Single Versus Double-Bundle PCL Reconstruction: Scientific Rationale and Clinical Evidence

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Abstract

Purpose of Review The goal of this paper is to review the biomechanical and clinical rationale for single-bundle versus double-bundle posterior cruciate ligament (PCL) reconstruction. The primary question is whether there has been demonstrated any clear biomechanical or clinical superiority of a double-bundle reconstruction over a single-bundle reconstruction.

Recent Findings There is some recent evidence demonstrating biomechanical superiority of double-bundle versus single-bundle reconstruction; however, this is not definitive. Clinical superiority has not been clearly demonstrated as of yet.

Summary The primary question which served as the basis of this review remains unanswered. There is recent biomechanical data to suggest a potential benefit of double-bundle versus single-bundle reconstruction, but not all studies are in agreement. Furthermore, the possible biomechanical advantages have not yet been borne out in clinical studies. At this point, we cannot clearly recommend one technique versus another and the decision should be left to the treating surgeon.

Keywords Posterior cruciate ligament · Double bundle · Knee injury · Ligament reconstruction

Introduction

The posterior cruciate ligament (PCL) is the main posterior stabilizer of the knee and is a unique knee ligament in that it is intra-synovial, yet extra-articular. Isolated injuries to the PCL are rare (annual incidence 2 per 100,000 persons) and are most commonly associated with concomitant ligament tears, articular cartilage injuries, and meniscal pathology. In fact, PCL

injuries in association with a posterolateral corner injury are far more common than an isolated PCL injury [1, 2].

One to 44% of reported knee injuries include an acute PCL injury, and the incidence of sport-specific PCL injuries ranges from 1–4% [1, 3, 4]. While overall sport-specific PCL injuries are reported between 2 and 3%, recent NFL data demonstrates PCL injuries in 3% of the player population [5, 6].

PCL tears are high energy injuries, and it has been reported that up to 87% of PCL injuries are part of a multi-ligamentous knee injury [7]. In another study, 95% of patients with PCL injuries that report to the emergency department have concomitant ligamentous injuries [8]. Upon initial evaluation, it is mandatory to perform a thorough examination of all the ligaments of the knee when a PCL injury is suspected.

Traditionally, PCL injuries have not been treated with surgery as frequently as other knee ligament injuries such as anterior cruciate ligament (ACL) tears. Historically, published outcomes of PCL reconstruction are not as favorable as ACL reconstruction [9]. Factors that may contribute to this discrepancy include surgical technique, familiarity with the procedure by surgeons, and variability in surgical procedures such as graft selection, fixation methods, tunnel placement, number and location of bundles, tensioning protocols, and postoperative rehabilitation programs. However, despite all of these factors, a recent systematic review has shown that surgical

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treatment of isolated PCL tears with reconstruction produces more consistent stability and higher satisfaction when compared to non-operative management [10]. The purpose of this review is to examine the specific factors of anatomy, biomechanics, and clinical outcomes as they relate to single- versus double-bundle PCL reconstruction, with a focus on the most recently published literature.

Anatomy

As stated earlier, the PCL is intra-synovial, yet extra-articular. This unique anatomic finding is possible due to the posterior capsular synovial reflections that cover the lateral, medial, and anterior aspects of the ligament [9].

The PCL originates from the anterior lateral aspect of the medial femoral condyle and inserts on the PCL facet of the tibia, which is located 1–1.5 cm below the articular surface of the plateau on the posterior tibia [9, 11, 12]. The length and cross-sectional area of the PCL are 32–38 mm and 31.2 mm [2, 4, 12]. The width of the PCL mid-substance is 13.3 ± 2 mm [13].

The PCL consists of two bundles (a posterior medial bundle (PMB) and an anterior lateral bundle (ALB)), made distinct by their fiber orientation and variable tensioning patterns throughout knee range of motion. The ALB is the larger and stronger of the two bundles. The average femoral footprint of the two bundles is 192 mm², with an average tibial footprint of 219 mm². The ALB serves as the primary restraint to posterior tibial translation when the knee is at 90° of flexion, and the PMB functions as the primary restraint to posterior tibial translation with the knee near full extension as well as a secondary restraint to knee rotation [14].

The PCL is more than a ligament; it is a complex. The PCL complex consists of the PCL and two meniscomfemoral ligaments. These two ligaments originate from the lateral meniscus and insert on the femur anterior (ligament of Humphrey) and posterior (ligament of Wrisberg) to the PMB of the PCL [11, 14]. Cadaver studies have demonstrated at least one of these meniscomfemoral ligaments in 95% of specimens and both meniscomfemoral ligaments in 60% of specimens [11, 14, 15].

