Article

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Abstract: The aim of this analysis was to compare the functional outcomes, knee stability, and complications of patients after the arthroscopic double-bundle anterior cruciate ligament (ACL) reconstruction with those of single-bundle ACL reconstruction. An electronic search of the PubMed, EMBASE and Cochrane Library databases was performed. The analyzed outcomes were Lysholm scores, Tegner scores, subjective and objective International Knee Documentation Committee Scores (IKDC), Pivot-shift test, Lachman test, KT-1000/2000 measurement and complications. A total of 26 randomized controlled trials were available for this meta-analysis. The final results suggested that the double-bundle ACL reconstruction showed significant better outcomes in both functional outcomes and stability of knee joint, as assessed by the Lysholm scores, Tegner scores, objective IKDC, Pivot-shift test, Lachman test, and KT-1000/2000 (P<0.05). However, we found no evidence of a difference in subjective IKDC and complication rate. Based on current evidence, double-bundle ACL reconstruction appears to yield better outcomes when compared with single-bundle ACL reconstruction. However, the results should be interpreted with caution and further large-scale, well-designed RCTs on this topic are still needed.

Keywords: Single-bundle, double-bundle, anterior cruciate ligament, reconstruction, meta-analysis

Introduction

The anterior cruciate ligament (ACL) is an important structure that is located within the knee joint, and plays an important role in stabilizing the knee. Anatomical and biomechanical studies have demonstrated that normal ACL can be divided into anteromedial bundle and posterolateral bundle [1, 2], and it acts to prevent anterior translation of the tibia relative to the femur as well as to control rotational movements within the knee joint. The anteromedial bundle is almost vertically oriented in the coronal plane, which means that it is only able to withstand little rotational tibial load. The posterolateral bundle, on the other hand, is thought to control tibial rotation more effectively, as its orientation is almost horizontal. It seems that the two bundles work in a synergistic manner during the movement to stabilize the knee under both anteroposterior and rotational tibial torque [3].

ACL disruption, usually as a result of sports activities, is the most common cause of instability of the knee joint [4]. Nowadays, surgical interventions have been developed to restore stability and allow patients to possess a more active life. Arthroscopic single-bundle ACL reconstruction with autologous tendons is a commonly performed procedure. Normally, single-bundle ACL reconstruction primarily reproduces the anteromedial bundle. Nevertheless, without the posterolateral bundle, reconstructed ACL could not withstand rotational load [5]. In order to reproduce a ligament that is more similar to the original ACL, double-bundle ACL reconstruction procedures have been developed.

Although both single- and double-bundle ACL reconstructions have been used, it remains debatable which technique has much more advantages based on current evidence [6, 7]. In recent years, several meta-analyses on this
topic have been published [8-11], but if the double-bundle is better than single-bundle technique still could not be determined. Besides, these studies did not distinguish short- and long-term outcomes clearly. Pooling these results together would absolutely increase the heterogeneity among studies. Furthermore, several randomized controlled trials (RCTs) have been published in recent years [12-15]. These studies might change some of the meta-analysis results because of the increased sample size. In order to identify and summarize the best available evidence, we carried out this up-to-date meta-analysis, pooled relevant data from all available RCTs, and tried to compare the results of the double-bundle ACL reconstruction with those of single-bundle reconstruction. Our null hypothesis is that there is no difference in outcomes between the single-bundle and double-bundle ACL reconstruction.

Materials and methods

**Literature search and inclusion criteria**

We searched the PubMed, EMBASE and Cochrane Library databases for studies that had been published before December 2015. The search strategies used the following format of search terms: (anterior cruciate ligament OR ACL) AND (surgery OR surgical OR reconstruction OR reconstructed OR reconstructive). The search was limited to English-language, human subjects, and RCTs. In addition, reference lists of all the selected articles were hand-searched to identify other potentially eligible trials. This process was performed iteratively until no additional articles could be identified.

The following inclusive selection criteria were applied: (1) study design: RCTs; (2) population: patients with a symptomatic rupture of the ACL; (3) intervention: anatomic double-bundle ACL reconstruction; (4) comparison: single-bundle ACL reconstruction; (5) outcomes: functional outcomes, stability of knee joint and complications. Trials were excluded if they (1) were abstracts, letters, reviews, or case reports; (2) had repeated data; and (3) did not report outcomes of interest.

