12 Graft Length in the Tunnel in Cruciate Ligaments Reconstruction

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Introduction

The essence of cruciate ligament reconstruction is to establish a new graft–bone connection. Although in the natural cruciate ligament, the ligament fibers are attached to the bone surface of the femur and tibia, no attempt has been made to attach the graft directly to the bone surface in cruciate ligament reconstruction. Although tendon–bone surface attachment is a common repair method for rotator cuff tears, it is difficult to believe that a strong tendon–bone connection can be achieved by tendon–bone surface attachment. Traditional cruciate ligament reconstruction involves four steps: preparation of the graft, establishment of the tibial and femoral bone tunnels, placement of the graft in the bone tunnels to bridge the tibia and femur, and fixation of the graft. In order for the graft tissue to function, a strong connection between the graft and bone must be achieved. The graft is placed in the tunnel first to provide a firm graft anchorage early on and then to achieve a satisfactory graft–bone healing in the long term.

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A variety of grafts have been used in cruciate ligament reconstruction. These can be divided into four types: synthetic or artificial grafts, two bone-ended grafts (e.g., bone–patella tendon–bone grafts), one bone-ended grafts (e.g., quadriceps tendon, Achilles' tendon grafts), and pure soft tissue grafts (e.g., popliteal tendon grafts).

Artificial grafts are made of synthetic materials and cannot be transformed into living tissue to achieve graft–bone healing. Bone tunnel is used for placement of grafts and interference screws to achieve long-term mechanical fixation. In this case, the artificial structure should be long to extrude the outer orifice of the bone tunnel.

For bone-ended grafts, the healing between the graft tissue and the host bone is not of concern because the nature of graft-to-bone tunnel healing is bone-to-bone healing and does not require the formation of new tendon–bone connections. For this graft end, the bone fragment in the tunnel should be long enough to allow the screw to safely purchase the graft when using interference screws to secure the graft end. In clinical practice, a bone end 25 mm long is usually formed and inserted into the tunnel. In recent years, suspension fixation has been widely used in bone tissue transplantation. However, whether and to what extent bone graft ends can be shortened in tunnels without affecting graft–host bone healing remains to be explored.

For soft tissue grafts, the length of the graft in the tunnel is more critical for initial graft fixation

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and eventual tendon–bone healing. The first related graft is one soft tissue ended graft consisting mainly of autogenous quadriceps tendon and allogeneic Achilles' tendon. This graft is more commonly used for posterior cruciate ligament reconstruction (PCL) than anterior cruciate ligament reconstruction (ACL). At present, there is no research report on the optimal length of the soft tissue end in the tunnel. A second related graft is one that has two soft tissue ends. The graft is usually made with an autologous hamstring or peroneus tendon and a boneless allograft tendon. In this chapter, we will discuss the required or optimal length of soft tissue grafts in the tunnel for cruciate ligament reconstruction, mainly two soft tissue-ended grafts, represented by hamstring grafts.

The Length and Zero-Time Biomechanics of the Graft in the Tunnel

There are few studies on the optimal length of soft tissue grafts in tunnels, especially for immediate bone graft anchorage in tunnels. Yang et al. [1] compared different intraosseous tendon lengths (20 mm and 40 mm) and the fixation strength of interfering screws in the study of ACL reconstruction in porcine tibial model. Although they found greater ultimate tensile strength of the flexor tendon in the tibial tunnel at 40 mm, they did not observe differences between groups in graft slip or total graft movement. They concluded that an intra osseous graft of 20 mm in the tibial tunnel is safe and of sufficient strength (>450 N) for adequate rehabilitation after ACL reconstruction.

This study is of great significance for tibial soft tissue transplantation and fixation. But the bone mineral density of human knee is different from that of porcine knee, and different patients have different bone mineral density. In clinical settings, it is not clear whether 20-mm-long tibial tunnel bone graft can achieve satisfactory anchorage with interference screws. In addition, bone density is different on the side of the femur. Lateral femoral interference screw fixation requires the establishment of a larger femoral tunnel than the graft, which reduces the fit between the graft and the tunnel. The optimal graft length under these conditions cannot be inferred from this study.

