ORIGINAL ARTICLE

Prediction of clinical outcomes of single- and double-bundle anterior cruciate ligament reconstruction techniques using magnetic resonance imaging

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ABSTRACT

BACKGROUND: The objective of the study is to compare the clinical results of the single-bundle (SB) and double-bundle (DB) anterior cruciate ligament (ACL) repairing techniques using magnetic resonance imaging (MRI).

METHODS: Thirty-eight patients were randomized by block randomization into two different groups of ACL reconstruction: DB (n=19) and SB techniques (n=19). MRI evaluation and clinical examination with modified Cincinnati Knee Rating Score and Lysholm knee scores were performed pre-operatively and at the end of a follow-up period of 36 months.

RESULTS: No significant differences were found in the ACL angle, posterior cruciate ligament angle, and tibial translation between the DB and the SB groups. Regarding the clinical scores, there were no significant differences between the techniques. As for the correlation of radiologic results with clinical scores in the SB group, there was a strong and significant correlation between the post-operative ACL angle values and the Lysholm clinical score (r=–0.66; p=0.002).

CONCLUSION: The post-operative ACL angle can predict the degree of clinical recovery in patients undergoing SB ACL reconstruction.

Keywords: Anterior cruciate ligament; double-bundle; magnetic resonance imaging; single-bundle.

INTRODUCTION

Reconstruction of the anterior cruciate ligament (ACL) is one of the most frequently performed operations in orthopedic sports medicine.[1] ACL consists of two distinct functional bundles, an anteromedial (AM) bundle and posterolateral (PL) bundle.[2] The standard treatment for ACL rupture is the reconstruction of the ACL using a single-bundle (SB) technique.[3] Nevertheless, only 67–76% of patients who underwent ACL reconstruction with either hamstring tendon graft or bone-patellar tendon-bone graft could return to their pre-injury level of activity.[4] Opponents of SB ACL reconstruction suggest that this approach does not restore the normal double-bundle (DB) anatomy and may, therefore, not restore normal knee kinematics.[5] DB reconstruction was developed to achieve better functional anatomy.

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At present, both SB and DB ACL reconstructions are performed. Prospective randomized controlled trials that compare SB and DB ACL reconstructions were published.[6,7]

In this study, we aimed to compare the clinical results of the SB and DB ACL repairing techniques using magnetic resonance imaging (MRI).

MATERIALS AND METHODS

Study Design

The study was approved by the local ethical committee, and written informed consent was obtained from every subject. Forty-five patients met these following inclusion criteria: (1) ACL injury diagnosed by clinical examination and by MRI, (2) absence of previous ACL surgery, (3) closed growth plates, (4) absence of ligament injury to the contralateral knee, (5) absence of multiligament injury of the knee, and (6) ACL injuries without meniscal tears. The exclusion criteria were (1) patients under 18 years old, (2) patients with graft failure resulted in revision ACL surgery, and (3) patients who were lost during the follow-up. Three patients who had an injury-induced graft failure were excluded from the study. Four patients were lost to follow-up. Thus, 38 patients operated either with the DB technique (DB group; n=19) or SB technique (SB group; n=19) were included in the study. There were 3 women and 35 men with a mean age of 27.1±4.6 (range: 19–36) years.

All patients had MRI examinations performed within two weeks before surgery. One experienced orthopedic surgeon performed all of the ACL reconstructions.

The same orthopedic surgeon examined patients before and after 36 months of surgery. Pre-operative and post-operative MRIs of the patients were evaluated, and their ACL angles, posterior cruciate ligament (PCL) angles, and tibial translations in the sagittal plane were noted and compared statistically.

The demographic data of the patients are presented in Table 1.

Functional Assessment

The routine clinical evaluation methods included Modified Cincinnati Knee Rating Score and Lysholm knee scores.[8,9] Before the operation and at the final follow-up (after 36 months of operation), clinical examinations were performed by an independent and blinded examiner, with no information on the patients' MRI results.

