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Primary repair of the anterior cruciate ligament: A paradigm shift

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ABSTRACT

Over the last century, many surgical treatments have been developed in the orthopedic field, including treatments of anterior cruciate ligament (ACL) injuries. These treatments ideally evolve in a process of trial and error with prospective comparison of new treatments to the current treatment standard. However, these evolutions are sometimes not linear and periodically undergo paradigm shifts.

In this article, we review the evolution of ACL treatment and explain how it underwent a paradigm shift. Open primary ACL repair was the most common treatment in the 1970s and 1980s, but because multiple studies noted deterioration of outcomes at mid-term follow-up, in addition to several randomized clinical trials (RCTs) that noted better outcomes following ACL reconstruction, the open primary repair technique was abandoned.

At the end of the primary repair era, however, several studies showed that outcomes of open primary repair were good to excellent and did not deteriorate when this technique was selectively performed in patients with proximal ACL tears, whereas primary repair led to disappointing and unpredictable results in patients with mid-substance tears. Unfortunately, enrollment of patients in the aforementioned RCTs was already finished, ultimately leading to abandoning of open primary repair, despite the advantages of ligament preservation.

In this review, we discuss (I) why the evolution of ACL treatment underwent a paradigm shift, (II) which factors may have played a role in this and (III) what the future role of arthroscopic primary ACL repair is in the evolution of ACL treatments.

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Introduction

Over the last century, many surgical techniques and treatments have been developed in the field of orthopedic surgery.

These evolutions generally consist of a process of trial and error with (prospective) comparison of new treatments to the current treatment standard. If carefully executed and well documented, techniques with superior outcomes would then

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be further developed. More often, however, evolutions of surgical treatments undergo periodic “paradigm shifts” instead of progressing in a linear way. Thomas Kuhn described this in 1962¹ and stated that, because of these paradigm shifts, the scientific truth cannot only be determined by objective criteria but is defined by a consensus of a scientific community.

The evolution of anterior cruciate ligament (ACL) treatments started in 1895 when Mayo Robson reported on primary repair of an ACL injury.² A 41-year old male, who had both cruciate ligaments torn from the femoral wall, underwent primary repair in which the ligaments were stitched back to the femur using catgut ligatures. Over the following decades, Ivar Palmer^{3,4} and Don O'Donoghue^{5,6} further popularized primary repair for the treatment of ACL injuries. Following their work, open primary ACL repair was the most commonly performed surgical treatment in the 1970s and 1980s for ACL injuries,^{7–12} and the initial short-term results of primary repair were good.^{9–15} However, Feagin and Curl were the first to note that the results deteriorated at mid-term follow-up.¹⁶ Reporting on only 50% of their original cohort, they found a 53% reinjury rate at five-year follow-up, along with high rates of pain, stiffness and instability. Following this study, some others also noted deterioration of the results at mid-term follow-up.^{17–19} In addition, several randomized, prospective clinical trials showed better results following ACL reconstruction when compared to primary ACL repair.^{20–26} Taken together, these studies led to the abandoning of open primary ACL repair as a treatment for ACL injury in the early 1990s, and also led to the eventual adoption of ACL reconstruction as the new standard for all patients. With primary repair, however, the native ligament is preserved and the surgery is less invasive, which has some advantages over ACL reconstruction, including maintaining proprioception^{27,28} and preventing complications in graft harvesting, tunnel widening and revisions.^{29–31}

The evolution of primary ACL repair is often believed to have been a natural and linear evolution of ACL treatments. However, with modern-day understanding we carefully reviewed the evolution and abandonment of primary ACL repair, and we noted that the evolution of treatment of ACL injuries underwent a paradigm shift. We feel that this shift led to the suboptimal treatment algorithm currently used for ACL injuries. In this article, we will discuss (I) why this evolution underwent a paradigm shift, (II) which factors may have contributed to this and (III) what the future role of primary repair might be in the evolution of ACL treatments.