**Data extraction and outcome measures**

We extracted data that included the general characteristics and the evaluated outcomes of each study. General characteristics referred to first author, year of publication, country, numbers of patients in each groups, mean length of follow-up, and types of implant. The outcomes involved three aspects: functional outcomes, stability of knee and adverse events, which included Lysholm scores, Tegner scores, subjective and objective International Knee Documentation Committee Scores (IKDC), Pivot-shift test, Lachman test, KT-1000/2000 measurement and complications.

Functional evaluation was performed with Lysholm scores, Tegner scores and IKDC. According to the objective IKDC scale, a normally functioning knee is graded as A, a normally functioning knee is graded as B, a fairly functioning knee is graded as C and a poorly functioning knee is graded as D. This scale was treated as a dichotomous outcome: grade A was normal and other grades were abnormal.

The stability of the knee joint was evaluated by Pivot-shift test, Lachman test and KT1000/
### Table 1. The basic characteristics of the included studies and participants

<table>
<thead>
<tr>
<th>First author</th>
<th>Publication year</th>
<th>Country</th>
<th>Mean age (years)</th>
<th>Total number</th>
<th>Single-bundle group</th>
<th>Double-bundle group</th>
<th>Mean follow-up (months)</th>
<th>Implant</th>
<th>Outcome</th>
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<tbody>
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<td>Adachi</td>
<td>2004</td>
<td>Japan</td>
<td>29.4</td>
<td>108</td>
<td>55</td>
<td>53</td>
<td>31.5</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>KT-2000 measurements</td>
</tr>
<tr>
<td>Jarvela</td>
<td>2007</td>
<td>Finland</td>
<td>33</td>
<td>55</td>
<td>25</td>
<td>30</td>
<td>14 (12-20)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Objective IKDC scores, Lysholm scores, Pivot-shift test, complications</td>
</tr>
<tr>
<td>Muneta</td>
<td>2007</td>
<td>Japan</td>
<td>23.7</td>
<td>68</td>
<td>34</td>
<td>34</td>
<td>25.3 (18-41)</td>
<td>Semitendinosus tendons</td>
<td>Pivot-shift test, Lachman test, KT-1000 measurements, complications</td>
</tr>
<tr>
<td>Jarvela</td>
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<td>Finland</td>
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<td>77</td>
<td>52</td>
<td>25</td>
<td>&gt;24 (24-35)</td>
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<td>Objective IKDC scores, Lysholm scores, Pivot-shift test, KT-1000 measurements, complications</td>
</tr>
<tr>
<td>Siebold</td>
<td>2008</td>
<td>Germany</td>
<td>28.5</td>
<td>70</td>
<td>35</td>
<td>35</td>
<td>19 (13-24)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, objective IKDC scores, Lysholm scores, Pivot-shift test, KT-1000 measurements, complications</td>
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<tr>
<td>Streich</td>
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<td>Germany</td>
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<td>49</td>
<td>25</td>
<td>24</td>
<td>24</td>
<td>Semitendinosus tendons</td>
<td>Subjective IKDC, Objective IKDC scores, Lysholm scores, Tegner scores, Pivot-shift test, KT-1000 measurements, complications</td>
</tr>
<tr>
<td>Zaffagnini</td>
<td>2008</td>
<td>Italy</td>
<td>26.5</td>
<td>72</td>
<td>35</td>
<td>37</td>
<td>36</td>
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<td>Objective IKDC scores, Tegner scores, Pivot-shift test, KT-2000 measurements</td>
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<tr>
<td>Ibrahim</td>
<td>2009</td>
<td>Kuwait</td>
<td>--</td>
<td>200</td>
<td>150</td>
<td>50</td>
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</tr>
<tr>
<td>Aglietti</td>
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<td>Italy</td>
<td>28</td>
<td>70</td>
<td>35</td>
<td>35</td>
<td>24</td>
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<td>Subjective IKDC scores, Pivot shift test, KT-1000 measurements, complications</td>
</tr>
<tr>
<td>Volpi</td>
<td>2010</td>
<td>Italy</td>
<td>28.5</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td>29.5</td>
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<td>Objective IKDC scores</td>
</tr>
<tr>
<td>Araki</td>
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<td>Japan</td>
<td>25</td>
<td>20</td>
<td>10</td>
<td>10</td>
<td>12.7</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Lysholm scores, Pivot shift test, Lachman test, KT-1000 measurements</td>
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<tr>
<td>Fujita</td>
<td>2011</td>
<td>Japan</td>
<td>25.2</td>
<td>55</td>
<td>37</td>
<td>18</td>
<td>32.9</td>
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<td>Lysholm scores, Pivot-shift test, KT-1000 measurements, complications</td>
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<tr>
<td>Hemmerich</td>
<td>2011</td>
<td>South Africa</td>
<td>30.2</td>
<td>32</td>
<td>17</td>
<td>15</td>
<td>5.2</td>
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<tr>
<td>Suomalainen</td>
<td>2011</td>
<td>Finland</td>
<td>32</td>
<td>121</td>
<td>60</td>
<td>61</td>
<td>27</td>
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<td>Objective IKDC scores, Pivot-shift test, KT-1000 measurements, complications</td>
</tr>
<tr>
<td>Ochiai</td>
<td>2012</td>
<td>Japan</td>
<td>27.8</td>
<td>84</td>
<td>44</td>
<td>40</td>
<td>24</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, Lysholm scores, Tegner scores, Pivot-shift test</td>
</tr>
<tr>
<td>Gobbi</td>
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<td>Italy</td>
<td>30.4</td>
<td>60</td>
<td>30</td>
<td>30</td>
<td>46.2 (36-60)</td>
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<td>Subjective IKDC scores, Objective IKDC scores, Lysholm scores, Tegner scores, Pivot-shift test, KT-1000 measurements</td>
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<tr>
<td>Hussein</td>
<td>2012</td>
<td>Slovenia</td>
<td>32.9</td>
<td>209</td>
<td>78</td>
<td>131</td>
<td>51.1 (39-63)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, Objective IKDC scores, Lysholm scores, Pivot-shift test, KT-1000 measurement</td>
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</tbody>
</table>
## Single-bundle versus double-bundle ACL reconstruction

