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Serial Evaluation of the Graft Maturity after ACL Reconstruction Using Quadriceps Tendon-Patellar Bone Autograft by Contrast Enhanced MRI

- Comparison between Remnant Preserving vs Non-preserving Technique

대퇴사두근건-슬개골 자가건을 이용한 전방 십자인대 재건술 후 조영제 증강 자기 공명 영상을 통한 이식건의 성숙도 평가

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Abstract

Serial Evaluation of the Graft Maturity after ACL Reconstruction Using Quadriceps Tendon-Patellar Bone Autograft by Contrast Enhanced MRI

- Comparison between Remnant Preserving vs Non-preserving Technique

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In order to determine the rehabilitation course after ACL reconstruction, it is important to understand the biological processes that occur during graft remodeling and maturation. Theoretically, quadriceps tendon-patellar bone (QTPB) autograft has advantage in rapid healing and regeneration by bone-to-bone contact. In cases of remnant preserving of native ACL, there are some reports of

favorable effects in healing process, revascularization, and proprioception because of mechanoreceptors in attachment site of remnant graft. In this study, we aimed to evaluate graft maturity and revascularization of QTPB autograft through serial evaluation by MRI, to find the effect of bone-to-bone contact and the role of native ACL remnant on graft healing after ACL reconstruction.

36 (27 with remnant preservation technique and 9 with non-preservation) who underwent an ACL reconstruction with QTPB autograft between January 2012 and April 2017 were studied and evaluated by Gd-DPTA enhanced MRI at 3 days, 3, 6 and 12 months after surgery. Signal-to-noise quotient (SNQ) was measured at 3 regions of intararticular portion of the graft (proximal 1/3, middle 1/3, distal 1/3) on oblique coronal scan of pre-contrast image to evaluate graft maturity, and on reverse coronal oblique view of subtraction image to evaluate revascularization.

Regarding the graft maturity, the proximal 1/3 of ACL graft was consistently greater than other regions, from postoperative 3 months to 12 months, which was significant in non-preserving group.

Regarding the degree of revascularization, proximal region was consistently greater than other regions from postoperative 3days to 12months in both groups. Also proximal region was significantly the fastest to achieve maximum revascularization state (at postoperative 3months). Comparing remnant preserving group and non-preserving group, there was no statistical significance in terms of graft maturity and revascularization measured in MRI, throughout the observed

period.
The proximal 1/3 of the intraarticular portion of QTPB autograft showed greater maturity from postoperative 3 months to 12 months, and faster revascularization from postoperative 3 days to postoperative 12 months compared to middle and distal regions, in contrast-enhanced MRI. There was no significant difference between remnant preserving group and non-preserving group in graft maturity and revascularization measured by MRI, until postoperative 1 year.

Keyword: ACL reconstruction; graft maturity; revascularization; remnant preserving technique; MRI

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Introduction

In order to successfully return to daily life or sports activities after anterior cruciate ligament reconstruction, it is important to determine the proper progress and timing of rehabilitation. To determine the timing of rehabilitation, biomechanical conditions of the graft such as the strength and fixation status are crucial. The grafts undergo a series of process to regenerate similar to that of normal anterior cruciate ligament, and this process has a huge impact on the biomechanical state of the implant.[1-3] If the healing process is fast enough for reconstructed anterior cruciate ligament to bear weight, the patient will be able to return to normal activity and exercise early.[4] Therefore, selecting the appropriate type and size of the graft is one of the important considerations in ACL reconstruction.

Meanwhile, healing process of the graft could be checked by graft maturity and revascularization.[4,5], To recognize the degree of regeneration of the graft, histological and morphological evaluations are important. Because there is a limitation to the histological evaluation of a human's ACL graft, Magnetic Resonance Imaging (MRI) is widely used due to its non-invasive features. Especially, contrast-enhanced MRI using Gd-DTPA provides important information for assessing vascularity of the graft. Weiler et al. reported that change in signal intensity of contrast-enhanced MRI reflects the degree of revascularization and biomechanical status of the graft.[6] They said that MRI volume and signal intensity of ACL graft predict clinical, functional, and patient reported outcome measures (PROMs) after ACL reconstruction. However, there were lack of studies of MRI evaluation of autologous quadriceps tendon graft, which is known to be biomechanically excellent and show good clinical results. To our knowledge, there is no serial MRI follow-up study to recognize the degree of graft maturity and revascularization process of ACL graft.

Theoretically, quadriceps tendon-patellar bone (QTPB) autograft has advantage in rapid healing and regeneration by bone-to-bone contact. It has been reported that healing process of the QTPB autograft was more rapid than that of the hamstring autograft in recent studies.[7] In cases of remnant preserving of ACL, there are some reports of favorable effects in healing process, revascularization, and proprioception because of mechanoreceptors in attachment site of remnant graft.[8-12]

The purpose of this study are 1) to estimate the temporal effect of bone-to-bone interface on ACL graft healing compared with tendon-to-bone healing, using contrast MRI, and 2) to evaluate the influence of native ACL remnant upon graft healing after ACL reconstruction, including clinical, radiological measurements. In serial follow-up, Magnetic Resonance Imaging (MRI) was taken on postoperative 3 days, 3, 6 and 12 months. The hypotheses were that 1) graft maturity and revascularization will progress more rapidly in proximal region of ACL graft because of bone-to-bone contact and 2) graft maturity and revascularization phase will progress more rapidly in remnant preserving group than non-preserving group.

