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Current Trends in Anterior Cruciate Ligament Reconstruction

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The advances in the knowledge of anatomy, surgical techniques, and fixation devices have led to the improvement of anterior cruciate ligament (ACL) reconstruction over the past 10 years. Nowadays, double bundle and anatomical single bundle ACL reconstruction that more closely restores the normal anatomy of the ACL are becoming popular. Although there is still no definite conclusion whether double bundle ACL reconstruction provides better clinical results than single bundle reconstruction, the trend has shifted to anatomic reconstruction regardless of single bundle or double bundle techniques. We could not find any significant differences in the clinical outcomes and stability after ACL reconstruction according to the type of graft or fixation device. Therefore, surgeons should select an ideal ACL reconstruction according to the patient's condition and surgeon's experience.

Keywords: **Anterior cruciate ligament, Anatomical reconstruction, graft, fixation**

Introduction

Rupture of the anterior cruciate ligament (ACL) is one of the most common knee injuries. The annual incidence of the ACL injury ranges between 100,000–200,000 in USA[1,2]. Due to the unsatisfactory outcomes of conservative treatment for ACL injuries, reconstruction surgery remains the treatment of choice in most young patients who want to maintain an active lifestyle. The main aims of ACL reconstruction are to restore intact knee stability and normal knee kinematics after reconstruction. Traditionally, ACL reconstruction has focused on non-anatomical single bundle reconstruction using a transtibial technique, which provides only anterior stability in knee flexion.

Owing to the better understanding of anatomy, improvement in surgical techniques, and advances in fixation devices, the single bundle ACL reconstruction has provided good clinical outcomes. However, some studies reported that 10%–30% of the patients with single bundle ACL reconstruction continued to show rotational instability and development of osteoarthritis[3]. It has been assumed that these kinds of problems arise from lack of the posterolateral (PL) bundle in the single bundle ACL reconstructed knee. Therefore, double bundle or anatomical single bundle ACL reconstruction, which more closely restores the normal anatomy of the ACL, was proposed for the treatment of ACL injury. However, problems including the development of osteoarthritis after ACL reconstruction still persist despite significant improvement in ACL reconstruction. In this paper, we will review the current trend of ACL reconstruction with regard to surgical techniques, fixation devices, and graft materials.

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Operative Techniques for ACL Reconstruction

1. Anatomical Double Bundle ACL Reconstruction

Single bundle ACL reconstruction has been considered the standard technique for restoring anterior instability, especially in flexion, by addressing the anteromeidal (AM) bundle only. However, 10%–30% of the ACL reconstructed patients complain of a feeling of rotational instability, so-called pivot-shift phenomenon[4]. Moreover, several biomechanical studies showed that single bundle reconstruction can restore anterior-posterior stabil-

Table 1. Current Outcome Studies of Double Bundle Anterior Cruciate Ligament Reconstruction

Study of subgroup	Graft	Femoral (mm)		Tibial		Fixation		Tension	
		PL	AM	PL	AM	Femur	Tibia	PL	AM
Yasuda et al.[7]	Hamstring	5–8 mm ant	10:30 (6–8)	PCL 5 mm ant	PCL 7 mm ant	Endobutton	Staples (×2)	10 Flexion, 30 N	10 Flexion, 30 N
Vidal et al.[8]	TA allograft	Footprint	10:30–11:00	Footprint	Footprint	Endobutton	Interference screw, staple	45 Flexion	10 Flexion
Brucker and Imhoff[9]	Hamstring	Footprint	10:30–11:00	Footprint	Footprint	Interference screw	Interference retroscrew	45 Flexion	20 Flexion
Tohyama et al.[10]	Hamstring	Footprint	Footprint	Footprint	Footprint	Endobutton	Spiked staples	10 Flexion, 40 N	90 Flexion, 40 N
Zaffagnini et al.[11]	Hamstring	10 mm ant	Footprint	Footprint	Footprint	Endobutton	Staples (×2)	15 Flexion	90 Flexion
Suomalainen et al.[12]	Hamstring	Footprint (7)	Footprint (6)	Footprint	Footprint	Bioabsorbable screw	Bioabsorbable screw	90 Flexion	30 Flexion

PL: posterolateral, AM: anteromeidal, ant: anterior, PCL: posterior cruciate ligament, N: newton ($kg \cdot m/s^2$), TA: tibialis anterior tendon.

ity but not rotational stability, which means it does not restore normal rotational kinematics[5].