<table>
<thead>
<tr>
<th>Author(s)</th>
<th>Year</th>
<th>Country</th>
<th>Age Mean</th>
<th>Follow-up Mean</th>
<th>Location</th>
<th>Tissue Used</th>
<th>Measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lee</td>
<td>2012</td>
<td>Korea</td>
<td>30.3</td>
<td>19</td>
<td>24</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, objective IKDC scores, Lysholm scores, Tegner scores, Pivot-shift test, Lachman test, KT-1000 measurements</td>
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<tr>
<td>Nunez</td>
<td>2012</td>
<td>Spain</td>
<td>30.7</td>
<td>29</td>
<td>24</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, Objective IKDC scores, Lysholm scores, Pivot-shift test, KT-1000 measurement</td>
</tr>
<tr>
<td>Suomalainen</td>
<td>2012</td>
<td>Finland</td>
<td>32.3</td>
<td>20</td>
<td>60</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Objective IKDC scores, Lysholm scores, Pivot-shift test, Lachman test, KT-1000 measurements</td>
</tr>
<tr>
<td>Ahlden</td>
<td>2013</td>
<td>Sweden</td>
<td>--</td>
<td>50</td>
<td>26 (22-42)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Subjective IKDC scores, Lysholm scores, Pivot-shift test, Lachman test, KT-1000 measurements</td>
</tr>
<tr>
<td>Xu</td>
<td>2014</td>
<td>China</td>
<td>31.7</td>
<td>34</td>
<td>16.3 (12-36)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Objective IKDC scores, Lysholm scores, Tegner scores, Pivot shift test, KT-1000 measurements</td>
</tr>
<tr>
<td>Zhang</td>
<td>2014</td>
<td>China</td>
<td>--</td>
<td>45</td>
<td>24</td>
<td>Semitendinosus tendons, gracilis tendons</td>
<td>Lysholm scores, Tegner scores, complications</td>
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<tr>
<td>Koga</td>
<td>2015</td>
<td>Japan</td>
<td>24.5</td>
<td>28</td>
<td>69 (36-140)</td>
<td>Semitendinosus tendons</td>
<td>KT measurements, Lysholm score, Tegner score, Pivot-shift test, Lachman test, complications</td>
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<tr>
<td>Mayr</td>
<td>2015</td>
<td>Germany</td>
<td>38.5</td>
<td>28</td>
<td>34</td>
<td>26 (23.3-32.7)</td>
<td>Semitendinosus tendons, gracilis tendons</td>
</tr>
</tbody>
</table>

