

The effect of feedback from post-operative 3D CT on placement of femoral tunnels in single-bundle anatomic ACL reconstruction

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Received: 8 April 2014 / Accepted: 23 September 2014 / Published online: 2 October 2014
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Abstract

Purpose To evaluate the effect of feedback from post-operative 3D CT in the learning process of placing the femoral graft tunnel anatomically using the anteromedial (AM)-portal technique in single-bundle anterior cruciate ligament (ACL) reconstruction.

Methods An experienced knee surgeon converting from transtibial to AM-portal technique was offered post-operative feedback on tunnel placement. Three groups of patients were included: transtibial drilling, (AM1) anteromedial drilling without feedback and (AM2) anteromedial drilling with post-operative CT feedback. Intra-articular landmarks were used as the only guidance for tunnel placement. Tunnel position was compared to an ideal anatomical ACL position using the Bernard and Hertel grid and visual feedback was given on tunnel placements. The effect of feedback was measured as the distance from the anatomical centre, and spread of tunnel placements on post-operative CT performed feedback was initiated.

Results When comparing the femoral tunnel placement to an ideal anatomical centre, there was an improvement in the mean tunnel position after (A) changing from a transtibial to an anatomical technique and a further improvement after (B) initializing the radiological feedback. There was a great

variation of femoral tunnel localizations when initially only using intra-articular landmarks as guidance for tunnel placement—this variation, however, converged towards the anatomical centre throughout the feedback period and the AM2 group had a femoral tunnel closer ($P = 0.001$) to the anatomical centre than the AM1 group.

Conclusions Post-operative 3D CT is effective in the learning process of placing femoral tunnels anatomically by giving post-operative feedback on tunnel placement. Bony landmarks and ACL remnants were found unreliable as the only guidance for femoral tunnel placement in the AM-portal technique—therefore, the use of an aid is recommended to reduce unwanted tunnel variations in a learning phase.

Level of evidence Cohort Study, Level III.

Keywords ACL · Anterior cruciate ligament reconstruction · Anteromedial portal · 3D CT

Introduction

A range of cadaveric and biomechanical studies has shed light on the shortcomings of the transtibial approach to anterior cruciate ligament (ACL) reconstruction [3, 4, 14, 21, 27, 31]. A non-anatomic placement of the femoral graft tunnel and, thus, an inferior rotational stability has contributed to a change from transtibial ACL reconstruction to “anatomic” reconstruction [20, 23, 26]. The latter technique aims to restore as closely as possible the native biomechanical properties of the ACL and has been shown to give superior stability and a good clinical outcome [16, 24, 32, 38].

The femoral footprint of the human native ACL has been the subject of thorough investigation, and recent anatomical

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insights have described the size, shape and bony insertions of the two-bundled ligament [9, 10, 13, 31]. The femoral bony landmarks—namely the residents ridge and the lateral bifurcate ridge are seen in the femoral insertion of the two bundles of the ACL and therefore demarcate the femoral ACL footprint [10]. Whether making a double-bundle or single-bundle ACL reconstruction, close attention has to be paid to these structures as they are considered the key landmarks for placing the femoral ACL graft tunnel in an anatomic position.

The intra-articular anatomy is subject to an inter-individual variability, and the bony ridges of the femoral condyle have been described as variably present in anatomic series [10, 33, 34]. Further, spatial localization of intra-articular structures can be challenging when performing arthroscopically assisted surgery, especially in chronic cases of ACL rupture [8]. A recent study from the Danish ACL registry has revealed a doubled revision rate after a major change from transtibial to anatomic ACL reconstruction [26]. It has been suggested that a significant learning curve of the new technique might be an important factor in explaining the cause [26, 28]. To our knowledge, few, if any, patient-level studies have explored the learning curve of placing the femoral tunnel based on bony intra-articular landmarks.

The purpose of the current study was to (1) investigate the effect on femoral tunnel position when changing from a transtibial to an anatomic approach of ACL reconstruction. Further, we wanted to examine (2) the effect of increased experience with a novel technique and finally (3) the effect of receiving radiological feedback on femoral tunnel placement. The null hypothesis was that these three factors did not influence the femoral tunnel placement (as evaluated by 3D CT).

Materials and methods

An experienced knee surgeon—performing more than 100 ACL reconstructions annually—in the midst of converting his approach to drilling the femoral tunnel (for the hamstrings graft) from transtibial (TT) to anteromedial (AM)—was offered the opportunity of 3D CT feedback of tunnel placement. A total of 172 consecutive patients undergoing primary ACL reconstruction were prospectively included in the study. Revision ACL surgeries were excluded from participation due to former femoral tunnels influencing any new tunnel placement.