Table 1. Demographic data of patients

	Double-bundle (n=19)	Single-bundle (n=19)	p-value
Male/female	1/18	2/17	>0.05
Age (yr) (mean [SD])	27.7±5.6	26.4±3.4	>0.05

Yr: Years; SD: Standard deviation.

Lysholm and Gillquist proposed the Lysholm questionnaire as a knee rating score for ligament injuries, directed at the young, athletic patients' evaluation of their symptoms and knee function, and with an emphasis placed on knee instability. Importance was attributed to an assessment of patients' perception of function in daily living activities most relevant to the patient and the patient's functional level in various intensities of athletic activities. The questionnaire consists of eight questions, with three to six statements after each item. Patients answering the questionnaire place a tick in the box next to the best fitting statement. Patients should give their opinions on their knee function in everyday activities, sporting activities, and symptoms of pain, instability, and swelling.

The Modified Cincinnati Knee Rating Score emphasizes patients' symptoms and their perception of knee function. It is more concise than the original version, it was validated in our setting, highlighting the critical aspects of symptoms and functioning in daily and athletic activities. Li et al.[10] demonstrated high validity, reliability, and responsiveness for the Cincinnati rating scale. The questionnaire is divided into two sections, the first assessing symptoms and the second function. There are eight questions, each with statements underneath. Each of the statements has a score next to it, and the patient is asked to circle the relevant score in each category. MR scanner (Signa Excite HD imager, GE Medical Systems, Milwaukee, WI, USA) using an 8-channel receiver/transmitter extremity coil. Routine sagittal plane images were obtained. The magnetic resonance images were interpreted by consensus by two musculoskeletal radiologists who were unaware of the patients' clinical data. The measurements were repeated in 20 randomly chosen patients after two months, and the intraobserver differences were evaluated. Repeated measures showed similar results in 59% of cases, and in 41% of cases, they differed from each other by ±1 mm. ACL angle, PCL angle, and anterior tibial translations (mm) were measured. All measurements were done with the Impax DS3000 workstation (Agfa HealthCare, Mortsel, Belgium). The ACL angle is the angle formed by the intersection of two lines: one along the centerline of the distal portion of the ACL graft and parallel to the ACL graft in the sagittal plane and the other tangential to the most anterior aspect of the intercondylar eminence and perpendicular to the long axis of the tibia. PCL angle is measured between a line from the femoral origin site to the site of angular change and a line from this same site to the distal-most insertion site on the posterior tibia. The MRI data at follow-up were compared with the pre-operatively documented measurements.

Statistical Analyses

Data were analyzed using the Statistical Package for the Social Sciences software (version 10.0 for Windows). All differenc-

