# Function of the rabbit supraspinatus muscle after detachment of its tendon from the greater tubercle

## Observations up to 6 months

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The supraspinatus tendon was detached from the greater tubercle in 30 rabbits. After 6 weeks (group A), 3 months (group B) and 6 months (group C) in vivo evaluation of the twitch-tension and fatigue index were done. Next the scapulas with muscles were examined by CT. During the first 6 weeks a marked reduction in power and fatigue index by about 20% and 10–15%, respectively, in comparison with the control side was noted. These findings remained unchanged at 3 and 6 months. The CT examination showed fatty muscle degeneration, mainly in the 1/3 distal part of supraspinatus, but not in the infraspinatus muscle.

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Rupture of the supraspinatus tendon leads to muscle atrophy and fatty degeneration, depending on the magnitude of rupture and time elapsed from injury (Goutallier et al. 1994, Nakagaki et al. 1994, Thomazeau et al. 1996, Postel et al. 1997). Experimental and clinical data suggest a correlation between the outcome of rotator cuff repair and degrees of fatty muscle degeneration (Björkenheim 1989, Nakagaki et al. 1994, 1996, Postel et al. 1997).

We quantitatively analyzed the relationship between the rabbit supraspinatus muscle contractile properties and CT image of the muscle belly, after detachment of its tendon from the greater tubercle.

## Animals and methods

We used 30 adult male grey rabbits (weight 3.7–4.6 kg). The animals were anesthetized with an intravenous vetbutal injection (30 mg/kg), supplemented by skin infiltration with 1% lidocaine. The left supraspinatus tendon was detached from the greater tuberosity (length of split about 1 cm). The rabbits—10 in each group—were reanesthetized after 6 weeks (group A), 3 months (group B), and 6 months (group C). In the shoulder that was operated on, the infraspinatus, teres minor and subscapularis tendons were detached from the humeral head. The supraspinatus tendon was separated from the infraspinatus and subscapularis tendons and grasped by a modified Mason Allen suture (Gerber et al. 1994) The scapula was stabilized by a special holder. The thread of the suture grasping the supraspinatus tendon was joined with a power sensor connected with a digital force converter, showing the value of muscle load and power in N on display. The power sensor was fixed on a special mobile frame to obtain a standardized muscle load. The suprascapular nerve was exposed and stimulated with a bipolar electrode for 4 minutes. The contralateral healthy shoulder was prepared in the same way. For nerve stimulation, the modified protocols described by Crisco et al. (1994) and Jacobson et al. (1994) were used. Tetanic contraction was caused by a supramaximal stimulus (12 V, 50 Hz, 0.05 msec duration) with a Grass S44 stimulator (Grass Instruments, Quincy, MA). The interval between each contraction was 2 minutes. The muscle loading was standardized and equaled 1/4 of the body weight (more than the weight of a superior limb). The value of load was converted into N. Every tendon was prestretched for 20 seconds, with loading equal to 1/4 body weight plus 1/2 of this value. The contralateral healthy supraspinatus muscle was evaluated in the same way. The power and fatigue index were calculated as a ratio of the power of the supraspinatus operated on to the power of the contralateral one which was measured at the beginning, after 2 minutes and at the end of stimulation. For statistical analysis, the contraction

**Table 1. The value of power and the fatigue index of rabbit supraspinatus muscle in groups A, B, and C. Mean (range) *SD***

| | Group A | Group B | Group C |
|---|---|---|---|
| Power, % | 79 (73–90) *5.0* | 78 (68–87) *6.0* | 76 (63–89) *10* |
| Fatigue index, % after 2 minutes | 84 (74–103) *9.0* | 79 (69–90) *7.9* | 79 (57–101) *17* |
| after 4 minutes | 90 (71–100) *8.4* | 79 (65–110) *15* | 86 (59–128) *23* |

with the highest power value from among the first three contractions which fulfilled strict conditions (return to > 85% of the value of the primarily applied standardized load within the first minute of the rest time) was chosen. If there were equal values of twitch-tension, an average of the fatigue index was calculated. After the experiment, both scapulas with muscles forming the rotator cuff were surgically removed and examined by CT. The classification of Gouttalier et al. (1994) was used. Owing to some difficulties in distinguishing between stage 1 and stage 2 of fatty muscle degeneration, observed also by Postel et al. (1997) in using this grading system, we modified the definition of stages 1 and 2 as follows: stage 1) fat appearance < 25% of muscle volume and stage 2) fat appearance between 25% and 50 % of muscle volume. Stage 3 means as much fat as muscle and stage 4 represents more fat than muscle. The average of the two measurements (by radiologist P.K. and orthopedist J.F.) of three scores from three scans perpendicular to the long axis of the scapula (from 1/3 of the proximal, medium and distal parts of the muscle) of the supraspinatus and infraspinatus of both sides were used.

Statistical analysis was done with the t-test for two samples with equal and unequal variances using an alpha level of 0.05 as minimum significance for comparisons between the contralateral healthy limb and the limb operated on.

