Journal of ISAKOS xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of ISAKOS

journal homepage: www.elsevier.com/locate/jisakos

The Classic

Review of Cha et al. (2005) on "Arthroscopic Double Bundle Anterior Cruciate Ligament Reconstruction: An Anatomical Approach"

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ARTICLE INFO

Keywords:
Anterior cruciate ligament
Knee instability
Ligament reconstruction

ABSTRACT

This classic discusses the original publication 'Arthroscopic double-bundle anterior cruciate ligament reconstruction (ACL): An anatomical approach', the first detailed description of the surgical technique popularised by Dr Freddie Fu. The technique, in which the anteromedial and posterolateral bundles of the ACL are reconstructed individually using two grafts with independent bone tunnels, was designed to more closely recreate the function of the native ACL by more closely reproducing the functional anatomy. This reconstruction was biomechanically superior to single-bundle reconstruction, particularly with regards to rotational control, leading to great interest from ACL surgeons around the world. Clinical superiority was more difficult to demonstrate; however, and the technical difficulty of the procedure has limited its use. Nevertheless, the pursuit of improved patient outcomes through attention to functional anatomical detail continues. 'Recreating the functional anatomy of the intact ACL remains the cornerstone of ACL reconstruction'.

Introduction

The saying 'form follows function' was originally coined by architect Louis H. Sullivan in an 1896 essay describing skyscraper design [1], but is readily applicable to many facets of the natural world and in particular to anatomy. In the field of orthopaedics, we have seen significant improvements in patient outcomes with the introduction of more anatomical techniques. Operations that respect and reproduce the native anatomy are less likely to restrict movement and lead to osteoarthritis than non-anatomical techniques. Examples include changes in our approach to the unstable shoulder, ankle, and patellofemoral joints.

With regards to surgery after injury to the anterior cruciate ligament (ACL), the approach has varied greatly over time. While some of the earliest attempts at reconstruction were quite anatomical in nature, many operations have been described to restrain instability which pay scant attention to the underlying anatomy and pathology.

The push towards more anatomical ACL reconstruction has been driven in no small part by the energy and enthusiasm of the late Dr Freddie Fu. His pursuit of improved outcomes via a more anatomical approach to ACL surgery has inspired countless surgeons and researchers. Beginning with biomechanical work investigating in situ forces in the ACL bundles in the late 1990's, through the development of his double-bundle (DB) reconstruction in the early 2000's, and encompassing embryology and cross-species anatomy, his contribution on the subject cannot be overstated.

Many articles from Dr Fu that could have been chosen as 'the classic' for anatomical ACL reconstruction. This paper by Cha et al. [2] has been selected not for its individual impact, but as it was the first published description of the double-bundle ACL technique we associate so closely with him today.

Summary of the classic

The authors present a technical note describing their novel technique for a more anatomical ACL reconstruction.

Firstly, the authors outline the anatomical and biomechanical rationale for their double bundle technique. Shortcomings of the single-bundle (SB) ACL reconstruction technique, in which only the anteromedial (AM) bundle of the ACL was reconstructed, are noted. The double-bundle anatomy of the ACL is described (Fig. 1), and complemented with supportive biomechanical data [3].

Next, the DB technique is described. This is the first detailed published description of the technique popularised by Dr Fu.

The technique involves reconstruction of both the anteromedial and posterolateral bundles of the ACL via independent bone tunnels (Fig. 2).

Prof Dr F Fu passed away in 2022.

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https://doi.org/10.1016/j.jisako.2023.02.005
Received 8 June 2022; Received in revised form 20 January 2023; Accepted 16 February 2023
Available online xxxx

Please cite this article as: Lording TD, Review of Cha et al. (2005) on "Arthroscopic Double Bundle Anterior Cruciate Ligament Reconstruction: An Anatomical Approach", Journal of ISAKOS, https://doi.org/10.1016/j.jisako.2023.02.005

Fig. 1. The anatomic insertions of the anteromedial bundle (dotted area) and posterolateral bundle (solid area) on the femoral site (medial femoral condyle removed). Reprinted from Cha et al. [2] with permission from Elsevier.