IKDC, International Knee Documentation Committee Scores.
2000 measurement. The Pivot-shift test was categorized as normal (negative), nearly normal (1+), abnormal (2+) and severely abnormal (3+). We recorded the number of individuals with negative pivot-shift test for meta-analysis.

The complications are the composite of meniscus secondary tear, wound infections, graft failures, re-rupture of ligament, Cyclops lesions as well as pain.

For continuous outcomes with no standard deviations reported, we tried to calculate standard deviations from standard errors and sample numbers; if a group was divided into several subgroups, the members, means and standard deviations were combined according to the methods described in the Cochrane Handbook for Systematic Reviews of Interventions [16]. Data were extracted independently by two authors. Any disagreements were resolved by discussion and consensus.

Assessment of methodological quality

The methodological quality of the studies was evaluated independently by two independent authors, without masking the trial names. The reviewers followed the instructions provided in the Cochrane Handbook for Systematic Reviews of Interventions [16]. The following domains were assessed: random sequence generation, allocation concealment, blinding, incomplete data outcomes, revealing of selective outcomes and any remaining biases.

Statistical analysis

Differences were expressed as risk ratios (RRs) with 95% confidence intervals (CIs) for dichotomous outcomes and mean differences (MDs) with 95% CIs for continuous outcomes. Heterogeneity was analyzed with both the chi-square test and the $I^2$ test. A $P$ value of <0.10 for the chi-square test was interpreted as evidence of statistical heterogeneity, and $I^2$ was used to estimate total variation across the studies. A fixed-effect model was adopted if there was no statistical evidence of heterogeneity, and a random-effect model was adopted if statistically significant heterogeneity was present. Studies with an $I^2$ statistic of 0%-25% were considered to have minor heterogeneity, those with an $I^2$ statistic of 25%-50% had low heterogeneity, those with an $I^2$ statistic of 50%-75% had moderate heterogeneity, and those with an $I^2$ statistic of >75% had high heterogeneity.

As the types of implant were not consistent between studies, we conducted sensitivity analysis to identify potential sources of heterogeneity. Furthermore, to examine the influence of follow-up on the overall results, we further carried out subgroup analysis. If the mean length of follow-up was less than 24 months, it was considered as short-term; otherwise, it was long-term.

A funnel plot was created to assess for publication bias, and bias can be seen if the plot is widely skewed. All statistical analyses were performed using Review Manager version 5.1 (The Cochrane Collaboration, Software Update, Oxford, UK). $P$ value <0.05 was judged as statistically significant, except where otherwise specified.

Results

Study identification and selection

A total of 328 records were identified by the initial database search. One hundred and thirty-seven records were excluded because of duplicates and 161 were excluded for various reasons (reviews, non-randomized studies, or not relevant to our analysis) on the basis of the titles and abstracts. The remaining 30 were retrieved for full text review, and 4 were excluded because they reported irrelevant outcomes.
Finally, 26 studies that met our inclusion criteria were included in the present meta-analysis [12-15, 17-38]. The selection process for RCTs included in the meta-analysis is shown in Figure 1.

