Observational Study

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Effects of flexible reamer on the femoral tunnel characteristics in anterior cruciate ligament reconstruction

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Abstract

To compare the femoral tunnel characteristics using a rigid versus flexible reamer during anterior cruciate ligament reconstruction. It was hypothesized that the employment of a flexible reamer along with femoral tunnel would exhibit longer tunnel length and more acute femoral graft tunnel angle compared to the case of a rigid reamer.

The study population included 28 patients who underwent anatomical single-bundle anterior cruciate ligament reconstruction using transportal technique and were able to take postoperative computed tomography (CT) evaluation. Of these, the femoral tunnel of 14 cases was drilled with a flexible reamer (group I) and in another 14 cases drill was performed with a conventional rigid reamer (group II). The femoral tunnel in group I was made at 90° of knee flexion. In group II, the femoral tunnel was created at 120° of knee flexion. The parameters of the femoral tunnels were compared in terms of the femoral tunnel length and femoral graft tunnel angle. Special software was used to create and manipulate (3-D) 3-dimensional knee models.

The difference in the mean femoral tunnel locations expressed in percentage distance between the 2 groups was not significantly different. The mean femoral tunnel length of group I was significantly longer than that of group II, ($P = .03$, 36.7 ± 2.9 vs 32.9 ± 9.0 mm). The angle formed by the femoral tunnel and the graft in group I was significantly smaller than in group II ($P = .01$, $109.8° \pm 9.4°$ vs $118.1° \pm 7.2°$).

Our data suggest that the flexible reamer can provide sufficient tunnel length for the suspensory fixation with a fixed loop. Whereas, the femoral graft-tunnel angle through flexible reaming at 90° of knee flexion was more acute compared to rigid reaming at 120° of knee flexion.

Study Design: level of evidence III

Abbreviations: 3-D = 3 dimensional, AAM = accessory anteromedial, AM = anteromedial, BMI = body mass index, CT = computed tomography, ICC = intraclass correlation coefficients.

Keywords: anterior cruciate ligament reconstruction, femoral, flexible, reamer, rigid, tunnel

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The authors have no conflicts of interest to disclose.

The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author on reasonable request.

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1. Introduction

Transportal femoral tunnel drilling in anterior cruciate ligament (ACL) reconstruction has been introduced to achieve more precise determination of the center of the native anatomical femoral footprint.[1,2] The transportal technique enables independent femoral drilling from the tibial tunnel, leading to unconstrained access to the desired anatomical femoral footprint. However, the transportal femoral tunnel drilling technique has several potential pitfalls such as iatrogenic medial femoral cartilage damage, short femoral socket, peroneal nerve injury and posterior wall breakage.[1–5] To overcome these technical difficulties, hyperflexion of the knee during femoral tunneling has been suggested. However, hyperflexion of the knee could cause shrinkage of the knee joint space thereby resulting in poor arthroscopic vision. Recently, the efficacy of a flexible guide system has been advocated based on several cadaveric studies. The femoral tunnel using a flexible guide system could provide several advantages over the traditional rigid reamer systems, such as longer femoral tunnel and the tunnel exit which is placed more away from the peroneal nerve.[6,7] Furthermore, the flexible guide system appears to provide better arthroscopic vision than rigid reamer system due to non-stipulation of knee hyperflexion. However, most of the studies regarding efficacy of the flexible guide system are based on cadaveric studies. Furthermore, the effect of flexible guide system on the femoral graft tunnel angle which might affect graft's attritional force is yet to be clearly understood. A sharper turn of the graft at the intra-articular orifice of the femoral tunnel has been suggested as one of the numerous factors for postoperative graft damage.[8–10]

The parameters regarding femoral tunnel characteristics including graft tunnel angle as well as tunnel length, measured in an in-vivo environment might be fundamentally different from the case of in-vitro cadaveric experiments. Based on the complexity of the knee motion and soft tissue balancing of living subjects, data from actual ACL reconstruction may have more direct clinical relevance than the data from the operation using in-vitro cadaveric knee models.[11,12] Therefore, the aim of the present study is to compare the femoral tunnel characteristics using a rigid versus flexible reamer during single-bundle ACL reconstruction using a transportal technique. To accomplish this aim, we reconstructed three-dimensional (3D) knee models based on the in-vivo computerized tomography (CT) images of the operated knee from the patients who had undertaken the single-bundle ACL reconstruction. It was hypothesized that the femoral tunnel with use of a flexible reamer at 90° of knee flexion would exhibit longer tunnel length and more acute femoral graft tunnel angle compared to the tunnel with a rigid reamer at 120° of knee flexion.

