The semitendinosus tendon regenerates after resection

A morphologic and MRI analysis in 6 patients after resection for anterior cruciate ligament reconstruction

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ABSTRACT – Recently, the surprising observation has been made, supported by clinical and MRI findings, that the semitendinosus tendon can regenerate after being harvested in its whole length and thickness for anterior cruciate ligament reconstruction. We studied 6 patients with previous anterior cruciate ligament reconstruction, using a quadruple semitendinosus tendon autograft. In 5 of these, physical examination and MRI showed that the tendond had regenerated. In all 6 patients, the findings were documented macroscopically by open surgical exploration and in the 5 regenerated tendons, also morphologically by biopsies. Macroscopically, histologically and immunohistochemically the regenerated tendons closely resembled normal ones with focal scar-like areas. Our present findings and earlier studies show that full length and thickness harvesting of the semitendinosus tendon in most cases result in full-length tendon regeneration with tissue closely resembling the normal tendon.

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Reconstruction of the anterior cruciate ligament using the tendons of the gracilis and/or semitendinosus muscles has become common. After harvesting the semitendinosus tendon in its full thickness and whole length (approximately 30 cm), MRI analysis has surprisingly suggested that the tendon can regenerate (Cross et al. 1992, Simonian et al. 1997, Eriksson et al. 1999). We studied 6 patients to obtain more information and morphologically confirm the regenerative ability of the semitendinosus tendons after whole length, full thickness harvesting.

Patients and methods

6 men with a mean age of 25 (18–32) years gave their informed consent to participate in the study, performed in the late half of 1999 and approved by the Ethics Committee at Karolinska Institutet. The patients were informed that the MRI and surgical biopsy were planned solely for scientific purposes and they received no benefits for participation in the study. All patients had undergone an anterior cruciate ligament reconstruction (7–28 months earlier) with a quadruple semitendinosus tendon autograft and endobutton technique (Barrett et al. 1995). The tendon graft had been harvested through a 5-cm long skin incision over the pes anserinus, followed by an L-shaped incision in the pes fascia, with the longer incision parallel to the fascia fibers. The tendon was harvested with a semi-blunt, semicircular open tendon stripper (Acufex, Mansfield, MA, USA) after the crural fascicles had been dissected and cut under direct visual control. The design of the stripper provides maximal length of the graft, since the harvester breaks the fibers of the semitendinosus fascia by blunt force. The length of each tendon graft was 28–30 cm. When closing the wound, the crural fascia and skin were sutured

in separate layers. In 3 patients (nos. 1, 5 and 6), a tourniquet for a bloodless field was used while harvesting the tendon. A standardized postoperative rehabilitation protocol was used, including full weightbearing and early range of motion exercises. When initiating the present study, 3 patients (nos. 3, 4 and 5) who had already been examined with MRI (7 months postoperatively) and been found to have regenerated semitendinosus tendons were asked to participate. In addition to these patients, who all had well-functioning knees following their ligament reconstruction, another 3 patients who had suffered new trauma to their reconstructed knee, and thus were about to undergo arthroscopic evaluation, were asked to participate. After approval to participate in the study, all 6 patients were examined with MRI from the distal part of the thigh to the pes anserinus below the knee joint. Thus, 3 patients were examined with MRI a second time after the ACL reconstruction. The investigation was performed using a low-field 0.2 Tesla Siemens open MRI machine. T1 transaxial sequences were used with 10 mm slice thickness, repetition time (TR) 912 ms, echo time (TE) 26 ms, field of view (FOV) 150–166 × 190–200 mm and matrix size 144–168 × 256 pixels. The topographic anatomy from approximately 10 cm proximal to the knee joint down to the pes anserinus was studied with particular attention to the semitendinosus tendon regenerate. The cross-sectional area and the pixel values (signal intensity) of the tendon were calculated. Within 2 weeks after the MRI examination, the 5 patients found to have a regenerated semitendinosus tendon underwent an open surgical biopsy of the newly-formed tendon. In 2 of these (nos. 1 and 2), general anesthesia was used since at the same time they underwent a diagnostic arthroscopy, showing traumatic graft rupture in both cases. In 1 of them, a tourniquet was used. In 3 patients (nos. 3, 4 and 5), the surgical biopsy was done using local anesthesia and no tourniquet was used. In the one patient (no. 6) where no obvious regeneration was seen on the MRI, an arthroscopy using general anesthesia was performed 4 weeks after the MRI, due to a meniscus injury and, at the same time, surgical exploration of the same region was performed. In this case, a tourniquet was used.