Biomechanics

Two key controversies surrounding PCL reconstruction are whether or not a double-bundle (DB) reconstruction provides biomechanical superiority over single-bundle (SB) reconstruction, and if either technique can replicate normal anatomy. Several factors complicate the ability to definitively answer this question, most notably the variability in different surgical techniques with respect to graft choices, tensioning techniques, tunnel positions,

fixation methods, and postoperative rehabilitation protocols. Previous studies on the SB technique have shown clinical and biomechanical efficacy at restoring the function of the anterolateral (AL) bundle, while the DB technique has been shown to restore knee kinematics similar to the intact knee [16–19]. In 2009, Kohen et al. reviewed the literature to date and failed to definitively determine an advantage of either technique [20]. Many more studies of SB and DB PCL reconstruction kinematics and biomechanics have been performed since then. Several recent review articles and systematic reviews have consolidated the published literature and found conflicting results regarding the optimal reconstruction technique with respect to biomechanical outcomes [21•, 22•, 23•]. Our review concentrates on more recent data, building upon the foundation of earlier studies, rather than reviewing previously described findings.

In 2010, Markolf et al. added to their previous work with an analysis of three reconstructive options in ten cadaveric specimens [24, 25]. They analyzed anterior-posterior laxity in the knee, graft length change, and mean forces at various flexion angles between 0 and 90°, and compared the values for an intact PCL to both a SB and two different types of DB reconstructions. They found that mean laxities for the SB were within 1.2 mm of normal at all flexion angles, and between 1.7–2.4 mm less than normal for the DB between 0 and 45°. The mean forces for the SB did not significantly differ from intact PCL forces at 0°, while the DB forces were 74–154 N higher. Additionally, it was found that the DB techniques contributed to increased external rotation of the tibia between 0 and 50° during passive knee extension, when compared to intact PCL knees.

In 2013, Wijdicks et al. compared SB and DB reconstructions to match-paired cadaveric specimens with sectioned PCLs [26]. They found that above 15° of knee flexion angle, and most notably at 105° of flexion, the DB reconstructions resulted in significantly decreased posterior tibial translation than SB reconstructions. Additionally, they found that at all flexion angles above 90°, the DB demonstrated improved rotational stability when compared to the SB reconstruction. Thus, this study analyzes a region of knee flexion (above 90°) not previously investigated by Markolf et al. and thereby concludes that DB PCL reconstructions more closely approximate native knee kinematics, especially at higher knee flexion angles. This is in agreement with previous work identifying the codominant relationship of the AL and PM bundles of the PCL, [16, 27, 28].

The codominant role of the AL and PM bundles of the PCL has been further investigated recently by Kennedy et al. [27]. Prior work reported that near-normal knee kinematics remained when the PMB was sectioned in isolation, providing an argument that an isolated reconstruction of the ALB will restore the knee to its near-normal state and be sufficient [29,

30]. However, Kennedy et al. demonstrated a similar finding with respect to knee kinematics when the ALB was sectioned in isolation and the PMB was left intact, in addition to showing that the PCL overall contributed a significant constraint to internal rotation beyond 90° of knee flexion [27]. This is further supported by work from Wijdicks et al. [26]. The authors' conclusion is that both the ALB and the PMB have a significant role in tibial translation across all knee flexion angles, in a codominant relationship.

Unfortunately, both of the previously described studies by Markolf et al. and Wijdicks et al., which report statistically improved anteroposterior stability of the knee with DB reconstructions, are in direct contrast to earlier work by Bergfeld et al. and Mannor et al. which showed no significant differences in the same metric between SB and DB reconstructions [24, 26, 31, 32]. These discrepancies are more easily explained when the details of the studies are reviewed and differences in graft characteristics, surgical techniques, and tensioning protocols are highlighted. Markolf et al. compared 11-mm bone-patellar tendon-bone (BTB) SB AL reconstructions with and without an additional 8-mm BTB PM bundle, thereby increasing the overall graft diameter of the DB technique as compared to the SB technique [24]. There is a theoretical advantage of overall increased cross-sectional graft area as an independent contributing factor to AP tibial translation. This is supported by the work of Bergfeld et al. in which there was no significant difference between SB and DB reconstructions with respect to AP stability when comparing SB to DB tibial inlay Achilles allograft reconstructions using the same overall size grafts [32]. To further confound the issue at hand, when critically evaluating this study which demonstrates equivalency of the SB technique, both techniques have been shown to result in increased posterior tibial translation of the knee (on average 5–7 mm for SB and 4–5 mm for DB) [32]. In essence, neither technique results in restoration of normal tibial translation.

Another study by Mutnal et al. in 2015 analyzed SB versus DB techniques in eight cadaveric specimens with posterior tibial translation as the primary outcome measure, yet they also factored in external tibial torque [33]. They found the only kinematic differences to be greater posterior translation in the DB group under external tibial torque across the entire flexion arc as well as specifically at 30° flexion [33]. They concluded that the SB technique more closely replicates the native knee rotational and translational kinematics than the DB approach [33]. With respect to addressing external rotation in addition to posterior tibial translation, Tsukada et al. presented data in a cadaveric study of eight knees measuring posterior tibial translation when a 100 N posterior force was applied with and without a 5-Nm external tibial torque [34]. They found that the DB reconstruction was better than the SB reconstruction at 0 and 30° of knee flexion without torque, and at 0° with applied external rotation torque. They concluded

that the DB PCL reconstruction might improve reducing knee laxity in extension, yet their main study limitation was similar to prior studies in that the overall graft size for the DB was not controlled for, and was significantly larger than the SB group [34].

