Review

The difference in clinical outcome of single-bundle anterior cruciate ligament reconstructions with and without remnant preservation: A meta-analysis

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ABSTRACT

Background: The aim of this study was to compare the clinical performance and complications between an ACL reconstruction with a remnant-preserving single-bundle technique and a standard single-bundle technique. Methods: A search was performed of RCTs comparing the clinical outcomes and complications of ACL reconstruction with remnant-preserving and standard single-bundle techniques during October 2014. Relevant data were extracted and CONSORT was used to assess the methodological quality. Stata/SE 12.0 was used to perform a meta-analysis of the clinical outcomes.

Results: Six RCTs were included, with a total of 378 patients: 190 in the remnant-preservation technique group and 188 patients in standard-technique group. Assessing anterior stability, no difference was found between the groups for the KT arthrometer, negative rate of Lachman, and the pivot shift test. Assessing functional outcome, there was no significant difference in IKDC scores and grades or Lysholm score. In terms of complications, the percentage of tibial tunnel enlargement in the group of remnant-preservation technique was significantly lower, despite no significant difference in the incidence of cyclops lesions.

Conclusions: The outcome of single-bundle ACL reconstruction with the remnant-preservation technique is similar to that with the standard technique in terms of anterior stability and functional recovery of the knee. Remnant preservation in ACL reconstruction decreases the percentage of tibial tunnel enlargement.

Level of evidence is II.

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1. Introduction

Arthroscopically assisted anterior cruciate ligament (ACL) reconstruction is the gold standard for treating ACL ruptures. The aim of ACL reconstruction is to restore knee stability, recover the patient’s pre-injury sports capability, and prevent the occurrence of a torn meniscus and osteoarthritis [1,2]. Due to its good clinical outcome, the single-bundle technique for ACL reconstruction has traditionally been the standard treatment [3–5]. However, in recent years, double-bundle ACL reconstruction has gradually become the preferred method. In theory, the double-bundle technique is considered to be superior to the single-bundle technique for ACL reconstruction. However, the latest meta-analyses have demonstrated no significant difference in the functional recovery between the two techniques, although the double-bundle technique had a better outcome in terms of rotational laxity [6, 7]. The single-bundle technique remains the most commonly used technique in ACL reconstruction, as its clinical outcome has continuously improved with advancements [8].

The afferent neural input of proprioception is a prerequisite of neuromuscular coordination as it influences the biomechanical behavior of the knee and ACL [9]. Therefore, restoration of knee function in ACL injury depends not only on arthroscopic techniques but also on the anatomical and biomechanical factors, and the precise complex interaction between the nervous and musculoskeletal systems [10]. Mechanoreceptors that control knee proprioception are found around the ACL, most of which are located in the inner membrane of the synovium near the tibial attachment of the ACL. They maintain knee stability by stimulating coordinated muscular contractions [11,12]. Mechanoreceptors can still be found in remnants of injured ACLs: Georgoulis et al. reported that residual mechanoreceptors could still be found in the stump of a ruptured ACL, attached to the posterior cruciate ligament, three years after ACL rupture [13]. For this reason, remnants should be preserved as much as possible, even in chronic injuries. Lee et al. found that even with 20% of the ACL remnant, most mechanoreceptors could provide relatively good proprioception [14]. Furthermore, retaining the stump could accelerate the revascularization and synovial coverage of the reconstructed ligament [15]. Therefore, it can be concluded that preserving the remnant can re-establish proprioception in the reconstructed ACL and accelerate functional recovery. Although recent studies [9,16–19] have demonstrated good clinical outcome with remnant-preserving single-bundle ACL reconstruction, some investigators have found that remnant preservation may increase the risk of certain complications and subsequently affect the functional performance of the knee [20–22].

Although a recent systematic review concluded that remnant preservation has some advantages over the standard technique [23], the studies included in the review were mostly retrospective, and the data were not pooled for evaluation of the clinical outcome. To overcome these drawbacks, in the present meta-analysis, only prospective, randomized, controlled trials (RCTs) were included and the data for clinical outcome were pooled to compare the clinical outcomes between the remnant-preserving and standard single-bundle technique.