Methods

Patient Selection and Study Design

This study was approved by the Health Sciences Institutional Review Board of our hospital (IRB No. 1111-098-387), and written consent was obtained from all participants. We conducted a prospective comparative study of patients who underwent arthroscopic single bundle ACL reconstruction with a quadriceps tendon-patellar bone (QTPB) autograft, performed by a single surgeon (M.C. Lee). From January 2012 to April 2017, a total of 36 patients were recruited. Mean age was 31.8 years (13-61 years). 29 were males and 7 were females. The number of patients who underwent ACL reconstruction with remnant bundle preservation was 27 (group 1) and non-preservation was 9 (group 2). The two groups showed no significant difference in demographics. (Table 1)

The enrolled criteria included a unilateral ACL injury, no history of surgery of the injured knee. The participants were excluded if they had any of the following; osteoarthritis, combined ligament injuries, nerve injuries, fractures, revision reconstruction case of the ACL ligament, severe chondral lesions (Outerbridge classification III or IV). Patients had MRI follow-up at 3 days, 3, 6, 12 months postoperatively. To quantify the degree of maturity and revascularization of the graft, signal-to-noise quotient (SNQ) value was measured on MRI. Specific methods to measure SNQ values will be mentioned below.

Surgical Technique

One senior surgeon (M.C. Lee) performed all operations using arthroscopic single-bundle ACL reconstruction techniques. Arthroscopic examinations were first performed to confirm the rupture and laxity of the ligament. All meniscal resections or repairs were completed before ACL reconstruction. Quadriceps tendon-patellar bone (QTPB) autograft was used in all cases. The ipsilateral central quadriceps tendon was harvested as a strip of quadriceps tendon 10-mm wide, 6- to 8-mm thick, and 6- to 7-cm long with a 10-mm wide, 20- to 25-mm long, 7-mm thick trapezoidal bone block. In the standard technique, a guide pin was inserted at an angle of 60 to the tibial plateau with the use of a tibial drill guide (Acufex, Andover, Massachusetts), which aimed the following intra-articular landmarks; the inner border of the anterior horn of the lateral meniscus, just lateral to the medial eminence, the posteromedial aspect of the native ACL footprint, and 7 mm anterior to the posterior cruciate ligament. In the remnant-preserving technique, the tip of the tibial guide was positioned at the central portion between the ACL footprints of the anteromedial and posterolateral bundles. The femoral tunnel was drilled using a modified transtibial technique, with the femoral drill-guide positioned at the lateral bifurcate ridge on the medial wall of the lateral femoral condyle with the knee flexed to 90' and applied an anterior drawer force, a varus force, and an external rotation force to the proximal aspect of the tibia while externally rotating the guide.

A metal interference screw (ConMed Linvatec, Largo, Florida) was used to fix the bone block on the femoral side. On the tibial side, the tendinous portion of the graft was fixed with a bioabsorbable screw (BioScrew; ConMed Linvatec) and augmented by suturing a bicortical screw, which was inserted 1cm inferior to the tibial tunnel.

Postoperative Rehabilitation

All patients were rehabilitated according to the same postoperative protocol. Full extension was obtained immediately after surgery and full flexion was obtained in six weeks. Patients wore a motion-controlled brace set at 0 to 90 degrees for four weeks and 0 degree to full flexion for an additional two weeks postoperatively. Weight-bearing was limited to partial weight-bearing for six weeks and progressed as tolerated. Full activity was allowed after six months postoperatively, confirming recovery of quadriceps strength.

Clinical Evaluation

Physical examinations were performed on all patients by the operator (MC Lee) in the outpatient clinic at 3, 6 and 12 months postoperatively. Physical examinations included manual laxity tests which consist of anterior drawer test, Lachman test, and pivot-shift test. In addition, anterior tibial translation was evaluated with the KT-2000 knee arthrometer (MEDmetric, San Diego, California). The side-to-side difference was used as an indicator of knee stability. International Knee Documentation Committee (IKDC), Tegner activity score, and the modified Lysholm score were evaluated for symptoms, activity level, and functional improvement. Preoperative data and data from the final follow-up evaluation were used for the assessment.

MRI Sequences and Imaging Analysis

Imaging was performed in a relaxed extended position with a 3.0-T MRI scanner (MAGNETOM Verio, A Tim system, Siemens, Munich, Germany). The knee was placed in the neutral position in an extremity coil. The coronal and sagittal images were acquired using fast spin-echo (FSE) proton density-weighted imaging (PDWI), sagittal FSE T2-weighted imaging, and axial and ACL oblique fat-saturated FSE PDWI. The repetition time (TR) range and echo time (TE) values were variable (3000-4000/10-30 milliseconds for PDWI and 3000-5000/100 milliseconds for T2-weighted imaging). The other imaging parameters were as follows: matrix, 220 3 247 (axial and coronal) and 304 3 301 (sagittal); field of view, 16 cm; slice thickness, 5 mm; and acquisition number, 1. The MRI evaluation was focused on 3 measurements. All the measurements were performed on a picture archiving and communications system (PACS) monitor (GE Healthcare, Barrington, Illinois) using a mouse point cursor and an automated computer calculation for the distance and angle.

(1) Tibial tunnel placement was determined using the method of Odensten and Gillquist. The placement of the ACL tibial tunnel was measured using the 2 methods described in a previous study. In the sagittal plane, the position of the axis of the tibial tunnel was

calculated by extending the center axis of the tibial tunnel to its intersection with the anteroposterior line of the tibial plateau, and multiplying the result by 100. In the coronal plane, the position of the axis of the tibial tunnel was calculated by dividing the distance from the medial edge of the tibia to the center of the tibial tunnel by the width of the articular surface of the tibial plateau, and multiplying the result by 100.