## Results

The power of the supraspinatus operated on after 6 weeks and 3 months of observation was reduced by about 20% when compared to the control side and about 24% after 6 months. The differences regarding twitch-tension and fatigue index between groups A and B, A and C and between groups B and C were not statistically significant (Table 1).

CT examination revealed fatty degeneration of the supraspinatus muscle of the side operated on (Figures

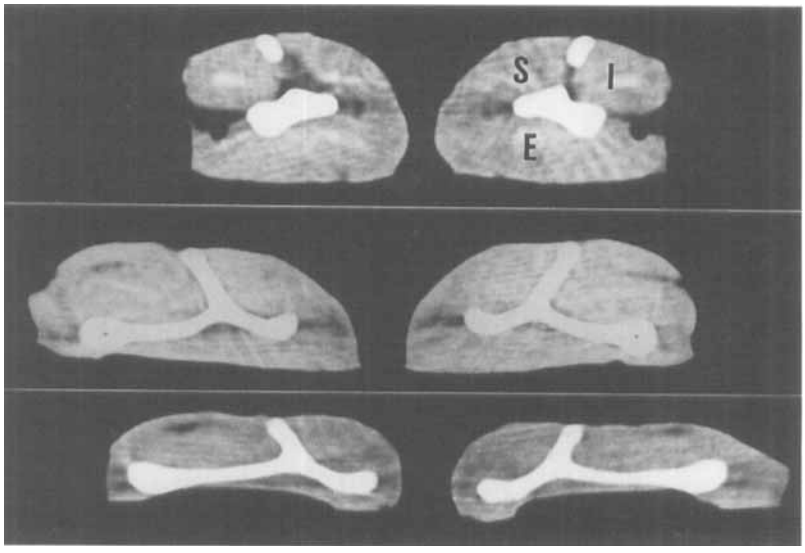


Figure 1. CT scans of rabbit scapulas with muscles with sagittal cross-section of distal (top), medium and proximal parts of the side operated on (left) and the control (right) at 6 months of observation; S) supraspinatus muscle, I) infraspinatus muscle and E) subscapularis muscle. Average fatty degeneration of the whole muscle calculated from 3 scans and from the distal scan of the supraspinatus of the side operated on (0.83 and 1.5) and the control side (0.66 and 1.0), respectively.

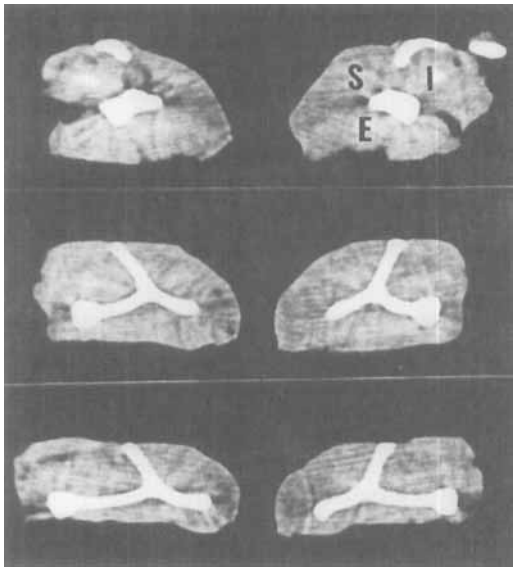


Figure 2. CT scans of rabbit scapulas with muscles with sagittal cross-section of distal (top), medium and proximal parts of the side operated on (left) and the control (right) at 6 weeks of observation; S) supraspinatus muscle, I) infraspinatus muscle and E) subscapularis muscle. Average fatty degeneration of the whole muscle calculated from 3 scans and from the distal scan of the supraspinatus of the side operated on (1.0 and 1.0) and the control side (0.33 1.0), respectively.

1, 2 and 3). There were no statistically significant differences between the measurements of fatty muscle degeneration. The average fatty degeneration of the supraspinatus operated on calculated from these two independent measurements was < 1 in all groups (Table 2). The fatty degeneration of the supraspinatus operated on was statistically significantly more advanced in group C than in group A, while the differences between groups A and B and B and C were not statistically significant. There were statistically significant differences between the side operated on and the control one in each group. The fatty degeneration was statistically significantly more advanced in the distal part of the muscle operated on and the contralateral muscle than in the medium and proximal parts of these muscles (Table 3). The differences between fatty degeneration of the distal part of the muscle between particular groups, so far as the side operated on and control ones are concerned, were not statistically significant. There was no important fatty degeneration of the infraspinatus muscle in any group.

