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Semitendinosus tendon regeneration after harvesting for ACL reconstruction

A prospective MRI study

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Abstract Utilisation of the semitendinosus and gracilis tendons in reconstruction of the anterior cruciate ligament (ACL) has become more common during the last few years. In recent studies a regeneration potential in the harvested tendons has been observed. In this study, 11 consecutive patients who underwent ACL reconstruction with a quadruple semitendinosus graft were examined 6–12 months postoperatively by MRI. Another two patients were examined within 2 weeks after surgery. The median age of the patients was 24 years and there were 8 males and 3 females. The right knee was involved in six patients and the left knee in five. A low-field 0.2 Tesla Siemens open MRI was used for examinations and T1 and T2 weighted transaxial sequences over the thigh and the knee joint were performed. In some instances, additional sagittal sequences were used. ROI analysis of the pixel value of the signal and area determinations on transaxial sequences was performed for both the involved and the healthy side. In 8 of the 11 patients examined 6–12 months postoperatively, a regeneration of the semitendinosus tendon with normal anatomical topographies to the level of the tibial plateau was found. Three of these eight patients were analysed more distally and fusion of the semitendinosus and gracilis tendons was found approximately 30 mm below the joint line before they inserted as a "conjoined tendon" into the pes anserinus. At the mid-thigh level, the semitendinosus muscle had a smaller area and a higher signal than that on the normal side. However, this difference was smaller in the patients showing normal distal tendon regeneration. This study indicates that the semitendinosus tendon has a strong potential for regeneration and that the muscle atrophy seems to be less in the patients with a more normalised distal insertion of the tendon in the pes anserinus.

Key words ACL reconstruction · Semitendinosus tendon · Regeneration · MRI

Introduction

Utilisation of the semitendinosus and gracilis tendons in reconstruction of the anterior cruciate ligament (ACL) has become more common during the last few years. In 1992 Cross [3] published findings indicating a regeneration potential of the harvested tendons. However, only 4 patients out of 225 were thoroughly examined. In 1997 Simonian et al. [5] reported findings showing regeneration of the hamstring tendons to a more proximal insertion point than normal. Therefore, the aim of this study was to examine a number of consecutive patients in whom only the semitendinosus tendon, but not the gracilis, was harvested for ACL reconstruction.

Materials and methods

This study consisted of 11 consecutive patients, 8 males and 3 females, with a median age of 24 years, who underwent ACL reconstruction for chronic ACL-insufficiency, using a quadruple semitendinosus graft in an endobutton technique described by Rosenberg and Graf [4]. The right knee was involved in six patients and the left knee in five. The patients were evaluated 6–12 months postoperatively by MRI (5 patients after 6 months, 4 after 7, 1 after 11 and 1 after 12 months). Two other patients were examined within 2 weeks after reconstruction surgery with a harvested semitendinosus tendon.

The tendon was harvested through a vertical, approximately 5-cm-long skin incision over the pes anserinus, followed by an L-shaped incision in the pes fascia, with one of the legs parallel to the fascia fibres. The tendon was harvested with a semi-blunt, semicircular open tendon stripper after the crural fascicles were dissected and cut under direct visual control. The design of the stripper provides maximal length of the graft as the harvester breaks the fibres of the semitendinosus fascia by blunt force. The length of the tendons ranged between 27 and 34 cm. When closing the wound, the crural fascia and skin were sutured in separate layers.

All patients participated in a standardised ACL rehabilitation programme with early ROM training, full weight-bearing and closed chain exercises.