Study characteristics

The main characteristics of the 26 citations included in the meta-analysis are presented in Table 1. These studies were published between 2004 and 2015. The sample sizes of the studies ranged from 20 to 209 patients, and the mean length of follow-up ranged from 5.2 to 69 months. All studies reconstructed ACL with hamstring tendons (semitendinosus and gracilis), with the exception of one study using both hamstring tendons and bone-patellar tendon-bone autograft [28]. Studies reported by Muneta et al. [36] and Koga et al. [13], as well as Jarvela et al. [35, 37] and Suomalainen et al. [18, 25] were considered to be the materials being reported in different ways or different follow-up time. We extract the most informative data to avoid duplication of information.

Assessment of risk of bias

The risk of bias is demonstrated graphically in Figure 2 and summarized in Figure 3. The randomization technique was mentioned in all trials. However, only 6 trials described the process of random sequence generation [15, 19, 23, 29, 32, 34], and 11 trials stated the method of allocation concealment [12, 14, 17-19, 23, 25, 27, 31, 35, 37]. Blinding is rarely used in orthopedic surgery trials but 16 studies were blinded in the assessment of outcome [13, 17-19, 21, 23-25, 29, 31-36, 38]. Five trials were judged to be at high risk of attrition bias [25, 28, 32, 36, 38], but the other 14 were at low risk [12-14, 17, 19, 22-24, 27, 29-31, 33, 34].

Outcomes

Lysholm scores: Information on the Lysholm scores was provided in 13 studies. The test for heterogeneity was not significant, and the studies have low heterogeneity ($P$ for heterogeneity = 0.11; $I^2$ = 35%). Using the fixed-effect model, the aggregated results suggested that the
Lysholm scores were lower in the single-bundle group in comparison to the double-bundle group at a statistically significant level (MD, -0.84; 95% CI, -1.67 to -0.02; P = 0.05) (Figure 4).

The subgroup analysis showed that there was no significant difference regarding the Lysholm scores between the two groups in a short-term follow-up (MD, 0.71; 95% CI, -2.20 to 3.62; P = 0.63); however, in the long-term follow-up,
Single-bundle versus double-bundle ACL reconstruction

Patients in double-bundle group had a significantly higher Lysholm scores compared with those in single-bundle group (MD, -0.92; 95% CI, -1.79 to -0.05; P = 0.04) (Table 2).

Tegner scores: Six RCTs reported the Tegner scores in study patients. The test for heterogeneity was not significant, and the studies have minor heterogeneity (P for heterogeneity = 0.08; I² = 15%). Using the fixed-effect model, the aggregated results suggested that there was no significant difference in subjective IKDC between the single-bundle and double-bundle groups (MD, -1.10; 95% CI, -2.33 to 0.14; P = 0.08) (Figure 6).

After subgroup analysis, we found that there was no significant difference regarding the Tegner scores between the two groups in a short-term follow-up (MD, -0.39; 95% CI, -0.98 to 0.20; P = 0.20); however, in a long-term follow-up, patients in double-bundle group had a significantly higher Tegner scores compared with those in single-bundle group (MD, -0.25; 95% CI, -0.35 to -0.16; P<0.01) (Table 2).

Subjective IKDC: Subjective IKDC was reported in 10 studies. The test for heterogeneity was not significant, and the studies have minor heterogeneity (P for heterogeneity = 0.08; I² = 15%). Using the fixed-effect model, the aggregated results suggested that there was no significant difference in subjective IKDC between the single-bundle and double-bundle groups (MD, -1.10; 95% CI, -2.33 to 0.14; P = 0.08) (Figure 6).

The subgroup analysis showed that there was no significant difference between the two groups in neither short-term follow-up (MD, 0.61; 95% CI, -2.13 to 3.34; P = 0.66) nor long-term follow-up (MD, -1.19; 95% CI, -3.23 to 0.85; P = 0.25) (Table 2).

Objective IKDC: Objective IKDC was reported in 10 studies. The test for heterogeneity was significant, and the studies have moderate heterogeneity (P for heterogeneity <0.01; I² = 68%). Using the random-effect model, the aggregated results suggested that there was a higher rate of normally functioning knee in double-bundle group compared with single-bundle group (RR, 0.83; 95% CI, 0.75 to 0.91; P<0.01) (Figure 7).

