Basic Science

Quadriceps Atrophy After Partial Resection of the Patellar Tendon: An Experimental Study in a Rat Model

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ABSTRACT

Quadriceps muscle atrophy of rats was examined after resection of the central third (group 1) or the lateral two thirds (group 2) of the patellar tendon, the tensor fascia lata (group 3), or the medial hamstring (group 4). The quadriceps atrophied in groups 1 and 2, and more so in group 2, but there was no atrophy in groups 3 or 4. Thus, after an anterior cruciate ligament reconstruction procedure using the patellar tendon, resection of the patellar tendon itself leads to quadriceps atrophy and the extent of atrophy is related to the resected width.

The central third of the patellar tendon is a popular tissue used in anterior cruciate ligament (ACL) reconstruction. Unfortunately, quadriceps muscle atrophy is a well-known complication of this procedure. Quadriceps atrophy is not only specific to ACL reconstruction using the patellar tendon but also occurs in all surgery of the knee.

Marder et al reported that when the semitendinosus and gracilis were used for ACL grafts, average values for peak quadriceps torque at 60°/second were 91% of control at 29 months postoperatively, which is not significantly different from the patellar tendon grafts. Shino et al showed that after ACL reconstruction using allografts wherein the quadriceps muscle and the patellar tendon were not under operative invasion, the extension torque decreased but the flexion torque did not.

Procedures using the central third of the patellar tendon induce more muscle atrophy in the postoperative rehabilitation phase (3 to 9 months postoperatively) than do other procedures. The quadriceps muscle that atrophies after ACL reconstruction using the patellar tendon seems to recover finally to almost the same level as when other reconstruction methods are used, but quadriceps atrophy in the postoperative rehabilitation phase is a complication to be avoided for athletes who must regain performance as soon as possible.

This animal study assessed methods of preventing quadriceps atrophy during the rehabilitation phase after ACL reconstruction using the patellar tendon by examining: 1) how the procedure of partial resection of the patellar tendon influences quadriceps muscle volume in comparison with resection of other autografts, 2) how the resected width of the patellar tendon influences quadriceps atrophy, and 3) how the quadriceps muscle recovers in time after the procedure of partial resection of the patellar tendon.

MATERIALS AND METHODS

A total of 27 inbred male Lewis rats weighing 270±10 g were used. All surgical procedures were performed on rats anesthetized with an intraperitoneal injection (0.05 mg/g) of sodium pentobarbital. The rats were divided into five groups:

- group 1—the central third of the patellar tendon was resected (n=5),
- group 2—the bilateral thirds of the patellar tendon were resected (n=5),
- group 3—the tensor fascia lata was resected (n=2),
- group 4—the medial hamstring was
TABLE 1
Quadriiceps weight after partial patellar tendon resection

<table>
<thead>
<tr>
<th>Length of Time After Resection</th>
<th>Total Body Weight (g)</th>
<th>Quadriiceps Weight (g)</th>
<th>Right/Left Ratio (%)</th>
<th>Total Body Weight (g)</th>
<th>Quadriiceps Weight (g)</th>
<th>Right/Left Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Right*</td>
<td>Left</td>
<td></td>
<td></td>
<td>Right*</td>
</tr>
<tr>
<td>Group 1†</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 week</td>
<td>320.2</td>
<td>2.4</td>
<td>2.6</td>
<td>92.3</td>
<td>320.4</td>
<td>2.6</td>
</tr>
<tr>
<td>2 weeks</td>
<td>330.2</td>
<td>2.7</td>
<td>2.9</td>
<td>93.1</td>
<td>336.0</td>
<td>2.9</td>
</tr>
<tr>
<td>4 weeks</td>
<td>397.2</td>
<td>3.3</td>
<td>3.4</td>
<td>97.1</td>
<td>438.3</td>
<td>3.7</td>
</tr>
<tr>
<td>8 weeks</td>
<td>464.0</td>
<td>3.8</td>
<td>3.9</td>
<td>97.4</td>
<td>443.4</td>
<td>3.6</td>
</tr>
<tr>
<td>12 weeks</td>
<td>480.0</td>
<td>3.9</td>
<td>4.0</td>
<td>97.5</td>
<td>470.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