2. Materials and methods

Institutional review board approval was obtained with a waiver of written informed consent for the retrospective review of records (HDT 2020-01-001). The study population included 28 patients who underwent anatomical single-bundle ACL reconstruction and were able to take postoperative CT evaluation between October 2012 and February 2017. Of these, the femoral tunnel of 14 cases was drilled with a flexible reamer (group I) and in another 14 cases, it was drilled with a conventional rigid reamer (group II). The inclusion criteria were as follows: The patients were diagnosed as having ACL injury by Lachman test, pivot shift test and magnetic resonance imaging. The patients underwent single-bundle ACL reconstruction in which the femoral and the tibial tunnel were created at the mid-position of the native femoral and tibial footprint. Patients who underwent the selective bundle reconstruction in which femoral tunnel was placed either anteromedial (AM) or posterolateral (PL) footprint were excluded. Furthermore, patients who had undergone multiple ligament reconstruction such as combined posterior cruciate ligament and posterolateral corner reconstruction, revision ACL reconstruction and double-bundle ACL reconstruction were excluded. The rigid reamer system was used in 14 patients between April 2012 and September 2015. Subsequently, a senior surgeon changed his reaming technique into flexible reamer. Hence, femoral tunneling during ACL reconstruction was used by the flexible reamer between October 2015 and February 2017. The tunneling technology has been changed because it appears to be easier to obtain proper femur tunnel placement under the flexible reamer system than the rigid reamer system. The patients who underwent ACL reconstruction using rigid reamer system were retrospectively evaluated and matched with group I population in terms of sex distribution, age, height, weight and body mass index (BMI).

3. Operative technique

The AM and anterolateral (AL) portals were established at just medial and lateral border at the proximal patellar tendon-bond junction. The AM portal was used to inspect the ACL femoral attachment. This portal enables visualization of the entire medial wall of lateral femoral condyle and the identification of the various ACL injury patterns. An accessory anteromedial (AAM) portal was subsequently established to prepare the femoral attachment using a shaver and thermal device.

In case of drilling of the femoral bone tunnel using a rigid reamer (ConMed Linvatec, NY, USA), a pilot hole of 5 mm depth was made by the guidewire with the help of a 7 mm offset guide, which was introduced through the AAM portal. The use of offset guide system enables reproducible femoral tunnel placement. The placement of pilot hole was carefully inspected and fine tuning of the location was performed by microfracture awl through the AAM portal to establish a final marking at the center of the femoral footprint in 90° of knee flexion. A guidewire tip was placed at the previously established hole through the AAM portal and then the knee was flexed to 120°. Next, the guidewire was inserted and pulled out of the skin on the lateral side of the knee. The reaming process for the suspensory fixation system (EndoButton CL, Smith & Nephew Endoscopy, Andover, MA) was performed while maintaining the same degree of knee flexion.

For the flexible reamer, the same method was used for the pilot hole at the center of the femoral footprint. Next, a 42 angled guide (Clancy Anatomic Cruciate Guide Flexible Drill System; Smith & Nephew, London UK) was introduced through the AAM portal at 90° of knee flexion (Fig. 1). Then, commercially available 2.4-mm Nitinol flexible guide pin was placed at the center of the ACL femoral attachment through the guide. A flexible guide pin was then drilled in at the same knee flexion angles. After removal of the curved guide, a flexible reamer of 4.5 mm diameter was used to drill the femoral tunnel on the opposite cortex for the passage of a suspensory fixation device. A flexible reamer of the desired diameter was used for final reaming. The reaming process was performed at same knee flexion angles for the guide pin passage (90° of knee flexion). The angle of knee flexion was verified by goniometer (Fig. 2A, B).