The subgroup analysis showed that there was no significant difference in rate of normally functioning knee.
functioning knee between double-bundle group and single-bundle group in neither short-term follow-up (RR, 0.50; 95% CI, 0.21 to 1.21; \( P = 0.12 \)) nor long-term follow-up (RR, 0.88; 95% CI, 0.77 to 1.01; \( P = 0.07 \)) (Table 2).

**Pivot-shift test:** A total of 15 studies provided data on Pivot-shift test. The test for heterogeneity was significant, and the studies have high heterogeneity (\( P \) for heterogeneity <0.01; \( I^2 = 84\% \)). Using the random-effect model, the rate of negative Pivot-shift test was significantly higher in double-bundle group compared with that in single-bundle group (RR, 0.79; 95% CI, 0.74 to 0.83; \( P < 0.01 \)) (Figure 8).

We further performed subgroup analysis, and the result showed that there was no significant difference regarding the rate of negative Pivot-shift test between the two groups in a short-term follow-up (RR, 0.85; 95% CI, 0.71 to 1.03; \( P = 0.09 \)); however, in a long-term follow-up, patients in double-bundle group had a significantly higher rate of negative Pivot-shift test compared with those in single-bundle group (RR, 0.79; 95% CI, 0.67 to 0.93; \( P < 0.01 \)) (Table 2).

**Lachman test:** There were 5 studies providing data on Lachman test. The test for heterogeneity was not significant, and the studies have minor heterogeneity (\( P \) for heterogeneity = 0.28; \( I^2 = 22\% \)). Using the fixed-effect model, the aggregated results suggested that there was significant higher rate of negative Lachman test in double-bundle group in comparison with
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Figure 9. Forest plot showing the comparison of the Lachman test between the single-bundle group and the double-bundle group. CI = confidence interval.

Figure 10. Forest plot showing the comparison of the KT-1000/2000 measurement between the single-bundle group and the double-bundle group. CI = confidence interval.

As all data were in long-term follow-up, subgroup analysis did not provide any new information.

KT-1000/2000 measurement: A total of 14 RCTs reported the KT-1000/2000 measurement in study patients. The test for heterogeneity was significant, and the studies have moderate heterogeneity (P for heterogeneity <0.01; I^2 = 60%). Using the random-effect model, the aggregated results suggested that the KT-1000/2000 measurement was significant lower in the double-bundle group in comparison with the single-bundle group (MD, 0.44; 95% CI, 0.07 to 0.82; P = 0.02) (Table 2).

Complications: Complications were reported in 10 studies. The test for heterogeneity was not significant, and the studies have minor statistical evidence of heterogeneity (P for heterogeneity = 0.42; I^2 = 3%). Using the fixed-effect model, the aggregated results suggested that there was no significant difference in complication rate between the single-bundle and double-bundle groups (RR, 1.46; 95% CI, 0.85 to 2.51; P = 0.17) (Figure 11).

The subgroup analysis showed that there was no significant difference between the two groups in neither short-term follow-up (RR, 2.56; 95% CI, 0.72 to 9.11; P = 0.15) nor long-term follow-up (RR, 1.22; 95% CI, 0.68 to 2.19; P = 0.51) (Table 2).
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Sensitivity analysis: The exclusion of one study [28] using both hamstring tendons and bone-patellar tendon-bone autograft did not affect the statistical significance of any of the meta-analysis outcomes.

Publication bias

Figure 12 were a funnel plot of 13 studies pooled for Lysholm scores, and the plot showed mild asymmetry, but nearly all studies fall within the 95% CI axis for a given standard error. Thus, there is minimal evidence of publication bias.

Discussion

As an effective method for integrating valid information, meta-analysis can provide a foundation for making clinical decisions. In this analysis, we collected evidence from outcomes of RCTs that compared single-bundle ACL reconstruction with double-bundle reconstruction. The final results of our review suggests that the double-bundle ACL reconstruction could have significantly better outcomes in both functional outcomes and stability of knee joint, as assessed by the Lysholm scores, Tegner scores, objective IKDC, Pivot-shift test, Lachman test, and KT-1000/2000 measurement. However, we found no evidence of a difference in subjective IKDC and complication rate. These findings may be useful for surgeons in clinical practice.