All patients were placed in supine position with their hip externally rotated and the knee flexed to approximately 70°. A 4–5 cm long skin incision was made on the dorsomedial aspect of the thigh about 2–6 cm proximal to the knee joint where the semitendinosus and gracilis tendons could easily be palpated. After blunt dissection of the subcutaneous tissue, the thin fascia was incised, the gracilis and semitendinosus tendons were visualized and the anatomy photographed. From the periphery of the regenerated semitendinosus tendon, a 15 × 3–4 mm longitudinaly biopsy specimen was taken, fixed in formalin and embedded in paraffin. It was cut into transverse and longitudinal 5 micron-sections in various parts and stained using standard techniques with HE and van Gieson's trichrome stain. Standard light and polarization microscopy were used. In addition, immunohistochemistry for collagen types I, II and III was performed according to routine protocols. In the patient without regeneration, the gracilis tendon was identified and the gross anatomy without a semitendinosus tendon was photographed. No complications were reported after the biopsy, except some local stiffness, tenderness and swelling for 3–6 weeks afterwards.

For histologic comparison, we took an additional 2 × 10 mm biopsy specimen from a harvested semitendinosus tendon in another patient who underwent anterior cruciate ligament reconstruction with a combined semitendinosus and gracilis graft during the same period. This specimen was taken from a part of the tendon that was discarded after preparation of the graft.

Results

In patients 1–5, regeneration of the semitendinosus tendon was seen, on the MRI images and macroscopically at the surgical biopsy procedure (Table, Figure 1). In the 5 patients with regenerated tendons, 2 separate tendons (semitendinosus and gracilis) could be clearly palpated in the dorsomedial aspect of the distal thigh, just proximal to the knee joint before the surgical procedure. This was facilitated by asking the patients to contract their hamstrings.

At macroscopic inspection, the topographic anatomy was similar in all 5 patients with the regenerated tendons, located dorsally to the gracilis

MRI findings in 6 patients, after semitendinosus tendon harvest for anterior cruciate ligament reconstruction. Regeneration of the tendon (patient nos. 1–5), and no regeneration (patient no. 6)

Patient no.	Time [a] months	ST [b] area, cm^2	ST [b] pixel value	ST insertion, cm below joint line	G [c] area, cm^2	G [b] pixel value
1	7	0.5	801	pes anserinus, 4	0.2	429
2	11	0.5	446	pes anserinus, 1.5	0.3	327
3	25	0.2	530	pes anserinus, 3	0.1	582
4	28	0.4	467	pes anserinus, 3	0.1	651
5	28	0.1	519	pes anserinus, 3	0.1	791
6	24	–	–	–	0.2	614

[a] Time between ligament surgery and biopsy/ MRI, months
[b] ST semitendinosus tendon
[c] G gracilis tendon

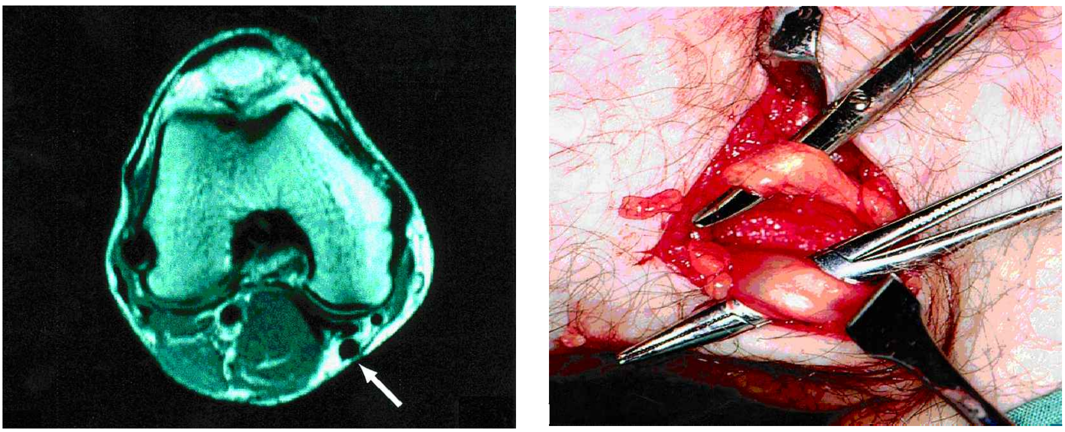

Figure 1. a. Transaxial MRI view, 3 cm proximal to the knee joint in patient no. 4. The regenerated semitendinosus tendon is indicated with an arrow.

b. The regenerated semitendinosus tendon and the gracilis tendon in patient no. 4. A clamp is held underneath the semitendinosus tendon. The gracilis tendon, lifted up by a closed scissors, is seen above the semitendinosus.