With better knowledge of ACL anatomy, double bundle ACL reconstruction was proposed to closely restore the normal structure of the ACL[3,6]. Although double bundle reconstruction is more effective than single bundle reconstruction for restoring normal knee kinematics, the operative techniques are various in terms of the fixation angle and device (Table 1)[7-12]. Moreover, double bundle reconstruction techniques are technically more demanding and necessitate longer operative times and more extensive bone loss, thereby potentially rendering revision surgery more difficult. Although a recent meta-analysis study showed that double bundle reconstruction provides better results in terms of anterior stability and pivot-shift test than single bundle reconstruction[13], some studies failed to demonstrate significant comparative advantages of double bundle techniques in terms of clinical outcomes[13,14]. Moreover, some studies reported 3%–16% of tears of the PL reconstruction grafts on second-look arthroscopy after double bundle ACL reconstruction[15].

According to the literature review, although double bundle reconstruction has theoretical advantages over single bundle reconstruction in terms of restoring normal anatomy and kinematics, we could not recommend double bundle reconstruction for all patients with ACL injuries. However, double bundle techniques can be useful for specific cases of substantial rotational instability in hyper-lax knee joints and revision surgery[16].

2. Anatomical Single Bundle ACL Reconstruction

With regard to single bundle ACL reconstruction, Woo et al.[17] reported that the standard high femoral tunnel in ACL reconstruction resists anterior tibial loading, but it is not sufficient to control combined rotatory loads. Furthermore, several biomechanical studies have shown that the more anatomic low femoral tunnel has some advantages over the high femoral tunnel in terms of rotational stability[3,18]. Therefore, anatomical graft placement has been emphasized for restoration of normal knee kinematics in ACL reconstruction. Although anatomical double bundle reconstruction can closely restore the normal ACL anatomy, it does not provide consistently good results because of the abovementioned disadvantages. In addition, it has been known that 6% of the reconstructions lead to a rupture in the contralateral intact knee.

Attention has returned to single bundle reconstruction with grafts placed at the center of anatomical position. Recently, several biomechanical studies showed that the single bundle ACL grafts placed in the center of their anatomic insertions can provide nearly normal knee kinematics comparable to double bundle reconstruction[14,19,20]. Sastre et al.[19] reported that single bundle ACL reconstruction in anatomical insertion site produced results comparable to those obtained using the double bundle technique, as determined by KT-1000 measurements, International Knee Documentation Committee scores, and pivot shift test results. In a study by Steiner et al.[14], a central anatomical single bundle ACL reconstruction was superior to the conventional non-anatomical single bundle ACL reconstruction in restoring normal anterior and rotational knee laxity.

Araki et al.[20] reported that anatomical double bundle ACL reconstruction showed superior results in stability measured with an electromagnetic system than anatomical single bundle reconstruction but there was no difference in clinical outcome (KT-1000 measurements, isokinetic peak muscle torque, and Lysholm score). Controversy exists regarding the fact that anatomical fem-

oral tunnel placement can be achieved using a transtibial tunnel drilling technique. Giron et al.[21] showed that the standard transtibial technique in ACL reconstruction could not restore the anatomic femoral origin of the ACL despite some technical modifications. To address problems related to a vertical femoral tunnel, some surgeons have advocated performing independent drilling (transportal technique) through an anteromedial portal to place the femoral tunnel in the anatomical position instead of using the standard transtibial drilling technique[3,19,22]. In addition, Kim et al.[22] reported excellent clinical results of anatomical ACL reconstruction using 3 portals by adding a far anteromedial portal to the frequently used 2 portals. While some studies have reported that anteromedial portal drilling could place the femoral tunnel in the anatomical position better than transtibial drilling, other studies reported that modified transtibial drilling technique can place a graft at anatomical position by adjusting flexion or rotational angle or using a flexible reamer during femoral drilling[3,18]. In addition, although the transtibial and transportal techniques have some advantages, outside-in technique has been recently reported as a reliable alternative. Lubowitz and Konicek[23] reported that the outside-in technique could be performed through a small incision and prevent excessively short femoral tunneling unlike the transportal technique. Seo et al.[24] suggested that there was no significant difference between the transtibial and outside-in techniques in the clinical outcome, and the outside-in technique provides superior knee joint rotational stability compare to the transtibial technique.

The standard location of a tibial tunnel was slightly posterior, which was more close to the PL bundle than the AM bundle to prevent graft impingement at the intercondylar notch. However, in the anatomical single bundle reconstruction, many surgeons make a tibial tunnel at the center of the AM and PL bundles (Fig. 1).