The first 47 patients were reconstructed with a transtibial technique and were included as a reference group (TT) before the change of technique was made. Thereafter, a total of 125 consecutive patients were included after the change of surgical techniques. These patients were defined as two groups; AM1 and AM2. AM1 ($N = 77$) was a first

group of patients reconstructed with the anatomic technique using only intra-articular landmarks as guidance (without radiological feedback), while AM2 ($N = 48$) was the consecutive group after the feedback based on post-operative CT scans was initiated.

Feedback was given at multiple sessions where individual and aggregated tunnel placements were displayed to the surgeon. Tunnel position(s) were drawn on a template 3D CT where an optimal femoral tunnel position was marked [6]. The 3D CT scan was performed in average between 6 and 12 weeks after surgery. The Regional Ethical Committee reviewed and approved of the study (REK Helse Vest ID 2014:264).

Surgical technique

All AM-portal technique ACL reconstructions were performed using a uniform single-bundle anatomic technique [7, 8]. A doubled, four-strand semitendinosus and gracilis autograft from the same knee were used for the reconstruction. A high lateral and a high medial parapatellar portal were used for visualization and instrumentation. An accessory AM portal was placed for unrestrained access to the femoral ACL insertion. Femoral tunnel placement was based on the bony landmarks and femoral remnants of the native ACL [8, 11]. A micro-fracture awl was used to demarcate the centre of the femoral footprint, aiming for a centre-to-centre ACL reconstruction. The knee was then moved to maximal flexion before the femoral tunnel was drilled over a guide pin with a graft-sized reamer. The femoral fixation device was an extra-cortical EndoButton CL (Smith & Nephew Endoscopy, Andover, MA), while the tibial fixation was a Biosure screw (Smith & Nephew Endoscopy, Andover, MA).

3D CT measurements

The post-operative CT was performed on an extended knee. A GE Lightspeed VCT 64-slice CT scanner was used at 100 kV, mAs 80 in standard and bone algorithm. The slice thicknesses of the images were 0.625. The imaging software used for the volume rendering was GE-AW Volume Share 2.A.

The 3D reconstruction was made positioning the knee in a true lateral view and removing the medial femoral condyle to visualize the inside of the lateral femoral condyle.

All measurements were performed in Mdesk 3.4.2.2 (RSA BioMedical, Umea, Sweden) using the Bernard and Hertel (B&H) grid [5]. The grid was customized based on the individual anatomy on the inside of the lateral femoral condyle. A mapping technique allowed for calculation of the centre of the femoral tunnel, independent of the shape of the tunnel aperture (Fig. 1). The centre of the graft

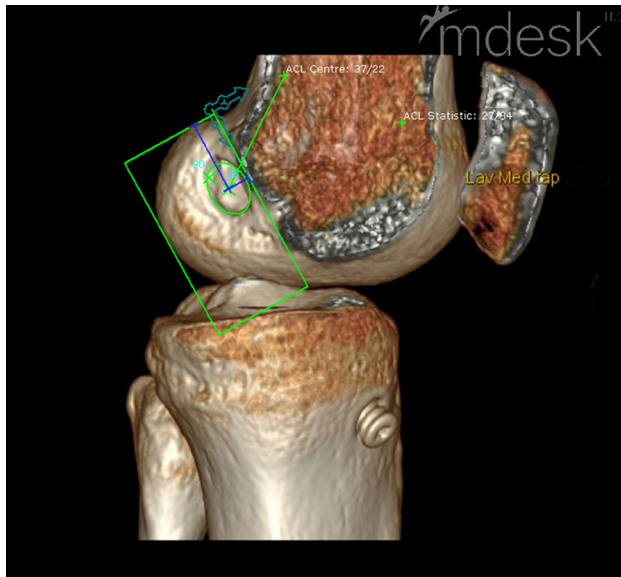


Fig. 1 Post-operative CT measurements in B&H grid adjusted for tunnel aperture

tunnel was reported as a coordinate along the high–low axis and the deep–shallow axis of the B&H grid (Fig. 1). The coordinates of the tunnel centre were then compared to an empirical optimal anatomical position (27 % along the deep–shallow axis and 34 % along the high–low axis), as introduced by Bird et al. based on average empirical femoral footprint localizations from cadaver studies [6].

Two independent examiners, not involved in the treatment of the patients, examined the tunnel placement on all post-operative CT scans. Repeated measurements were performed with a minimum of 3 months apart to establish the intra-rater reliability.