2. Materials and methods

2.1. Searching strategy

Two researchers independently searched international databases from 1966 to October 2014, including: PubMed, Embase, the Web of Science, and the Cochrane central database. There was no restriction to specific languages or years of publication. A manual search of all reference lists contained in the literature was also performed. Search terms used for the PubMed search are presented in Table 1. In addition, OpenGrey, the World Health Organization International Clinical Trials Registry Platform, the International Standard Randomised Controlled Trial Number (ISRCTN) registry, and Current Controlled Trials were searched to review the trial registry and grey literature.

2.2. Inclusion and exclusion criteria

Inclusion criteria were as follows: [1] subject — all adult patients who underwent arthroscopy-assisted ACL reconstruction, with no limitation to sex and race; [2] intervention method — arthroscopy-assisted single-bundle ACL reconstruction and comparison of clinical outcome between the standard and remnant-preservation technique; [3] outcome parameters — pivot shift test, Lachman test, KT1000/2000 arthrometer, International Knee Documentation Committee (IKDC) scores, Lysholm scores, and complications, including cyclops lesions and tibial tunnel enlargement; and [4] study type — RCT.

The exclusion criteria were: [1] non-prospective trials (e.g., retrospective studies, observational studies, case series, and reviews); [2] animal or cadaver studies; [3] comparisons that were not between standard and remnant preservation in ACL reconstruction; and [4] studies with <1 year of follow-up.

Table 1

PubMed search strategy.

2.3. Literature selection and quality assessment

Two researchers independently selected all articles by following the abovementioned criteria, while assessing the qualities of the selected articles. Any disagreement was resolved through discussion with the corresponding researcher. The Physiotherapy Evidence Database (PEDro) scale, which comprises 11 items based on the Delphi list, was used to assess the methodological quality of each article [24]. Each item was scored yes or no, with a maximum score of 10 because criterion one was not scored. The PEDro score demonstrated moderate inter-rater reliability (intraclass correlation coefficients (ICC) = 0.68 (95% CI 0.57 to 0.76%)) for clinical trials; a trial with a score of ≥6 was considered to be of high quality.

2.4. Data extraction

Using the same format, the two researchers independently extracted data from the articles. The extracted data were compared, and the extraction and comparison processes were repeated for items with inconsistencies. The items included article information (author and publication date), participant demographics, sample size, follow-up period, implant type, and outcome parameters. The authors of some articles were contacted by e-mail to obtain the omitted data, including: the tibial tunnel diameter before and after operation [25], and the Lysholm score for the knees [26]. The cyclops lesion was confirmed by magnetic resonance imaging (MRI) or repeat arthroscopy. The percentage of tibial tunnel enlargement was determined by comparing the lateral and

Fig. 1. Flowchart of article selection process.

Table 2.
Description of included trials.

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Age (years)</th>
<th>Male/Female</th>
<th>Follow-up (months)</th>
<th>Number of patients</th>
<th>Implant</th>
<th>Fixation type</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gohil</td>
<td>2007</td>
<td>33</td>
<td>27/22</td>
<td>12</td>
<td>24/25</td>
<td>HT</td>
<td>EB + BS</td>
<td>Anterior laxity; IKDC score; Lysholm score; MRI</td>
</tr>
<tr>
<td>Burak</td>
<td>2012</td>
<td>29.5</td>
<td>36/4</td>
<td>24.3</td>
<td>20/20</td>
<td>Allograft</td>
<td>EB + BS</td>
<td>IKDC score; Lysholm score; X-ray; MRI</td>
</tr>
<tr>
<td>Hong</td>
<td>2012</td>
<td>31</td>
<td>67/23</td>
<td>25.7</td>
<td>45/45</td>
<td>Allograft</td>
<td>Rigifix + transfix</td>
<td>Anterior laxity; IKDC grade; MRI; Lachman test; PS</td>
</tr>
<tr>
<td>Nicholas</td>
<td>2012</td>
<td>30.1</td>
<td>43/43</td>
<td>12</td>
<td>43/43</td>
<td>HT</td>
<td>Rigifix + transfix</td>
<td>Anterior laxity; IKDC grade; PS; ACL-QOL</td>
</tr>
<tr>
<td>Pujol</td>
<td>2012</td>
<td>30</td>
<td>33/21</td>
<td>12</td>
<td>29/25</td>
<td>HTBPB</td>
<td>EB + BS</td>
<td>Anterior laxity; IKDC score; Lysholm score; PS; KOOS</td>
</tr>
<tr>
<td>Zhang</td>
<td>2012</td>
<td>24.3</td>
<td>40/9</td>
<td>24</td>
<td>27/24</td>
<td>HT</td>
<td>Rigifix + BS</td>
<td>Anterior laxity; Lysholm score; X-ray</td>
</tr>
</tbody>
</table>