The investigation was performed using a low-field 0.2 Tesla Siemens open MRI machine. T1 and T2 weighted transaxial sequences over the thigh (Fig. 1) and the knee joint were employed and, in some instances, additional sagittal sequences were used. In all images the knee was held in full extension with an external rotation of 15–20°. In the transaxial sequences over the knee, the slice thickness was 5 mm, the repetition time (TR) 920 ms and 4000 ms and the echo time (TE) 26 ms and 102 ms, in T1 and T2 weighted sequences, respectively. The field of view was 135×180 mm in T1 and 158×180 mm in T2 and the matrix size was 144×256 pixels in T1 and 158×180 pixels in T2 weighted sequences. For the sagittal views, we used gradient echo sagittal slices, (DESS, Siemens), with a slice thickness of 2 mm. The TR was 41 ms, the TE 12 ms, the matrix size 144×256 pixels and the field of view 135×180 mm. Over the thigh we used T1 and T2 transaxial sequences with a slice thickness of 10 mm, a TR of 672 ms in T1,and 4000 ms in T2, a TE of 15 ms in T1 and 102 ms in T2,and a field of view of 278×370 mm in T1 and 380×380 mm in T2 weighted sequences. The matrix size was 165×256 and 144×256 pixels in T1 and T2, respectively. The signal intensities (pixel values) were measured on each structure, and the muscle and tendon thickness, e.g. cross-sectional area, were calculated and the topographical anatomy was analysed. The MRI analysis was performed by an experienced MRI radiologist. Both the operated and non-operated side were examined in all but one patient where the data from the non-operated knee is missing due to technical problems.

Statistical methods

The results of a comparison of the distal anatomical regeneration in the operated leg and the non-operated leg of the patients were tested using ANOVA for repeated measurements [7].

The differences in pixel values and cross-sectional areas of the legs between the patient groups appeared as an interaction effect (group * leg). It should be noted that the power of the statistical analysis was low due to the small number of patients included. Thus, there was a high risk of committing type II errors, i.e. accepting a false nil hypothesis.

Results

No semitendinosus tendon could be seen on the MRI in the two patients examined 2 weeks postoperatively and there was only an unclear defect in the location of the previous tendon, indicating an absence of tissue according to the MRI signal (Fig. 2). The semitendinosus muscle in these two operated legs showed no difference in pixel value compared to the non-operated sides. Nor were there any conclusive differences in muscle belly diameter between operated and non-operated sides in these two patients. The gracilis tendon on the operated side looked normal in both patients and the pixel value for the gracilis tendon was higher than on the non-operated side in one case and lower in the other (Tables 1, 2).

In the group examined 6 months or more after surgery, 8 of the 11 patients showed a regeneration of the semitendinosus tendon with normal anatomical topography to the level of the joint line (Figs. 3, 4). Three of these eight patients were analysed more distally and a fusion of the

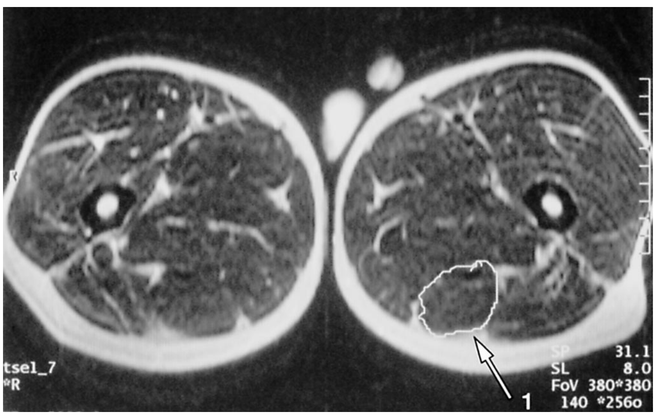

Fig. 1 MRI view of transaxial T2 weighted sequences over the thigh on the operated and non-operated leg showing the topographical anatomy. Note the well defined semitendinosus muscle *(1)*