| Group 2§                      |                       |        |      |                          |                       |        |      |                          |
| 1 week                        | 307.9                 | 2.2    | 2.5  | 88.0                    | 305.4                 | 3.5    | 2.5  | 100                        |
| 2 weeks                       | 354.2                 | 2.7    | 2.9  | 93.1                    | 358.3                 | 2.9    | 2.9  | 100                        |
| 4 weeks                       | 400.1                 | 3.1    | 3.3  | 94.0                    | 364.3                 | 3.1    | 3.1  | 100                        |
| 8 weeks                       | 409.1                 | 3.4    | 3.4  | 100.0                   | 469.6                 | 4.2    | 4.2  | 100                        |
| 12 weeks                      | 492.0                 | 4.4    | 4.3  | 102.3                   | 507.0                 | 4.2    | 4.2  | 100                        |

*Operated side.
†Patellar tendon central one-third resection group.
§Patellar tendon two-thirds resection group.

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were sutured with 5-0 nylon. The operations were all performed during a single session, and the five rats were subsequently housed in one standard cage (40×30×20 cm) with food available ad libitum.

These rats were sacrificed at 1, 2, 4, 8, or 12 weeks postoperatively; both quadriceps muscles (the operated side and the contralateral side) were excised and weighed on an electronic scale. The rat quadriceps muscle lies under the tensor fascia lata and can be easily separated from the surrounding soft tissues and bone. One control rat was sacrificed with each experimental rat sacrificed from this group, and both quadriceps muscles from the control rat also were measured.

Group 2. Both the lateral and medial third of the right patellar tendon were resected in the second group; the central third of the tendon remained (Fig). Surgical schedules and postoperative maintenance was the same as in the first group. Similarly, these animals were sacrificed and their quadriceps muscles weighed in the same fashion as the first group. Five control rats were sacrificed along with the experimental animals.

Group 3. Rats in this group underwent resection of the tensor fascia lata of the right leg. Unlike humans, the muscle belly of the rat tensor fascia lata extends almost to the level of the patella and joins with the quadriceps muscle belly. The tensor fascia lata was removed from its pelvic attachment to the patellar-level fascia. The 2 rats that underwent resection of the tensor fascia lata were sacrificed at 1 or 2 weeks postoperatively.

Group 4. The two animals in the fourth group underwent resection of the hamstring; the semitendinosus, gracilis, and sartorius muscles of the right leg were resected. In rats, the bellies of these muscles are developed, and these muscles were removed from their origin at the pelvis to the tibial insertion. These animals were sacrificed at 1 or 2 weeks postoperatively.

Three control rats were sacrificed with the groups that underwent tensor fascia lata and hamstring resection. One control rat was sacrificed when these groups underwent surgery and two control rats were sacrificed when the experimental rats were sacrificed.

For all specimens, the ratio of right quadriceps muscle weight to left quadriceps muscle weight was calculated.

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Fig: Resection of the central third or two thirds of the patellar tendon. The width of the central third was approximately 1.5 to 1.8 mm. (PT 1/3=central third of the patellar tendon and PT 2/3=two thirds of the patellar tendon.)

resected (n=2), and
• group 5—the rats did not undergo surgery and were used as controls (n=13).

Group 1. The central third of the right patellar tendon (1.5 to 1.8 mm) was resected via a parapatellar medial incision (Fig). Following the resection, superficial loose soft tissue and skin
RESULTS

The quadriceps weights, body weights, and right/left ratios of the quadriceps weight of the groups that underwent one-third and two-thirds resection of the patellar tendon are shown in Table 1. In the first group, the quadriceps weight on the operated (right) side was lower compared with the nonoperated side at 1 and 2 weeks postoperatively, but some recovery was evident by week 4. In the second group, quadriceps atrophy was more pronounced than in the group that underwent one third resection of the patellar tendon (approximately 12.0% versus 7.7%, respectively), and this effect persisted to week 4 postoperatively. The atrophied quadriceps recovered with time, returning to control levels by 8 weeks postoperatively.

