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Evaluation of tibial bone-tunnel changes with X-ray and computed tomography after ACL reconstruction using a bone-patella tendon-bone autograft

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Abstract Thirteen patients who underwent anterior cruciate ligament (ACL) reconstruction with bone-patella tendon-bone autografts (BTB) using interference screws were the subjects of this study. We analysed the relationship between bone-tunnel changes and clinical results 2 years after ACL reconstruction. To investigate changes, X-ray images were used to evaluate bone-tunnel enlargement, and computed tomography (CT) was used to evaluate the sclerotic area around the bone tunnel. The KT-2000 was used to measure the discrepancy of tibial anterior displacement between the affected and nonaffected sides (DTAD). There was no correlation between bone-tunnel enlargement and DTAD. On the other hand, in the CT evaluation, there was a significant correlation between the sclerotic area and DTAD. Our results suggest that it is more significant to analyse the area of sclerotic change than bone-tunnel enlargement for clinical evaluation. We cannot evaluate bone-tunnel changes correctly with two-dimensional X-rays and cannot analyse the sclerotic area using X-rays. Therefore, we recommend that CT, with which it is possible to analyse the sclerotic area, be used to evaluate bone-tunnel changes and clinical results.

Résumé 13 patients ayant bénéficié d'une reconstruction du ligament croisé antérieur avec une auto-greffe à partir de la rotule et du tendon rotulien par des vis d'interférence ont été le support de cette étude. Nous avons utilisé la relation entre les modifications des tunnels osseux et les résultats

cliniques deux ans après la reconstruction du ligament croisé antérieur. Afin d'analyser les modifications au niveau du tunnel osseux, les images radios montrant un élargissement au niveau du tunnel osseux ont été utilisées de même que le scanner afin d'évaluer également la sclérose osseuse autour du tunnel. Les résultats cliniques ont été analysés à l'aide du KT 2000 mesurant le tiroir intérieur entre les deux genoux (genou normal, genou opéré). Il n'y a aucune corrélation entre l'élargissement du tunnel osseux et des modifications du tiroir intérieur, d'autre part, lors de l'évaluation par scanner, il existait une relation significative entre l'aspect sclérotique du tunnel et les modifications de tiroir. Notre étude nous permet de suggérer, qu'il est plus utile d'analyser la sclérose du tunnel plutôt que son élargissement. Il n'est pas possible d'évaluer les modifications du tunnel osseux avec une radio face/profil de même en ce qui concerne l'os scléreux. C'est pour cette raison que nous recommandons l'utilisation du scanner qui permet cette analyse de façon précise et qui permet par ailleurs de faire la relation entre ces modifications et les résultats cliniques.

Introduction

Reconstruction of the anterior cruciate ligament with an autograft has become popular since the clinical results of primary repair and conservative treatment are poor [19, 20]. The technique using a bone-patella tendon-bone (BTB) autograft is one of the most common reconstruction methods [11, 21].

The qualitative and biomaterial changes of a reconstructed ligament are very important together with the histology and the failure strength at the graft's attachment to the inner wall of the bone tunnel. Twelve weeks after surgery in a dog model, collagen fibers resembling Sharpey's fibers were histologically demonstrated from the graft invading the bone tunnel, and biomechanically the graft-bone tunnel failure strength was stronger than the midsubstance rupture strength of the graft [17]. Early, firm attachment of the autograft to the walls of the tunnels is essential for successful reconstruction.

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The bone tunnel suffers various directional mechanical stresses from the graft which may cause changes in the tunnel. In recent years there have been some reports of bone-tunnel enlargement after ACL reconstruction using autografts [4, 5]. Most reports have identified that the bone-tunnel enlargement as evaluated with X-rays did not correlate with knee instability [1–4, 14]. On the other hand, a few reports have shown that bone-tunnel enlargement was related to clinical results [7]. The clinical significance of bone-tunnel enlargement has not yet been fully explained.

In our study, we used X-rays and computed tomography (CT) to evaluate bone-tunnel changes, and we assessed whether the images of bone-tunnel enlargement with the two-directional X-rays reflected knee instability. We then evaluated the sclerotic area around the bone tunnel with CT to clarify the relationship between the sclerotic area and knee instability.