Evolution of primary ACL repair through the prism of modern-day understanding

Looking back at the evolution of primary ACL repair, several interesting observations can be made. The most important observation was made by Sherman et al., in 1991,¹⁹ when they reported their mid-term results in what was considered a landmark paper on primary ACL repair.¹⁹ The authors also noted a deterioration of their results at mid-term follow-up, although not as severe as in the cohort of Feagin and Curl, and they sought to find an explanation for this. They performed an

extensive subgroup analysis and found a trend of better clinical results in certain subgroups of patients, including those with proximal (type I) tears. They were, however, not the first to note the role of tear location on the outcomes of primary ACL repair. Already in the early 1980s several authors suggested this correlation.^{12,13,32–34} Weaver et al., for example, reported their outcomes of primary ACL repair in patients in the four Aspen skiing areas in 1985¹² and found that 52 of the 66 patients (79%) with proximal tears were satisfied following primary repair, while only 3 out of 13 patients (23%) with midsubstance tears reported being satisfied with the result at 3.5-year follow-up. They stated, “selection can be made with some predictability of the type of injury to the ligament as to which patients will do better.”¹² Surprisingly, however, this study by Weaver et al., and other studies that suggested a role for proximal tears,^{32–34} were not frequently cited and did not seem to be a part of the worldwide discussion in the literature regarding the treatment of ACL injuries.

Outcomes of open primary ACL repair stratified by tear location

Many of the early authors did not specify the location of the ACL tear,^{16,35–38} which is not surprising, since a possible relationship between tear location and outcomes was made relatively late in the evolution of primary ACL repair. When looking at studies that mainly, or only, treated patients with midsubstance tears (Fig. 1a), it was noted that the results of primary ACL repair were poor. As mentioned, Weaver et al., showed only a 23% satisfaction rate in 13 patients with midsubstance tears. Frank et al., reported similar poor results of primary repair in 42 patients with midsubstance tears. At four-year follow-up, they reported that 22% of the patients had a positive pivot shift, 44% had a +2 or +3 anterior drawer test, and only 61% reported being satisfied with the procedure.³⁹ Odensten et al., reported the outcomes of primary repair in a subgroup of 22 patients with all midsubstance tears and noted a revision rate of 20% at 1.5-year follow-up.²⁵ Furthermore, Kaplan et al., reported their mid-term follow-up of 70 patients treated with primary ACL repair, of which 56 had midsubstance tears.¹⁸ They reported a 17% failure rate, 42% laxity on KT-1000, and only a 62% return to sport rate. They concluded that, “although ... primary repair of the anterior cruciate may work in some patients, it is an unpredictable operative procedure.”

On the contrary, when reviewing studies that treated patients with mainly, or only proximal tears (Fig. 1b), it was noted that good to excellent results were seen in the literature.^{14,32,33,40–43} Kühne et al., reported treatment of 75 patients with proximal tears treated with primary ACL repair at four-year follow-up and reported 0% failure rate, negative pivot shift in 88% of the patients, a 0 or +1 Lachman test in 87% and a return to sports in 89% of patients.⁴² Similarly, Genelin et al., reported their results of 42 patients treated with proximal tears at five- to seven-year follow-up.⁴¹ They found negative pivot shift in 81% of patients, 0 or +1 Lachman test and anterior drawer test in 81% of cases, and reported that 86% of patients were satisfied with the procedure at mid-term follow-up. Raunest et al., reported outcomes of primary repair in 51 patients with proximal ACL tears at average 3.5-year