While viewing from the AM portal, the tibial footprint was carefully inspected and a tibial bone tunnel with an equal diameter to the femoral tunnel was subsequently made. The auto hamstring or allo-tibialis anterior graft was passed from the tibial tunnel to the femoral tunnel. All femoral fixations were

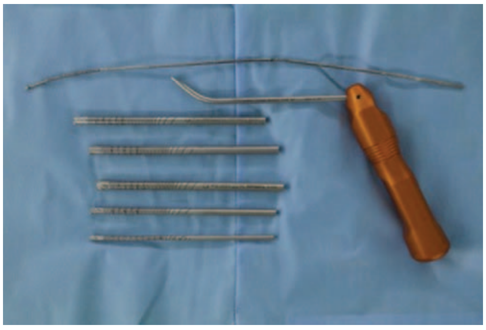

Figure 1. Flexible guide pin, 42° angled curved guide and flexible reamers with various diameters (from the top).

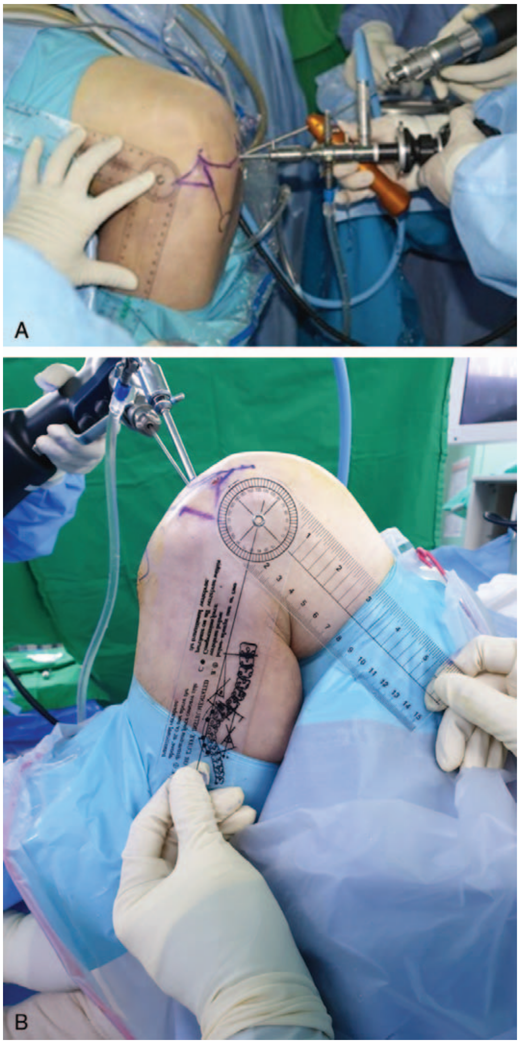

Figure 2. During femoral reaming, a flexible guide pin was introduced at 90° of knee flexion (A) and rigid guide pin was inserted at 120° of knee flexion (B). The angle of knee flexion was verified by sterilized goniometer.

performed using the EndoButton CL (Smith & Nephew) with 15 mm tape.

4. Measuring methods

High resolution computed tomography (HRCT, Siemens, Germany) was taken postoperatively. To avoid the tunnel image distortion due to postoperative tunnel widening, which was known to be evident at least 3 months postoperatively,[13] the CT was performed at mean 11 ± 4 days postoperatively. The axial and sagittal images with 1 mm slices were obtained and the Digital Imaging and Communications in Medicine file obtained from postoperative CT was uploaded to a special software program (Rapidform 2006 INUS, Korea) to create a 3 dimensional (3-D) knee model using reverse engineering tool contained in the program. The reverse engineering is an image processing method which was used to segment a region of interest from a CT image and construct the 3-D model by stacking the segmented regions.[14] We have established an anatomically detailed 3-D knee model built from the reverse engineering algorithm, the accuracy of which was verified in the previous researches.[14–16]

The measurement method of the femoral tunnel location was adopted from the technology using 3-D CT models as suggested by Forsythe et al.[17]

A true side view of the lateral femoral condyle was established after the medial and lateral femoral condyle were superimposed, followed by removal of the medial condyle image at the center of the intercondylar notch from the 3-D knee model. Similar to the radiographic quadrant method as suggested by Bernard et al, a 4 × 4 grid was aligned with the intercondylar notch roof, posterior and anterior edge of the lateral femoral condyle on the 3-D CT images.[18]

The tunnel positions were determined in the posterior-to-anterior (deep/shallow) and proximal-to-distal (high/low) directions and presented as the percentage distance from the posterior border of the lateral femoral condyle and intercondylar notch roof.