Materials and methods

The subjects were 13 patients (five male, eight female) who received ACL reconstruction using BTB. Their average

age was 29.9 ± 10.6 years old, and postoperative follow-up lasted at least 20 months (average follow-up term 23.5 ± 5.0 months). All patients had a recreational or higher level of sports activity and underwent the same postoperative rehabilitation. They had no problems and returned to their preoperative sports levels after the operation.

The reconstruction using BTB was performed by making 8- or 9-mm bone tunnels in both the femur and tibia at general isometric points. For this technique, we used interference screws to fix BTB bone plugs to the bone tunnel. They were fixed to the femoral side inside-out and to the tibial side outside-in.

Anterior-posterior (A-P) and lateral X-ray views were taken at the last follow-up visit. The last follow-up X-rays showed sclerotic margins in both the femoral and tibial bone tunnel. According to the measurement points described by Nebelung, we measured the distance between the two sclerotic outer margins of the bone tunnel perpendicular to the axis of the tunnel as the bone tunnel width. The widths of the bone tunnels were evaluated at a point 3 mm below the tibial plateau and above the openings of the articular side of the femur with A-P and lateral X-ray views (Fig. 1a,b) [2].

Fig. 1 Anterior-posterior (a) and lateral (b) X-ray views. c Computed tomography scan of sclerotic area around the tibial bone tunnel

The widths at the last follow-up were compared with the known intraoperative sizes of the drill holes, and we defined the discrepancy between them as the bone-tunnel enlargement.

CT (GE Yokokawa, Tokyo, Japan) images were also taken at the last follow-up. CT was used to measure the sclerotic area around the tibial bone tunnel (Fig. 1c). The CT images were sliced parallel to the tibia plateau every 3 mm from the openings of the articular side to the distal openings. We measured the sclerotic area of each slice 3 mm distal from the tibia plateau at the same level at which the width was measured with X-rays. The X-ray and CT images were analysed using a computer equipped with Bell design software (Bell Design/Pro7; Bell Software, Tokyo, Japan).

A KT-2000 arthrometer (MED Metric, CA, USA) was used in the standard way to evaluate knee instability. We measured the discrepancy of tibial anterior displacement between the affected and nonaffected side (DTAD) at the last follow-up visit [9, 10]. A large DTAD indicated high knee instability and the likelihood of poor clinical results.

We compared and analysed the bone-tunnel enlargement from X-rays and the sclerotic area in CT with DTAD. The relationship between them was expressed by Pearson's correlation coefficient. Student's *t*-test was used for statistical analysis. *P*-values <0.05 were considered significant.

Results

In the X-ray evaluation, the enlargement of the tibial bone tunnel was 1.7 ± 1.7 mm for the A-P diameter and 1.5 ± 1.3 mm for the transverse diameter at the intraarticular side. In all cases, 69.2% cases in the A-P diameter and 76.9% cases in the transverse diameter showed more than 1 mm of enlargement of the tibial bone tunnel. The enlargement of the femoral bone tunnel was 0.9 ± 1.1 mm in the A-P diameter and 0.9 ± 0.9 mm in the transverse diameter. There was no significant difference between the A-P and transverse diameters in either the tibia or femur ($p > 0.05$; Fig. 2).

Fig. 2 Evaluation of bone tunnel enlargement on X-ray. The largest enlargement is the tibial bone tunnel for the anterior-posterior diameter

Fig. 3 **a** Relationship between the transverse enlargement of tibial bone tunnel and DTAD with X-ray ($R^2=0.0054$; $p>0.05$). **b** Relationship between the anterior-posterior enlargement of the tibial bone tunnel and the discrepancy of tibial anterior displacement between the affected and nonaffected side with X-ray ($R^2=0.0035$; $p>0.05$)

The mean DTAD was 3.0 ± 3.0 mm. The relationship is shown between the transverse enlargement of the tibial bone tunnel and DTAD (Fig. 3a). The correlation coefficient had low correlation ($R^2=0.0054$; $p>0.05$), and a similar result in the A-P enlargement indicated a low correlate coefficient ($R^2=0.0035$, $p>0.05$; Fig. 3b).

On the other hand, the findings of bone-tunnel changes with CT showed a sclerotic ring-shaped area in all cases, which included various shapes such as oval, round, and irregular (Fig. 4a,b). The mean sclerotic area was 115.1 ± 49.1 mm². A high correlation coefficient for the relationship between sclerotic areas and DTAD was clearly noted ($R^2=0.5261$, $p<0.05$; Fig. 4c).

