Computed tomography based evaluation of the bone mineral density around the fixation area during knee ligament reconstructions: Clinical relevance in the choice of fixation method

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ABSTRACT

Introduction: This study examined the bone density around the fixation area during knee ligament reconstructions and assessed how this clinical relevance can be applied to a firm construction for a reconstructed ligament.

Materials and methods: Fifty consecutive patients (25 healthy men and 25 healthy women) were enrolled in this study. A quantitative computed tomography was used to determine the trabecular bone density at the 7 clinically relevant areas (anteromedial area of proximal tibia, anterolateral area of proximal tibia, posteromedial area of the proximal tibia, posteroentral area of the proximal tibia, near femoral tunnel entrance of the ACL, near the femoral funnel entrance of the PCL). The means and standard deviations of the areas of interest were measured using a 10 mm diameter circle and the bone density was compared.

Results: A comparison of the fixation areas in the proximal tibia, anteromedial area of proximal tibia showed the highest bone density and posteroentral area showed the lowest bone density. A comparison of the PCL tibial fixation with interference screws or trans-condylar fixation revealed the posteroentral area to have the lowest bone density. A comparison of the femoral fixation areas in the ACL and PCL reconstruction revealed no differences in bone density.

Conclusion: The anteromedial area of the proximal tibia was most acceptable in the interference screw fixation and the posteroentral area had the lowest bone density in the proximal tibia. There were no differences in the femoral fixation areas in the ACL and PCL reconstruction.

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1. Introduction

During a ligament reconstruction of the knee joint, adequate initial fixation is essential for knee stability and it provides stability to the graft during the initial post-operative period before biological integration. For the fixation of a reconstructed anterior cruciate ligament (ACL), the femoral side is usually fixed with an interference screw, cross-pin, and other suspensory devices [1–3]. The tibial side is normally fixed with interference screws at the entrance of the tibial tunnel [1–3]. For the posterior cruciate ligament (PCL), the femoral side is usually fixed with an interference screw, cross-pin and other suspensory devices [4,5]. There are some another options evolving in the fixation of the tibial side of a PCL reconstruction according to the direction of the route (anteromedial vs. anterolateral approach) and fixation point (entrance vs. near posterior orifice of tibial tunnel) [5–8]. Recently, for the fixation of tibial tunnel, an interference screw is not only used for fixation, but a cross-pin or suspensory devices are also used with some advantages [1,2,5,6,8–10].

The bone density around the fixation area, size of the screw, type and features of the screw, and the point of fixation etc. are factors affecting the primary fixation strength [11–13]. Some studies examined the effect of the bone density on the primary fixation, and many of these reported a direct correlation between the failure load and bone density [11–14]. It was reported that the optimal fixation strength can be achieved when the bone mineral density (BMD) is > 0.6 g/cm² for ACL fixation even though this value is not constant in all subjects [11,15,16].

The majority of graft fixation is performed in the cancellous part of the tunnel. Therefore, a quantitative computed tomography (QCT) scanner is more favorable for an evaluation of BMD around the fixation point than dual-energy x-ray absorptiometry (DEXA) because it can achieve in vivo-like volume-selective measurements of the trabecular bone density [14,17]. Generally, the Hounsfield units (HU) are used to evaluate the bone density using a QCT, and a high correlation has been shown between the HU and BMD [18,19].

This study examined the bone density around the fixation area during knee ligament reconstructions (ACL and PCL) and assessed...
how to apply this clinical relevance to a firm construct for a reconstructed ligament. The hypotheses of this study were (1) tibial tunnel (interference screw fixation area) would show different bone densities and three posterior aspects of proximal tibia (PCL tibial fixation using an interference screw, cross-pin, or suspensory device) would show different bone densities, with the posterior-central area where the interference screw is fixed near the posterior orifice showing the lowest bone density, and (2) the bone density between ACL and PCL in the femoral side would be similar.