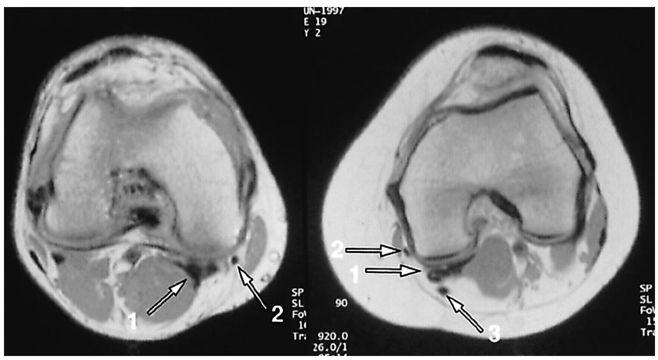

Fig. 2 Illustration of a 2 week postoperative MRI view after semitendinosus harvesting for ACL reconstruction in one patient. The operated knee with the semimembranosus tendon *(1)*, and the gracilis tendon *(2)* are shown on the *left*. Note the missing semitendinosus tendon. A normal semitendinosus tendon *(3)* is shown on the *right*

Table 1 Cross-sectional area of and pixel values for the semitendinosus muscle (ST muscle) 2 weeks postoperatively in males ($n = 2$)

ST muscle cross-sectional area (mm^2)			ST muscle pixel value			Anatomical appearance
Operated side	Non-operated side	Ratio	Operated side	Non-operated side	Ratio	
114	130	0.88	611	610	1.00	No signs of degeneration
124	106	1.17	590	549	1.07	No signs of degeneration

Table 2 Pixel values in semitendinosus (ST) and gracilis (G) tendons 2 weeks postoperatively ($n = 2$)

ST tendon	G tendon			Anatomical appearance
Non-operated side	Operated side	Non-operated side	Ratio	
506	334	478	0.70	No tendon in the “canal”
712	615	560	1.10	No tendon in the “canal”

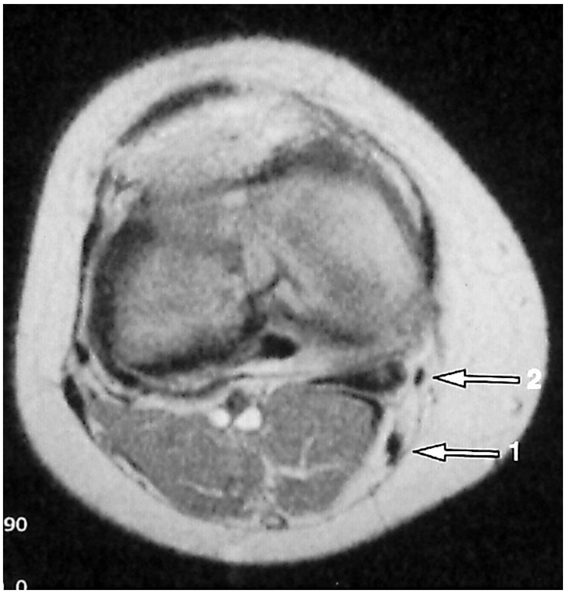

Fig. 3 Illustration of the semitendinosus regeneration 6 months postoperatively. The transaxial T1 weighted view illustrates the appearance at the level of the knee joint in one patient. The semitendinosus tendon *(1)* and gracilis tendon *(2)* are shown

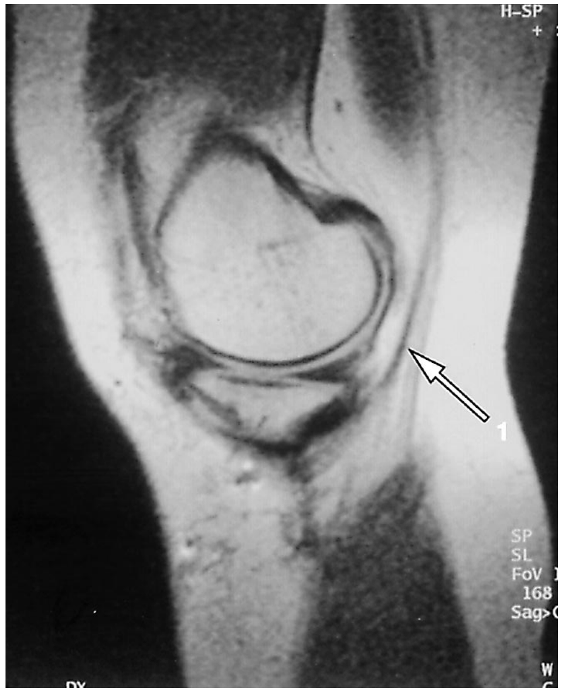

Fig. 4 Sagittal view illustrating semitendinosus regeneration with the tendon aiming at the proximal part of the pes anserinus *(1)* 6 months postoperatively