Discussion

It has been reported that the width of the bone tunnel increases up to 2 years after ACL reconstruction, but after 2 years the width dose not change [18]. Because the bone tunnel continued to change up to 2 years in the above-mentioned paper, we chose to evaluate the bone-tunnel changes about 2 years after reconstruction in our study. Our results show the same ratio as that described before [2], more than 1 mm of bone-tunnel enlargement, and are also thought to be reasonable.

Fig. 4 **a, b** Various ring-like shapes of sclerotic area on computed tomography (CT). **c** Relationship between sclerotic areas and discrepancy of tibial anterior displacement between the affected and nonaffected side on CT ($R^2=0.5261$, $p<0.05$)

We examined both bone-tunnel enlargement and sclerotic changes around the bone tunnel about 2 years after ACL reconstruction, with the concept that bone-tunnel enlargement and sclerotic changes are different aspects of the problem.

The radiographic definition of bone tunnel enlargement is confusing. Some reports customarily use the distance of the sclerotic outer margins of the bone tunnel as a sign of enlargement [1–5]. However, inclusion of the sclerotic area in the enlargement is controversial. The sclerotic area actually shows calcification of the cancellous bone and, strictly speaking, does not indicate enlargement. If sclerotic change is regarded as one of the reactive changes after ACL reconstruction, we agree that measuring the bone tunnel outside the sclerotic area is reasonable, and in our study we also evaluated the enlargement by this method.

However, it was not clear whether the bone-tunnel changes occurred because of the maturation of the attachment or from mechanical stress from the graft. Our results suggest a link between bone tunnel enlargement and mechanical stress. The bone-tunnel enlargement on the tibial side was larger than that on the femoral side. This suggests that bone-tunnel enlargement may be related to mechanical stress, since the longer lever arm on the tibial side produced the higher mechanical stress (Fig. 5).

However, our results and those presented in some other papers showed that bone-tunnel enlargement as evaluated with X-rays did not seem to be related to knee instability in

Fig. 5 Lateral view of the knee after anterior cruciate ligament reconstruction with bone-patella tendon-bone autografts fixed by interference screws. The bone tunnel of the tibia (**a**) is longer than that of the femur (**b**). The longer lever arm on the tibial side causes more mechanical stress

clinical results [1–4, 14]. We have one explanation for this result: the bone-tunnel changes are not only circular. CT images showed that all cases had sclerotic changes in areas around the tibial bone tunnel, which were of various shapes including oval, round, and irregular. Thus two dimensional, X-rays are of limited value in evaluating these various-shaped bone-tunnel changes. From these results, we conclude that X-rays are unsuitable for a correct evaluation of the bone tunnel.

On the other hand, we recommend evaluating the sclerotic area with CT because there was a high correlation coefficient of the relationship between sclerotic areas and DTAD. Sclerotic changes are recognized more clearly with CT than with magnetic resonance imaging (MRI) because the essence of sclerotic changes is calcification, although low signal intensity areas along the walls of bone tunnels have been shown by MRI [8]. This indicates that CT is more useful than MRI for showing bone-tunnel changes.

Considering why the relationship between sclerotic areas and DTAD is significant, first of all we must clarify the nature of sclerotic changes around the bone tunnel. The cause of bone-tunnel enlargement has not even been clearly and completely proven, although some reports have attributed it to mechanical or biological causes [3, 6, 12, 13, 15, 16]. However, we agree that biological factors such as immunological reactions and biomechanical stresses cause bone tunnel enlargement and sclerotic changes. Brown et al. [22] reported that mechanical stress caused bone reactive changes. The identified mechanical stress concentration area led to bone hypertrophy, and the stress shielding area underwent bone atrophy. If these phenomena are reproduced in reconstructed knees, bone tunnels probably undergo sclerotic changes due to mechanical stress exerted by the graft a couple of years after operation.

A well-reconstructed ligament that gives better knee stability causes high tension and more mechanical stress to the bone tunnel. It is probable that higher mechanical stress causes the larger sclerotic areas along the bone tunnel [13]. Good knee stability shows lower DTAD. Consequently, it is accepted that a significant negative correlation exists between the sclerotic area and DTAD. Our results support this opinion.

In conclusion, although it is impossible to clarify why the sclerotic area has a high correlation with clinical results, we recommend evaluating the sclerotic area with CT to assess knee instability.

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