The Rapidform program was also used to measure the parameters of femoral tunnels in the 3-D plane. The femoral tunnel lengths of both the groups were compared in terms of the distance between the center of the intraarticular orifice and outer exit. The intraarticular centers of the femoral and tibial tunnels were marked and a virtual line connecting each center was formed (virtual graft line). The angle formed by the virtual line along the longitudinal axis of the femoral tunnel and the virtual graft line was defined as a femoral graft tunnel angle (Fig. 3A, B).

5. Statistics

Power analysis was performed to determine the number of subjective necessary to distinguish the significant differences in femoral tunnel lengths. Based on the pilot study, the sample size to detect the difference with a confidence level of 95% and a power of 80% required 12 knees per group. Hence, 14 patients were identified as enough to detect significance between the groups.

The demographic characteristics of the 2 groups were compared by Fischer exact test and the Student t test. The Student t test was also used to compare the parameters measured in each group. The inter- and intra-observer reliability of each measurement were represented with the intraclass correlation coefficients (ICC). To access ICC, 2 observers evaluated each measurement twice with one-week interval. Significance was accepted for P values of $<.05$. The statistical approach was done using Statistical Package for Social Science (Version 13.0; SPSS Inc, Chicago, Illinois).

6. Results

6.1. Basic demographics

There were 9 men and 5 women in the group I, and 10 men and 4 women in group II (P = n.s). Mean age at the time of surgery was 32.3 ± 9.9 years (19–42 years) in group I, and 37.5 ± 7.4 years (30–49 years) in group II with no significant difference. Mean height, weight and BMI of the subjects in both groups exhibited no significant differences. The basic demographics are shown in Table 1.

6.2. Femoral tunnel location

The femoral tunnel for the flexible reaming group (group I) was located at 28.0% ± 6.3% in posterior-to-anterior (deep/shallow)

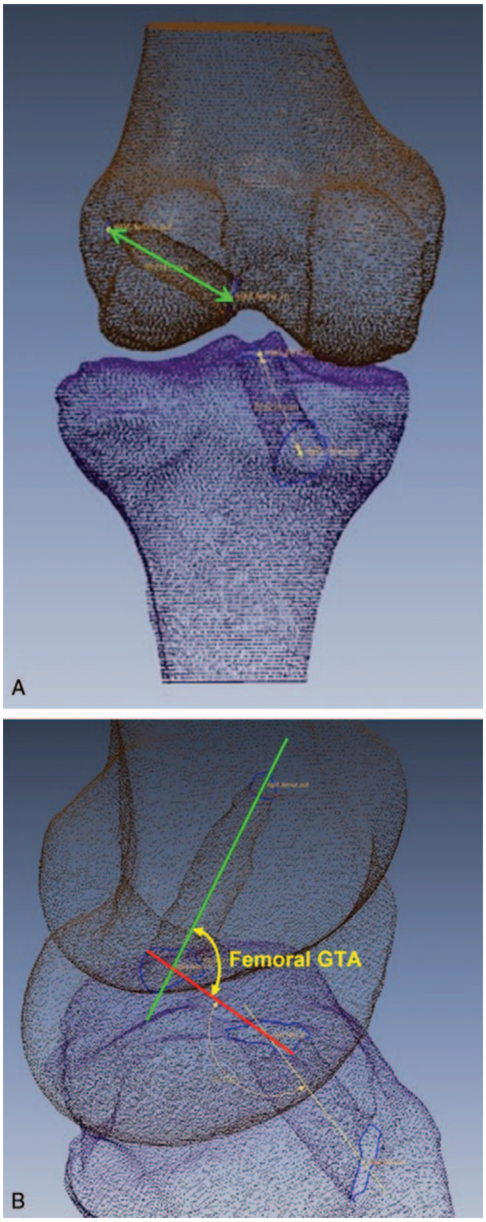

Figure 3. The femoral tunnel length was defined as the distance between the center of the intraarticular orifice and outer exit (green line) (A). The femoral graft-tunnel angle (GTA) was defined as the angle formed by the longitudinal axis of the femoral tunnel (green line) and the line along with the virtual ACL graft (red line) (B).

and at 23.7% ± 5.8% in proximal-to-distal (high/low) directions. The femoral tunnel of the rigid reaming group (group II) was located at 32.1% ± 4.3% in posterior-to-anterior (deep/shallow) and at 21.5% ± 5.2% in proximal-to-distal (high/low) directions. The difference in the mean femoral tunnel locations expressed in percentage distance between the 2 groups was not significantly different in terms of posterior-to-anterior (deep/shallow) and proximal-to-distal (high/low) directions. The ICC values for the inter- and intra-observer reliability were 0.95 and 0.93 respectively, which was considered to be excellent. The tunnel positions are displayed in Figure 4.

