximal tears and less deterioration at mid-term follow-up could be explained by several factors, including the vascularity of the ACL. The ACL gets most of its blood supply via a synovial membrane covering the ACL. The ACL is mostly vascularized by the middle genicular artery while the distal end is vascularized by the inferior genicular artery. Petersen and Hansen assessed the vascularity of the ACL and reported that the vascularity of the ACL is not homogeneous [49]. They noted that the richest blood supply is found in the proximal part of the ACL while they also noted that there is an avascularity at the junction of the middle and distal one-thirds, which is the watershed zone of the middle and inferior genicular artery. This could also explain why some case reports [50,51] and case series [52–54] have reported spontaneous healing of proximal tears and perhaps also why better results at short-term and mid-term follow-up are seen in this current study. Studies assessing the role of ACL vascularity with different tear locations are necessary to confirm this hypothesis.

In our preliminary and final systematic search, we identified several reasons that may have contributed to the fact that the role of tear location on outcomes of primary repair was unknown for a long time. First of all, it was noted that a search with terms “anterior cruciate ligament” and “repair” would result in far fewer studies as are included now. This was especially true for studies that reported outcomes of proximal ACL repair, since many studies were in non-English languages, such as German and French. In the era of primary repair, this likely led to less understanding of other results and findings. Furthermore, it was noted that many studies used other terms rather than open primary repair, such as “reinsertion”, “suture” and even “primary reconstruction”, which likely added to the confusion. Finally, it was noted that only three out of 11 proximal repair studies were reported in large international journals at the time [9,42,46], which also could have contributed to the fact that the role of tear location on open primary repair outcomes was not widely understood [55].

Several studies had reported the deterioration of outcomes at mid- to long-term follow-up [10,12,13]. Therefore, randomized clinical trials were started in order to identify the optimal treatment for ACL injuries comparing open primary repair with open ACL reconstruction [34,35,37,56]. Unfortunately, enrollment of patients for these studies was already completed before 1991, when Sherman et al. and others published the potential role of tear location on outcomes, and it is therefore not surprising that many of these studies did not report tear location in their populations. Given the fact that midsubstance tears are reported to occur in approximately 50%–60% of all adult ACL tears [14,57], it is also not surprising that inferior results of primary ACL repair were reported when compared to ACL reconstruction [34,35,37,56]. This raises the question whether primary ACL repair was prematurely abandoned in favor of ACL reconstruction,

and what the outcomes of these prospective randomized clinical trials would have been if only patients with proximal tears were treated with open primary repair.

It is difficult to compare results of this current study with more recent outcomes of ACL reconstruction. However, outcomes of this study in patients with proximal tears were relatively good, even by modern standards [58–60]. Even better results could be expected from primary ACL repair with modern advancements, such as arthroscopy and early rehabilitation motion protocols. In the included studies, patients were treated with arthrotomy and the historic standard was to postoperatively immobilize the knee joint with a lower leg cast for six weeks, which often results in stiffness, pain and suboptimal outcomes [61]. Recent studies with arthroscopy and early rehabilitation motion protocols indeed reported excellent outcomes of arthroscopic primary repair of proximal ACL tears [18,19,21,62–66]. DiFelice et al. reported a case series of 11 patients treated with arthroscopic primary ACL repair of proximal tears followed by an early motion rehabilitation protocol and they indeed reported good outcomes at a 3.5-year follow-up [21]. Furthermore, Achtnich et al. performed arthroscopic primary repair or proximal tears and found equivalent functional outcomes and stability examination when compared to ACL reconstruction of proximal tears [18]. These studies, combined with the findings of this current systematic review, suggest that good to excellent outcomes are possible following primary repair of proximal tears. Future studies are necessary to assess the mid-term outcomes of modern arthroscopic primary repair in proximal tears, and compare these with the current gold standard of ACL reconstruction.

5. Conclusions

This study assessed the role of tear location on outcomes of open primary ACL repair in historical studies and assessed outcomes of open primary ACL repair in proximal tears. The data showed that better outcomes were present in studies with a larger percentage of proximal tears in their cohorts, and that excellent results were noted in studies treating only proximal tears. These findings suggest that primary repair might be a reasonable treatment option for those patients with proximal ACL tears, especially when considering modern day advancements, such as arthroscopy and early motion rehabilitation protocols.

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