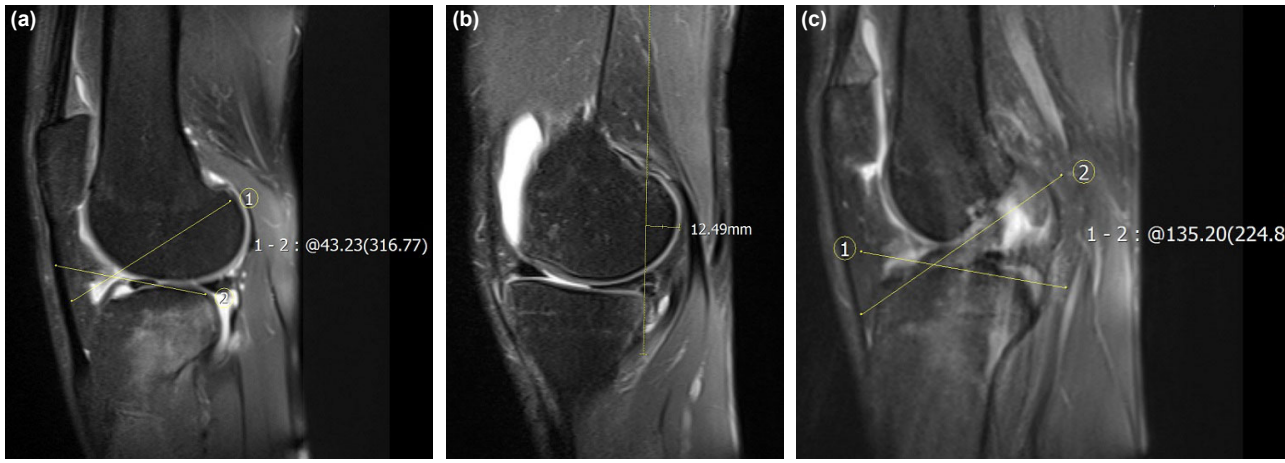

Figure 1. (a) Pre-operative ACL angle showing 43.2°. **(b)** Pre-operative tibial translation of 12.4 mm. **(c)** Post-operative ACL angle of 135.2° in the SB group.

es associated with a chance probability of 0.05 or less were considered statistically significant. Continuous variables are presented as mean±SD. The operation techniques were compared using Student's t-test. The relationship between MRI measurements and clinical scores was evaluated using Spearman correlation.

RESULTS

After the follow-up period of 36 months, patients in both groups were able to practice a full extension and flexion of their knees. In the SB group, mean post-operative Cincinnati and Lysholm scores were 29.2 and 93.2, respectively. In the DB group, mean post-operative Cincinnati and Lysholm scores were 28.9 and 90.4, respectively. Regarding the clinical scores, there was no significant difference between the groups.

In the SB group, mean pre-operative ACL angles, PCL angles, and tibial translations were 30.2, 111.8 degrees, and 5.4 mm, respectively (Fig. 1a-c). Mean post-operative measurements were 61.8, 122.7 degrees, and 3.1 mm, respectively (Fig. 2a and b). In the DB group, the mean pre-operative ACL angle, PCL angle, and tibial translation were 28.2, 112.8 degrees, and 4.8 mm, respectively. Mean post-operative measurements were 54.5, 120.5 degrees, and 3.8 mm, respectively. No significant differences were found in the ACL angle, PCL angle, and tibial translation between the DB group and the SB group ($p<0.05$).

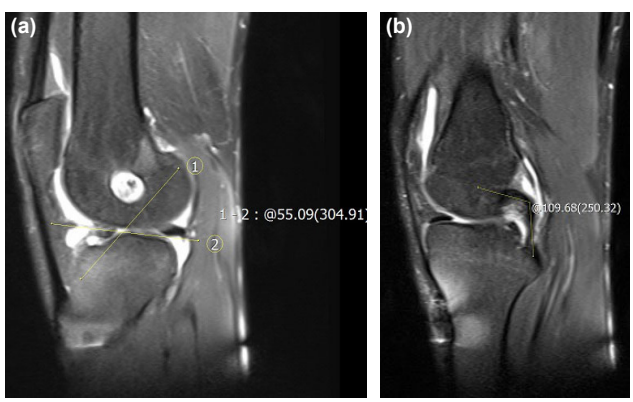

Figure 2. (a) Post-operative ACL angle of 55°, tibial translation 2 mm in the DB group. **(b)** Post-operative PCL angle of 109.6° in the DB group.

Table 2. Correlation of measurements with the clinical scores in the single-bundle group

	Modified Cincinnati Score	Lysholm Score
Pre-operative ACL angle	-0.190	0.190
Pre-operative PCL angle	0.135	0.328
Pre-operative tibial translation	-0.281	0.012
Post-operative ACL angle	-0.325	-0.666 (p=0.002)
Post-operative PCL angle	-0.162	0.355
Post-operative tibial translation	-0.084	0.085

ACL: Anterior cruciate ligament; PCL: Posterior cruciate ligament.