Statistical analysis

All data handling and statistical processing were done in SPSS 21.0.0.0 (SPSS Inc., Chicago, IL, USA). The a priori significance level was set at 0.05. Intra-class Correlation Coefficients (ICC) was calculated using the Chronbach's alpha statistics for inter-observer and for intra-observer reliability.

Student's *t* test for independent samples was used to make comparisons of tunnel placement between groups. Chi-square statistics were used to compare demographical data between groups. Tunnel placement in the *x*-axis (deep–shallow) of the B&H grid was chosen as the primary outcome measure. A post hoc power calculation, using a minimal detectable difference of 5 % in the *x*-axis and a SD of 8, from piloting CT measurements, showed that a group size of 50 would give a statistical power of 84 % given the significance level of 0.05.

Results

One hundred and seventy-two patients were eligible for inclusion in the study. Thirty-three patients declined to participate due to various reasons including long travelling distance and pregnancy. Of those available for analysis ($N = 139$; 81 %) no differences were found in the demographical data between the three patient groups (n.s.). Mean age in the TT group was 33.6 years (SD 9.2) with 59 % being male. In the AM1 group, the mean age was 30.5 years (SD 10.9) and 44 % were male, while in the AM2 group mean age was 30.3 years (SD 10.4) and 54 % were male.

Inter-observer reliability between the two examiners were analysed both for the high–low measurements and for the deep–shallow measurements. They were both very good, with the ICC of 0.964 and 0.983, respectively. Intra-observer reliability of the first and second measurement of the high–low and the deep–shallow measurements was 0.976 and 0.990, respectively.

Tunnel placement

The mean femoral tunnel placement, with 95 % CI for the TT, AM1 and AM2 groups are all presented in Table 1. The spread of the femoral tunnels in all three groups are shown in Fig. 2.

The absolute distance from the anatomical reference point [6] as a factor of time is shown in Fig. 3. There was a significant improvement in the distance from the reference point with time throughout the feedback period; when

Table 1 Mean tunnel placement in the high–low and the deep–shallow direction within the Bernard and Hertel grid for the three groups

	High–low direction (%) ^a	95 % CI	Deep–shallow direction (%) ^b	95 % CI
Transtibial group	8	6.2–10.5	32	30.6–33.7
AM1 (before feedback)	26	23.6–27.6	43	41.6–45.2
AM2 (after feedback)	29	25.2–31.9	27	25.8–29.2

^a With 0 % representing the highest point and 100 % representing the lowest point—corresponding to the *y*-axis in Fig. 1

^b With 0 % representing the deepest point and 100 % representing the most shallow point—corresponding to the *x*-axis in Fig. 1

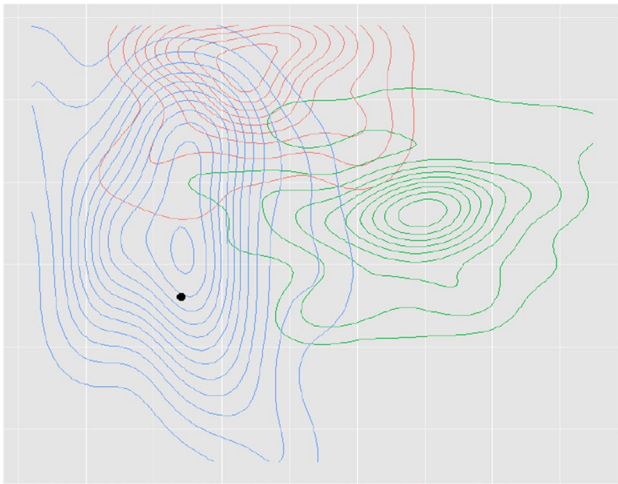


Fig. 2 Contour plot (The plot represents a cut-out of the posterior $\frac{1}{2}$ of the Bernard and Hertel Grid in Fig. 1) of the spread of the femoral tunnels in TT, AM1 and AM2 groups (Red transtibial group, green no feedback, blue after feedback). Black dot = anatomical reference of 27 % in deep–shallow and 34 % in high–low directions [6]