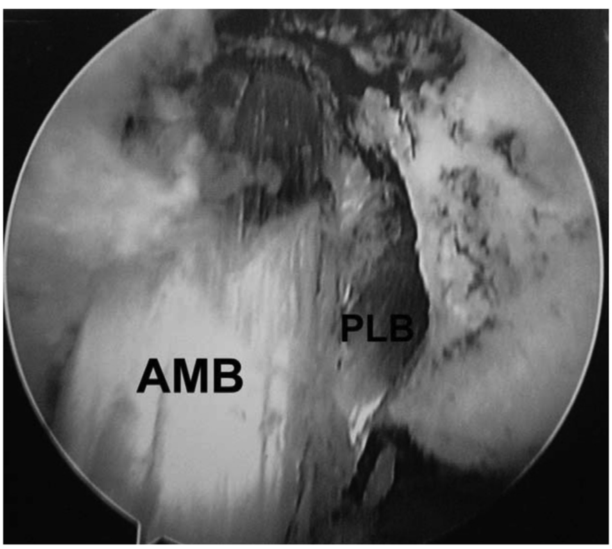

Fig. 2. Anteromedial bundle (AMB) and posterolateral bundle (PLB) in situ. Reprinted from Cha et al. [2] with permission from Elsevier.

Quadrupled semitendinosus and gracilis autografts are used for the AM and PL bundles, respectively, giving a total of eight hamstring strands crossing the knee. Suspensory cortical buttons are used for femoral fixation with suture post fixation on the tibial side. An alternative technique for allograft reconstruction, using tibial interference screws, is also described.

Specific technical details include the use of an accessory anteromedial portal for trans-portal drilling of the PL bundle femoral tunnel. Trans-tibial drilling is employed for the AM bundle. Viewing of the medial wall of the femoral condyle is performed through the standard anteromedial portal while drilling via the accessary portal, to better appreciate the anatomy and allow the safe creation of the two femoral tunnels. The two grafts are tensioned at different knee flexion angles prior to final graft fixation, with the PL bundle tensioned at 45° and the AM bundle in full extension.

Lastly, the authors discuss previously described DB reconstruction techniques, highlighting as the key point of difference the attention to anatomical detail in their technique. 'Recreating the functional anatomy of the intact ACL remains the cornerstone of ACL reconstruction' [2].

Consideration

Historical perspective

Since the early 1900's, ACL injuries have been managed with a wide variety of surgical approaches. The first ACL reconstruction, by Hey Groves of Bristol in 1916, was remarkably anatomic in nature, routing the fascia lata through a femoral tunnel and obliquely through the knee [4]. Since that time, a host of different operative techniques have been employed, both anatomical and non-anatomical in nature.

In the 1970s and 80s, non-anatomic reconstructions came to dominate. In 1976, Hughston described anterolateral rotatory instability, a pattern of instability that we would associate with ACL injury today [5]. He believed this to be due to injury to the middle one-third of the lateral capsular ligament. A tear of the ACL was thought to accentuate this instability pattern but was not the essential causative lesion.

Against this backdrop, extra-articular reconstruction techniques developed. These non-anatomical operations were felt to address the injured anterolateral structures, with their peripheral location considered advantageous in rotational control [6]. Some of these techniques, such as the Lemaire and Ellison procedures, were isolated extra-articular procedures [7,8]. Others, such as the MacIntosh II, combined intra- and extra-articular components into a single technique [9].

The introduction and widespread uptake of arthroscopy moved attention back to intra-articular ACL reconstruction. Whilst a great step towards more anatomical reconstruction, many early arthroscopic reconstructions were still quite non-anatomic. Many surgeons placed the tibial tunnel posteriorly in the tibial footprint to avoid notch impingement [10]. Trans-tibial femoral tunnel drilling was commonly employed, meaning the femoral tunnel position was constrained by the tibial tunnel position, which frequently led to a vertical tunnel position that controlled antero-posterior movement but did not adequately restrain rotational instability [11].

To improve rotational control, surgeons next began to explore ACL graft obliquity. Independent anteromedial portal tunnel drilling unshackled the femoral tunnel position from that of the tibial tunnel, allowing the femoral tunnel to be brought into a more central position in the ACL footprint. While a more oblique graft was shown to improve kinematics [12], it still did not restore rotational control to that of the intact knee [13]. Furthermore, graft forces were increased in these oblique grafts [14], with some authors reporting increased failure rates [15].

At the same time, there was a growing interest in ACL functional anatomy. Girgis had described the ACL as having two functional bundles, a smaller anteromedial band and a larger posterolateral band, that became taut at different degrees of flexion [16]. Amis and Dawkins expanded this concept to include a third, intermediate bundle [17]. While early double-bundle reconstruction techniques were described in the 1980's [18], the concept gained popularity firstly in Japan with the techniques of Muneta [19] and Yasuda [20] in the late 1990's and early 2000's. The work of Dr Fu brought the technique front and centre into the orthopaedic consciousness.

Scientific and societal impact

The impact and influence of the work of Dr Fu in the field of ACL reconstruction has been immense. His championing of the concepts of anatomical reconstruction and his double-bundle reconstruction technique drove enormous research interest and changed clinical practice. His personal record is impressive, with over 700 published articles and 70,000 citations. A web-based analysis of ACL publications found Dr Fu to be the most prolific author in the ACL literature over the decade to 2018 [21].