semitendinosus and gracilis tendons was found approximately 30 mm below the joint line before they inserted as a combined complex into the pes anserinus. In the three patients (all males) in whom no anatomical regeneration of the distal portion of the tendon was seen, the semitendinosus tendon fused into the semimembranosus tendon proximal to the knee joint (Fig. 5). In four patients the anatomy and the tendon structure were normalised on the MRI recording and, in three of these, the pixel values were also normalised. In the remaining four patients, the anatomy was normalised but the tendon structure was slightly thickened and had a higher pixel value on the MRI (Tables 3, 4). The cross-sectional area of the semitendinosus tendon on the non-operated side was 20 mm^2 in all but one patient, who had a tendon thickness of 30 mm^2. This patient was a professional soccer player and his quadruple graft diameter of 11 mm was also the largest in the group:. The cross-sectional area of his gracilis tendon was larger as well: 20 mm^2, compared to 10 mm^2 in all other patients. The gracilis tendon thickness was the same on both the operated and the non-operated side for the whole group.

The cross-sectional area of the semitendinosus muscle was calculated for the operated side and compared with the contralateral side. In the female group ($n = 3$), in which all patients showed anatomical regeneration to the level of the joint line, the cross-sectional area was, on the average, 85% of that on the non-operated side (Table 5). In the male group, in which five patients showed anatomical regeneration, the corresponding figure was 94%. In the three patients in whom the semitendinosus tendon fused with the semimembranosus tendon, the average cross-sectional area was only 79% of that on the con-

Fig. 5 Fusion between the semimembranosus muscle *(1)* and the partly regenerated semitendinosus tendon *(2)*

tralateral side (Table 6, Fig. 6). The difference between the "regenerated" and "non-regenerated" patients was statistically significant [F(1,9) = 5.19, $P < 0.05$]. There was also a significant difference in muscle area between the operated and the non-operated leg [F(1,9) = 5.19, $P < 0.05$]. All in all, the anatomically regenerated patients averaged 91% of the cross-sectional area of the non-operated side.

The pixel value of the semitendinosus muscle also showed differences between those patients with signs of more anatomical regeneration distally and those without. The pixel ratio between the operated semitendinosus and the non-operated side was lower (closer to 1.0) in the regenerated group than in the "non-anatomically regenerated group" (fusion with the semimembranosus) (Table 6), but was not statistically significant. The difference between the non-operated and the operated leg was, however, highly significant [F(1,9) = 28.27, $P < 0.001$]. In the female group, in which all three tendons regenerated more distally, the ratios corresponded to those in the male group showing no regeneration (Table 4).

Discussion

The data from our study confirm earlier findings by Cross et al. [3] and Simonian et al. [5] that the apparent regeneration of the hamstring tendons seen on MRI is possible and actually takes place. However our results differ from those of Cross et al. [3] as most of our patients (8/11) showed anatomical regeneration of the tendon to the level of the tibial plateau and when images were made more distally in three patients, the semitendinosus tendon was observed to be fused with the gracilis tendon approximately 30 mm below the joint line. In contrast, in the four patients examined by Cross et al. [3], the tendon seemed

Table 3 Pixel values in the semitendinosus *(ST)* and gracilis *(G)* tendons in male patients ($n = 8$) at 6 or 7 months following operation