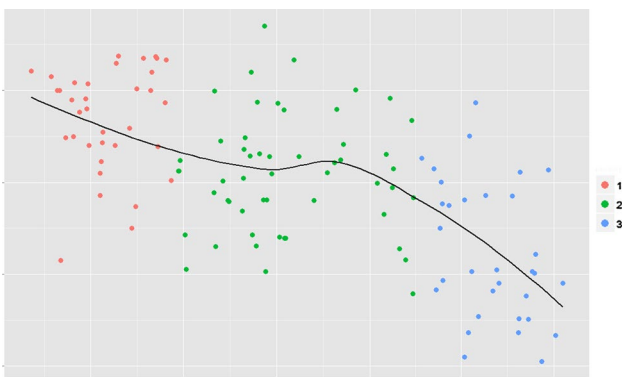


Fig. 3 Relative distance (Y-axis represents relative distance from ideal tunnel centre in absolute value) from femoral tunnel to anatomical reference as a function of time (X-axis represents time from first to last surgery). Red (1) transtibial group, green (2) no feedback, blue (3) after feedback

performing pairwise testing of the absolute difference from the ideal point (sum of absolute distance from ideal point in x-axis and y-axis), in the *TT*, *AM1* and *AM2* groups—the results showed significant differences between *TT* and *AM1* ($P = 0.004$, Mean difference = 5.0) and between *AM1* and *AM2* ($P = 0.001$, Mean difference 13.8).

Discussion

The most important finding of the current study is the improvement of the femoral tunnel placement, as compared to an optimal anatomical centre; both (A) after changing

from *TT* to *AM* approach and (B) after initiating feedback based on post-operative CT analysis. Secondly, as shown in Fig. 3, the placement gradually approaches the ideal (anatomic) point in all groups over time, indicating the importance of repetition (regardless of technique). Thus, it seems that changing technique to *AM*, performing repeated surgery and receiving radiological feedback are all important factors for improving the femoral tunnel placement. Lastly, the results of the study indicate that the bony ridges on the inside of the lateral femoral condyle and the femoral remnants of the ACL are unreliable as the only guidance for placing the femoral tunnels during ACL reconstruction—without a post-operative radiological feedback.

Post-operative 3D CT has become an important tool for the assessment of tunnel placement in ACL reconstruction, and an increasing amount of studies report on post-operative results using this technique [17, 22, 30, 31, 35, 39, 40]. To date, there is no consensus on the methodology used for such evaluation and the standards by which the graft tunnel placement should be evaluated [12]. The present study did use the Bernard and Hertel (B&H) grid, also called the quadrant method, as first published by Bernard et al. [5]. This method has proven to be versatile and can be used both on plain radiographs, during intra-operative fluoroscopy as well as on CT measurements [5, 6, 15, 40].

The empirical anatomical centre, used as a reference for the tunnel localization in the present study, represents a summation of findings from a range of cadaveric studies [6]. To date, this represents the most comprehensive measure for the centre of the femoral footprint that can be projected onto the B&H grid for use as a representation of an ideal position of the femoral graft tunnel when performing a single-bundle anatomic reconstruction and evaluating by post-operative 3D CT. A recent publication from Westermann et al. [36] described the femoral insertion of the ACL in seven cadaveric knees, marking the outline and performing CT scans to obtain an average CT reference for tunnel placement. In a 2D coordinate system, similar to the B&H grid, a quadrant representing the location of the femoral ACL insertion was then suggested by the mean borders of the ACL in the two axes of the coordinate system. Another work from the same group used this “radiographic reference” to evaluate post-operative femoral tunnel placement by 6 surgeons in a total of 72 cadaveric knees [37]. A total of 82 % of the tunnels were found to be within the “radiographic reference” of the femoral ACL footprint. A critique of using such a theoretically constructed centre for evaluating success or failure in placement of femoral tunnels would be that a “one-position fits all” approach is a simplification of the natural inter-individual variation. However, as found in the present study, such a reference point clearly contributes to reduce unwanted non-anatomic variability and thereby, hopefully preventing unwanted early graft

failure in patients reconstructed using the AM-portal technique. Also in cases of revision surgery, where the anatomy has been distorted due to the former surgery, such a reference point would be very useful if aiming to make an anatomic reconstruction.

