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Modified technique for preparation and placement of quadrupled semitendinosus autograft in anterior cruciate ligament reconstruction

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Цель. Усовершенствовать способ кортикальной фиксации аутотрансплантата из сухожилия полусухожильной **Purpose** To improve technique of cortical fixation of quadrupled semitendinosus autograft in anterior cruciate ligament (ACL) reconstruction providing a tight contact of the tendon and bone inside the tunnels. **Material and methods** Application of the technique offered earlier for preparation and placement of quadrupled semitendinosus autograft in ACL reconstruction for a maximal tendon-bone contact is reviewed. The technique uses cortical buttons for semitendinosus graft fixation. Proximal and distal ends of the graft are corrugated at placement, thus increasing the diameter and providing additional fixation inside the bone tunnels. The modified technique employs same corrugated sutures with an easier placement practice. Potential fixation tightness in the tunnels is assessed by an increase in the diameter at both ends of the prepared graft while tightening corrugated sutures. Six semitendinosus tendons of 3 cadavers were used for testing. **Results** Diameters of the proximal and distal ends of the graft prepared with modified technique increased by 1.33 ± 0.52 mm and 1.5 ± 0.55 mm, respectively, at tightening the corrugated sutures. The ends of the corrugated sutures were tightened with a force of 50 N with a tension of 80 N applied to the graft. Elastic deformation was observed at 364.83 ± 69.16 N during the tensile test for the graft prepared with earlier technique and cortical fixation thread with the focus on the strength of transverse threads. The modified technique ensured a reliable construct being comparable with that provided by all-inside technique (760 N) by removing the weak link. Tendon graft preparation time reduced by 30 %. **Conclusion** Modification of the earlier described technique for preparation and placement of quadrupled semitendinosus autograft facilitated tight contact of the tendon and bone inside the tunnels, easier placement practice and improved strength characteristics of the prepared graft.
Keywords: anterior cruciate ligament reconstruction, fixation technique, hamstring tendons, quadrupled semitendinosus autograft

INTRODUCTION

Bone tunnel enlargement (BTE) after anterior cruciate ligament (ACL) reconstruction is a well-known phenomenon that has been described by many authors during the last 25 years. The incidence of tunnel enlargement is particularly related to hamstring autografts with reported variability ranging from 25 to 100 % in femoral tunnels and 29 to 100 % in tibial tunnels [1]. Although the majority of studies revealed no correlation between bone tunnel enlargement and clinical outcomes of ACL reconstruction [2, 3, 4, 5] revision surgery can be complicated by severe widening eventually making the two-stage ACL revision surgery necessary [6]. The total second ACL reinjury is reported to be 7 % [7]. The success of ACL reconstruction requires solid graft incorporation within the tunnels to enable graft remodeling. Collagenous fibers developing between the graft and bone tunnel walls are initiated by Sharpey fibers being directly dependent on graft-bone interface. Resorbable interference screws provide limited tendon-bone contact because much of the tunnel circumference is occupied by the screw itself, while cortical fixation provides larger contract zones [8]. Among the biomechanical factors related to the micro-motion of the graft within the bone tunnel wall are the bungee cord effect associated with longitudinal graft motion, and the windshield wiper motion effect associated with transverse graft motion, both of which are well known. The greater the distance between the graft fixation site and the articular surface the more micro-motion of the graft within the bone tunnel observed. Both effects make graft incorporation within the tunnels difficult [1]. Both extracortical fixation and interference screw fixation techniques have been shown to be associated with bone tunnel enlargement. The insertion of

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interference screws apparently compresses the graft in the bone tunnel and using a purely extracortical fixation technique increases the tibial and femoral tunnel area during the first 6 postoperative months, while it decreases slightly thereafter [9].