Summary: In the porcine ACL reconstruction model, the optimal graft length for interference screw fixation in tunnel was 20 mm. However, the optimal intra-tunnel graft length for this special fixation has not been evaluated in humans.

The Length of the Graft in the Tunnel and the Tendon–Bone Healing

The graft–bone union following soft tissue transplantation for reconstruction of cruciate ligament is tendon–bone union. After cruciate ligament reconstruction, the graft must be firmly fixed in zero time to prevent mechanical failure of the graft complex. In the long term, graft function depends on good tendon–bone healing to prevent the graft from pulling out of the tunnel. Theoretically, the longer the graft end in the tunnel, the larger the tendon–bone interface and the stronger the tendon–bone adhesion.

Greis et al. [2] assessed the effects of tendon length and fit on the strength of the canine tendon–bone tunnel complex. They placed the extensor digitorum longus tendon into the epiphysis tunnel outside the joint, with tendon lengths of 10 mm and 20 mm. After a 6-week biomechanical study, they found that the maximum tendon length within the bone tunnel maximized the strength of the tendon–bone tunnel complex. However, Yamazaki et al. [3] came to the opposite conclusion. In a canine model of anterior cruciate ligament flexor tendon reconstruction, 5-mm and 15-mm grafts were inserted into the tibial tunnel. After a biomechanical study at 6 weeks, they concluded that placement of excessively long flexor grafts in the bone tunnel did not lead to additional increases in graft anchoring strength and stiffness during ACL reconstruction. The difference in the conclusions of the two studies may be due to the possible threshold of the minimum graft length in the tendon–bone healing tunnel. When the minimum graft length in the tunnel was 15 mm, the graft length in the tunnel in the two groups in the study of Greis et al. was separated by threshold, which could reflect the difference as better anchorage effect of the graft in the 20 mm group. In the study of Yamazaki et al., neither group exceeded the threshold (5 mm and 15 mm) and the difference may not be reflected. The results of Yamazaki et al.'s study could be interpreted to mean that both 5 mm and 15 mm graft lengths in the tunnel were insufficient, rather than that both 5 mm and 15 mm graft lengths in the tunnel were sufficient because longer graft lengths were not assessed.

Zantop et al. [4] evaluated the effect of graft length in the tunnel on the biomechanics of the knee joint for cruciate ligament reconstruction in a goat model with an Achilles tendon. A 15-mm and 25-mm-long graft was inserted into the femoral tunnel. Using 6- and 12-week biomechanical studies, they concluded that there was no negative correlation between short graft length (15 mm) in the femoral tunnel and the resulting kinematic and structural characteristics of the knee, suggesting a minimum graft length of 15 mm in the tunnel. Qi et al. [5] evaluated the effect of soft tissue grafts of different lengths in the tibial tunnel in a canine ACL reconstruction model with Achilles tendon. The 5 mm, 10 mm, 15 mm, and 20 mm tendons were inserted into the tibial tunnel. Biomechanical and histological studies at 6 and 12 weeks concluded that tissue maturity and biomechanical strength of the tendon–bone connection after canine ACL reconstruction were delayed early if the graft length in the bone tunnel was less than 15 mm. This also indicates a minimum graft length of 15 mm for tendon–bone healing.

Yuan et al. [6] reported their study on the optimal graft length in ACL reconstruction tunnels. They conducted a biomechanical study on beagles after anterior cruciate ligament flexor tendon reconstruction. The tendon lengths of tibial tunnel and femoral tunnel were 5 mm, 9 mm, 13 mm, 17 mm, 21 mm, and 25 mm, respectively. Biomechanical examination was performed at 45, 90, and 180 days, respectively. They observed that the maximum tensile strength and stiffness of the grafts increased with the length of the graft in the tunnel, but reached a plateau at 17 mm, indicating that the optimal graft length in the tunnel was 17 mm. This suggests that the long graft end occupying the entire length of the tunnel is not a necessary condition for optimal tendon–bone adhesion. They also found that with respect to the strength of the graft complex, tendon–bone adhesions or healings play an important role in the early (45 days) and late (180 days) stages, rather than in the intermediate stage when the weak point of the reconstructed structure was at the intra-articular part of the graft.

