Effects of extremity positioning on femoral tunnel localisation after anatomic single bundle anterior cruciate ligament reconstruction - evaluation by digitally reconstructed radiographs

Poster No.: B-1214
Congress: ECR 2015
Type: Scientific Paper
Authors: P. S. Mahajan, P. Chandra, N. Ahamad, S. A. Hussain; Doha/QA
Keywords: Musculoskeletal joint, Bones, Computer applications, CT, Digital radiography, CT-High Resolution, Computer Applications-3D, Computer Applications-General, Computer Applications-Detection, diagnosis, Grafts, Athletic injuries, Economics
DOI: 10.1594/ecr2015/B-1214

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Purpose

Anterior cruciate ligament (ACL) reconstructions are routinely performed to treat ACL injuries [1].

ACL reconstruction techniques [2]:

- Anatomic double-bundle
- Anatomic single-bundle (SB) and
- Non-anatomic SB

In anatomic SB ACL reconstruction the femoral tunnel is placed at the site of insertion of the native ACL and correct tunnel positioning is essential for an optimum clinical outcome in all these techniques [2-5].

Landmarks and reference points to aid correct tunnel positioning on plain x-rays [2-7]:

- Blumensaat's line (BL) and
- Bernard and Hertel's (BH) technique

In a lateral plain x-ray of knee the BL is seen as a projection of the femoral intercondylar notch ceiling or dome [2-7].

In BH's grid based technique [Fig. 1 on page 4 B], the ACL graft tunnel position in the distal femoral shaft is computed as a proportion or percentage of the length along the BL from the proximal or anterior femoral cortex to the distal or posterior, and the junction of BL and the distal or posterior cortex is considered as 0% [2, 6, 7]. This technique is frequently used in both morphological research examinations and examinations reporting the result of ACL reconstruction [2]. For SB reconstruction, 25% with a liberality of ±7% was suggested as an ideal value [2, 8].

Three-dimensional (3D) imaging techniques, like computerized tomography (CT) and magnetic resonance imaging (MRI) are now commonly used to evaluate ACL injury and progress following ACL reconstruction [2].

Nevertheless two-dimensional (2D) imaging measurements, such as BL on plain x-rays, remain the most common technique for estimating the position of the distal femoral tunnel [2], due to
• simplicity
• easy access
• easy availability
• low radiation exposure and
• low costs

Spatial orientation of the knee joint in the X-ray setup may affect the comparative position of landmarks in a 2D image [2]. Hence, it is envisaged that 2D-radiography is less accurate than 3D-imaging techniques [2]. However a recent study suggests similar levels of accuracy with 2D-radiography and 3D-imaging techniques in assessing tunnel position with similar outcome in limb alignment [2]. To the best of our knowledge there are no previous studies evaluating tunnel placement by radiographs in anatomic single-bundle ACL reconstruction [1-28].

**Hypothesis:** Radiographic projection of BL is modified with femoral rotation, and that extremity malalignment (in comparison to a true lateral x-ray) will induce inaccuracies in estimating the graft tunnel position post SB ACL reconstruction.

**Objectives:**

We aimed to

(1) radiographically evaluate the femoral tunnel position post anatomic SB ACL reconstruction;

(2) radiographically evaluate the influence of femoral rotation on the position of the tunnels in the distal femur relative to BL after anatomic SB ACL reconstruction; and

(3) assessed clinical usefulness of radiographic evaluation of femoral tunnel and discuss its role as compared to that of the 3D-imaging techniques after anatomic SB ACL reconstruction.
Fig. 1: A and B: Digitally reconstructed radiographs showing distal femoral tunnel (arrowheads) and tunnel aperture (arrow) in 1A and Bernard and Hertel grid in 1B.

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Methods and materials

All 3D CT scan examinations of knee joints post anatomic single-bundle ACL reconstruction performed in our institute from May 2005 to November 2012 with available 3D CT scan data (22 knees of 22 different subjects) were evaluated after the study was approved by our Institutional Research Ethics Committee (Ethics Committee, Medical Research Center, Hamad Medical Corporation, Doha, Qatar). All 22 subjects underwent 3D-CT examination of the operated knee with a 64 slice helical scanner. A three-dimensional volumetric model of femur was created by first segmenting the femur from the adjoining soft tissues and then interposing its CT volume (described as the entire bone volume from external cortical surface to the entire internal tissue) with every single voxel illustrating radiographic density of the local bone. Radiographs were digitally reconstructed by using a custom computer application [10]. These reconstructed radiographs (RRs) were obtained by ray-tracing through the femoral CT volume model. Spatial orientation inside the virtual radiograph setup that the custom computer application uses is same as that used during obtaining a regular knee x-ray, maintaining a distance of 1 meter between the source and the subject [2]. It renders an image very similar to an actual x-ray, with prominent radiographic features (such as BL) clearly visible [ Fig. 1 on page 7 ].