A technique we offered to prepare and place quadrupled semitendinosus autograft in ACL reconstruction facilitated the tight contact of the tendon within the bone tunnels and maximal tendon-bone interface using corrugated sutures that allowed increased diameter of the proximal and distal ends, less motion in the tunnel and prevention of intraarticular fluid between the graft and tunnel walls. This technique included femoral fixation with cortical flip button (Fliptack Karl Storz) with constant loop length. Strength characteristics of our earlier construct were inferior to those observed in cortical fixation and standard method of preparing the hamstring ACL graft. The technique featured multiple specific steps of graft placement [10] that resulted in longer operating time. Stump-preserving ACL reconstruction carries the advantage of rapid biological graft incorporation. Tissues of the stump prevented synovial leakage inside the bone tunnel arresting adverse effect of cytokine [11]. Remnant preservation in ACL reconstruction can resist tibial tunnel enlargement [6]. The all-inside ACL reconstruction cannot be performed with maximally preserved ACL remnant. Cortical suspension devices with adjustable loop have been widely used for ACL reconstruction because of sufficient failure loading and the simplicity of fixation. Biomechanical testing suggests that adjustable-loop devices can be considered a safe alternative to fixed-loop devices in ACL reconstruction [12].

The purpose of the work was to improve technique of cortical fixation of quadrupled semitendinosus autograft in anterior cruciate ligament (ACL) reconstruction providing the tight tendon-bone contact inside the tunnels.

MATERIAL AND METHODS

Application of the technique offered earlier for preparation and placement of quadrupled semitendinosus autograft in ACL reconstruction for a maximal tendon-bone contact was reviewed [10]. The technique employed cortical fixation of the graft with proximal and distal ends surrogated and increased in diameter providing a tight intra-tunnel fixation in bone tunnels in absent implants. The earlier technology with quadrupled semitendinosus autograft is schematically illustrated in Figure 1 [10].

Facilitating a tight intra-tunnel graft fixation the technique had several major weaknesses. The transverse sutures (suture threads 7 and 8 in Figure 1) decreased elastic deformation of the construct. Elastic deformation measured 364.83 ± 69.16 N at biomechanical testing of the graft and threads fixing the graft to the cortical buttons with the strength of transverse sutures playing the leading role [10].

The technique was used for preparation and placement of the four-strand semitendinosus tendon autograft in 25 patients who underwent ACL reconstruction. There were 18 male and 7 female patients aged from 21 to 54 years. MRI of bone tunnels evaluated at 6 months postsurgery showed femoral tunnel enlargement in 15 % and tibial tunnel widening in 12 % measuring not more than 2 mm with use of surrogated sutures. Along with strengths of the technique we encountered some technical difficulties preparing and placing the graft and using multiple threads including temporary positioning threads (suture threads 1 and 2 in Figure 1).

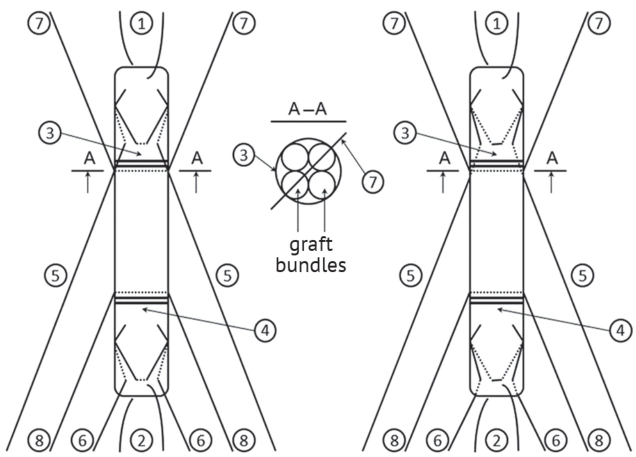

Fig. 1 Four-strand semitendinosus tendon autograft prepared with earlier technology. On the left, anterior view of the graft, on the right, posterior view of the graft. 1 – suture thread in the proximal graft to pull it through the tibial and femoral bone tunnels, 2 – suture thread in the distal graft for initial tensioning, 3 – proximal thread to suture and wrap around all graft bundles forming proximal circular suture, 4 –distal thread to suture and wrap around all graft bundles forming distal circular suture, 5 – proximal surrogated suture thread, 6 – distal surrogated suture thread, 7 – proximal thread for definitive graft fixation to the femur, 8 – distal thread for definitive graft fixation to the tibia

Average time for graft preparation was 36 minutes. The technology employed cortical fixation with fixed loop that aggravated the complicated placement with no possibility of additional graft retensioning following tibial fixation [13]. Cortical fixation with adjustable loop is an evolutional continuation of fixed-loop devices to allow efficient positioning in short femoral tunnels [14].