Table 1

The basic demographics of the patients.

	Group I (flexible reamer)	Group II (rigid reamer)	*P* value
Height (cm)	172.3 ± 3.0	168.7 ± 6.0	n.s
Weight (kg)	73.8 ± 16.1	64.9 ± 12.5	n.s
BMI (kg/m^2)	22.3 ± 2.8	24.8 ± 4.6	n.s
Sex (male/female)	9/5	10/4	n.s

All values are presented as a mean ± standard deviation.
BMI = body mass index, n.s = not significant.

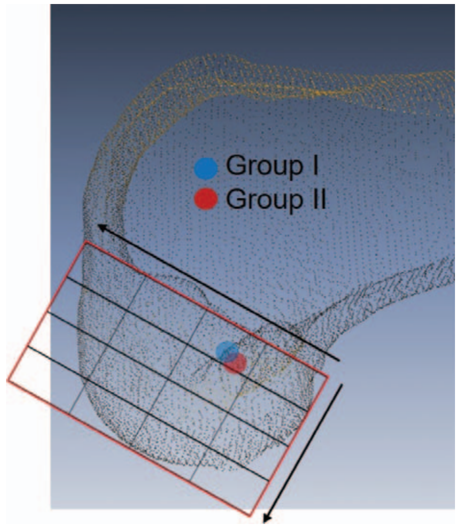

Figure 4. A side view of the lateral femoral condyle reconstructed as a 3 D model. The mean femoral tunnel locations in terms of the percentage distance (deep/shallow and high/low) were not statistically different between the 2 groups. Arrows indicate directions of percentage distance. Blue circle is the mean location for the flexible reamer group (group I) and red circle is for the rigid reamer group (group II).

6.3. Femoral tunnel length

Mean femoral tunnel length of the flexible reaming group (group I) was significantly longer than that of the rigid reaming group (group II), (P=.03, 36.7 ± 2.9 in group I vs 32.9 ± 9.0 mm in group II). The entire tunnel length of the group I (flexible reaming group) was greater than 30 mm; whereas, the tunnel length of the group II (rigid reaming group) was less than 30 mm (27.0 and 28.5 mm) in 2 knees. The ICC values for the inter- and intro-observer reliability were 0.91 and 0.95 respectively, which was considered to be excellent.

6.4. Femoral graft tunnel angle

The mean femoral graft tunnel angle in the flexible reaming group (group I) was significantly smaller than that in the rigid reaming group (group II), (P=.01, 109.8° ± 9.4° in group I vs 118.1° ± 7.2° in group II). The data indicate that the femoral graft tunnel angle of the flexible reamer was more acute than that of the rigid reamer. The ICC value for the inter- and intro-observer reliability was 0.94 and 0.90 respectively, which was considered to be excellent. The overall data are illustrated in Table 2.

Table 2

Intergroup comparisons of the various femoral tunnel parameters.

	Group I (flexible reamer)	Group II (rigid reamer)	*P* value
Tunnel location (%)			
Posterior-to-anterior (deep/shallow)	28.0±6.3	32.1±4.3	n.s
Proximal-to-distal (high/low)	23.7±5.8	21.5±5.2	n.s
Tunnel length (mm)	36.7±2.9	32.9±9.0	.03
Graft tunnel angle (°)	109.8°±9.4°	118.1°±7.2°	.01

All values are presented as mean±standard deviation.
n.s = not significant.

7. Discussion

The most significant findings of this study were that the femoral tunnel length of the flexible reamer system at 90° of knee flexion was longer than that of the rigid reamer system at 120° of knee flexion, but the mean femoral tunnel length was longer than 30 mm in both the groups. In addition, the femoral graft tunnel angle of the flexible reamer was more acute than that of the rigid reamer. However, the mean difference was only 7.1°.