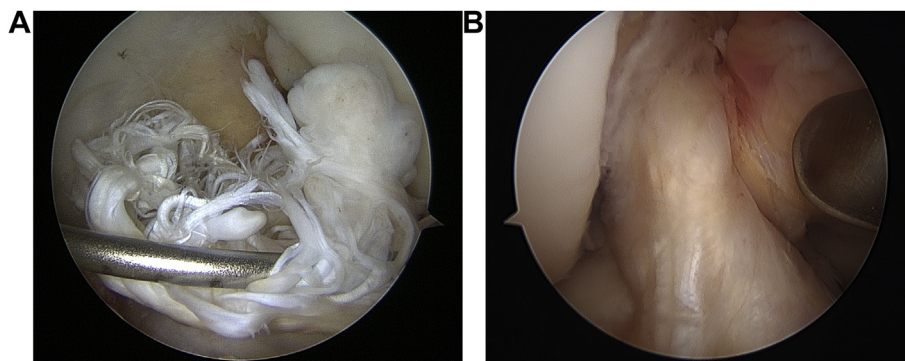


Fig. 1 – a. Arthroscopic view is shown with a “mop-end” midsubstance tear of the anterior cruciate ligament. Outcomes of primary repair of these tears were considered to be mixed and unpredictable.¹⁸ b. Arthroscopic view is shown with a “peel-off” proximal (type I) tear of the anterior cruciate ligament. These tears often have excellent tissue quality and outcomes of these tears are excellent.⁷³

follow-up. They noted 0% revisions, negative pivot shift and anterior drawer test in 84% of patients, return to sports in 71% and satisfaction in 75% of patients. These studies that reported results of treating patients with mostly proximal ACL tears showed that good to excellent results could clearly be achieved following open, primary ACL repair. In addition, Bram et al.,⁴⁰ and Genelin et al.,⁴¹ showed that the results did not deteriorate at a mean follow-up of seven and six years, respectively. It seems that, when the decision was made to abandon primary repair due to marginal results, the surgical community did not recognize the role of tear location on the outcomes of primary repair.

Factors that played a role in this paradigm shift

When reviewing the literature, and bearing in mind the findings of Sherman et al. and others, we identified several factors that may have contributed to why primary repair was abandoned for all tears. Performing a search to identify studies that reported outcomes of primary ACL repair in the 1980s and 1990s, we encountered several limitations in identifying these studies. It must have been even harder for the orthopedic surgeon in those days to be up to date on all studies, and therefore to make a well-informed decision regarding the optimal treatment for ACL injuries.

First of all, modern advances in computer technology enable us to use search engines, such as PubMed and Embase, to identify studies. The fact that search engine capabilities of the time were more rudimentary made it relatively difficult for the orthopedic surgeon to be up to date on all the recent literature. Secondly, numerous authors reported outcomes of primary ACL repair in the 1980s and 1990s in their own language and, therefore, were neither easily readable, nor easily searchable at the time. With modern search engines, many Italian,^{44,45} French,⁴⁶ Norwegian⁴⁷ and especially German,^{32,40,42,48–52} studies were identified that were published on the topic of primary ACL repair in their respective languages. This could have led to the fact that most of these studies were not available, and thus, may not have been

included in the worldwide discussion regarding ACL treatment. Finally, and perhaps most importantly, the nomenclature describing the procedure differed throughout the literature. Primary repair was sometimes referred to as “ACL reinsertion”,^{32,41,50,51} instead of “ACL repair”. This makes sense because for proximal tears the ACL remnant could be described as being “reinserted” into the femoral footprint, whereas for midsubstance tears this was likely considered more of a true “repair” technique. It is likely that this nomenclature issue contributed to significant bias in the historical literature, since multiple positive outcome studies were largely omitted from the discussion in the English speaking literature.^{32,41,50,51} Certainly the observations of poor accessibility and readability, in addition to the varying descriptive nomenclature, suggest that not all studies may have been used to make a well-informed decision regarding the abandonment of primary ACL repair for all patients instead of only abandoning this technique for mid-substance tears.

Taking these observations into account, and reviewing the results of open primary ACL repair stratified by tear location, it seems clear that the decision to abandon open primary ACL repair in favor of augmented ACL repair and eventually ACL reconstruction, was, at least partially, based on studies that did not factor in the importance of the tear type to the outcome of surgery.^{20–26} When reviewing these results, it raises the question, “what would have happened if the observation of the importance of tear location was recognized earlier?” Intuitively, it makes sense that a more natural evolution of trial and error would have taken place. The technique of primary repair would have likely only been abandoned for midsubstance tears, whereas the repair techniques for patients with proximal tears would have been refined given the significantly better results that were actually reported in the world literature as discussed above.