(2) The orientation of the ACL ligament was measured using 3 different methods described elsewhere: sagittal ACL angle, ACL–Blumensaat line angle, and coronal ACL angle. The sagittal ACL angle was defined as the angle between a line parallel to the ACL graft and a reference line parallel to a line perpendicular to the long axis of the tibia. The ACL–Blumensaat line angle was defined as the angle between the posterior surface of the femur and the distal portion of the ACL. These two parameters were measured on the midsagittal MRI images. The coronal ACL angle was defined as the angle between a straight line drawn along the anterior border of the ACL and a straight line drawn from the articular surface of the tibial plateau.

(3) To measure the degree of the graft maturity, pre-contrast image with T2-weighted oblique coronal view of MRI was used. Region-of-interest (ROI) technique was used for calculating the signal-to-noise quotient (SNQ). The ROIs used to quantify the MRI signal were created using ITK-SNAP free medical imaging software (National Institutes of Health, Bethesda, Maryland). Circular ROIs 20

㎟ in area were evaluated for measuring the signal of the PCL. And then the most visible image cut of the whole ACL was chosen from oblique coronal images. (Figure1-A) The background was defined as the portion placed approximately 2cm anterior to the patellar tendon. The noise of the background was measured with circular ROI 100㎟ in area. The three intraarticular portions of ACL grafts were chosen to analyze signal intensities. The proximal (femoral), middle, distal (tibial) region were defined as the first, second and third zone, and then circular ROIs 20㎟ in area were measured in the same way as PCL, respectively. (Figure1-B) Finally SNQ value was measured at the three point, using the following equation, introduced by Ma Y et al.[7] Lower SNQ value indicates greater graft maturity.

$$\textit{SNQ (signal-to-noise quotient)} = \frac{ROI(graft) - ROI(PCL)}{Noise\,background}$$

(4) To measure the degree of revascularization, subtraction image (post-contrast enhanced image - pre-contrast image) with reverse oblique coronal view was used. In reverse oblique coronal images, the cross-section of the graft was best expressed. After choosing three points (proximal, middle, distal region) on sagittal view, we calculated SNQ values on subtraction image of the reverse oblique coronal view respectively, using the following equation. Higher SNQ value indicates faster revascularization.

$$\textit{SNQ (signal-to-noise quotient)} = \frac{ROI(graft)}{Noise\,background}$$

All MRI studies were reviewed by 2 experienced musculoskeletal radiologists who were unaware of the arthroscopic findings, clinical history, and initial MRI interpretations.

Statistical Analysis

Data analysis was performed with SPSS version 25.0 software (SPSS Inc., Chicago, IL, USA). The continuous data were reported as mean and SD. According to the normality and homogeneity of variances, the paired t-test or nonparametric Wilcoxon signed rank test was used to compare the pre- and postoperative continuous variables; the student t-test or nonparametric Mann Whitney U-test was used to analyze difference between groups. A Pearson's Chi-square test or Fisher's exact test was used to compare categorical variables between groups. The Shapiro-Wilk test was used for the normality test, and the Levene's test was used for homogeneity of variances. This was a pilot study, and a pre-study power analysis was not performed; however, post hoc power analysis for outcome of SNQ value was calculated. Statistical significance level was set at 0.05.

Results

Radiographic evaluation

Postoperative sagittal ACL angle, ACL - Blumensaat line angle, and coronal ACL angle showed no significant difference. (Table 2)

Clinical Evaluation

Manual laxity tests (Anterior drawer test, Lachman test, pivot shift test), clinical scores (IKDC, Tegner score and modified Lysholm score), and KT-2000 knee arthrometry, which quantifies anterior knee laxity, improved postoperatively in both groups, and there were no significant differences in preoperative and postoperative values between two groups. All the participants returned to normal sports activities at the follow-up time point, as all of them acquired full functional strength and stability. No infection and no synovitis were found in all the participants. There were no significant differences between remnant preserving group and non-preserving group in IKDC score, Tegner score, and modified Lysholm score. Also, KT-2000 was not significantly different between two groups, preoperatively and postoperatively. (Table 3)

MRI Evaluation

1. Comparison of graft maturity among the regions of ACL graft

On oblique coronal scan of pre-contrast image in MRI, SNQ values of the proximal region were consistently lower than SNQ values of the middle, distal region from postoperative 3months to 12months, both in remnant preserving group & non-preserving group. Statistical significance was found in non-preserving group. (Figure 3)

In remnant preserving group, SNQ was significantly decreased from postoperative 3months to 12months on proximal & middle region of ACL graft, and significantly decreased from 6months to 12months on distal region of the graft.

2. Comparison of revascularization among the regions of ACL graft

On reverse coronal oblique view of subtraction image in MRI, SNQ values of the proximal region were consistently higher than SNQ values of the middle & distal region from postoperative 3days to 12months in both groups. Statistical significances of higher SNQ value of proximal region were found on postoperative 3 & 6months in remnant preserving group and postoperative 3months in non-preserving group. (Figure 4)

SNQs of all regions were increased from postoperative 3 days to 12 months continuously. Especially in remnant preserving group, SNQ of proximal region of ACL graft reached a peak at postoperative 3months, and middle region reached at postoperative 6months. Distal region of the graft continuously increased to postoperative 12months.

3. Comparison of graft maturity & revascularization between remnant preserving group vs. non-preserving group

In pre-contrast image of MRI, SNQ values of remnant preserving group were consistently lower than that of non-preserving group from postoperative 3 months to 12 months on distal region, with no statistical significance. (Figure 5) In subtraction image of MRI, there was no consistent differences of SNQ values between two groups in all three regions of ACL graft.