The modified technique employed same corrugated sutures with an easier placement practice and higher strength of the construct. The goal of the new technology was to provide proximal and distal fixation of the four-strand semitendinosus tendon autograft in the tibial and femoral tunnels in ACL reconstruction providing a tight graft-bone interface and augmentation with sutures. Semitendinosus tendon was used for grafting that was fixed to the femur and tibia with cortical devices. Proximal and distal ends of the graft were surrogated and increased in diameter providing additional intra-tunnel fixation, incorporation of hamstring graft within bone tunnels without intra-tunnel implants preventing intraarticular fluid between tunnel walls. Semitendinosus tendon autograft was harvested through a standard anteromedial approach in the upper third of tibia or a posterior approach. Muscle tissues and tendinous intersections were removed from the harvested tendon on the dissection table. A cortical button with a loop for subsequent femoral fixation and a thread loop used for tibial fixation was attached to the clamps of the preparation table. Two loops opposite each other were shaped for femoral and tibial fixation. The tendon was pulled through the loops to allow each of the ends running twice with one end being pulled clockwise while the other end being pulled anticlockwise. Both ends were adjusted and stitched with a single retention suture. A contact site of free ends was displaced either to the proximal or distal portion of the graft to ensure the quadrupled conglomerate. Graft preparation technique has been described by Lubowitz J.H. [15]. Moderate tightening of threads 1 and 2 attached to the clamps of the preparation table transformed the rounded graft into an oblong shape. The bundles were arranged in such a way that the contact site of free ends was overlapped by the surrounding bundles. Then distal and proximal circular sutures followed by surrogated stiches were applied. Figure 2 demonstrates a diagram of prepared graft before the proximal surrogated suture (5) was applied. Figure 3 shows a diagram of applying the proximal surrogated suture. Step-by-step description of sutures is given below. The distal surrogated suturing was performed in an identical manner.

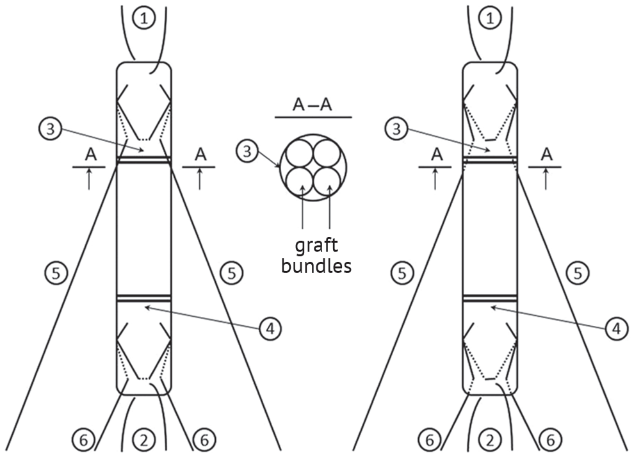

Fig. 2 Four-strand semitendinosus tendon autograft prepared with modified technique. On the left, anterior view of the graft, on the right, posterior view of the graft. 1 – thread of the femoral cortical button, 2 – thread for cortical tibial fixation, 3 –proximal circular suture, 4 – distal circular suture, 5 – thread of the proximal surrogated suture, 6 – thread of the distal surrogated suture