Table 3. Correlation of measurements with the clinical scores in the double-bundle group

	Modified Cincinnati Score	Lysholm Score
Pre-operative ACL angle	-0.309	-0.370
Pre-operative PCL angle	-0.348	-0.124
Pre-operative tibial translation	0.231	0.298
Post-operative ACL angle	0.016	-0.065
Post-operative PCL angle	-0.346	0.013
Post-operative tibial translation	0.298	0.211

ACL: Anterior cruciate ligament; PCL: Posterior cruciate ligament.

As for the correlation of radiologic results with clinical scores in the SB group, there was a strong and significant correlation between the post-operative ACL angle values and the Lysholm clinical score (r=–0.66 p=0.002). That means, clinical wellness is related to the post-operative ACL angle in the SB group. The higher angle measurement means lower clinical complaints (Tables 2 and 3).

DISCUSSION

The primary goal of ACL reconstruction is to restore physiologic function by reproducing the ACLs anatomic structure. However, conventional ACL reconstruction procedures focus only on replacing the AM bundle while ignoring the PL bundle.[11] DB ACL reconstruction has been proposed as an alternative to compensate for the incompleteness of the conventional procedure. ACL and PCL angles in MRI must be in some range for the stable knee, which may deter after an ACL injury. The reconstruction procedures should aim for the correction of altered measurements also in MRI. ACL reconstruction techniques and graft variety may differ from center to center and case to case. Measurements on sagittal MR images are mainly uniform.

Muneta et al.[12] reported the clinical results of DB ACL reconstruction and found that this procedure afforded better anterior stability than conventional SB reconstruction. Yasuda et al.[13] performed a prospective randomized study comparing DB and AM SB reconstructions. Although they found better results for anterior stability with DB reconstruction than with AM SB reconstruction, they did not include the PL SB reconstruction technique in their comparison. In these studies, operative techniques of SB reconstruction varied considerably. A prospective, randomized clinical study conducted by Siebold et al.[6] to compare the outcome of 70 patients undergoing either four-tunnel DB or SB ACL reconstruction with autogenous semitendinosus and gracilis tendon showed that anterior stability assessed by KT-1000, pivot-shift test, and objective International Knee Documentation Committee (IKDC) score were significantly better in the DB reconstruction group than in the SB reconstruction group. The subjective Cincinnati knee score, Lysholm score, and subjective IKDC score did not show any statistical difference between the groups. On the other hand, Meredick et al.[14] and Park et al.[15] performed comparisons of the clinical outcome of SB versus DB ACL reconstruction. They showed that DB reconstruction yielded no significant differences in anterior/posterior stability results, pivot-shift test results, or any other clinical aspects. Tsarouhas et al.[16] also reported that DB ACL reconstruction at a one-year follow-up does not reduce knee rotation as evaluated by an optoelectronic three-dimensional motion analysis system (Vicon MX; Oxford Metrics, Oxford, England). A prospective, randomized study presented by Adachi et al.[17] did not find any advantage of DB reconstruction over SB reconstruction in terms of stability or proprioception. Moreover, several meta-analyses proposed that there was no useful and valid data to support that the outcome of DB reconstruction is better than that of SB reconstruction.[14,18,19] Park et al. stated several reasons why the DB ACL reconstruction does not produce a better clinical outcome. First, there is the lack of an isometric point of the PL bundle of the ACL. Hence, the PL bundle showed more excursion when cyclic loading was performed during surgery. Second, mistakes are common regarding tunnel position with the DB technique.

As for the clinical outcomes, the two published clinical comparisons by Wang et al.[20] and Houe and Jorgensen[21] did not show any statistically significant difference in anteroposterior stability between patients who received SB or DB reconstructions. Wang et al. also showed no difference in functional assessment, functional score, or radiographic examination. Houe and Jorgensen likewise described no difference in subjective outcome or patient satisfaction. As for the correlation of radiologic results with clinical scores in the SB group, there was a strong and significant correlation between the post-operative ACL angle values and the Lysholm clinical score. This finding showed that a higher post-operative ACL angle on MRI has good clinical recovery in patients with the SB graft replacement.