Discussion

The most important finding of the present study was that the mean SNQ of proximal region of the QTPB graft was consistently higher and achieved the maximum state faster than middle and distal regions in subtraction image of contrast enhanced MRI, indicating greater and faster revascularization in proximal region than other regions of ACL graft, from postoperative 3days to 12months. Also, we found the trend that mean SNQ value (in pre-contrast image) of the proximal region of the grafts was consistently lower than that of other regions of the grafts from postoperative 3 months to 12 months, indicating the greatest maturity in proximal region of ACL graft. Our second hypothesis was not supported by the data, as there was no significant difference between remnant preserving group and non-preserving group. However, we found that graft maturity of remnant preserving group was tend to be higher than that of non-preserving group in middle and distal regions.

For successful ACL reconstruction, adequate incorporation of ACL graft onto its new environment and morphologic changes over time that make similar to a native ACL, a process termed ligamentization, are required. This process consists of several steps, including necrosis, revascularization and cellular proliferation, and remodeling.[2-4, 13-20] Among these phases, revascularization is important for recovering blood supply which supports long-term survival of the graft, and this phase should be completed appropriately during the graft maturation. Therefore, appropriate evaluation of graft maturity and revascularization of the graft is important for evaluation of graft remodeling process after ACL reconstruction. There are several kinds of methods to evaluate graft maturity and revascularization, including histologically, biomechanically, and radiologically, and contrast-enhanced MRI is known to be a gold standard non-invasive method to document graft maturity and revascularization.[21-25]

The histological and biomechanical distinctions of bone-to-bone healing after ACL autograft reconstruction has been studied in animal models. In their B-PT-B autograft study in canine model, Tomita et al.[27] showed that the pull-out strength of the B-PT-B graft was superior to that of the soft tissue graft, explaining the process of bone-to-bone incorporation that the bone block underwent osteonecrosis and replaced by a process of creeping substitution, forming a new host bone at 3 weeks postoperatively. Papageorgiou et al.[28] directly compared bone-to-bone to tendon-to-bone healing of B-PT-B autograft in goat model, reporting complete incorporation of the patellar bone block within the femoral tunnel, compared to partial incorporation at the tendon-to-bone interface in the tibial tunnel in histological evaluation.

Several studies have evaluated the serial maturation of ACL graft quantitatively using Gd-DPTA enhanced MRI. Yong ma et al. evaluated ACL graft maturity 6 months postoperatively, and reported significantly lower mean SNQ of the QTPB autografts than that of hamstring (HS) autografts, indicating greater graft maturity in the QTPB autografts.[7] Ntoulia et al. studied the change in signal intensity of ACL bone-patellar tendon-bone (B-PT-B) grafts in three distinct graft sites (intra-articular site, intra-osseous tibial tunnel site, intra-osseous juxta screw site) over time (at the postoperative 3days, 3months, 6months, and 12months), and found that the intra-articular site of the graft was the first to reach maximum revascularization state.[26] To the best of our knowledge, we are the first to report the serial change of maturation and revascularization in distinct regions of the intra-articular part of the graft after ACL reconstruction using QTPB autograft.

The difference of the present study compared to the previous studies was that we divided the intraarticular part of the ACL graft into proximal 1/3 (near femoral tunnel), middle 1/3 (mid-substance), distal 1/3 (near tibial tunnel) region, to compare the effect of bone-to-bone healing near femoral tunnel which was contacted with bone block in QTPB autograft, and the effect of tendon-to-bone healing near tibial tunnel after ACL reconstruction, which was the primary objective of this study. We found the trend that mean SNQ value (in pre-contrast image) of the proximal region of the grafts was consistently lower than that of middle and distal regions of the grafts from postoperative 3 months to 12 months, indicating the greatest maturity in proximal region of the ACL graft. Especially the difference was statistically significant in non-preserving group whereas not significant in remnant preserving group, which can be explained by masking effect of graft healing by native ACL remnant in middle & distal regions of the graft.

We also demonstrated that mean SNQ value (in subtraction image) of the proximal region of ACL grafts was consistently higher than that of other regions from postoperative 3days to 12months, which was statistically significant. And the proximal region of the graft was shown to be the first and fastest to achieve maximum revascularization state at 3 months postoperatively, while middle region reached the maximum state at postoperative 6 months and distal region still increased until postoperative 12 months, indicating the revascularization phase progressed most rapidly in proximal region compared with other regions of the graft, which confirmed our first hypothesis. It seemed that the bone-to-bone interface created by femoral tunnel and bone block of QTPB autograft promoted friendly environment for vascular ingrowth of ACL graft.

Favorable effects of ACL remnant preservation technique in ACL reconstruction have been reported in several studies.[8-12] Revascularization process of the ACL graft after reconstruction is known to be partially contributed by soft tissues of the knee, including tibial remnant of the native ACL.[14] Gohil et al.[29] demonstrated that minimal debridement of the infrapatellar fat pad, the ligamentum mucosa, and the residual stump of the ACL leads to earlier revascularization compared to standard technique, based on MRI evaluation. Ahn et al.[8] reported that the remnant bundle preservation group had significantly larger ACL grafts than the standard group, but the difference in SNQ values of the ACL grafts was not statistically significant. Although there was no consistent trend of difference in SNQ of revascularization between remnant preserving group and non-preserving group in the present study, we found that graft maturity of remnant preserving group was tend to be higher than that of non-preserving group in middle and distal region, from which it was derivable that graft maturation might be influenced by its surrounding microenvironment condition mainly formed by native ACL remnant.