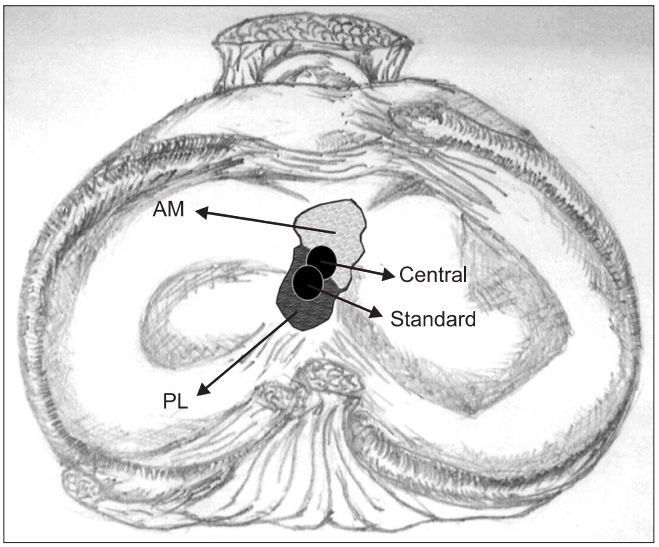

Fig. 1. Schematic drawing of the central and standard tunnel positions in anatomical single-bundle anterior cruciate ligament reconstructions. AM: anteromedial bundle, PL: posterolateral bundle.

The paradigm of anterior cruciate ligament reconstruction has shifted from isometric reconstruction to anatomic reconstruction using a single bundle or double bundle technique. Due to the questionable advantages of double bundle ACL reconstruction in clinical studies, anatomical single bundle ACL reconstruction in the mid bundle position has received more attention recently.

3. Remnant Preserving ACL Reconstruction

Because of the potential problem including impingement or poor visualization during reconstruction, ACL remnants are totally debrided in traditional ACL reconstruction. However it is well known that tibial remnants contain several types of mechanoreceptors. These mechanoreceptors may provide positive effects on the proprioceptive function of the knee[25,26]. It has been suggested that the ACL secondarily functions as a sensory organ providing proprioceptive feedback and initiating protective reflexes and stabilizing muscular reflexes. In addition, some studies have shown that the ACL remnants provide some biomechanical stability to the knee[25,26]. Moreover, posterior cruciate ligament (PCL) reconstruction with a remnant preserving technique showed better stability than PCL reconstruction without remnant tissue. Hence, some surgeons proposed remnant preserving

Table 2. Differences in the Clinical Outcomes of Remnant Preserving Anterior Cruciate Ligament (ACL) Reconstruction

No.	Author	Yr	No. of patients	F/U (mo)	Outcomes	Study results
1	Ahn et al.[26]	2010	68	6.3	MRI	Larger ACL grafts No cyclops lesion
2	Ahn et al.[15]	2011	63	27.7	MRI Clinical score	Good clinical results Cyclops lesions ↑ (no clinical significance)
3	Gao et al.[29]	2010	235	50	MRI KT-1000	Very good clinical results
4	Gohil et al.[30]	2007	49	12	MRI KT-1000	No difference
5	Kim et al.[22]	2009	27	12	Clinical	Remnant preservation could be effective methods
6	Lee et al.[25]	2008	42	35.1	Clinical KT-1000	Good proprioceptive and functional outcomes

F/U: follow-up, MRI: magnetic resonance imaging.

Table 3. Summary of Advantages and Disadvantages of Graft Materials

Type	Autograft			Allograft
	Patellar tendon	Hamstring	Quadriceps	
Advantage	Strongest healing method Similar length to the ACL Quicker healing process	Small incision & less painful harvest No violation of the extensor mechanism Less problem with knee pain Less Q-muscle atrophy, Faster return of Q-muscle strength Eligible for younger patients with growth plates	Rare sensory loss Thicker cross sectional area than BPTB	No risk pain or scar from donor site Decreased surgical time Reduced Q-muscle atrophy Reduced Joint stiffness Ideal for patients with previously harvested
Disadvantage	Pain in donor site Larger incision Permanent sensation loss Possibility of patella fracture Ant knee pain	Slower healing process for soft tissue-to-bone High incidence of tunnel widening Harvest-technical demanding Diffuse multiligamentous laxity	Q-muscle atrophy Violation of extensor mechanism	Risk of infection Increased transmitted diseases Reduced graft strength Low grade immune rejection Cost & decreased availability Delayed incorporation

ACL: anterior cruciate ligament, BPTB: bone-tendon-bone grafts.