Research interest in double-bundle reconstruction grew greatly from the early 2000's. Prior to 2005 there were 30 PubMed listed publications for 'double-bundle ACL'. Since that time, there are more than 1000 further publications on the subject.

In particular, the pursuit of a more anatomical ACL reconstruction saw a significant increase in biomechanical research. To compare various reconstruction techniques to the intact knee, increasingly sophisticated techniques were employed. Cadaveric studies moved from mechanical rigs to the use of six degree of freedom robots. In-vivo analysis has utilised optical navigation systems [22], gait analysis [23], and bi-planar radiography [24] to evaluate rotation, as well as novel accelerometer [25], electromagnetic [26], and handheld tablet-based systems [27] to quantify the pivot shift.

Popularised in Japan in the late 1990's, the work of Dr Fu drove uptake of the double-bundle technique in North America and Europe. It is difficult to find accurate data on current usage of DB reconstruction. A survey of the members of the American Orthopedic Society for Sports Medicine (AOSSM) in 2006 found 4% of respondents had experience with the DB technique [28]. A review of national surveys performed between 2011 and 2016 reported utilisation rates between 3 and 10% [29]. In the most recent biennial survey of the members of the ACL Study Group, 7% of surgeons routinely utilise the DB technique [30].

Current evidence

Biomechanics

Significant biomechanical investigation of the anatomical double-bundle technique has been performed. Time zero cadaveric studies generally favour DB over SB techniques. Working with Dr Fu and Dr Savio Wu in Pittsburgh, Yagi et al. compared SB and DB reconstructions in a cadaveric model using a robotic testing system [3]. They found the DB technique to more closely restore knee kinematics to normal than the SB technique, with in situ forces seen in the DB graft much closer to those seen in the native ligament (97% vs. 89% under anterior translational load, 91% vs. 66% under a combined rotatory load). Kondo et al. examined conventional SB, anatomical SB with a more obliquely oriented graft, and anatomical DB reconstructions using a six degree of freedom rig [31]. They found rotational laxity to be better controlled by both the more anatomical SB reconstruction and by the DB reconstruction compared to the non-anatomic SB reconstruction; however, there was no significant difference between the anatomical SB and DB techniques. More recently, a cadaveric comparison of conventional SB, anatomic SB and anatomic DB was performed using a novel accelerometer to quantify the pivot shift [32]. In this study, anatomical DB reconstruction restored acceleration to that of the intact knee, which both SB techniques failed to accomplish.

In vivo biomechanical studies are less supportive of the DB technique. Feretti et al. compared anterior and rotational laxity intra-operatively after sequential AM bundle reconstruction and DB reconstruction in 10 patients using a navigation system [22]. The addition of the posterolateral bundle did not improve rotational control. Claes et al. compared SB and DB reconstructions with healthy controls undertaking low- and high-demand tasks using kinematic 3D gait analysis six months post-operatively [33]. There was no significant difference in tibial rotational excursion between the groups. In a recent stereo X-ray analysis of dynamic knee function during downhill treadmill running, both anatomic DB and SB reconstructions restored near normal kinematic results with no difference between the two techniques [24].

Clinical outcomes

Clinical outcomes after anatomical double-bundle ACL reconstruction have been extensively reported. Early reports were encouraging. In 2004, Yasuda et al. reported two-year results in 57 patients treated with DB reconstruction [20]. One patient demonstrated a grade 1 pivot shift post-operatively, and a mean side to side difference on KT-2000 testing of 1.5 mm was observed between groups. In 2007, Muneta et al. compared SB and DB techniques in a randomised trial involving 68 patients with a mean follow-up of 2.5 years [34]. There was a significant reduction in positive pivot shift and Lachman examination findings in the DB group, however, no difference in International Knee Documentation Committee (IKDC) scores was found. Similarly, in 2008 Kondo et al. reported two-year results of a comparative cohort study comparing single- and double-bundle techniques with over 150 patients in each group [35]. The double-bundle group showed improved outcomes in terms of anterior laxity and pivot shift grading. Again, these differences did not translate into improved clinical outcome measures, with the Lysholm and IKDC scores not being significantly different. There was no difference in complications and graft failures between groups. Dr Fu's group conducted a randomised trial comparing anatomic double-bundle, conventional single-bundle, and anatomical single-bundle reconstructions. Hussein et al. found that anatomical SB reconstruction was biomechanically superior to conventional SB reconstruction, and that anatomical DB reconstruction was superior to both SB techniques [36]. There was, however, no difference in IKDC scores between groups and complications and graft rupture rates were not reported.