Quadriceps weight, body weight, and right/left ratio of the quadriceps weight of the groups that underwent resection of the tensor fascia lata and hamstring muscle are shown in Table 2. In both groups, there was no quadriceps atrophy even at 1 and 2 weeks postoperatively, unlike in the patellar tendon resection groups.

DISCUSSION

These results demonstrate that in the rat model, partial resection of the patellar tendon results in quadriceps muscle atrophy, unlike resection of the tensor fascia lata or medial hamstring. The extent of muscle atrophy is related to the width of the resected patellar tendon, and the atrophy disappears with time.

It is well-known that operative stress or trauma to the knee joint can lead to quadriceps atrophy via artrography, muscle weakness or reflex inhibition.10,11 According to our data, even though resection of the patellar tendon led to moderate reflex inhibition, this phenomenon was not observed following resection of the tensor fascia lata or medial hamstring muscle. This is not surprising, and several explanations can be offered.

One explanation involves the anatomical relation between the quadriceps muscle and resected substitutes. The patellar tendon is more intimately related to the knee joint than other substitutes, as Arvidsson et al indicated. Pain is the most important factor causing reflex inhibition.2,6,10-12 Resection of the medial hamstring or tensor fascia lata may not be as painful as resection of the patellar tendon because both the medial hamstring and tensor fascia lata are separated from the joint capsule. The patellar tendon is an extension of the quadriceps muscle, and there should be a more intense nerve network from the patellar tendon to the quadriceps, one of which would be related to the patellar tendon reflex.

Another explanation is joint effusion, which is also a well-known stimulant to reflex inhibition.10,13,14 Effusion would undoubtedly follow partial resection of the patellar tendon because the joint is opened by the procedure (whereas a joint is not opened during resection of the medial hamstring or tensor fascia lata). Reflex inhibition through pain or effusion may introduce the disuse of the quadriceps.

Other possible factors leading to atrophy include a decrease of muscle tonus resulting from elongation of the remaining patellar tendon. Kamps et al showed that in the rabbit model, the remaining patellar tendon (after resection of the central third) elongated approximately 20.8% through 3 months of treadmill exercise. Such an elongation would be expected to occur in our group 2, the two-thirds resection group. Engel et al reported that tenotomy of the Achilles' tendon in the cat results in greater atrophy of type 1 fibers; our model possibly creates the same condition as does Engel's model. Arvidsson et al suspected that in clinical cases after ACL reconstruction using the medial third of the patellar tendon, type 1 fiber atrophy in the quadriceps muscle would manifest itself from the comparison of extension strength at slow and fast angular velocities.

The central third of the patellar tendon is the most popular tissue used in ACL reconstruction, offering excellent postoperative stability.3,4 The flaw in this method is that it appears to cause more quadriceps atrophy in the postoperative rehabilitation phase than do other methods. According to our results, quadriceps atrophy immediately following partial resection of the patellar tendon is related to the width of the resected patellar tendon.

In clinical studies, Shelbourne et al...
examined the relationship between width of the remaining patellar tendon and quadriceps strength up to 1 year after ACL reconstruction. At 3 months postsurgery, they found a significant difference between patients with a narrow segment of patellar tendon remaining and patients with a relatively wide segment. While the amount of tendon resected should be restricted as much as possible to minimize quadriceps atrophy in the postoperative rehabilitation phase, the quadriceps may eventually fully recover even if the initial resection is wide.

**Conclusion**

These results cannot be directly extrapolated to humans because the rats used in the present study were in their growth stage. Further, in human ACL reconstruction, there is additional operative stress (e.g., preparation of the bone tunnel). In fact, there have been no reports of perfect recovery of quadriceps muscle power after ACL reconstruction. The results of the present study only suggest that limited resection may lead to less atrophy and earlier recovery in humans.

**References**