The study had some limitations. First, a comparatively small number of patients were investigated. Second, the follow-up period was concise for this type of research. In the future, we would like to conduct a longer-term follow-up study to compare the outcome between the two groups. We cannot speculate whether there will be any differences between the SB and DB procedures in terms of longer-term outcomes of knee function. Third, the range of motion and the pivot-shift test were not recorded for the clinical evaluation. The pivot-shift test is an important outcome for the comparison between SB and DB ACL reconstruction, and it is the only available clinical examination to detect rotational instability. However, the pivot shift is highly subjective, showing large variability among different observers. Fourth, we were unable to perform a quantitative meta-analysis of the rotational laxities among the biomechanical studies. Although such an analysis could potentially answer the critical question of whether DB ACL reconstruction can restore rotational stability better than SB ACL reconstruction, more investigations with a standardized measure are needed to answer such a question better. More randomized controlled trials with accurate measurements of the outcomes need to be conducted. They could play a significant role in confirming or refuting the superiority of a particular reconstruction over another.

Conclusion

This prospective, randomized study showed that both SB and DB techniques are equally effective in patients with ACL rupture. Post-operative ACL angle in MRI can predict the degree

of clinical recovery in patients undergoing SB ACL repair operations.

Ethics Committee Approval: This study was approved by the University of Health Sciences Sisli Hamidiye Etfal Training and Research Hospital Clinical Research Ethics Committee (Date: 03.09.2019, Decision No: 2499).

Informed Consent: Informed consent was obtained from all individual participants included in the study.

Peer-review: Internally peer-reviewed.

Authorship Contributions: Concept: M.B.; Design: Ö.Y.U.; Supervision: M.U.; Resource: B.G.; Materials: M.B., Ö.Y.U.; Data: B.G.; Analysis: Ş.M.E.; Literature search: M.U., Ö.Y.U.; Writing: Ö.Y.U., M.U.; Critical revision: Ş.M.E., O.T.E.

Conflict of Interest: None declared.

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ORİJİNAL ÇALIŞMA - *ÖZET*

Tek ve çift demet ön çapraz bağ rekonstrüksiyonu teknikleri klinik sonuçlarının manyetik rezonans görüntüleme kullanılarak değerlendirilmesi

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AMAÇ: Manyetik rezonans görüntüleme kullanarak tel demet ve çift demet ön çapraz bağ tamir yöntemlerinin klinik sonuçlarını değerlendirmek ve karşılaştırmak.

GEREÇ VE YÖNTEM: İki farklı ön çapraz bağ (ÖÇB) rekonstrüksiyon grubuna 38 hasta blok randomizasyon ile randomize edildi: çift demet tekniği (n=19) ve tek demet tekniği (n=19). Ameliyat öncesi ve takip süresinin sonunda onikinci haftada hastaların değerlendirilmesi klinik muayenesi, manyetik rezonans görüntüleme değerlendirmesi, Modifiye Cincinnati Diz Değerlendirme skoru ve Lysholm diz skorları ile yapıldı.

BULGULAR: Ön çapraz bağ açısı, posterior çapraz bağ (PÇB) açısı ve tibial translasyonda çift demet grubu ile tek demet grubu arasında anlamlı bir fark bulunmadı. Klinik skorlar ile ilgili olarak teknikler arasında anlamlı bir fark yoktu. Tek demetli grupta radyolojik sonuçların klinik skorlarla korelasyonuna göre, ameliyat sonrası ÖÇB açısı değerleri ile Lysholm klinik skoru arasında negatif, güçlü ve anlamlı bir korelasyon vardı (r=-0.66, p=0.002).

TARTIŞMA: Ameliyat sonrası ÖÇB açısı, tek demetli ÖÇB rekonstrüksiyonu yapılan hastalarda klinik iyileşme derecesini öngörebilir.

Anahtar sözcükler: Çift demet; manyetik rezonans görüntüleme; ön çapraz bağ; tek demet.

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