Unfortunate timing

The timing of abandoning primary ACL repair was an unlucky one for multiple reasons. First of all, the observations on tear

type by Sherman et al., were made in 1991, which was relatively late in the evolution of primary ACL repair. With the introduction of augmented repair and reconstruction techniques, several randomized clinical trials were undertaken towards the end of the 1980s to determine the optimal treatment for ACL injuries.²⁰⁻²⁶ At the time that Sherman et al. reported their findings, the enrollment of patients for these randomized clinical trials were already closed. These studies, therefore, did not stratify their results by tear location. It is likely that the majority of tears were midsubstance tears, since this is reportedly the most common tear type in the adult population (estimated to be between 70 and 90%, although observational studies assessing this are lacking).⁵³⁻⁵⁵ With the critical role of tear location to the outcomes of primary ACL repair, combined with the fact that tear location does not play a role in ACL reconstruction where the entire ligament is removed, it is not surprising that superior outcomes of augmented repair and reconstruction were found when compared to primary repair.²⁰⁻²⁴

Furthermore, there was an increased interest in minimally invasive surgical techniques and improved rehabilitation techniques around this time. The surgical technique of primary ACL repair during the 1980s and 1990s consisted of an arthrotomy, which is an invasive and morbid procedure when compared to arthroscopic surgery.⁵⁶⁻⁵⁸ It is intuitive that a significant contribution to the sub-optimal results of ACL treatment in the 1980s and 1990s could have been attributed to the morbidity of the arthrotomy, combined with immobilization. Although arthroscopy became available around the 1970s and 1980s, there were significant technologic limitations in the ability to control bleeding and reliably visualize and manipulate the internal anatomy of the joints. As with all innovations, it takes time until the technique can be developed sufficiently, and for the surgeon to become experienced enough to successfully utilize it. Despite the high pace of arthroscopic advances, the technology was not developed enough to reliably attempt arthroscopic primary repair in the early 1990s.⁵⁹ By the time arthroscopic surgery was more developed, primary repair had been abandoned and reconstruction had become the standard treatment for all ACL injuries.

Over the ensuing decades, ACL reconstruction benefited from, and evolved with the less invasive arthroscopic procedures, while primary ACL repair did not benefit from such development. Therefore, the question remains, "what would the outcomes of primary ACL repair have been if it had evolved to be performed arthroscopically." Interestingly, Strand et al. recently reported their 20-year follow-up results on 81 patients with 71% good or excellent knee function, 13% reconstructions and 27% total failure of stability.⁶⁰ They stated, "...open procedures cannot be recommended for any type of patients. However, if the same results could be accomplished by a smaller, arthroscopic procedure, primary repair might reduce the number of patients needing later reconstructions with small 'costs' in the way of risk and inconvenience for the patients. We therefore believe that further research and development of methods for closed (arthroscopic) repair are justified."

Similarly as for the invasive arthrotomy, it was noted that rehabilitation in the 1980s and 1990s consisted of joint

immobilization for at least five or six weeks using a long leg cast.^{11,13,19,22,41,61,62} The concept of early mobilization was being developed in the late 1980s and early 1990s,^{63,64} and thus, most patients treated with primary ACL repair or ACL reconstruction around this time still received joint immobilization. However, it is now known that knee joint immobilization may cause pain, loss of range of motion and decreased function.^{65,66} The technique of ACL reconstruction has evolved over three decades and early mobilization has significantly improved the results of ACL reconstruction.⁶⁷⁻⁶⁹ However, studies reporting outcomes of primary ACL repair all used postoperative joint immobilization, which raises another question, "would the results of primary ACL repair have further improved if the repairs were performed only on patients with proximal tears, and they were mobilized early?" Indeed, Genelin et al., also noted this in their study on proximal ACL tears, which was one of the last original studies reporting results of primary ACL repair in 1994.⁴¹ They stated, "nevertheless we believe that, even with the same operational technique, the results can be improved still further by early postoperative treatment with a continuous passive motion machine, combined with a brace providing limited knee joint motion."