ACL-QOL, anterior cruciate ligament quality of life; BPB, bone–patellar tendon–bone; BS, bioabsorbable screw; EB, Endobutton; HT, hamstring tendon; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; MRI, Magnetic resonance imaging; N/A, not applicable; PS, pivot shift test.
anteposterior (AP) radiographs taken in the early postoperative period and at the last follow-up, in order to measure the tibial tunnel width at the widest point and at one centimeter from the aperture of the tunnels.

2.5. Statistical methods

The meta-analysis was conducted using Stata/SE 12.0. When the outcome indicator was dichotomous, relative risk (RR) was calculated for effect size. For continuous outcomes, a weighted mean difference (WMD) was calculated when the same measurement criterion was used; otherwise, a standardized mean difference (SMD) was calculated. Both calculations used 95% CI. The intervening effect of an indicator was considered as zero difference if 95% CI for WMD or SMD contained 0 and otherwise, a standardized mean difference (SMD) was calculated. For continuous outcomes, a weighted mean difference (WMD) was calculated when the same measurement criterion was used; otherwise, a standardized mean difference (SMD) was calculated. Both calculations used 95% CI. The intervening effect of an indicator was calculated using the random-effects model. The result indicated no significance difference between the two groups in terms of the postoperative anterior laxity (WMD = −0.24, 95% CI (−0.69, 0.20)). A subgroup analysis based on the type of graft was performed. The allograft subgroup showed no heterogeneity, and the pooled result did not change. The heterogeneity was due to the different types of graft.

<table>
<thead>
<tr>
<th>Study</th>
<th>WMD (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gohil (2007)</td>
<td>0.45 (0.02, 0.88)</td>
<td>23.96</td>
</tr>
<tr>
<td>Hong L. (2012)</td>
<td>-0.20 (-0.97, 0.57)</td>
<td>16.13</td>
</tr>
<tr>
<td>Nicholas (2012)</td>
<td>-0.80 (-1.54, -0.06)</td>
<td>16.58</td>
</tr>
<tr>
<td>Pujol (2012)</td>
<td>-0.63 (-1.36, 0.10)</td>
<td>16.82</td>
</tr>
<tr>
<td>Qiang Z (2012)</td>
<td>-0.30 (-0.63, 0.03)</td>
<td>26.52</td>
</tr>
<tr>
<td>Overall (I-squared = 68.5%, p = 0.013)</td>
<td>-0.24 (-0.69, 0.20)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

NOTE: Weights are from random effects analysis.
3.4.2. Pivot shift tests
Postoperative pivot shift tests were conducted in three studies. The analysis of negative pivot shift results showed some heterogeneity among the studies ($P = 0.116$, $I^2 = 53.6\%$). The postoperative negative pivot shift of 104 patients in the remnant-preservation group and 102 patients in the standard group were analyzed using a random-effects model, with no significant difference between the two methods (RR = 1.00, 95% CI (0.87, 1.15), $P = 0.96$) (Figure 3). Subsequently, to explore the potential source of heterogeneity, the pivot shift test was subjected to a sensitivity analysis by omitting one article at a time and calculating the pooled WMDs for the remaining studies. It was found that there were no changes in effect when any one study was excluded.

3.4.3. Lachman tests
Postoperative Lachman tests were conducted in two studies. No heterogeneity was found among the studies ($P = 0.809$, $I^2 = 0\%$). The postoperative negative Lachman test of 59 patients in the remnant-preservation group and 62 patients in the standard group was analyzed using a fixed-effects model. There was no significant difference between the two groups (RR = 1.04, 95% CI (0.87, 1.22), $P = 0.686$) (Figure 4).