In the case of femoral tunnel drilling with a rigid reamer using transportal technique, the drilling trajectory is close to the posterior femoral cortex. This type of tunnel trajectory has potential problems including short tunnel length and posterior femoral wall blowout, as the lateral exit of the tunnel becomes a posterior femoral border. To overcome these technical problems, numerous cadaveric and clinical studies have suggested that an appropriate tunnel length can be accomplished through knee hyperflexion during femoral pin placement and reaming.[4,5,19–24]

The evidence regarding the minimum tunnel length, which should be adequate for suspensory fixation is still lacking. In a recent study, the attempt to increase the length of the graft in the femoral tunnel involved the use of an adjustable cortical button system. However, several cadaveric and animal experiments have suggested that the system may create gradual loosening of the loop phenomenon under repetitive cyclic loadings, thereby creating a concern for consequent postoperative laxity development.[25–27]

Therefore, the most popular suspensory fixation method remains a cortical button method that involves a connection with the tape in fixed length. The method most technically preferred and commonly used by surgeons is the suspensory fixation method with a 15-mm-long tape (Endobutton CL). In this method, if the femoral tunnel is 30 mm long, the graft in the tunnel is 15 mm long. Several studies have suggested these lengths as the minimum lengths deemed as adequate for proper graft pull-out strength as well as the intra-tunnel healing process.[28–31]

On the contrary, there is no consensus on how much hyperflexion of the knee is appropriate. Basdekis et al in their cadaveric study demonstrated that knee flexion past 110° did not provide more intra-osseous length.[19] Whereas, Alavekios et al in their cadaveric study demonstrated that the femoral tunnel length increased as knee flexion increased. Furthermore, the authors demonstrated appearance of greater guide pin distance from the back wall cortical margin with higher knee flexion angles, suggesting that femoral tunneling in transportal technique should be performed with maximum hyperflexion.[32]

Regarding reports of femoral tunnel length created by a flexible reamer system, in the cadaveric study by Silver et al, the authors showed that the mean femoral interosseous length created by femoral guide pin system was 43.5 mm, which was longer than that created by rigid pin with 120° of knee flexion.[6] Similar results were also shown by Steiner et al. The authors compared the femoral tunnel parameters between rigid and flexible guide systems using 6 matched pairs of cadaveric knees. Both rigid and flexible pins were inserted as the knee was flexed 110°. The mean tunnel lengths through anteromedial drilling with flexible pins were longer (42.0 mm) compared with tunnel lengths with rigid pins (32.5 mm).[7]

Whereas, hyperflexion of the knee makes arthroscopic vision very poor as it causes shrinkage of the knee joint space and displaces the fat pad further into the joint, ultimately making the surgery technically demanding. Hence, flexible guide pin is considered as advantageous as lesser knee flexion angles can be required during femoral tunneling. This advantage of flexible reaming was demonstrated by Kalra et al. In their study, using 7 fresh frozen cadavers, the authors reported that the mean femoral tunnel length of 32.1 mm was obtained using flexible instrument with 90° of knee flexion, which was regarded as an adequate femoral tunnel length.[33]

However, all of the above-mentioned studies regarding the flexible reamer system were performed using cadaveric knees. Kinematics and soft tissue laxity in the process of knee flexion may be different in real operations, and the studies may have biases depending on the sizes of the femoral condyles at the knees of the sample cadavers. The present study is more clinically relevant because the data was obtained from the real patients, who underwent an actual ACL operative situation with a different flexion angle. Furthermore, 2 groups were matched pairs in terms of basic demographics to minimize selection bias.

Given the previous reviews based on adequate femoral tunnel length, the mean femoral tunnel lengths (36.7±2.9 [range 32.5 to 39.7]) obtained through flexible reamer at 90° knee flexion in this study appears to be appropriate. Our data are consistent with the appropriate lengths suggested by previous reports.[28–31]

In the group, where a rigid reamer was used in hyperflexion (120° of knee flexion), a shorter femoral tunnel was created (mean: 32.9±9.0 mm, range from 27.0 mm to 35.7 mm) and the difference was statistically significant compared with the group with the flexible reamer. However, all except 2 patients exhibited the femoral tunnel length greater than 30 mm. In 2 patients, the tunnel length was 27.0 and 28.5 mm, respectively. The estimated graft length within the femoral tunnel was 12.0 mm and 13.5 mm in the 2 patients, respectively, because Endobutton CL with 15 mm tape was used in the patients. Even though the graft length less than 15 mm may compromise with the graft healing process, the effect of about 3 mm shorter graft length in the femoral tunnel on the resulting knee kinematics and structural properties still remains unclear. Zantop et al demonstrated absence of negative effect of reducing soft tissue graft length within the tunnels measuring 25 mm to 15 mm on the resulting knee kinematics and structural properties.[31]

In general, the results of this study state that proper tunnel length could be obtained with either the flexible reamer with 90° flexion or rigid reamer with 120° flexion for ACL single-bundle reconstruction using transportal technique, as the mean femoral tunnel length was greater than 30 mm in both techniques.