There are several limitations of this study. First, some results that were not statistically significant when comparing remnant preserving group and non-preserving group can be explained by its small and different sample size (27 cases vs. 9 cases). However, it was a pilot comparative study using prospectively collected data. Although it showed no statistical significance due to its small sample size in the study, future studies are needed to confirm the effects of remnant preservation technique upon the graft healing. Second, follow-up period was up to 12 months, which was not enough to observe the maximum states of graft maturity and revascularization in distal region of ACL graft. Third, we could not correlate our clinical outcomes and MRI findings to histological or biomechanical properties of ACL grafts. However, the study aimed at human patients who had uncomplicated ACL surgery, so any kind of interventional procedure was not appropriate.

Despite these limitations, the results of this study suggested that bone-to-bone contact is important factor for biologic healing of ACL graft. Therefore, presence of absence of bone block in the graft used in ACL reconstruction might be one of the most critical standard we should consider in determining postoperative rehabilitation protocol, as the rehabilitation protocol that is specific for individual patient and take the surgical aspects into account makes the patient functions optimized for return to normal life and sports activity after ACL reconstruction.

Conclusion

The proximal 1/3 of the intraarticular portion of QTPB autograft showed greater maturity from postoperative 3 months to 12 months, and faster revascularization from postoperative 3 days to postoperative 12 months compared to middle and distal regions, in contrast-enhanced MRI. There was no significant difference between remnant preserving group and non-preserving group in graft maturity and revascularization measured by MRI, until postoperative 1 year.

References

1. Janssen RP, van der Wijk J, Fiedler A, Schmidt T, Sala HA, Scheffler SU. Remodelling of human hamstring autografts after anterior cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2011;19(8):1299-1306.
2. Marumo K, Saito M, Yamagishi T, Fujii K. The "ligamentization" process in human anterior cruciate ligament reconstruction with autogenous patellar and hamstring tendons: a biochemical study. The American journal of sports medicine. 2005;33(8):1166-1173.
3. Scheffler SU, Unterhauser FN, Weiler A. Graft remodeling and ligamentization after cruciate ligament reconstruction. Knee Surg Sports Traumatol Arthrosc. 2008;16(9):834-842.
4. Amiel D, Kleiner JB, Roux RD, Harwood FL, Akeson WH. The phenomenon of "ligamentization": anterior cruciate ligament reconstruction with autogenous patellar tendon. Journal of orthopaedic research. 1986;4(2):162-172.
5. Bicer EK, Lustig S, Servien E, Selmi TAS, Neyret P. Current knowledge in the anatomy of the human anterior cruciate ligament. Knee surgery, sports traumatology, arthroscopy. 2010;18(8):1075-1084.
6. Weiler A, Peters G, Mäurer J, Unterhauser FN, Südkamp NP. Biomechanical properties and vascularity of an anterior cruciate ligament graft can be predicted by contrast-enhanced magnetic resonance imaging: a two-year study in sheep. The American journal

of sports medicine. 2001;29(6):751-761.
7. Ma Y, Murawski CD, Rahnemai-Azar AA, Maldjian C, Lynch AD, Fu FH. Graft maturity of the reconstructed anterior cruciate ligament 6 months postoperatively: a magnetic resonance imaging evaluation of quadriceps tendon with bone block and hamstring tendon autografts. Knee Surgery, Sports Traumatology, Arthroscopy. 2015;23(3):661-668.
8. Ahn JH, Lee SH, Choi SH, Lim TK. Magnetic resonance imaging evaluation of anterior cruciate ligament reconstruction using quadrupled hamstring tendon autografts: comparison of remnant bundle preservation and standard technique. The American journal of sports medicine. 2010;38(9):1768-1777.
9. Ahn JH, Lee YS, Ha HC. Anterior cruciate ligament reconstruction with preservation of remnant bundle using hamstring autograft. Archives of orthopaedic and trauma surgery. 2009;129(8):1011-1015.
10. Lee B-I, Kwon S-W, Kim J-B, Choi H-S, Min K-D. Comparison of clinical results according to amount of preserved remnant in arthroscopic anterior cruciate ligament reconstruction using quadrupled hamstring graft. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2008;24(5):560-568.
11. Lee B-I, Min K-D, Choi H-S, Kim J-B, Kim S-T. Arthroscopic anterior cruciate ligament reconstruction with the tibial-remnant preserving technique using a hamstring graft. Arthroscopy: The Journal of Arthroscopic & Related Surgery.

2006;22(3):340. e341-340. e347.

12. Kim S-J, Jo S-B, Kim T-W, Chang J-H, Choi H-S, Oh K-S. A modified arthroscopic anterior cruciate ligament double-bundle reconstruction technique with autogenous quadriceps tendon graft: remnant-preserving technique. Archives of orthopaedic and trauma surgery. 2009;129(3):403-407.

13. Amiel D, Kleiner JB, Akeson WH. The natural history of the anterior cruciate ligament autograft of patellar tendon origin. The American journal of sports medicine. 1986;14(6):449-462.

14. Arnoczky SP, Tarvin G, Marshall J. Anterior cruciate ligament replacement using patellar tendon. An evaluation of graft revascularization in the dog. The Journal of bone and joint surgery American volume. 1982;64(2):217-224.

15. Janssen RP, van der Wijk J, Fiedler A, Schmidt T, Sala HA, Scheffler SU. Remodelling of human hamstring autografts after anterior cruciate ligament reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy. 2011;19(8):1299-1306.