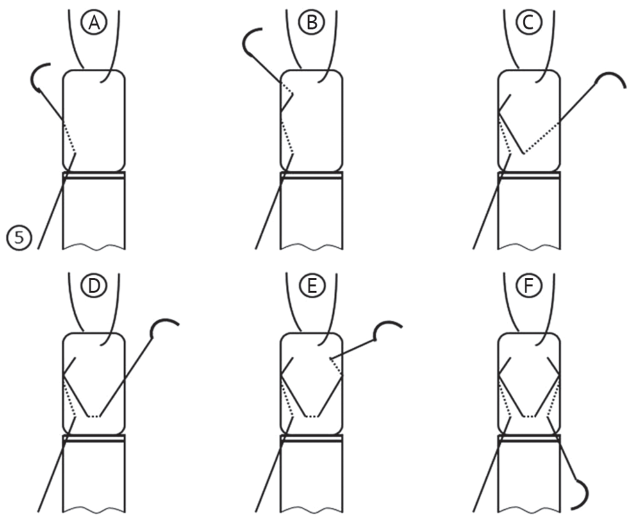

Fig. 3 Steps of surrogated suturing

For proximal surrogated suturing, the thread run anterior-to-posterior 0.3 cm proximally of the thread 3 getting off the graft edge by 1/5 of its thickness to allow anterior-to-posterior suturing of two bundles. Then the thread was placed proximally on the surface of the graft at 1.3 cm for anterior-to-posterior suturing getting off the graft edge by 2/5 of its thickness to allow anterior-to-posterior suturing of two bundles. The graft was sutured posterior-to-anterior at the same level getting off the graft edge by 2/5 of its thickness against the opposing side to allow anterior-to-posterior suturing of two bundles. The thread was placed proximally on the surface of the graft at 1.3 cm for posterior-to-anterior suturing getting off the graft edge by 1/5 of its thickness to allow anterior-to-posterior suturing of two bundles. The thread was placed distally on the surface of the graft at 1.3 cm for posterior-to-anterior suturing getting off the graft edge by 1/5 of its thickness and 0.3 cm proximally off thread 3 to allow anterior-to-posterior suturing of two bundles. Finally the ends of the suture were submerged along the graft and drawn to the surface below the circular distal sutures. The sutures were meant to additionally augment the graft.

For distal surrogated suturing, the thread run anterior-to-posterior 0.3 cm distally of the thread 4 getting off the graft edge by 1/5 of its thickness to allow anterior-to-posterior suturing of two bundles. Then the thread was placed proximally on the surface of the graft at 1.3 cm for anterior-to-posterior suturing getting off the graft edge by 1/5 of its thickness to allow anterior-to-posterior suturing of two bundles. Then the thread was placed distally on the surface of the graft at 1.3 cm for anterior-to-posterior suturing getting off the graft edge by 2/5 of its thickness to allow anterior-to-posterior suturing of two bundles. The graft was sutured posterior-to-anterior at the same level getting off the graft edge by 2/5 of its thickness against the opposing side to allow anterior-to-posterior suturing of two bundles. The thread was placed proximally on the surface of the graft at 1.3 cm for posterior-to-anterior suturing getting off the graft edge by 1/5 of its thickness to allow anterior-to-posterior suturing of two bundles. The thread was placed distally on the surface of the graft at 1.3 cm for posterior-to-anterior suturing getting off the graft edge by 1/5 of its thickness and 0.3 cm proximally off thread 4 to allow anterior-to-posterior suturing of two bundles.