A "true lateral" x-ray was obtained by spatially manipulating the femoral 3D CT model inside the virtual imaging program. The BH illustrated quadrant technique [2-7] was employed to estimate the ACL graft tunnel position in relation to the BL. A grid was marked onto the RR using a computer application called ImageJ (ImageJ version 1.47, National Institutes of Health, United States of America). The tunnel outline was observed and its midpoint was estimated. Four lines were drawn to form a grid and four distances (x, y, m and n) were measured along these lines. The "x" is the distance along BL from proximal or anterior aspect of femoral cortex to its distal or posterior aspect. The "y" is the distance along the line which is oriented 90-degree to the BL, from BL to the posterior aspect of the femoral cortex. The "m" is the distance from the proximal or anterior aspect of the femoral cortex to the midpoint of the tunnel along "x", and the "n" is the distance from the BL to the midpoint of the tunnel along "y". The midpoint of the ACL graft tunnel was illustrated as a percentage of two lengths along each axis. The percentage of the length along BL was called as "%BL" and computed as m/x. The %BL was measured from the distal or posterior to the proximal or anterior femoral condylar cortex, and 0% denoted the junction of this line with the distal or posterior femoral condylar cortex. The percentage of the length along the line 90-degree to BL was called as %DP. The %DP was computed as n/y and measured from BL to the inferior cortex of the femoral condyle [Figure 1A and B], with 0% at the position on BL.
Subsequently, the femoral 3D CT reconstruction was moved spatially within the setup of virtual radiograph computer program to simulate varus, valgus, internal rotation and external rotation in 5-degree additions from the base level of 0 degree to 20-degree. An RR was produced at each 5-degree augmentation. The BH technique as explained above was applied to each reconstructed radiograph to estimate the ACL graft tunnel position in relation to the BL [2]. All parameters were measured by two radiologists to determine the inter-observer reliability. Final statistical analysis was performed after averaging the measurements by the two radiologists.

**Statistical Analysis**

- Intra-class correlation coefficient (ICC).
- Repeated-measures ANOVA
- Post hoc tests with the Wilcoxon matched-pairs signed ranks test.
- Statistical packages SPSS 19.0 (SPSS Chicago, IL).
Fig. 1: A and B: Digitally reconstructed radiographs showing distal femoral tunnel (arrowheads) and tunnel aperture (arrow) in 1A and Bernard and Hertel grid in 1B.

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Results

The inter-observer variability and standard error of measurement (SEM) along with 95% CI of the measured ACL graft tunnel orifice positions in relation to the BL are presented in [ Table 1 on page 9 ]. Very good inter-observer agreement was observed under this study. Intra-class correlation coefficient for x (distance from posterior to anterior cortex along BL), y (distance from BL to femoral cortex), m (distance of tunnel from posterior femoral cortex to center of tunnel along BL), n (distance of tunnel from BL to center of tunnel perpendicular to BL), %BL (% BL of tunnel) and %DP (% DP of tunnel) values were 0.971 (95% CI: 0.962-0.980), 0.930 (95% CI: 0.906-0.950), 0.887 (95% CI: 0.848-0.919), 0.758 (95% CI: 0.675-0.827), 0.829 (95% CI: 0.770-0.878) and 0.758 (95% CI: 0.675-0.827) respectively.

The mean ACL graft tunnel orifice positions for all 5-degree augmentations for all rotation types: external, internal, valgus and varus, are presented in [ Table 2 on page 9 ]. In our study which included cases of only anatomic SB ACL reconstruction, the ACL graft tunnel position was 30.6 (±4.4) %BL and 33.1 (±5.4) %DP.

Fifteen and more degree of varus rotation resulted in a significant different position of the tunnel (only for %BL measurements) along Blumensaat's line (P = <0.0001) [ Fig. 2 on page 10 ].

Ten and more degree of external, internal and valgus rotations resulted in a significant different position of the tunnel (only for %DP measurements) along Blumensaat's line (P < 0.0001) [ Fig. 3 on page 11 ].

The %BL measurements of tunnel position did not show any significant change for 0 to 20 degree of external, internal and valgus rotations (P>0.05) [ Fig. 2 on page 10 ].

The %DP measurements of tunnel position did not show any significant change for 0 to 20 degree of varus rotation (P>0.05) [ Fig. 3 on page 11 ].
Table 1 Intra-observer variability and standard error of measurement of quadrant methods for evaluation of tunnel aperture orifice after anatomic single-bundle anterior cruciate ligament reconstruction

<table>
<thead>
<tr>
<th>Method Description</th>
<th>ICC⁴</th>
<th>CI</th>
<th>SEM⁵</th>
</tr>
</thead>
<tbody>
<tr>
<td>x - Distance from posterior to anterior cortex along BL</td>
<td>0.971</td>
<td>0.962, 0.980</td>
<td>3.06</td>
</tr>
<tr>
<td>y - Distance from BL to femoral cortex</td>
<td>0.930</td>
<td>0.906, 0.950</td>
<td>2.46</td>
</tr>
<tr>
<td>m - Distance of tunnel from posterior femoral cortex to center of tunnel along BL</td>
<td>0.887</td>
<td>0.848, 0.919</td>
<td>3.73</td>
</tr>
<tr>
<td>n - Distance of tunnel from BL to center of tunnel perpendicular to BL</td>
<td>0.758</td>
<td>0.675, 0.827</td>
<td>2.80</td>
</tr>
<tr>
<td>% BL of tunnel</td>
<td>0.829</td>
<td>0.770, 0.878</td>
<td>1.69</td>
</tr>
<tr>
<td>% DP of tunnel</td>
<td>0.758</td>
<td>0.675, 0.827</td>
<td>2.36</td>
</tr>
</tbody>
</table>