16. Kleiner JB, Amiel D, Harwood FL, Akeson WH. Early histologic, metabolic, and vascular assessment of anterior cruciate ligament autografts. Journal of orthopaedic research. 1989;7(2):235-242.

17. Murray MM, Martin S, Martin T, Spector M. Histological changes in the human anterior cruciate ligament after rupture. JBJS. 2000;82(10):1387.

18. Rougraff BT, Shelbourne K. Early histologic appearance of human patellar tendon autografts used for anterior cruciate ligament

reconstruction. Knee Surgery, Sports Traumatology, Arthroscopy. 1999;7(1):9-14.
19. Zaffagnini S, De Pasquale V, Reggiani LM, et al. Neoligamentization process of BTPB used for ACL graft: histological evaluation from 6 months to 10 years. The Knee. 2007;14(2):87-93.
20. Zaffagnini S, De Pasquale V, Reggiani LM, et al. Electron microscopy of the remodelling process in hamstring tendon used as ACL graft. Knee Surgery, Sports Traumatology, Arthroscopy. 2010;18(8):1052-1058.
21. Leung DA, Pelkonen P, Hany TF, Zimmermann G, Pfammatter T, Debatin JF. Value of image subtraction in 3D gadolinium enhanced MR angiography of the renal arteries. Journal of Magnetic Resonance Imaging. 1998;8(3):598-602.
22. Ruehm SG, Nanz D, Baumann A, Schmid M, Debatin JF. 3D contrast enhanced MR angiography of the run off vessels: Value of image subtraction. Journal of Magnetic Resonance Imaging: An Official Journal of the International Society for Magnetic Resonance in Medicine. 2001;13(3):402-411.
23. Staeubli H-U, Adam O, Becker W, Burgkart R. Anterior cruciate ligament and intercondylar notch in the coronal oblique plane: anatomy complemented by magnetic resonance imaging in cruciate ligament‐intact knees. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 1999;15(4):349-359.
24. Tanaka Y, Shiozaki Y, Yonetani Y, Kanamoto T, Tsujii A, Horibe S. MRI analysis of the attachment of the anteromedial and

posterolateral bundles of anterior cruciate ligament using coronal oblique images. Knee Surgery, Sports Traumatology, Arthroscopy. 2011;19(1):54-59.
25. Tanaka Y, Yonetani Y, Shiozaki Y, et al. MRI analysis of single-, double-, and triple-bundle anterior cruciate ligament grafts. Knee Surgery, Sports Traumatology, Arthroscopy. 2014;22(7):1541-1548.
26. Ntoulia A, Papadopoulou F, Ristanis S, Argyropoulou M, Georgoulis AD. Revascularization process of the bone - patellar tendon - bone autograft evaluated by contrast-enhanced magnetic resonance imaging 6 and 12 months after anterior cruciate ligament reconstruction. The American journal of sports medicine. 2011;39(7):1478-1486.
27. Tomita F, Yasuda K, Mikami S, Sakai T, Yamazaki S, Tohyama H. Comparisons of intraosseous graft healing between the doubled flexor tendon graft and the bone - patellar tendon - bone graft in anterior cruciate ligament reconstruction. Arthroscopy: The Journal of Arthroscopic & Related Surgery. 2001;17(5):461-476.
28. Papageorgiou CD, Ma CB, Abramowitch SD, Clineff TD, Woo SL. A multidisciplinary study of the healing of an intraarticular anterior cruciate ligament graft in a goat model. The American journal of sports medicine. 2001;29(5):620-626.
29. Gohil S, Annear P, Breidahl W. Anterior cruciate ligament reconstruction using autologous double hamstrings: a comparison of standard versus minimal debridement techniques using MRI to assess

revascularisation: a randomised prospective study with a one-year follow-up. The Journal of bone and joint surgery British volume. 2007;89(9):1165-1171.

Table 1. Patient demographics

	Remnant preserving group	Non-preserving group	p-value
Number of knees	27	9	
Mean age (years)	32.1	30.9	0.808
Sex (Male / Female)	23 / 4	6 / 3	0.224
Direction (Right / Left)	13 / 14	4 / 5	0.847
Time to surgery from injury (months)	11.9	10.3	0.754

Table 2. Radiographic parameters

	Remnant preserving group (n=27)	Non-preserving group (n=9)	*p*-value
Sagittal ACL angle	76.1±12.8	75.0±14.7	0.685
ACL-Blumensaat angle	8.9±4.5	8.2±5.9	0.697
Coronal ACL angle	69.8±7.3	67.2±2.3	0.794

ACL, anterior cruciate ligament

Table 3. Clinical parameters

	Remnant preserving group (n=27)		Non-preserving group (n=9)		p-value
	preop	postop	preop	postop	
Manual laxity tests					
Anterior drawer test	1.27	0.27	1.83	0.16	n.s.
Lachman test	1.47	0.13	1.33	0.16	n.s.
Pivot shift test	2.20	0.27	2.50	0.33	n.s.
Knee arthrometer					
KT-2000	3.1±1.8	1.9±1.5	3.5±1.7	2.5±1.1	n.s.
Clinical scores					
IKDC subjective score	45.8±14.8	56.5±13.9	48.2±12.8	52.8±13.7	n.s.
Tegner score	3.1±2.1	3.0±1.7	3.0±2.3	2.9±2.0	n.s.
Modified Lysholm score	71.4±17.7	85.1±12.0	73.2±13.1	79.0±8.4	n.s.

n.s., not significant

Figure 1. T2-weighted oblique coronal view of pre-contrast image in MRI. (A) The most visible cut of the whole ACL graft was chosen. (B) Proximal (1), middle (2), distal (3) regions were defined.