Finally, the study by Feagin and Curl was often quoted by studies in the 1980s and 1990s, despite the fact that their methods were already outdated by the late 1970s. The authors used figure of eight absorbable sutures and secured the sutures over the iliotibial band.^{16,70} The authors reported instability in 94% of the cases, and a reinjury rate of 53%, which is significantly worse than any other paper published on primary repair. More recent preclinical studies on ACL repair have shown that the strength of a repair significantly decreased when absorbable sutures were used, compared to non-absorbable sutures.⁷¹ Not surprisingly, a few years later, Marshall and colleagues introduced a different technique using multiple looped, non-absorbable sutures that they tied directly over the bone of the femoral condyle without the iliotibial band between it.^{10,13} The results in their studies were significantly better, even though most of these patients in their study had midsubstance tears.^{18,22,50} It is likely that the use of absorbable sutures, the fact that only a figure of eight loop was used, and that the sutures were tied over the iliotibial band, could have worsened the results as reported by Feagin and Curl.¹⁶ It is interesting to note that the study by Feagin and Curl is more often quoted than any other study on primary ACL repair and remained an important study leading to the abandonment of primary ACL repair, yet there were multiple aforementioned limitations regarding the surgical technique, including the high risk for selection bias given that they had only a 50% follow-up rate on the original cohort.

The future role of primary repair in the evolution of ACL treatment

After the discussion in the historic literature regarding the limitations of open primary repair, one would expect that the results of primary ACL repair would have improved over the second part of the 1990s and into the next century. With the introduction of magnetic resonance imaging (MRI) for patient selection, with the advances made in arthroscopic

surgery for a minimally invasive approach, and with improved rehabilitation understanding that focuses on early mobilization, both techniques of primary repair and reconstruction would have ideally been further developed and both techniques could have been used for proximal and mid-substance tears, respectively. However, over the last two decades no original cohorts have been started using primary repair,⁷² and it is only very recently that studies have reported outcomes of arthroscopic primary repair^{73,74,75} or primary repair augmented with an external device^{76–78} or with an internal brace^{79–81} (Table 1).

The first study of arthroscopic primary ACL repair was performed by DiFelice et al.⁷³ They reported a case series of 11 patients with proximal tears that were treated with arthroscopic suture anchor primary ACL repair (Fig. 2).⁷³ They applied all modern developments and only treated patients with proximal tears that were predicted by MRI, utilized an arthroscopic, minimally invasive surgical approach using non-absorbable sutures, and their patients underwent rehabilitation focusing on early range of motion. Not surprisingly, after the discussion of these topics above, the authors found excellent results at a mean of 3.5-year follow-up. They reported a mean Lysholm score of 93.2, modified Cincinnati score of 91.5, pre- and postoperative Tegner score of 7.3 and 6.9, respectively, SANE score of 91.8 and subjective IKDC-score of 86.4. They reported only one clinical failure (9%) who had a KT-1000 leg difference of 6 mm. Nine patients had an objective IKDC A score, one an IKDC B score, and one an IKDC C score. Of the eight patients who had post-operative KT-1000 tests, all except the clinical failure, had <3 mm side-to-side, maximum manual differences. The authors concluded that a modern approach to ACL preservation, using an arthroscopic suture anchor primary ACL repair technique, could achieve short-term clinical success in carefully selected patients. Although they did report good results in three patients with four- to five-year follow-up, they concluded that more studies are necessary to determine whether the clinical successes will be sustained at longer follow-up.

More recently, Achtnich et al. compared arthroscopic primary repair in 20 patients with proximal ACL tears and with single-bundle reconstruction in 20 patients with proximal ACL tears at 2.3-years follow-up.⁷⁴ Although this study was not

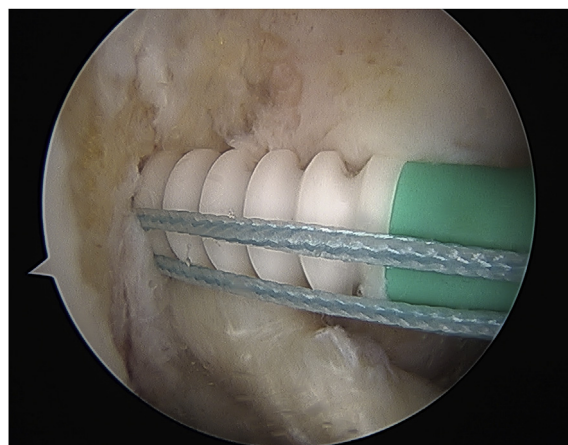


Fig. 2 – Arthroscopic view of a suture anchor primary ACL repair.

randomized, they reported excellent stability testing and patient-reported outcome scores in both groups but a higher revision rate following primary repair (15% vs. 0%). Despite this higher revision rate, they concluded that in a significant amount of patients good results could be achieved with this minimally invasive treatment option of arthroscopic primary repair.