The graft was placed in a retrograde manner through the tibial tunnel to the knee cavity and the femoral tunnel using the standard method of cortical femoral fixation. Ends of thread 1 (threads of the femoral cortical fixator with adjustable loop) were used for the graft proximal traction through the femoral tunnel. The graft was placed into the femoral tunnel in compliance with recommendations from manufacturer of femoral fixation. However, the length of the femoral graft was to be calculated so that an extra 5 mm length of a wider part of the femoral tunnel was available for additional tensioning with adjustable loop after tibial fixation. With the graft in place, its central portion was located in the cavity of the knee joint with the proximal graft sutured with thread 6 being in the femoral tunnel and the distal graft sutured with thread 6 being in the proximal tibial tunnel. Then several cycles of passive flexion and extension in the knee were produced using the constant traction of thread 2. The ends of threads 2, 6 and 5 were pulled in pairs to the tibial cortical fixator. The loop of the femoral fixation was pulled for additional tension with available extra 5 mm length of the femoral tunnel. Finally, pulling the ends of the surrogated sutures, first proximal and then distal, they were tied in pairs to ensure greater diameter of the graft in the femoral and tibial tunnels. The ends of the sutures were cut off. Functional concept of the surrogated sutures is presented in Figure 4.

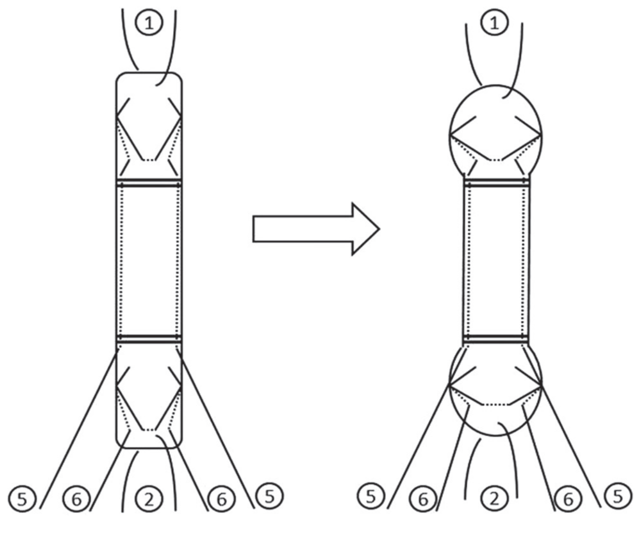

Fig. 4 Functional concept of the surrogated sutures. On the left, prior to tightening of surrogated sutures (5 and 6), on the right, surrogated sutures tightened (5 and 6). Numerical designation is identical to that in Figure 2

Experimental study was performed to determine magnitude of extended graft ends at traction of the surrogated sutures. Six semitendinosus tendons of 3 cadavers (two females and a male aged 65.3 ± 11.2 years) were used for the study. The tendons were examined immediately after harvesting without conservation. Tendinous grafts were produced according to the above technique. The diameter of the proximal and distal portions of the graft was measured with graft thickness gauge (Karl Storz 28729SA) before and after pulling the ends of surrogated sutures. The force of 50N was applied to surrogated sutures with stress of 80 N to the graft using tensiometer (Karl Storz 28729TM). There has been no force identified for graft tensioning and the graft tension of 78.5 до 90 N was considered to be optimal [16]. We determined suturing time for objective evaluation of hardships at preparation of the graft. The mean time of the graft preparation with the technique offered was 36 ± 4 minutes (25 semitendinosus tendons used in vivo). Use of modified technique required 24 ± 3 minutes (6 cadaveric semitendinosus tendons used).

RESULTS

Increase in the diameter at the ends of semitendinosus tendon grafts prepared with modified technique measured 1.33 ± 0.52 mm proximally and 1.5 ± 0.55 mm distally (Table 1) at tightening of the surrogated sutures. Elastic deformation was observed at 364.83 ± 69.16 N during the tensile test for the graft prepared with earlier technique and cortical fixation thread with the focus on the strength of transverse threads [10]. The modified technique ensured a reliable construct strength being comparable with that provided by all-inside technique (760 N) by removing the weak link [17], because changes in the modified technique did not include key sutures and fixation providing overall strength of the construct. No tensile strength test was performed for the graft. Semitendinosus tendon graft preparation time was noted to reduce by 30 % as compared with earlier technology (36 ± 4 and 24 ± 3 minutes, correspondingly).