A femoral tunnel position related to an ideal anatomical centre, as in the current study, can only be seen as an intermediate outcome after ACL reconstruction. The true benefit of anatomical tunnel placement can only be found by clinical assessment, patient rated questionnaires, functional testing of the knee and long-term evaluation of osteoarthritis. There are, however, a very limited number of publications reporting on clinical outcomes related to post-operatively assessed femoral tunnel placement. Aglietti et al. [1] reported on a series of 89 patients who had been reconstructed with a central third patellar tendon graft 7 years after the surgery. They used plain lateral radiographs and assessed the femoral tunnel placement along the Blumenstaat's line. In a group of patients where the femoral tunnel was placed in the anterior 50 % along this line, graft failure (defined as KT-2000 *I-N* difference of >5 mm or 2+ pivot shift) was found in 62 % of patients. At 18 months after surgery, Khalfayan et al. [19] reported on a similar group of 42 patients. In their patient population, a significant better clinical outcome (in terms of KT-1000 *I-N* difference, Pivot shift and Lysholm) was found in patients that had a posterior femoral tunnel placement along the Blumenstaat's line of 60 % or more compared patients anterior to this point. Pinczewski et al. [25] followed a prospective cohort of 200 patients and evaluated clinical outcomes related to tunnel placement at 7 years after surgery. Of the 184 patients available at the follow-up, 21 had suffered graft rupture. When comparing the radiologically assessed tunnel placement in this group to those with an intact graft, the only significant difference was found on the anterior-posterior placement of the tibial tunnel. The femoral tunnel placement was, however, very consistently placed in the whole group with a mean of 86 % (SD 5) in the posterior direction of the Blumenstaat's line.

Even though good results have been described for the AM-portal technique [2, 16], concerns have risen on the finding of increased revision rates after the change from TT to AM-portal technique [26]. Rahr-Wagner et al. [26] investigated 1,945 patients operated with the AM-portal technique and 6,430 operated with the TT technique between 2007 and 2010 in the Danish Knee Ligament Reconstruction Register. The cumulative revision rates after 4 years with the two techniques were 5.16 and 3.20 %, respectively; and the relative risk of revision ACL surgery for the AM group was 2.04 compared to the TT group. The learning curve of a new technique was proposed as one of the possible factors leading such a difference. The present finding of a great variability in early tunnel placement adds to

the concern for surgeons switching to the AM-portal technique and those in training of becoming an ACL surgeon. Although anatomical studies have thoroughly described the outline and centre-points of the femoral ACL footprint—along with the bony landmarks demarcating the insertion site—these are substantially more challenging to locate through an oblique view of the arthroscope in the narrow compartment of the inter-condylar notch. Several aids have been suggested to help the tunnel placement intra-operative [6, 18, 23, 29]. Bird et al. [6] validated the use of an arthroscopic ruler as an easy and instant way of placing a correct mid-bundle femoral tunnel when doing a single-bundle ACL reconstruction. Post-operative CT confirmed a relatively small spread of the tunnel placements and a mean placement close to an empirical anatomical centre. The finding from the current study supports the need for an aid in placing femoral tunnels, but also displays an effect of the post-operative CT per se in improving the anatomical placement. Even though there was a significant convergence towards the anatomical centre, there is still considerable variability in the tunnel placement after feedback sessions (Fig. 2). It may be speculated whether simple intra-operative fluoroscopy—giving immediate feedback and the ability to correct the placement of the guide pin before drilling—could further improve the reliability of obtaining an anatomical placement. Further studies should attempt to validate the use of intra-operative fluoroscopy for accurate graft tunnel placement.

There are several limitations to the current study. Firstly, although a successful outcome can be seen as a convergence towards a reference point for the centre of the femoral ACL footprint, there is a need for clinical outcome data to establish the superiority of such an anatomical tunnel position. Even though cadaveric and biomechanical studies have displayed the biomechanical advantages of such tunnel positioning, further clinical data are needed to back these theories. A clinical follow-up based on stratified femoral tunnel position is planned as a sequel to the current patient material. Secondly, there was only one surgeon performing the ACL reconstructions in the current study. Intra-surgeon variability can yield differences in tunnel placement by using intra-articular landmarks, and therefore an examination of early tunnel placement in a group of surgeons would elaborate on the current results. Thirdly, there was a significant time span between the surgery and the post-operative CT. This was due to different locations of the Surgical Clinic and the CT scanner. Ideally, the post-operative CT would have been done within the first post-operative day to give the surgeon more instant feedback on the tunnel placement. We believe that this would have shortened the so-called “learning curve” and therefore reduced the time before the convergence towards the anatomical centre was seen.

Conclusion

In conclusion, the current study has shown that the introduction of post-operative 3D CT for feedback on femoral tunnel placement did increase the accuracy in anatomical tunnel placement as compared to an empirical anatomical centre. Further, bony femoral landmarks and remnants of the femoral insertion of the ACL can be unreliable as the sole guidance for anatomical placement of the femoral graft tunnel in ACL reconstruction—therefore, it is recommended that an aid for femoral tunnel placement is used in the learning process of the AM-portal technique.

Conflict of interest No conflict of interest reported from any of the authors.

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