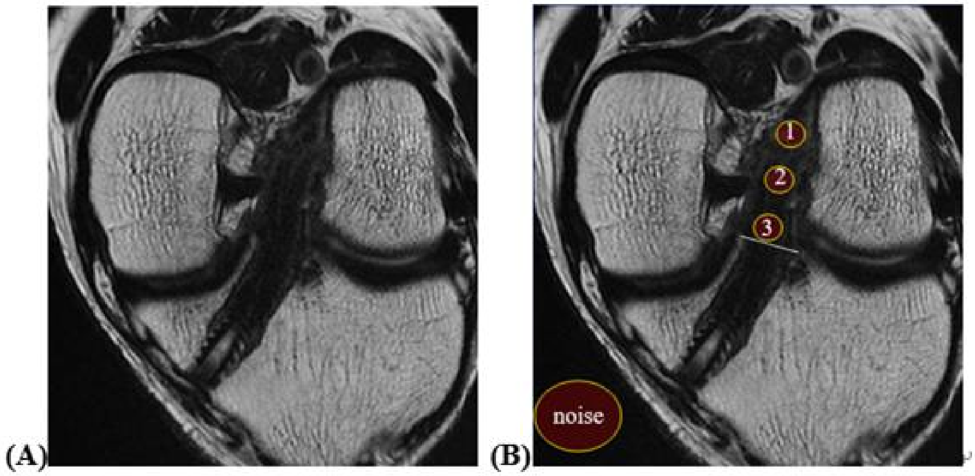


Figure 2. Subtraction image in contrast-enhanced MRI. Proximal (1), middle (2), distal (3) regions were chosen on sagittal view, and ROIs of each region were measured on reverse oblique coronal view.

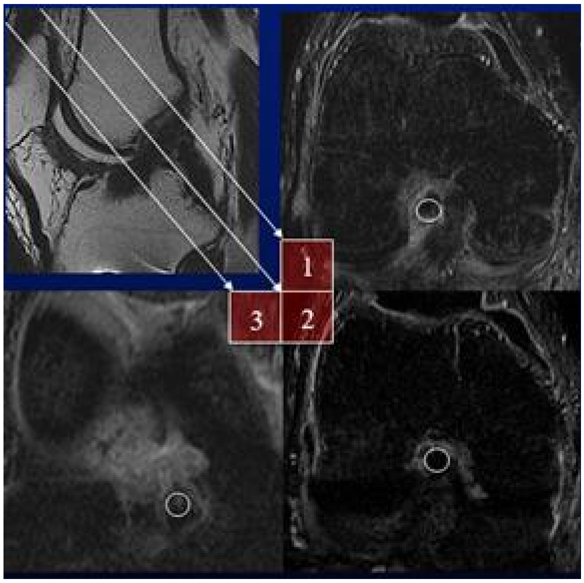


Figure 3. The relationship between postoperative time and signal-to-noise quotient (SNQ) value of ACL graft in pre-contrast image of MRI. (A) In remnant preserving group, SNQ was significantly decreased from postoperative 3months to 12months on proximal & middle region of ACL graft, and from postoperative 6months to 12months on distal region. (B) In non-preserving group, SNQ of proximal region was significantly lower than other regions at postoperative 3, 6months.

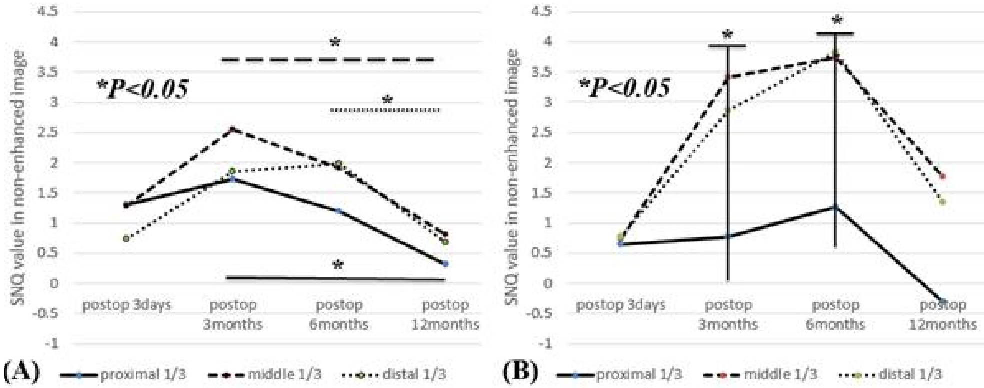


Figure 4. The relationship between postoperative time and signal-to-noise quotient (SNQ) value of ACL graft in subtraction image of MRI. In both groups, SNQ values of all regions of ACL graft increased continuously from postoperative 3days to 12months, and SNQ of proximal region was consistently higher the other regions. (A) In remnant preserving group, SNQ of proximal region of ACL graft reached a peak at postoperative 3months and middle region reached at 6months. Statistical significances of higher SNQ of proximal region were found on postoperative 3 & 6months in remnant preserving group and postoperative 3months (B) in non-preserving group.