In this article, we discussed why we feel that the evolution of treating ACL injuries with primary ACL repair underwent a paradigm shift. We also described the flaws and biases in the historic literature that may have led to the decision to abandon the technique of ACL primary repair for all patients. If we acknowledge the importance of tear location on outcomes of primary repair, the encouraging preliminary results by DiFelice et al.⁷³ and Achtnich et al.⁷⁴ and the modern developments, such as MRI, early motion rehabilitation and arthroscopy, then it certainly seems that a new approach to ACL treatment might be emerging. That is that primary ACL repair may be a good and minimally invasive solution for patients with proximal tears, whereas ACL reconstruction or augmentation is the preferred technique in patients with non-proximal tears.⁸²

Table 1 – Overview of studies reporting outcomes of primary repair and augmented repair (primary repair with augmentation using external device or graft tissue).

Authors	Year	Journal	Design	Surgery	No.	Age (y)	Fixation	FU (y)	Failure	Reop. ^a
Primary repair of proximal tears										
DiFelice et al. ⁷³	2015	Arthroscopy	Case series	Repair	11	37	Suture anchor	3.5	1 (9%)	1 (9%)
Achtnich et al. ⁷⁴	2016	Arthroscopy	Case control	Repair	20	30	Suture anchor	2.3	3 (15%)	4 (20%)
Augmented repair of proximal tears using external device or graft tissue or internal										
Anthony and Mackay ⁷⁹	2015	Orthop Muscul Syst	Case series	Repair	68	34	Internal Brace	1.0	1 (1%)	4 (6%)
Eggli et al. ⁷⁶	2015	KSSTA	Case series	Repair	10	25	DIS Device	2.0	1 (10%)	1 (10%)
Henle et al. ⁷⁷	2015	BMC Musc.	Case series	Repair	278	31	DIS Device	3.0	11 (4%)	78 (28%)
Eggli et al. ⁷⁸	2016	BMC Musc.	Case series	Repair	10	23	DIS Device	5.0	2 (20%)	6 (60%)
Smith et al. ⁸⁰	2016	KSSTA	Case reports	Repair	3	6	Internal Brace	1.5	0 (0%)	0 (0%)

No. indicates number of knees; FU, follow-up; y, years; reop., reoperation; recon., reconstruction; KSSTA, Knee Surg Sports Traumatol Arthroscopy; BMC Musc, BioMed Central Musculoskeletal Disorders; DIS, Dynamic Intraligamentary Stabilization.

^a Reoperation includes failures and reoperations for removal of hardware or concomitant injuries.

Conclusions

When reviewing the historical outcomes of primary repair, it becomes clear that the evolution of ACL treatment underwent a paradigm shift. In hindsight, we have learned of multiple factors in the historical literature that negatively influenced the reported results of primary ACL repair, including: non-strict patient selection, invasive surgical techniques, prolonged joint immobilization, and the use of absorbable sutures. Furthermore, modern search engines enabled us to do a more thorough search of the world literature and identify more historical studies that reported excellent results of primary repair of proximal ACL lesions than were previously appreciated.

It is possible that, if this paradigm shift in ACL treatment had not occurred, these limitations would have been addressed, and an arthroscopic repair technique, focusing only on proximal tears and rehabilitation with an emphasis on early range of motion would have evolved. It is encouraging that the first results of arthroscopic primary repair of proximal ACL tears have been recently published and that the treatment may shift back to a treatment algorithm that takes tear location into account.

Conflict of interest

Jelle P. van der List has nothing to disclose.

Gregory S. DiFelice is a paid consultant for Arthrex (Naples, FL, USA).

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