Although these studies have important implications for minimum and optimal graft lengths for tendon–bone healing in tunnels, they were conducted in small animals. The minimum graft length of 15 mm deduced by Zantop et al., Qi et al., and the optimal graft length of 17 mm deduced by Yuan et al., cannot be directly applied to clinical practice. In addition, in clinical practice, dual fixation can be performed, always including suspension and interference fixation, especially on the tibial side. Dual fixation can increase the initial fixation strength of tendon, but interference screw can reduce the area of tendon–bone contact. Under these conditions, the minimum and optimal graft length in the tunnel is unknown.

Summary: In the canine ACL reconstruction model, the minimum graft length in the tunnel is 15–7 mm to ensure graft–tendon healing. No studies support longer intra-tunnel graft lengths in this respect. The optimal intra-tunnel graft length to ensure tendon–bone healing in human ACL reconstruction is unknown.

Internal Fixation Method and Length of Tendon Graft in Tunnel

There are three main fixation methods for femoral end soft tissue graft in single-bundle cruciate ligament reconstruction, namely, interface fixation, suspension fixation, and cross-pin fixation, among which the cross-pin fixation has the best fixation strength [7]. In the latter two fixation methods, the initial anchorage strength of the femoral graft end should not depend on the friction between the graft and the tunnel wall, but on the strength of the suspension structure or the cross-fixation structure. Graft length may play an important role in interfacial fixation. For 25-mm-long interference screws, a 25-mm-long graft is required in the tunnel. However, it is not clear whether the longer graft ends in the tunnel have better anchoring effects.

At the tibial end, there are two main methods of graft fixation, interface fixation and suspension fixation. Intrafix fixation, fixation with a special interface device, provided the best fixation strength [8]. As suspension fixation on the femoral side, fixation strength does not depend on the length of the graft in the tibial tunnel but the suspension complex. In interfacial fixation, the length of the graft in the tunnel may be significant. When using interference screws, they can be placed at the intra-articular aperture, in the middle potion of the tunnel, or at the extra-articular aperture. The end of tibial tunnel–tendon graft should not be shorter than the interference screw when the joint line or inner-aperture fixation is taken. When outer aperture fixation is taken, the tibial graft end should be longer than the tunnel. When the Intrafix device is used, the graft end should also protrude from the outer hole of the tibial tunnel. In the last two cases, the graft end had to occupy the entire length of the tibial tunnel.

Interfacial fixation and cross-pin fixation are generally not suitable for femoral side fixation in double-bundle anterior cruciate ligament reconstruction, and suspension fixation is the most appropriate method. Therefore, there is no prior tendon graft length corresponding to the fixation required in the femoral tunnel. There was no corresponding length of prior tendon graft in the tunnel for tibial side suspension fixation [9]. For the use of interference screws, a graft end longer than the length of the screw in the tunnel is required.

In our clinical practice, no graft bone union failure has been observed following the placement of 18-mm-long grafts into the bone tunnel in either ACL or PCL reconstruction. We believe that tendon grafts of more than 30 mm in the tunnel are not necessary for tendon healing. Therefore, when the length of the graft in the tunnel is greater than 30 mm, we consider that as long as the length of the graft in the tunnel is greater than 18 mm, the length of the graft can be shortened, and the size of the graft can be increased to achieve super ACL or PCL reconstruction. Switching from a two-stranded graft of a single-stranded tendon to a three- or four-stranded graft will significantly increase the initial strength of the graft, improve the ultimate stability of the joint, and reduce the failure rate.

Summary: Suspension fixation methods support shorter graft lengths in tunnels.