ACL reconstruction. Although the preservation of a remnant ACL stump might lead to incorrect tibial tunnel placement or cyclops formation[26], it has many theoretical advantages including accelerated revascularization and ligamentization, preservation of the proprioceptive nerve fibers, enhanced biological environment for healing, and reduced incidence of tibial bone tunnel enlargement[5,25-28]. Ahn et al.[27] reported that remnant preserving ACL reconstruction provided good clinical outcomes and stabilities without compromising accuracy of tunnel position. However, cyclops lesions were found in 12 out of 48 patients on MRI even though they did not have any limitation in extension (Table 2)[15,22,25,26,29,30]. Mifune et al.[31] reported that remnant preserving selective bundle augmentation showed good anterior and rotational stability in patients with only AM or PL tear, and they recommended remnant preserving augmentation for partial ACL tears. In terms of tunnel widening, Zhang et al.[32] showed less tibial tunnel enlargement after remnant preserving ACL reconstruction than remnant removing ACL reconstruction, but no difference was seen in clinical outcomes.

Although some studies showed that remnant preserving ACL reconstruction provided promising results in terms of clinical outcomes and tunnel widening, we could not find any literature that this technique improves proprioception or stability and allows for rapid rehabilitation compared to traditional remnant removing ACL reconstruction. Moreover, there are no prospective randomized studies comparing the remnant preserving and traditional ACL reconstruction. In conclusion, the present literature does not conclusively support the benefits of remnant preserving ACL reconstruction.

Graft Materials for Anterior Cruciate Ligament Reconstruction

Graft choice for ACL reconstruction is influenced by patient age, activity level, gender, associated injuries, degree of laxity, and planned concomitant operations. As a general guideline, autografts are recommended for young patients because it is presumed that these patients are more active. Allografts are not as strong as autografts and are only indicated in patients undergoing revision ACL surgery or in those who only want to return to lower demand activities. Allografts in ACL reconstruction have advantages including decreased operative time, smaller incisions, and less post-operative pain. However, autografts are still preferred because allografts carry the possibility of disease transmission (Table 3).

In a meta-analysis study and systematic review on the comparison of clinical outcomes of ACL reconstruction using autografts and allograft, there was no difference in the outcome scores, laxity, clinical failure rates, and return to sports[33] (Tables 4, 5)[34-41].

The two most commonly used autografts in ACL reconstruction are the patellar tendon (PT) autograft and the four-strand hamstring (HS) tendon autograft consisting of the gracilis and semitendinosus tendons. The other sources of autografts include the quadriceps tendons. Although there has been little research on quadriceps tendon grafts, several recent studies support their use in ACL reconstruction[42]. To date, there have been a number of prospective and retrospective studies comparing patellar tendon bone-tendon-bone grafts (BPTB) and four-strand hamstring grafts (DSTG; double semitendinosus and gracilis tendon grafts).

Table 4. Instrumented Laxity Measurement of >5 mm Pooled according to Graft Source

Study of subgroup	Autograft	Allograft	Odds ratio (95% CI)
Barrett et al.[34]	25	38	0.20 (0.01–4.02)
Chang et al.[35]	22	34	1.03 (0.16–6.74)
Edgar et al.[36]	37	46	3.97 (0.40–39.86)
Harner et al.[37]	26	64	1.25 (0.21–7.28)
Kleipool et al.[38]	26	36	1.42 (0.19–10.77)
Peterson et al.[39]	30	30	5.35 (0.25–116.31)
Saddemi et al.[40]	25	18	0.23 (0.01–5.95)
Total	191	266	1.23 (0.52–2.92)

Odd ratio was calculated using the Mantel-Haenszel method and random-effects analysis model.
CI: confidence interval.

Table 5. Clinical Failures Pooled according to Graft Source

Study of subgroup	Autograft	Allograft	Odds ratio (95% CI)
Barrett et al.[34]	25	38	0.49 (0.02–12.52)
Chang et al.[35]	33	46	0.19 (0.01–3.72)
Edgar et al.[36]	37	46	1.94 (0.31–12.28)
Kleipool et al.[38]	26	36	Not estimable
Peterson et al.[39]	30	30	1.00 (0.06–16.76)
Saddemi et al.[40]	31	19	0.60 (0.04–10.20)
Victor et al.[41]	48	25	0.07 (0.00–1.34)
Total	280	240	0.61 (0.21–1.79)

Odd ratio was calculated using the Mantel-Haenszel method and random-effects analysis model.
CI: confidence interval.

Some studies found similar laxity values and functional results between the two types of graft tissues[43-45], while others[2,46,47] found the patellar tendon graft produced significantly better results in terms of stability, but this did not correlate with the functional outcome. The advantage of the hamstring tendon autograft is relatively low overall postoperative pain, especially anterior knee pain. Thus, it would be the preferred choice of graft in ACL reconstruction for patients with a low pain tolerance, a job that requires kneeling, or a history of knee pain. In addition, it would be a better option for patients concerned about aesthetics because it requires a relatively small incision. The disadvantage is that it takes relatively long time for the graft to heal into the tunnel since there is no "bone-to-bone" healing.