2. Materials and methods

From 2005, 50 consecutive patients (25 healthy men and 25 healthy women) who visited the emergency department or outpatient clinic and showed no definite bony abnormality (including bony contusion) were enrolled in this study. They had to fulfill the following criteria for inclusion in this study: (1) no medication affecting the bone metabolism, (2) no previous major knee surgery or injury, (3) no definite mal-alignment or mal-formation, and (4) less than grade II degenerative change [14]. Institutional review board approval was obtained before initiation of the study, and all patients provided informed consent for participation. We did not check CT scan only for this study’s purpose. The mean ages of the male and female patients were 33.6 years (ranging from 19 to 44 years) and 32.4 (ranging from 18 to 46), respectively.

A QCT (Somatom Sensation 16 channel, TRCT-500-140, Siemens, Germany) was used to determine the trabecular bone density at the tibia, T (PM): posteromedial area of proximal tibia, T (PC): posterocentral area of proximal tibia, T (AL): anterolateral area of proximal tibia, T (PM): posteromedial area of proximal tibia, T (PC): posterocentral area of proximal tibia, T (PL): posterolateral area of the proximal tibia, F (ACL): near femoral tunnel entrance of ACL, F (PCL): near femoral tunnel entrance of PCL) (Table 1). The means and standard deviations (SD) of the areas of interest were measured using a 10 mm circle in diameter. To measure the T (AM) and T (AL), the axial slice below 1.5 cm to the articular cartilage and just above the level of the fibula head was chosen, and the T (AM) and T (AL) were measured at the 5 mm inner side from the cortex and 1 cm medial and lateral side from the anterior shin, respectively (Fig. 1). To measure the T (PM), T (PC), and T (PL), the same axial slice was chosen, and the T (PM), T (PC), and T (PL) were measured at the 5 mm inner side from the cortex and 1 cm medial, central, and 1 cm lateral side from the posterior center, respectively (Fig. 2). To measure the F (ACL), the 1st sagittal slice of the medial wall of the lateral femoral condyle was chosen and the measurement was performed at the entrance of the femoral tunnel (Fig. 3). To measure the F (PCL), the 1st sagittal slice of the lateral wall of the medial femoral condyle was chosen and the measurement was performed at the entrance of the outside-in femoral tunnel (Fig. 4).

SAS 9.1.3 (SAS institute Inc., Cary, NC, USA) was used mainly for the statistical analysis. SPSS 17.0 (SPSS Inc., Chicago, USA) was also used to determine the specific p-values of each comparison. A p-value < 0.05 was considered significant. Two-way ANOVA or Friedman test was used to compare the bone densities in the 7 areas. Two-way ANOVA test was used if the data show normal distribution and Friedman test was used if the data do not show normal distribution. The p-values were corrected using a Tukey’s test with ranks for multiple comparisons. Power analysis was performed to determine the power with our sample size. If the difference in bone density was more than 20 HU and the alpha was 0.05, 25 patients showed >95% power.

3. Results

Table 2 lists the means and SDs of seven fixational areas. T (AM) showed the highest bone density in the tibial side with statistical significance but F (PCL) showed highest bone density in the femoral side with no statistical significance.

A comparison of T (AM), T (AL) and T (PC), which are the areas fixed with an interference screw during tibial fixation of the ACL or PCL reconstruction (Table 1), revealed T (AM) and T (PC) to have the highest and lowest bone density, respectively, in the male patients (T (AM) vs. T (AL): P < 0.001, T (AM) vs. T (PC): P < 0.001, T

Fig. 1. For the measurements of the T (AM) and T (AL), the axial slice below 1–1.5 cm to the articular cartilage and just above the level of the fibula head was chosen and T (AM) and T (AL) were measured at the 5 mm inner side from the cortex and the 1 cm medial and lateral side from the anterior shin, respectively.