Abbreviations: BL, Blumensaat’s line

⁴Intra-class correlation coefficient

⁵95% confidence interval of the intra-class correlation coefficient

Standard error of measurement

Table 1: Intra-observer variability and standard error of measurement of quadrant methods for evaluation of tunnel aperture orifice after anatomic single-bundle anterior cruciate ligament reconstruction

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Table 2: Tunnel positions relative to Blumensaat’s line

<table>
<thead>
<tr>
<th>Rotation Type</th>
<th>Lateral</th>
<th>Valgus</th>
<th>Varus</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>%BL</td>
<td>30.6±4.3</td>
<td>30.8±4.1</td>
<td>31.7±4.5</td>
<td>32.1±5.1</td>
</tr>
<tr>
<td>%DP</td>
<td>33.1±5.4</td>
<td>31.4±5.7</td>
<td>29.9±5.1</td>
<td>28.6±4.2</td>
</tr>
</tbody>
</table>

Rotation Type | Lateral | External | Varus |  |
<table>
<thead>
<tr>
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<td>29.9±3.4</td>
</tr>
<tr>
<td>%DP</td>
<td>33.1±5.4</td>
<td>30.8±6.5</td>
<td>28.3±5.0</td>
<td>26.4±4.2</td>
</tr>
</tbody>
</table>

Abbreviations: BL, Blumensaat’s line, DP, perpendicular to Blumensaat’s line.

P-value were computed using repeated-measures ANOVA.

10 and more degree of external, internal and valgus rotations results in a significant different position of the tunnel (only for %DP measurements) along Blumensaat’s line (P < 0.0001)

15 and more degree of varus rotation results in a significant different position of the tunnel (only for %BL measurements) along Blumensaat’s line (P = <0.0001)
Fig. 2: Graph showing femoral ACL tunnel aperture location expressed as percentage along Blumensaat's line in relation to degree of rotation for various rotation types.

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**Fig. 3:** Graph showing femoral ACL tunnel aperture location expressed as percentage along the line perpendicular to the Blumensaat's line in relation to degree of rotation for various rotation types.

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Conclusion

- Femoral tunnel location can be reliably estimated from lateral radiographs post anatomic SB ACL reconstruction.

- There was no significant effect of changes in less than 10-degree alterations of limb positioning on estimating tunnel position on x-rays relative to BL.

- Although, ten and more degree of external, internal, valgus and varus rotations can introduce significant inaccuracies in tunnel location estimates, our study suggests that BL is overall reliable for assessing location of the distal femoral tunnel after anatomic SB ACL reconstruction and more so if a strict limb positioning algorithm is followed to restrict limb malpositioning within 5-degree of any rotation.

- Very good inter-observer agreement.

Practical Implications:

From a clinical point of view, our study indicates that the BL is quite reliable in evaluating graft tunnel position post ACL reconstruction. However, if the lateral x-ray is taken with inappropriate extremity positioning, significant inaccuracies may occur. Therefore, we would advise implementation of methods that consider the individual subject’s anatomy and standardize extremity positioning. If a strict limb positioning algorithm is followed to restrict limb malpositioning within 5-degree of any rotation, the radiographic evaluation can be clinically as useful as 3D-imaging techniques. 3D CT scan or MRI scanning may be utilized where available to yield higher accuracy [2, 18, 20].

Study limitations:

- We calculated the ACL graft tunnel position in percentage terms. Expressing the ACL graft tunnel position in percentage terms (%BL along the BL and %DP along the line 90-degree to the BL), may compensate these distortions.

- Performing the measurements on computer generated x-rays (RRs), rather than actual x-rays is one of the limitations of our study. Though the appearance and quality of the RRs is slightly different from regular x-rays, use of computer generated images
provided precise definition of imitated rotation and true lateral position with a resolution of 1 degree accuracy. Moreover, our technique had very good inter-observer agreement.

- Comparatively **smaller number of included subjects** is another limitation of our study. More such studies with larger number of subjects may be needed to confirm the findings of our study.

**Acknowledgements:**

**Financial support** came from Medical Research Center, Hamad Medical Corporation, Doha, Qatar.
Personal information

Parag Suresh Mahajan, MD
mdfrcr (at) gmail.com
Department of Clinical Imaging, Hamad Medical Corporation, P.O. Box 3050, Doha, Qatar

Prem Chandra, PhD
Medical Research Center, Hamad Medical Corporation, P.O. Box 3050, Doha, Qatar

Nazeer Ahamad, MD, FRCR
Department of Clinical Imaging, Hamad Medical Corporation, P.O. Box 3050, Doha, Qatar

Sheik Akbar Hussein, MD, DNB, FRCR
Department of Clinical Imaging, Hamad Medical Corporation, P.O. Box 3050, Doha, Qatar
References