Patient no.	Time (months)	ST tendon			G tendon			Anatomical appearance ST tendon operated side
		Operated side	Non-operated	Ratio	Operated side	Non-operated	Ratio	
1	7	1011	664	1.52	273	526	0.52	Normal insertion, thicker
2	6	1023	579	1.77	400	449	0.89	Normal insertion, thicker
3	7	535	658	0.81	400	417	0.96	Normal insertion, thicker
4	6	400	393	1.02	257	331	0.78	Normal anatomy
5	7		767		312	820	0.38	No tendon distally, fusion with semimembranosus
6	7		712		340	517	0.66	No tendon distally, fusion with semimembranosus
7	6	312			240			Normal anatomy
8	6		403		512	377	1.36	No tendon distally, fusion with semimembranosus

Table 4 Pixel values in semitendinosus *(ST)* and gracilis *(G)* tendons in females ($n = 3$)

Patient no.	ST tendon			G tendon			Anatomical appearance
	Operated side	Non-operated side	Ratio	Operated side	Non-operated side	Ratio	
1	436	933	0.47	401	743	0.54	Normal insertion and anatomical appearance
2	807	670	1.20	650	460	1.41	Normal insertion and anatomical appearance
3	745	590	1.26	446	593	0.75	Normal insertion and anatomical appearance

Table 5 Cross-sectional area and pixel values in the semitendinosus muscle *(m. ST)* in female patients

Patient no.	Time between surgery and MRI (months)	m. ST cross-sectional muscle area (mm^2)			m. ST pixel values		
		Operated side	Non-operated side	Ratio	Operated side	Non-operated side	Ratio
1	12	67	74	0.91	780	703	1.11
2	6	88	98	0.90	678	578	1.17
3	11	75	87	0.86	670	597	1.12

Table 6 Cross-sectional area and pixel values in the semitendinosus muscle *(m. ST)* in males (n = 8). (*R* anatomically regenerated tendon distally, *NR* not anatomically regenerated tendon distally)

Patient no.	Time between surgery and MRI (months)	m. ST cross-sectional muscle area (mm^2)			m. ST pixel values			Regenerated tendon
		Operated side	Non-operated side	Ratio	Operated side	Non-operated side	Ratio	
1	7	164	187	0.88	698	687	1.02	R
2	6	112	141	0.79	763	708	1.08	R
3	7	125	116	1.08	687	629	1.09	R
4	6	173	172	1.01	619	634	0.98	R
5	7	88	128	0.69	617	543	1.14	NR
6	7	125	151	0.83	784	694	1.13	NR
7	6	193	198	0.97	642	604	1.06	R
8	6	114	132	0.86	649	595	1.09	NR

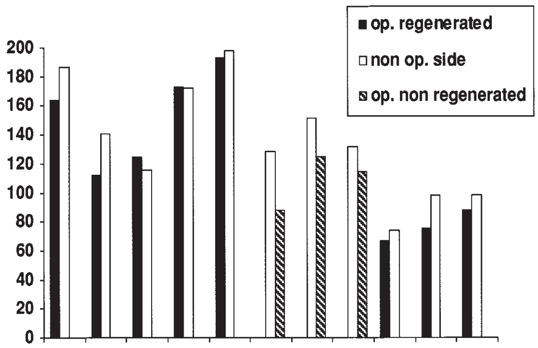

Fig. 6 Semitendinosus muscle cross-sectional area (mm^2) in the operated and non-operated legs of all 11 patients. The first eight *bars* are measurements from the males and the last three *bars* are measurements from the females