Usually, better functional outcomes are the primary goal of surgeons. Although some studies have supported the evidence that the clinical outcomes of double-bundle ACL reconstruction are superior to those of single-bundle reconstruction [6, 13], some trials have not found significant differences in clinical outcomes between the two techniques [7, 39].

In a previous meta-analysis conducted by Li et al. [9], Lysholm scores and Tegner scores showed no significant difference between the two ACL reconstruction techniques. However, an apparent limitation of this meta-analysis is that it did not take the length of follow-up into account.
consideration, which was important to the assessment of clinical outcomes. In this study, we included some new RCTs and divided these trials into the short-term group (<24 months) and long-term group (≥24 months) according to the length of follow-up. In the short-term subgroup, there was no significant difference in Lysholm scores and Tegner scores between the single-bundle and double-bundle groups. However, in the long-term subgroup, double-bundle technique results in significantly higher scores when compared with the single-bundle technique. From the above results, we can make a consideration that possibly because of the reconstruction of the posterolateral bundle, the double-bundle technique yields a better clinical outcome when compared with the SB technique in a long-term follow-up.

Although the result showed a significant difference in the objective IKDC grading, we could not detect the significant difference in the subjective IKDC score between the two techniques. This could be due to the fact that objective and subjective IKDC scores are different measurements, and the subjective score may not be sensitive enough to detect the discrepancy resulting from the restoration of anatomical structure and the stability of knee.

Pivot-shift test, Lachman test and KT-1000/2000 measurement were used in this study to evaluate the stability for ACL reconstruction. Among them, Pivot-shift test was designed to evaluate knee rotational instability, and side-to-side anteroposterior stabilization was measured with KT-1000/2000 and Lachman test. Previous cadaveric and biomechanical studies had proved that single-bundle anteromedial or posterolateral reconstruction alone was insufficient in controlling the combined rotatory load and valgus torque, and double-bundle ACL reconstruction was better for control of knee rotational instability \[40, 41\]. However, Desai et al. \[8\] pooled 15 studies and concluded that anatomic double-bundle ACL reconstruction did not lead to significant improvements in Pivot-shift test, Lachman test, or anterior drawer test compared with single-bundle ACL reconstruction. In contrast to their findings, our study supported the other previously published studies and demonstrated that double-bundle reconstruction is superior to the single-bundle technique in restoring anterior and rotational stability, as evidenced by the Pivot shift test, Lachman test, and KT-1000/2000 measurements. Based on the current studies, we assumed that double-bundle reconstruction of ACL is a better technique, which had an advantage of preventing anterior translation of the tibia relative as well as controlling rotational movements within the knee joint.

As graft failures were few among either group, we analyzed some adverse events after surgery. In the current meta-analysis, we found results pointing to a trend favoring double-bundle reconstruction when it comes to adverse events without being able to show statistically significant difference, and our data concur with a prior study \[9\]. However, more studies are still needed to draw a definite conclusion.

We acknowledge that this study has several limitations. First, the general lack of random sequence generation and allocation concealment methods in some included RCTs decreased the methodological quality, and there were the potential to overestimate the effect. Second, it is usually impossible to blind surgeons regarding surgical procedures, so performance bias is inevitable in the present meta-analysis. Third, the length of follow-up and study quality varied across the studies, which was a definite source of heterogeneity and would impact the final results. Finally, we only included English-language studies. Despite our best efforts to use multiple literature search approaches, we may have omitted some non-English-language studies with results that may have been applicable to our meta-analysis.

Despite these limitations, this study has clinical value. Overall, our meta-analysis demonstrated the superiority of double-bundle over single-bundle ACL reconstruction. Patients with double-bundle reconstruction of ACL could have better functional recovery and more stabilized knee, without increased complications. Therefore, we still recommend the use of double-bundle technique in the process of ACL reconstruction. Anyhow, the results should be interpreted with caution and further large-scale, well-designed RCTs on this topic are still in need.

**Disclosure of conflict of interest**

None.

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Single-bundle versus double-bundle ACL reconstruction

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Single-bundle versus double-bundle ACL reconstruction


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