3.4.4. Lysholm scores
Four studies reported postoperative Lysholm scores. No heterogeneity was found among the studies ($P = 0.361$, $I^2 = 6.4\%$). Using the fixed-effects model in analysis, with 115 patients in the remnant-preservation group and 120 patients in the standard group, the result showed a difference in Lysholm scores between the two groups (WMD = 1.60, 95% CI (0.17, 3.04), $P = 0.028$). The remnant-preservation group had higher Lysholm scores (Figure 5).

3.4.5. IKDC scores
Three studies demonstrated postoperative IKDC scores, with no heterogeneity being found among the studies ($P = 0.790$, $I^2 = 0\%$). Using the fixed-effects model, 71 patients in the remnant-preservation group and 104 patients in the standard group were analyzed with no significant difference in the postoperative IKDC scores (WMD = 0.07, 95% CI (−1.53, 1.67), $P = 0.934$) (Figure 6).

3.4.6. IKDC grades
Three studies included IKDC grades, and no heterogeneity was found among the studies ($P = 0.585$, $I^2 = 0\%$). The 106 patients in the remnant-preservation group and 104 patients in the standard group were analyzed using the fixed-effects model, with no significant difference being found between the two groups (RR = 1.158, 95% CI (0.978, 1.372), $P = 0.088$) (Figure 7).

3.4.7. Cyclops lesion
The incidence of cyclops lesions was compared in three studies, with no heterogeneity being found among the studies ($P = 0.813$, $I^2 = 0\%$). The fixed-effects model was used to analyze 81 patients in the remnant-preservation group and 85 patients in the standard group, showing no significant difference in the incidence of cyclops lesion between the two groups (RR = 1.51, 95% CI (0.84, 2.70), $P = 0.167$) (Figure 8).

3.4.8. Percentage of tibial tunnel enlargement
Two studies compared the percentage of tibial tunnel enlargement from the completion of operation to the last follow-up. Heterogeneity was found among the studies ($P = 0.067$, $I^2 = 70.3\%$). The random-effects model was used to analyze 47 patients in the remnant-preservation group and 44 patients in the standard group, showing a significant

Fig. 3. Forest plot of negative pivot shift test.

Fig. 4. Forest plot of negative Lachman test.
difference in the percentage of tibial tunnel enlargement (WMD = 5.65, 95% CI (1.81, 9.49), P = 0.004). The percentage of tibial tunnel enlargement in the remnant-preservation group was less than that in the standard group (Figure 9). The percentage of tibial tunnel enlargement in one study was 6.6 ± 0.8% and 2.4 ± 0.3%, and 34 ± 8.9% and 25.7 ± 6.7% in the other, with significantly different results. The allograft was used in one study and planted in the other. These factors may have caused the obvious heterogeneity.

3.4.9. Publication bias

For anterior laxity, used as an indicator in most studies as an example, Begg’s test was used to access the publication bias, showing the lack of bias among the included studies (Begg’s test, P = 0.806, Figure 10).

4. Discussion

Remnant preservation has been attributed to have an important role in ACL reconstruction. However, its actual effectiveness is still debatable. Several studies have shown that the remnant-preservation technique can obtain similar clinical effects to the standard technique of ACL reconstruction [30–32]. Moreover, some researchers have concluded that in ACL reconstruction, the remnant-preservation technique is superior to the standard technique in terms of the position sense and anterior stability [14,18]. On the contrary, others have claimed that remnant preservation may increase the risk of impingement and cyclops formation [20–22]. In the present study, the clinical performances of the ACLs reconstructed with the two techniques were compared in terms of anterior stability, functional recovery, and common complications.

The biology of graft healing is a process of ‘creeping substitution’ [33,34]. In theory, the preserved remnant may accelerate the revascularization and ligamentation of the graft, and provide better synovial coverage, as well as improve its incorporation and the proprioception of the knee [35–38]. Animal studies have also proven that remnant preservation may facilitate faster graft-bone healing and achieve better biomechanical properties [39–41]. Gohil et al. compared the postoperative revascularization time between the remnant preservation and the standard techniques [15]. The results showed that the high signal intensity of vascularization manifested six months after surgery in the remnant-preservation group. Further, no significant difference was found between the two groups at the one-year follow-up, indicating that the grafts were revascularized earlier in the preservation group. However, the clinical outcomes were similar between the two groups. Ahn et al. conducted a
secondary arthroscopic examination in patients who underwent remnant-preserving ACL reconstruction, showing that 91% of the grafts received good synovial coverage [30]. However, Hong et al. found that the grafts in the standard technique group also received good synovial coverage, as did those in the remnant-preservation group [28].