Fig. 2. For the measurement of the T (PM), T (PC), and T (PL), the same level of the axial slice was chosen and T (PM), T (PC), and T (PL) were measured at the 5 mm inner side from the cortex and 1 cm medial, central and 1 cm lateral side from the posterior center, respectively.

Table 1

<table>
<thead>
<tr>
<th>Area</th>
<th>Clinical applications</th>
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<tbody>
<tr>
<td>T (AM)</td>
<td>Interference screw fixation in ACL or PCL with anteromedial route</td>
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<tr>
<td>T (AL)</td>
<td>Interference screw fixation in PCL with anterolateral route</td>
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<tr>
<td>T (PM)</td>
<td>Expansion or suspensory fixation in PCL</td>
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<tr>
<td>T (PC)</td>
<td>Interference screw fixation in PCL near posterior orifice</td>
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<tr>
<td>T (PL)</td>
<td>Expansion or suspensory fixation in PCL</td>
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<tr>
<td>F (ACL)</td>
<td>Femoral fixation in ACL, mainly interference screw</td>
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<tr>
<td>F (PCL)</td>
<td>Femoral fixation in PCL, mainly interference screw</td>
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4. Discussion

The principal findings of this study were as follows: (1) the anteromedial area of the proximal tibia (ACL tibial fixation or PCL tibial fixation with anteromedial route) showed the highest bone density and the posteroentral area (interference screw fixation in PCL near posterior orifice) showed the lowest bone density (with statistical significance in the male patients and without statistical significance in the female patients), and (2) on the comparison of femoral fixation areas in the ACL and PCL reconstruction, there were no differences about bone densities in both male and female patients.

Mariani et al. [14] compared the bone density between the area adjacent to the fixation of the PCL (corresponding to T (PC) in our study) and a similar area at the ideal site for the ACL (corresponding to T (AM) in our study). Their results showed a significantly higher bone density in the anterior region (162 ± 33.8 HU) than in the posterior one (104 ± 24.6 HU). We also evaluated the correlation according to the different age groups, but there was no specific correlation or change with our results. The present study also showed a similar result to Mariani et al.’s. This suggests that the fixation should provide a firm construct with additional post-tie fixation for a PCL reconstruction using interference screw fixation or that an improved technique or materials are necessary. Lancianese et al. [20] reported that analyzing the measured mechanical properties according to the location resulted in significant (P<0.05) differences in yield stress (medial: 8 MPa, central: 5.5 MPa, lateral: 6.26 MPa) and ultimate stress between the specimens from the lateral versus central and medial versus central sides. Only the lateral versus central comparisons resulted in significant differences in Young’s modulus. No mechanical property differences were determined between the lateral and medial sides. In this report, the central area shows the lowest strength than the medial or lateral areas.

For ligament fixation, there are three fixation mechanisms: compression, expansion, and suspension. The compression mechanism is represented as an interference screw and the Expansion mechanism is represented as a cross-pin. The suspension mechanism is sub-divided into cortical as an endobutton, cancellous and cortico-cancellous [5,21,22]. Recently, soft tissue grafts including a 4 strand hamstring tendon and tibialis allografts have attracted increasing attention, and new methods of graft fixation are being reported [5,23–25]. For the fixation of these soft tissue grafts, suspensory and expansion mechanisms have some merits in the length of the graft, and stable fixation that is comparable to an already well-established technique was devised [5,7,26].

Our study’s results could be basis for the prevention of potential complications and hence gain greater fixation strength by additional fixation or changing fixation methods. However, our study has several limitations that must be considered. First, this is not a direct measurement of bone density although a high correlation has been shown between the HU and BMD. Second, we could not state exactly about the cutoff point that is critical for the fixation strength. We could only predict the relative strength of the locations around knee.
5. Conclusion

The anteromedial area of the proximal tibia was most acceptable in the interference screw fixation and the posterocentral area had the lowest bone density in the proximal tibia. There were no differences in the femoral fixation areas in the ACL and PCL reconstruction.

References