tendons. The regenerated tendon had a fairly uniform appearance in all 5 cases. It was thicker than the adjacent gracilis tendon. Macroscopically, the tendon regenerate had an essentially normal smooth appearance, although some small areas, especially in patient no. 1, had a slightly rougher and scar-like surface. The regenerated tendons were slightly more adherent to the surrounding fat than the gracilis tendons. However, sharp dissection was not needed to expose the tendon in any case. In patient 3, the "relaxation tension" (with the knee slightly flexed and without voluntary contraction) was somewhat less than in the gracilis tendon. However, in this and the other 2 patients where the surgery was performed under local anesthesia, the patients could easily contract their hamstrings including the semitendinosus tendon when they were asked to during surgery. The tendon tension, created by this voluntary muscle contraction, in all 3 cases was thought to be adequate when tested with manual traction and compared to the gracilis tendon. The contracted muscles could also be palpated in the proximal part of the thigh. In the patient without a MRI-identified regenerated semitendinosus tendon, the surgical exploration showed a normal gracilis tendon. There were no signs of scar tissue or other remnants of the semitendinosus tendon.

Histologic evaluation

The 5 regenerated semitendinosus tendons obtained for histologic evaluation all showed the essential

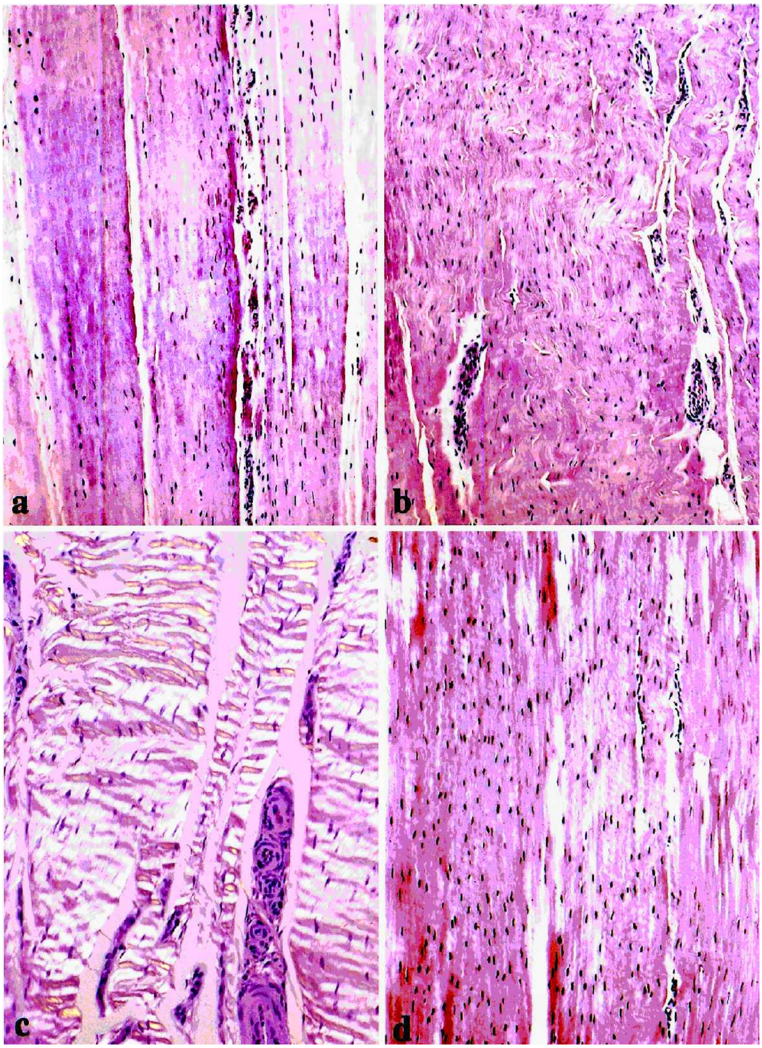

Figure 2.

a. Control biopsy of a normal semitendinosus tendon showing regularly arranged collagen bundles separated by scattered fibroblasts with small uniform oval to elongated nuclei (HE ×200).

b. Focal area of a regenerated semitendinosus tendon in patient no.1, with more irregularly oriented collagen, increased fibroblastic proliferation and capillary formation (HE ×200).

c. Regenerated semitendinosus tendon in patient no.4. Under polarized light, the collagen bundles are seen to be uniformly arranged in parallel bundles (HE ×250).

d. Regenerated semitendinosus tendons in patient no. 4, showing a near normal appearing tendon structure. Focally, an increased number of small uniform fibroblasts are seen between the collagen bundles (HE ×200).

features of a normal tendon. The collagen fibers were of similar orientation and dimension as in the control tendon (Figure 2). Focally, there were small scar-like areas with more irregularly oriented collagen, increased fibroblastic proliferation and capillary formation. In all 5 tendons there were some areas of normal appearing tendon tissue with an increased number of mature-looking fibroblasts, arranged in parallel with the collagen bundles. All regenerated tendons showed a diffuse, uniform immunoreactivity for collagen I and III, while stains for collagen II were negative.