Fig. 7 Transaxial view of an operated knee 3 cm distal to the joint line. The tendons of the semitendinosus *(1)* and the gracilis *(2)* are seen as thickenings on the proximal aponeurosis of the pes anserinus

to fuse distally to the popliteal fascia. It is possible that in the five patients from whom we did not collect data below the joint line the confluence of the semitendinosus and gracilis tendons could be similar to that found in the three patients who were investigated more distally, as the gracilis tendon was left intact in all our patients. Perhaps this could explain the differences in distal insertion points. From a clinical point of view, the exact level of confluence of the two tendons is of minor importance as they will work as a part of the pes anserinus. However, if the insertion point is proximal to the knee joint it is obvious that it could influence the biomechanics of the muscle tendon complex and thus affect the muscular strength of the hamstrings. Simonian et al. [5] also reported a regeneration potential of the hamstring tendons in some cases, but they always inserted more proximally with a fairly wide variation in the insertion point. That study also demonstrated the difficulties of using MRI for exact anatomical analysis, as the semitendinosus and gracilis tendons varied in sequence in the pes anserinus, even on the healthy side (in one non-operated leg they even reported the semitendinosus insertion more proximal than the gracilis).

As for possible muscle degeneration postoperatively, we found that degeneration occurs to a certain extent and that it seems to be correlated with whether or not the tendon regenerates with a close-to-normal anatomical distal insertion. In no case, however, were there signs of active denervation with extended fatty degeneration of the muscle.

No clear signs of degeneration of the semitendinosus muscle were found 2 weeks postoperatively, nor were there any obvious signs of muscle retraction on comparison with the non-operated leg.

Whether or not the MRI-detectable regeneration of the tendon is real tendon tissue or just scar tissue organised like a tendon has not of course been proved. Our data suggest that a regeneration takes place. In a previous study by Coupens et al. [2], a gradual return to normal signal intensity in the middle third of the patellar tendon over an 18-month-long period after harvesting for ACL reconstruction was noted. Postoperatively, however, the signal intensity was initially higher, indicating scar tissue according to findings in a canine model of Burks et al. [1]. Thus, "tendonisation" might possibly occur involving the initial haematoma which is organised into scar tissue that is gradually remodelled into a tendon-like structure with decreasing signal intensity on the MRI. In an earlier study by Von Bachmann et al. [6], the signal intensity was also used to evaluate remodelling of the semitendinosus tendon graft, where decreasing pixel values indicated a normalised structure. In our material we found a similar pattern in the tendons that were regenerated and also normalised in the cross-sectional area.

In summary, it seems the semitendinosus tendon has a clear potential for regeneration and, in most cases, that the regenerated tendon fuses with the gracilis tendon into the pes anserinus when the surgical technique described is used. There is a slight degeneration of the muscle, but in no case to a severe extent. In the cases (3/11) where the insertion point was changed to the semimembranosus tendon, the muscle degeneration appeared to be somewhat greater indicating that the regenerated tendon acts in the muscle tendon complex.

References

1. Burks RT, Haut RC, Lancaster RL (1990) Biomechanical and histological observation of the dog patellar tendon after removal of its central one-third. Am J Sports Med 18:146–153
2. Coupens SD, Yates CK, Sheldon C et al. (1992) Magnetic resonance imaging evaluation of the patellar tendon after use of its central one-third for anterior cruciate ligament reconstruction. Am J Sports Med 20 : 332–335
3. Cross MJ, Roger G, Kujawa P et al. (1992) Regeneration of the semitendinosus and gracilis tendons following their transection for repair of the anterior cruciate ligament. Am J Sports Med 20 : 221–223
4. Rosenberg TP, Graf B (1992) Endoscopic technique for ACL reconstruction with Protrac tibial guide; endobutton fixation. Acufex Microsurgical, Mansfield, Massachusetts
5. Simonian PT, Harrison SD, Cooley VJ et al. (1997) Assessment of morbidity of semitendinosus and gracilis tendon harvest for ACL reconstruction. Am J Knee Surg 10 : 54–59
6. Von Bachmann G, Cassens J, Heinrichs C et al. (1994) MRT des Knies der Verlaufskontrolle der vorderen Kreuzbandsplastik aus autologer Semitendinosussehne. Fortschr Röntgenstr 161 : 446–452
7. Winer BJ (1962) Statistical principles in experimental design. McGraw-Hill, New York