Despite the disadvantage, the hamstring autograft has recently been widely used as the primary graft of choice in ACL reconstruction because of the relatively low postoperative knee pain, low comorbidity due to preservation of the extensor mechanism by not violating the patellar tendon and quadriceps tendon, and little clinical and functional difference compared to the BPTB.

Fixation Devices for ACL Reconstruction

The fixation device for graft in ACL reconstruction should be secure and allow graft healing within the tunnel. Because more aggressive rehabilitation program has been adopted in ACL reconstruction recently, the strength of fixation device should be enough to allow immediate range of motion exercises, weight bearing, and early return to sports without any loss of fixation strength. Over the past 10 years, significant advances in fixation have led to the development of many different fixation devices for bony and soft tissue graft fixation.

1. Bone Plug Fixation Device

Metal or bio- interference screws are most commonly used fixation device for bone plug in ACL reconstruction. Metal interference screws designed by Kurosaka have been used as the standard fixation device in ACL reconstruction with patellar tendon autograft[48]. However, with the increasing use of hamstring soft tissue grafts, bioabsorbable interference screws, poly-L-lactic acid (PLLA) screws, and polyglyconate screws[49] are becoming more popular. While the bioabsorbable screw has the advantages, such as incorporation into the surrounding tissue, almost no need for implant removal, and less interference with MRI[50], it seems to provide clinical results similar to those of metal screws according to a systematic review.

Cross biodegradable or metal pins (Rigid Fix; DePuy Mitek Inc., Raynham, MA, USA) can be used for the fixation of the bone plug. The principal failure mode with cross pins in this utilization is bone block fracture, and the cross pin fixation strength improves with larger bone plug diameters. Cross pins showed similar fixation strength as interference fixation screws with bone plugs[51]. The RetroScrew (Arthrex, Naples, FL, USA), recently designed to be inserted from the articular side of the tibia, may actually increase the graft tension as the screw is advanced[19]. In a recent biomechanical study, however, the fixation strength and fixation failure load of RetroScrew was not found to be as good as interference screws[52].

2. Soft Tissue Fixation Device

Interference screws are also commonly used for the fixation of soft tissue graft. The adequate length of interference screw is required for improved fixation strength (30–35 mm screws). Cross biodegradable pins (Rigid Fix) and RetroScrews (Arthrex) can also be used for the fixation of soft tissue graft. When used

in ACL reconstruction using a hamstring tendon, they produce clinical results that can be comparable to those of reconstruction using interference screws and the EndoButton[22,51,53].

The EndoButton CL (Smith & Nephew Endoscopy, Andover, MA, USA), an extra cortical suspensory fixation device, has been widely used as a fixation device for the hamstring graft on the femoral side. Although EndoButton has a higher failure load and less stiffness than interference screws, it induces some micro motion of the graft within the bone tunnel during loading, and can be a cause of tunnel widening[49]. Baumfeld et al.[54] reported that 2 cross pin fixation resulted in less femoral tunnel widening than the EndoButton fixation. On the other hand, Kong et al.[55] suggested that the clinical results were comparable between the cross pin fixation and EndoButton fixation and there was no significant difference in femoral tunnel widening between the two fixation devices. An advantage, however, of the same is that extra cortical fixation creates a long bone-tendon interface, making it suitable for many types of ACL reconstruction techniques as well as single- and double-bundle reconstruction. Suture tying around the screw post is also another established technique. This fixation system has adequate strength for graft fixation and also has advantages of tendon healing into the bony tunnel.

In summary, most of modern fixation devices have enough strength to fix the graft in ACL reconstruction regardless of graft materials. All systems have their specific advantages and disadvantages. Therefore, the choice of a fixation device should be based on the type of graft or quality of bone.

Conclusions

Although there are still no definite conclusions whether double bundle ACL reconstruction can provide better clinical results than single bundle technique, the main trend for ACL reconstruction has shifted to anatomic reconstruction regardless of single bundle or double bundle techniques during the past 10 years. In the literature, the type of graft or fixation device did not make significant differences in clinical outcomes or stability of ACL reconstruction. Because there are a variety of options available today, selection of optimum combination should be individualized to the patient's condition and the experience of the surgeon. Further advances in surgical techniques should continue to be developed so as to restore near normal knee kinematics and anatomy.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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