Therefore, better synovial coverage on the graft implies better integration with the implant and, as a result, possible better clinical outcomes. In the present research, the stability outcome indicators were the KT arthrometer, the pivot shift test, and the Lachman test; no significant difference was found in stability between the two techniques. This indicates that the graft strengths of the reconstructed ACLs in both techniques are similar and that remnant preservation may not enhance the biomechanical properties of the reconstructed ACLs. With respect to knee function, the results in the present research showed no significant difference in IKDC evaluation. A mean difference of 1.6 was found in the Lysholm score between the two techniques, in favor of the remnant-preservation technique. Although statistically different, the minor difference is clearly clinically insignificant and not sufficient to differentiate the function of the knees. It is generally accepted that the main aim of ACL remnant preservation is to restore and improve the proprioceptive function of the knee after ACL reconstruction. However, Hong’s research, which was included in the present study, demonstrated that remnant-preserving ACL reconstruction had no evident advantages over the standard technique in terms of proprioception recovery [28]. However, the remaining five studies included in the present meta-analysis did not involve this outcome indicator in their original research; therefore, the proprioception between the two ACL reconstruction techniques could not be compared. Overall, it can be concluded that there is no difference in functional recovery between the remnant-preserving technique and the standard single-bundle technique of ACL reconstruction. At this stage, it is clear that the theoretical advantages do not translate into a superior clinical performance of the remnant-preserving reconstruction over the standard reconstruction.

A common complication of ACL reconstruction is widening in the bone tunnel, which has been shown to be related to adverse clinical outcomes [42]. An enlarged tunnel may compromise the clinical

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**Fig. 7.** Forest plot of IKDC grades.

**Fig. 8.** Forest plot of the incidence of cyclops lesion.
outcome of the reconstructed ACL and cause further complications when the reconstructed ACL needs revision surgery. Thus, surgeons must aim to avoid or reduce tunnel enlargement. It has been found that the intra-articular synovial fluid contains osteolytic cytokines that increase during ACL injury or reconstruction [43,44]. After ACL reconstruction, the synovial fluid may seep into the gap between the graft and bone tunnel, and widen the tunnel by osteolysis. In the present study, the results indicated that remnant preservation could prevent tibial tunnel widening, with a significantly lower percentage of tunnel enlargement. The postoperative leakage of synovial fluid into the tibial tunnel is reduced by remnant preservation, in turn reducing the spread of cytokines and their osteolytic effects [45].

Extension loss after ACL reconstruction may be associated with the formation of a ‘cyclops’, a fibrous nodule with a central area of vascularized granulation tissue that maturates similarly to a healing scar [46,47]. In the present study, the incidence of cyclops lesion was no different between the two techniques, which may have been partially due to the formation of the cyclops lesion being stimulated by drilling and preparation of the tibial tunnel, and not the ACL stump [48].

The limitations of this study were as follows: [1] in the included studies, the grafts used for ACL reconstruction were not of the same type, ranging from autologous and allogeneic grafts to hamstring tendons and bone–patellar tendon–bone grafts. Moreover, the devices used for graft fixation were also different. All of these factors may have interfered with the outcome. [2] The longest follow-up duration in the studies was approximately two years, which may not have been sufficiently long to evaluate the difference between the two techniques. [3] The main aim of remnant preservation in ACL reconstruction is to restore the proprioceptive function of a joint, but only one study compared this function with and without ACL remnant preservation among the included studies. [4] The whole sample size was not large, which may have influenced the outcome.

5. Conclusion

The outcome of single-bundle ACL reconstruction with the remnant-preservation technique is similar to that with the standard technique in terms of anterior stability and functional recovery of the knee. Remnant...
preservation in ACL reconstruction decreases the percentage of tibial tunnel enlargement.

Conflict of interest statement
The authors declare no conflict of interest.

Acknowledgments
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