Another factor affecting femoral tunnel length is the location of the femoral tunnel center. It has been reported that the lengths of femoral tunnels produced using the transportal technique became shorter with the placement of the femoral tunnel center at a much more lower (anatomically posterior) position.[34]

In this study, all the operations were performed by a single surgeon, who created 9 to 10 mm tunnels by placing the center 7 mm distant from the posterior back wall. And desired inferior edge of the femoral tunnel was located at 5 mm above the inferior cartilage margin. In addition, the surgeon rechecked the tunnel center's location after creating a pilot hole for the tunnel, using a 7 mm offset guide introduced into the accessory anteromedial tunnel. Finally, the guide pin was inserted, resulting in creation of a reproducible tunnel center in each consecutive patient. In terms of known measurement method for the femoral tunnel location, the results of this study led to verification that the femoral tunnel positions in the 2 groups were placed in a similar position.

Regarding the femoral graft tunnel angle, our results show that the graft tunnel angle by the flexible reamer provided more acute angle than that of the rigid reamer system. These results partly concur with the results of a previous retrospective study by Muller et al.[11] The authors reported that the flexible reamer system provided slightly more horizontal angle based on simple X-ray. Even though their measuring method was simple and reproducible under same strict protocol, angle assessment of tunnel angle on 2 dimensions based on simple radiograph may have a potential bias because rotation and flexion angles of the knee may affect the data measurement. Whereas, it is hypothesized that our 3D -based measurement method would provide more realistic trajectory of the graft-tunnel angle. One of the issues regarding the graft-tunnel angle is sharp turn around the acute edge of the tunnel entrance. Attritional stress could develop when the graft is turned sharply at the tunnel entrance.[35]

The present study demonstrated that the graft tunnel angle of the flexible reamer group was 7.1° more acute than that of the rigid reamer group. Eventhough the difference of 7.1° was statistically significant, it would not likely be clinically significant because the small magnitude of the difference would likely have little impact on clinical failure.[36]

There are several limitations to address. First, this is a retrospective study without blind randomization in group assignments. However, there was no demographic difference between the 2 groups including height, weight and BMI to minimize selection bias. Second, even though the power analysis confirmed that 14 patients were enough for the detection of significant difference in the tunnel length between the 2 groups. A large population of subjects would be needed for future investigation to minimize potential selection bias. Third, the present study analyzed the graft tunnel angle in only one static phase of CT examined. Several studies have demonstrated that the graft tunnel angle becomes more acute with an increase in knee flexion, implying that graft tunnel angle at higher flexed position may have more greater effect on the graft attritional force.[37,38] Fourth, the position of the tibial tunnel was not analyzed in this study. The femoral graft tunnel angle could be influenced by the position of the center of the tibial tunnel, even though all the tibial tunnels included in this study were created at the center of the native footprint relevant to the femoral tunnel position.

8. Conclusions

Our data suggest that the flexible reamer can provide a sufficient tunnel length for suspensory fixation with a fixed loop, despite the fact that flexible reamer does not require knee hyperflexion, which is considered essential in the case of the rigid reamer technique. Furthermore, the femoral graft-tunnel angle through flexible reaming at 90° of knee flexion was more acute than that through the rigid reaming at 120° of knee flexion. However, further investigations are needed because the effect of small magnitude of the difference in the graft tunnel angle on the graft survival remains unclear.

Author contributions

Conceptualization: Young-Jin Seo.
Data curation: Young-Jin Seo.
Formal analysis: Young-Jin Seo.
Investigation: Young-Jin Seo.
Methodology: Young-Jin Seo, Si Young Song, Yoon Sang Kim, Seong-wook Jang.
Project administration: Young-Jin Seo.
Software: Yoon Sang Kim, Seong-wook Jang.
Supervision: Young-Jin Seo.
Validation: Young-Jin Seo.
Visualization: Young-Jin Seo, Woo-Young Im, Yoon Sang Kim, Seong-wook Jang.
Writing – original draft: Young-Jin Seo.
Writing – review & editing: Young-Jin Seo.

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