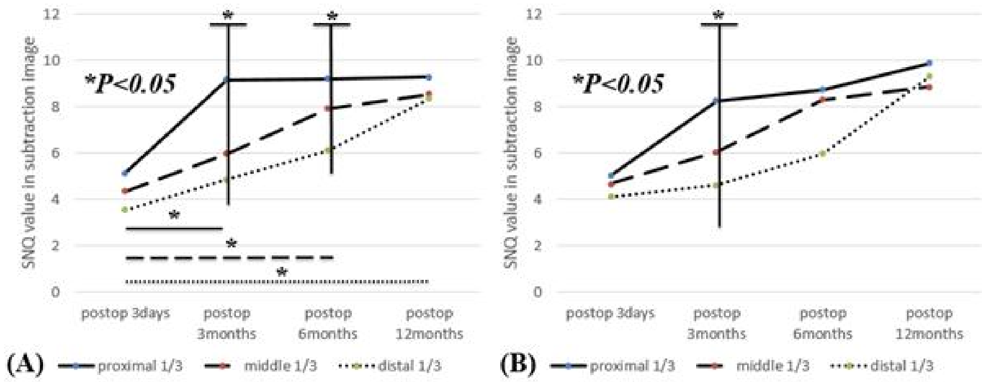
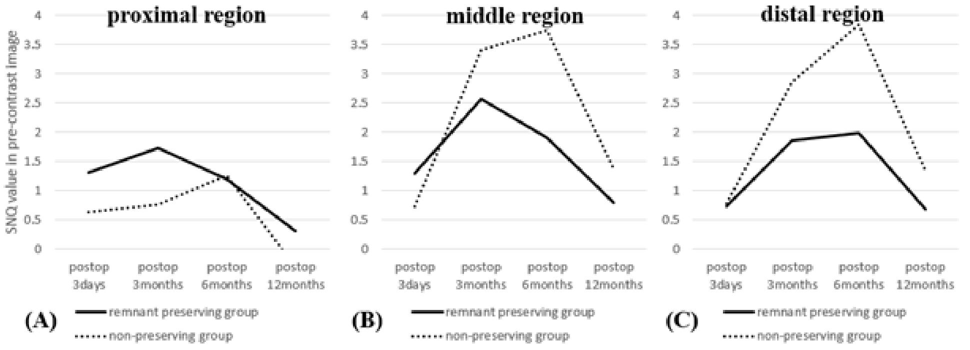


Figure 5. Graft maturity comparison between remnant preserving group and non-preserving group. In pre-contrast image of MRI, SNQ values of remnant preserving group were consistently lower than that of non-preserving group from postoperative 3 months to 12 months on (B) middle & (C) distal regions, with no significance.



국 문 초 록

대퇴사두근건-슬개골 자가건을 이용한 전방 십자인대 재건술 후 조영제 증강 자기 공명 영상을 통한 이식건의 성숙도 평가 -잔류조직 보존술과 제거술의 비교

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전방십자인대 재건술 후 재활 과정을 결정하기 위해서는, 이식건의 재형성 및 성숙이 발생하는 생물학적 과정을 이해하는 것이 중요하다. 이론적으로, 대퇴사두근건-슬개골 자가건은 뼈와 뼈의 직접적인 접촉을 통해 빠르게 회복되고 재생성된다는 장점이 있다. 전방십자인대의 잔류 조직을 보존할 경우, 이식건의 치유, 재혈관화, 고유 감각의 보전에 도움이 되었다는 연구들이 있다. 본 연구는 대퇴사두근건-슬개골 자가건을 이용한 전방십자인대 재건술 후 이식건의 성숙도 및 재혈관화 정도를 자기 공명 영상 장치(MRI)로 시간에 따라 측정하여 골 간 접촉의 효과 및 전방십자인대 잔류 조직 보존술의 효과를 평가하고자 하였다. 2012년 1월부터 2017년 4월까지 대퇴사두근건-슬개골 자가건을 이용한 전방십자인대 재건술을 시행한 총 36명의 환자들(27명의

잔류조직 보존군 및 9명의 잔류조직 제거군)에 대해 수술 후 3일, 3개월, 6개월, 12개월 째 조영제 증강 MRI를 시행하였다. 관절 내 이식건을 근위 1/3, 중위 1/3, 원위 1/3로 구분하여 각각의 신호 대 잡음 비(SNQ)를 측정하였고, 조영제 증강 전 MRI 영상에서의 SNQ 측정을 통해 이식건의 성숙도를, 조영제 증강 후 영상에서의 SNQ 측정을 통해 이식건의 재혈관화 정도를 평가할 수 있었다.

그 결과, 수술 후 3개월 째부터 12개월 째까지 이식건의 근위 1/3에서 성숙도가 다른 부위들에 비해 일관되게 높았으며, 특히 잔류조직 제거군에서 통계적으로 유의했다. 재혈관화 정도도 수술 후 3일 째부터 12개월 째까지 이식건의 근위 1/3에서 다른 부위들에 비해 일관되게 높게 나타났다. 뿐만 아니라 근위 부위는 다른 부위들에 비해 유의하게 가장 일찍 재혈관화의 최대치에 도달하였다. 잔류조직 보존군과 제거군을 비교했을 때, 이식건 성숙도나 재혈관화 정도의 차이가 관찰 기간 동안 통계적으로 유의하지 않은 것으로 관찰되었다.

전방십자인대 재건술에서 대퇴사두근건-슬개골 자가 이식건의 근위 1/3에서 MRI에서 평가한 이식건 성숙도 및 재혈관화가 다른 부위에 비해 우월함을 관찰할 수 있었다. 이를 통해 골 간 접촉이 전방십자인대 이식건의 생물학적 치유에 중요한 요인임을 알 수 있었다. 그리고 잔류조직 보존군에서 수술 후 1년까지 임상적, 영상학적으로 이식건의 성숙도나 재혈관화 측면에서 유의한 차이를 확인할 수 없었다.

주요어: 전방십자인대 재건술; 이식건 성숙도; 재혈관화; 잔류조직 보존술; 자기 공명 영상

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