Clinical Procedures Regarding the Length of the Graft in Tunnel

In animal experiments, the minimum graft length in the tunnel to ensure tendon–bone healing was 15 mm, and the optimal graft length in the tunnel was 17 mm. No further increase in length benefit was observed. Clinically, in single-bundle ACL reconstruction, it is usually possible to form four-stranded grafts from a single ST and six- or seven-stranded grafts from ST and GT, with sufficient total graft length and intra-tunnel graft length.

In double-band ACL reconstruction, it is usually possible to form a four-stranded graft from a single ST for the AM bundle and another four-stranded graft from a single GT for the PL bundle with sufficient graft length. The length of graft necessary in the tunnel for cruciate ligament reconstruction also depends on the fixation devices available. For allografts of soft tissue, longer grafts in the tunnel may be required to ensure tendon–bone healing.

Because the length of a four-stranded ST graft is usually 6–7.5 cm, with a mean of approximately 7 cm. For the reconstruction of the anteromedial bundle of the ACL with the four-stranded ST or for single-bundle ACL reconstruction with a seven-stranded graft from the ST and GT, we usually put 2.5-cm-long graft in the femoral tunnel, 2-cm-long graft within the joint, and 2.5-cm long in the tibial tunnel, as for a 7-cm-long graft [10]. The length of a four-stranded GT graft is usually 5.5–7 cm, with a mean of 6 cm. For the reconstruction of the posterolateral bundle of the ACL, we usually put 2.2-cm-long graft in the femoral tunnel, 1.5-cm-long graft within the joint, and 2.3-cm-long graft in the tibial tunnel, as for a 6-cm-long graft [11] (Fig. 12.1).

In PCL reconstruction, the intraarticular portion of the graft should be 3–4 cm based on the exact reconstruction method, whereas the intraarticular portion of ACL reconstruction is usually 2–2.5 cm. Therefore, a single tendon is usually not long enough to make a four-stranded graft but suitable to make a three-stranded graft. We usually make a six-stranded graft from the hamstring tendons (in some cases, a seven-stranded graft) or nine-stranded graft from the hamstring tendons and the anterior half of the peroneus longus tendon. The usual graft length is 8–9 cm to put 2.5-cm-long graft in the femoral tunnel, 3- to 3.5-cm-long graft in the joint, and 2.5–3 cm long or even longer graft in the tibial tunnel [12].

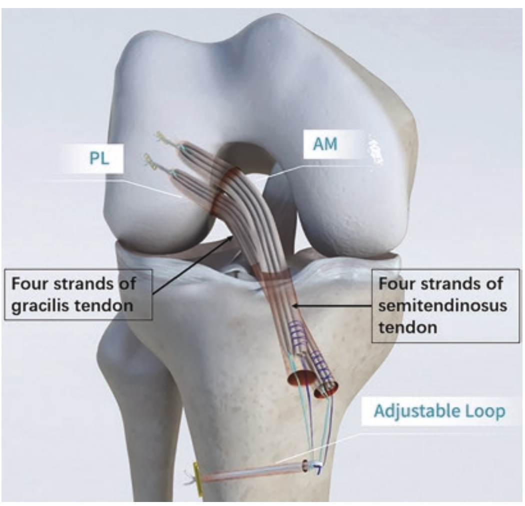

Fig. 12.1 Illustration of double-bundle ACL reconstruction with one four-stranded graft made from the semitendinosus tendon and another four-stranded graft made from the gracilis tendon. Suspension fixation is the main fixation method on both the femoral and tibial sides to accommodate the relatively short graft length in the tunnel. *AM* anteromedial bundle, *PL* posterolateral bundle

However, we are opposed to using two hamstring tendons to make just a four-stranded graft, no matter for ACL or PCL reconstruction. It is really a waste of graft source. Since graft size is associated with successful cruciate ligament reconstruction [13], we should increase graft size without affecting the optimal graft length in the tunnel.

Summary: One eight-stranded graft or two four-stranded grafts can be made from the semitendinosus tendon and the gracilis tendon for single- or double-bundle ACL reconstruction, and one six- or seven-stranded graft can be made from the semitendinosus tendon and the gracilis tendon for single-bundle PCL reconstruction with enough graft length in the tunnel.

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