Table 1

Results of laboratory testing of prepared grafts

Graft №	Increase in thickness of the proximal portion of the graft at tightening of the surrogated sutures (mm)	Increase in thickness of the distal portion of the graft at tightening of the surrogated sutures (mm)
1	1	2
2	2	3
3	1	3
4	1	3
5	2	3
6	1	2
	1.33 ± 0.52	1.5 ± 0.55

DISCUSSION

Use of implants in bone tunnels for ACL reconstruction has been rejected due to implant related complications. Such conventional fixators as cortical buttons, interference bioresorbable and metal screws, clamps lead to bone defects that pose difficulties in revision procedures. Implant-free ACL reconstruction techniques employs bone blocks for fixation that requires specific instrumentation which is unavailable for the majority of surgeons [18]. One of implant-free techniques consists of hamstring tendon graft fixed to the femoral stepwise tunnel (wider graft portion being located proximally and narrower portion being located distally) by wedging up the proximal graft that is pre-sutured with multiple stitches for greater width. Fixation in the tibial tunnel is secured by knotting sutures in the distal part of the graft over a bone bridge between the tibial tunnel and the tunnel that is connected with the bone tibial tunnel [19]. One of the shortcomings with the technique is the necessity of using two tendons (semitendinosus and gracilis tendons) and an additional approach on the lateral surface of the femur for graft placement thus considerably increasing an operating injury. This type of fixation results in a space between the graft and the tunnel walls to allow intraarticular fluid in that prevents integration of the tendon and the bone. The all-inside technique of ACL reconstruction with quadrupled semitendinosus tendon employs stepwise femoral and tibial tunnels with the graft placed from the articular cavity and fixed to the femur and tibia with cortical buttons [15]. However, the practice leads to a space between the graft and tunnel walls to allow intraarticular fluid in that prevents integration of the tendon and the bone. Another technique of ACL reconstruction with quadrupled semitendinosus tendon includes standard suturing and button fixation of the proximal part of the graft placed in the femoral tunnel with the distal portion of the graft stitched with surrogated suture at tightening the threads. With the graft in place the surrogated suture is tensioned and knotted over the bone bridge [20]. The weaknesses of the technique are the impossibility of using surrogated suture in the femoral tunnel (additional intratunnel graft fixation cannot be provided), problems of tensioning and placing the graft prior to final fixation (shifting the graft distally at the tensioning) associated with curling of the free distal end (that is surrogated/extended at suture tightening).

Modified quadrupled semitendinosus autograft fixation in ACL reconstruction using surrogated sutures was shown to facilitate the reliable contact of the tendon within the bone tunnels without additional implants in them. Increase in the diameter at the ends of the graft prepared with modified technique measuring 1.33 ± 0.52 mm proximally and 1.5 ± 0.55 mm distally was less than that observed in earlier method and measured 2.5 ± 0.55 mm proximally and 2.67 ± 0.52 mm distally. The values were sufficient enough for tight intra-tunnel fixation because the burr diameter matched the size of the graft prepared with conventional technique, and diameter increase of less than 0.5 mm was needed for a tight graft-bone contact. Modification of the new technique appeared to increase strength characteristics of the construct because changes in the modified technique did not include key sutures and fixation with the characteristics being comparable with those of the known and popular all-inside technique. Modified technique also allowed additional graft tensioning following its placement due to adjustable loop. The graft preparation procedure was much easier due to lesser sutures without use of temporary stitches and semitendinosus tendon graft preparation time was noted to reduce by 30 %.

CONCLUSION

Modified technique of preparation and placement of quadrupled semitendinosus autograft in ACL reconstruction has several advantages over the earlier technique offered with use of surrogated sutures and persisted increase in the diameter of the graft ends in bone tunnels. The graft preparation and placement was noted to be simplified. Strength characteristics were found to be comparable with those of the known and popular all-inside technique. The new technique allowed usage of buttons with adjustable loop for femoral fixation that resulted in reduced fixation time and additional graft tensioning on the tibia.

***Conflict of interests**: The author declares no conflict of interests.*

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