Discussion

Until now there are no morphologic studies of the regenerated semitendinosus tendon reported in the literature. Our findings support our own and other previous MRI studies (Cross et al. 1992, Simonian et al. 1997, Eriksson et al. 1999). In a prospective study by Eriksson et al. (1999), the incidence of regeneration was found to be 8/11 6–12 months after harvesting the tendon. It was also noted that the semitendinosus muscle was slightly atrophic, having a smaller cross-sectional area than the unoperated side. In a later prospective study, the rate incidence of regeneration was confirmed, there were no signs of muscle retraction and histochemistry (fiber type distribution and fiber areas) of semitendinosus muscle specimens as well as testing indicated a functional semitendinosus muscle-tendon complex (Eriksson et al. 2000). In our study, the equal tension in the regenerated semitendinosus tendons and the adjacent gracilis tendons, when performing a voluntar hamstring contraction, also indicates a functional muscle-tendon complex.

The MRI findings of the regenerated tendons in the previous (Eriksson et al. 1999, 2000) and present study together with the macroscopic findings showed that the regenerate often regrows with a larger cross-sectional area. The signal intensity, i.e., pixel values, in 1 of our patients (no. 1) was higher than in the other 4 patients with regenerated tendons. This may be due to a higher water content (edema) in the tendon, since this patient had been investigated earlier postoperatively than the others were. The pixel values of the regrown tendons in the 4 other patients corresponded well to that of the intact gracilis tendons, as well as to those of the contralateral, unoperated semitendinosus tendons previously examined in the study by Eriksson et al. (1999). In that study, the MRI investigations were performed 6–12 months postoperatively and the pixel values of the regenerated semitendinosus tendons were then found to be higher than in the contralateral, unoperated sides.

After harvesting of the central third of the patellar tendon, MRI studies have indicated a continuous regeneration process in the tendon-gap during at least a 2-year period (Coupens et al. 1992, Bernicker et al. 1998, Kartus et al. 1999a, Kartus et al. 1999b). Histological studies of the regenerative tissue in the patellar tendon defect have also shown newly formed tendon-like tissue (Berg1992). However, in that case, only one third of the tendon thickness was harvested and normal tendon tissue was left on both sides of the tendon defect, i.e., a situation resembling the restoration of a large intratendinous defect.

The mechanisms of tendon healing after injury or surgical intervention may be of both extrinsic and intrinsic origin although none has shown a regenerative process of a full length tendon (Potenza 1962, Manske et al. 1985, Abrahamsson 1991, Hefti and Stoll 1995, Wang 1998). Extrinsic healing involves regeneration from the peritendinous tissues with gradual ingrowth of capillaries and granulation tissue while intrinsic healing is considered to be regeneration arising from the two ends of a cut tendon with no vascular or granulation tissue ingrowth from the peritendinous tissues (Jozsa and Kannus 1997). In our cases, no obvious tendon material that could act as a scaffold or guide for the regenerative process was left after the complete semitendinosus tendon resection. Regeneration therefore involves extrinsic mechanisms. In an animal model, Gelberman et al. (1992) found that in an extrasynovial environment, complete vascular integration between a tendon graft and surrounding tissue was achieved in 6 weeks, but in an intrasynovial environment, vascular proliferation occurred without adhesions to the surrounding tissue. In our patients, the extrasynovial post-harvest hematoma in the tendon canal may act as a scaffold for fibroblast precursor cells from the surrounding tissue that could invade the area and start fibroblast proliferation and collagen production (Caplan 1994). When the fibroblasts were established in the organized hematoma, the intrinsic healing was probably initiated. Since the semitendinosus muscle always acts together with other knee flexors in the hamstring group (Tesch 1999), excessive stretch impairing collagen fiber formation in the tendon canal may be avoided. Some tensile loading of the tendon, however, probably helps to enhance the collagen fiber orientation and tensile properties and induces the intrinsic healing processes (Seyfer and Bolger 1989, Mass et al. 1993, Tanaka et al. 1995, Stehno-Bittel et al. 1998).

The fact that the semitendinosus tendon can completely regenerate raises the question whether the tendon could be harvested a second time, if graft material is needed for new reconstructive procedures. In an animal study by Reddy et al. (1999), the mechanical strength of the regenerated area following Achilles tendon injury was evaluated and found to be half of the intact tendon 14 days postoperatively. In our study, the mechanical properties of the neotendons can only be speculated on, but judging from the morphological impression, good mechanical properties can be expected.

In conclusion, our findings show a surprising ability of the semitendinosus tendon to regenerate after whole length stripping.

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