Thus, given the conflicting biomechanical data across various procedural techniques, it is not possible to make a definitive conclusion with respect to the superiority of the DB versus SB technique when considering AP tibial translation.

Another biomechanical factor to consider is the in situ graft tension of the reconstruction within the knee. Markolf et al. more recently reported that graft tension with the SB technique was more closely related to those observed within the native knee than the DB reconstruction (showing increased graft tension) [24]. This is in direct contrast to previously published work by Harner et al. that reported improved in situ graft forces in DB reconstructions as compared to the SB technique [16]. These conflicting results highlight the complexity of this topic and the many factors that contribute to biomechanical endpoints of surgical reconstruction of the PCL. The ideal graft tension remains unknown, as there is support for both decreased tensions to protect the graft from early failure and elongation as well as increased tensions to initially protect secondary restraints in the knee. Again, as with AP tibial translation, the lack of clear supporting biomechanical data in favor of the DB technique prevents us from determining the advantage of the DB technique with respect to graft tensioning.

Clinical Outcomes

A number of studies have been published since 2004 comparing the clinical outcomes of SB and DB PCL reconstructions [35–42]. These are heterogeneous studies in terms of study design, number of patients, technique, graft selection, outcome measures, and follow-up. These studies are well summarized in two recent systematic reviews [21•, 43•].

The purpose of this review is to focus on more recent data. Since 2014, three clinical outcome studies and two systematic reviews have been published. In 2014, Li et al. published a prospective, randomized study of isolated SB versus DB PCL reconstructions using tibialis anterior allograft [44]. Twenty-two patients were included in the SB group and 24 in the DB group. There were no differences in patient demographics, time to surgery, or preoperative posterior translation between groups. Both groups followed the same rehabilitation protocol. At a minimum follow-up of 2 years, there were no significant differences in Lysholm or Tegner scores. However, there was a significant difference in posterior translation, as measured by KT-1000 at final follow-up (4.1 ± 1.3 SB versus 2.2 ± 1.3 DB). Also, the DB group had a better IKDC grade

distribution and the IKDC subjective score was statistically higher in the DB group (71.6 ± 6.7 versus 65.5 ± 7.8).

Deie et al. published their results in a retrospective comparison of SB versus DB reconstructions in patients with more than 10-year follow-up (mean 12.5 years) [45]. There were 27 cases in the SB group, but only 13 in the DB group. Preoperative characteristics were similar between groups. Combined ligament reconstructions (ACL, PLC, and MCL) were included in both groups. All patients in both groups had identical graft choice for the PCL (autograft hamstring) and postoperative rehabilitation protocols. Outcome measures included Lysholm scores, radiographic evaluation with the gravity sag view, and knee arthrometry. No significant differences were found among any measures between the SB and DB reconstruction groups.

Most recently, Jain et al. published a retrospective study of isolated SB versus DB reconstructions using hamstring autograft with a minimum 24-month follow-up [46]. There were 22 patients in the SB group and 18 in the DB group. Surgery in both groups was performed in a delayed fashion (average over 100 days after injury), and both groups underwent the same postoperative rehabilitation protocol. There were no significant differences in postoperative Lysholm or IKDC scores between the SB and DB reconstructions. The authors did report significant differences in KT-1000 data (2.44 mm SB versus 1.78 mm DB, p 0.0487) and posterior translation on kneeling X-ray (1.95 mm SB versus 1.33 mm DB, p 0.017), but the clinical relevance of these statistical differences is unclear.

Two recent systematic reviews have been published comparing outcomes of SB versus DB reconstructions [21•, 43•]. The study by Qi et al. found no differences in clinical outcomes, while the study by Chahla et al. found significantly improved objective posterior laxity and objective IKDC scores in the DB group, but no differences in patient-reported outcomes [21•, 43•]. Both reviews emphasized the methodological limitations of the studies that were included and the need for further high-quality research in this area.

Conclusions

Recent research into the anatomy and biomechanics of the PCL has led to the development of newer surgical techniques including double-bundle reconstructions and different tensioning protocols associated with this procedure. Unfortunately, biomechanical studies have shown conflicting results with respect to the effect of the DB reconstruction as it compares to SB reconstruction. Similarly, high-quality level 1 prospective studies are lacking with respect to clinical outcomes comparing the SB and DB reconstruction techniques, with many of our current recommendations and guidelines

based on lower-level studies or biomechanical data without clinical correlation. Despite this conflicting data, there are several clinical studies that have shown good to excellent short-term clinical outcomes with the DB reconstruction. Further research into the DB PCL reconstruction is warranted to more completely evaluate the clinical outcomes, further define the important details of the procedure, and report longer-term patient-reported outcomes.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

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