Systematic reviews have generally shown improved stability but no clear improvement in clinical outcome measures for DB reconstructions. Meredick et al. published an early review in 2008, finding no improvement in anterior laxity or rotational control with the DB technique [37]. In 2010, Yasuda reviewed ten prospective comparative trials and found improved anterior and rotational control in 8 of 10 studies [38]. More recently, Björnsson et al. found improved results after DB reconstruction for the pivot shift in 18 of 42 studies, reduced graft rupture rates in 2 of 23 studies, but minimal differences in patient reported outcome measures [39]. In a systematic review of meta-analyses, Mascarenhas et al. also found the DB technique superior in terms of knee stability, with no difference in clinical outcomes or risk of graft rupture [40].

Evidence regarding graft failure after double-bundle reconstructions is mixed. Some authors have reported reduced rates of failure. In the ten year results of a randomised trial, Järvela et al. reported significantly fewer graft ruptures after DB reconstruction (3.3% DB vs. 16.7% SB) [41]. Other studies have failed to identify a survival benefit to DB reconstructions. In a study of over 60,000 patients from the Scandinavian ACL registries, including 994 DB reconstructions, the risk of revision was not reduced in the DB group [42]. Conversely, in another study published in the same year looking at only data from the Swedish registry, DB was superior to SB with revision rates of 2.0% and 3.2%, respectively [43].

There is an association between ongoing rotational instability and the development of osteoarthritis (OA) following ACL injury and reconstruction [44,45]. It has been suggested that the improved rotational biomechanics of DB reconstruction may result in lower rates of OA. A recent study from Mao et al. found a greater degree of cartilage degeneration on magnetic resonance imaging (MRI) in SB compared to DB reconstructions at 12 years [46]. A systematic review by Belk et al. showed no difference in radiographic OA between SB and DB techniques in seven studies, although meniscal and other ligament injuries were not controlled in all included studies [47].

Complications

Regarding complications of the technique, there were concerns from an early stage that the increased complexity of the double-bundle strategy would lead to new technical issues [48]. Of particular worry was the potential for tunnel conflict, and issues with subsequent revision surgery caused by the presence of multiple tunnels. Tunnel communication could occur intra-operatively, or develop post-surgery due to tunnel widening [49]. Indeed, significant tunnel widening was reported in some series [49,50]. Hofbauer, working with Dr Fu's group, published an algorithm for approaching revision surgery after prior DB reconstruction [51]. Tomihara et al. reported the results of revision after DB primary reconstruction using a patella tendon graft in 22 patients, with results similar to those seen after patella tendon primary reconstruction [52]. There are no studies directly comparing outcomes of revision after SB and DB primary reconstruction.

Lessons learned

While biomechanically superior to single-bundle ACL reconstructions, ultimately the clinical outcomes of the double-bundle technique are not clearly different. Coupled with the increased complexity of the procedure, this has seen an anecdotal decline in the use of double-bundle reconstruction after initial enthusiasm.

Despite the recognised advantages of anatomical surgery, not all progress has been towards this paradigm, as evidenced by a recent renewed interest in anterolateral tenodesis. Since the well-known description of the anterolateral ligament in 2013 [53], significant research has been undertaken examining the role of this ligament, as well as the various layers and attachments of the iliotibial band, in rotational control of the knee. Whilst anatomical reconstructions of the anterolateral ligament have been described [54], older, non-anatomical techniques have been repopularised with excellent clinical outcomes [55].

Recently, a new concept of ACL anatomy has been proposed; the ribbon ACL [56]. In this model, the ACL is described as a flat, ribbon-like structure that runs from a linear attachment along the lateral intercondylar ridge of the femur to a C-shaped attachment on the tibia surrounding the anterior horn attachment of the lateral meniscus [57]. Reconstructive techniques have been described [58], including associated techniques for creating flat grafts from hamstring tendons [59]. To date, there is little biomechanical data to support this new technique, although there are potential benefits for graft tunnel healing with rectangular tunnels [60]. It remains to be seen if the increased complexity of the procedure, particularly with respect to creating a C-shaped tibial tunnel, will be justified.

Conflict of interest

The authors declare the following financial interests/personal relationships that may be considered as potential competing interests:Timothy Lording reports a relationship with Smith and Nephew Inc Advanced Surgical Devices that includes: consulting or advisory, funding grants, and speaking and lecture fees. Timothy Lording reports a relationship with Arthrex Inc that includes: speaking and lecture fees. Timothy Lording reports a relationship with Medacta International SA that includes: speaking and lecture fees.

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