## Discussion

Itoi et al. (1997), Kirschenbaum et al. (1993) and Rokito et al. (1996) noted a decrease in abduction strength, ranging from 19% to 63% in a full thickness rotator cuff tear. Björkenheim (1989) observed in an in vitro study reduction in power and increase in fatiguability of the rabbit supraspinatus muscle after division of its insertion. Our study showed that during the first 6 weeks of observation, the loss of power and

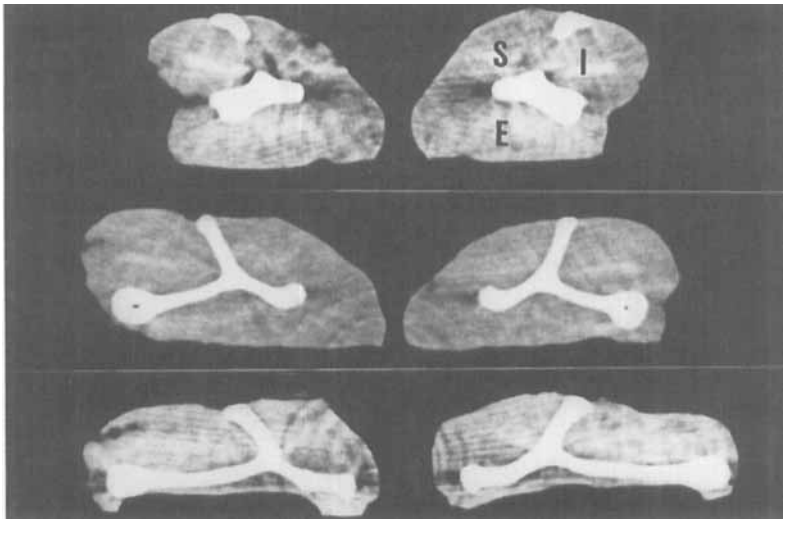


Figure 3. CT scans of rabbit scapulas with muscles with sagittal cross-section of distal (top), medium and proximal parts of the side operated on (left) and the control (right) at 3 months of observation; S) supraspinatus muscle, I) infraspinatus muscle and E) subscapularis muscle. Average fatty degeneration of the whole muscle calculated from 3 scans and from the distal scan of the supraspinatus of the side operated on (1.0 and 2.0) and the control side (0.5 1.0), respectively.

**Table 2. CT examination of rabbit supraspinatus muscle (5 stage classification modified after Goutallier et al. 1994). Mean (range) *SD***

| Group | Supraspinatus muscle fatty degeneration | |
|---|---|---|
| | Side operated on | Control side |
| A | 0.63 (0.33–1.33) *0.28* | 0.26 (0.0–0.66) *0.16* |
| B | 0.81 (0.33–1.33) *0.35* | 0.44 (0.33–0.66) *0.16* |
| C | 0.86 (0.33–1.33) *0.35* | 0.49 (0.33–1.0) *0.16* |

**Table 3. CT examination of distal 1/3 of rabbit supraspinatus muscle. Mean (range) *SD***

| Group | Supraspinatus muscle fatty degeneration | |
|---|---|---|
| | Side operated on | Control side |
| A | 1.4 (1.0–2) *0.5* | 0.8 (0.0–1) *0.42* |
| B | 1.5 (1.0–2) *0.51* | 0.9 (0.0–1) *0.31* |
| C | 1.55 (1.0–2) *0.5* | 0.9 (0.0–1) *0.32* |

fatigue index were most marked, which is consistent with Björkenheim's (1989) observations. Björkenheim (1989) noted some reversibility of fatigue at 9 and 12 weeks. Our data also suggest some tendency to reversibility of fatigue. Recently, Iannotti et al. (1996) pointed out a correlation between postoperative fatigue symptoms and objective measures of shoulder strength, after reconstruction of a full-thickness rotator cuff tear.

Phoenix et al. (1996) has developed a method to record muscle mass and fat in human dystrophic muscle by MRI. Goutallier et al. (1994) used a 5-stage CT scale for evaluation of supraspinatus muscle fatty degeneration. Nakagaki et al. (1994) and Thomazeau et al. (1996) used MRI for the same purpose. Thomazeau et al. (1996) found that the ratio between the surface of the cross-section of the muscle belly and that of the scapular fossa in the sagittal plane in patients with isolated supraspinatus tears decreased by about 21%. Our experimental CT results showed development of fatty muscle degeneration below 25% of the rabbit supraspinatus muscle cross-sectional area, after detachment of its bone insertion. We found that the separate comparison of CT scans from different parts of the muscle may partly eliminate the weakness of the Goutallier et al. (1994) grading system and answer the question whether the muscle fatty degeneration is within or outside the established norm. On the other hand, the objective calculation ratio by Thomazeau et al. (1996) did not take intramuscular fatty infiltration into account and is influenced by the patient's obesity. The Nakagaki et al. (1994) ratio may also depend on the height and weight of patients.

Impaired rabbit supraspinatus muscle-twitch tension and fatiguability is mainly caused by the muscle's atrophy (Cooper 1972, Booth 1987, Michelsson et al. 1990). Another factor which may influence the function of the supraspinatus muscle is motor endplate dysfunction (Grana et al. 1996).

The relative stability of the rabbit supraspinatus muscle-twitch tension and fatigue index during 6 months of observation was provided by preserved interdigitation (Clark et al. 1992) between the supraspinatus and infraspinatus and the supraspinatus and subscapularis tendons. Due to this interdigitation, the supraspinatus is able to contribute to elevation and abduction (Sharkey et al. 1994). Our experimental data supported the idea about the function of the rotator cuff cable-crescent complex (Burkhart 1997).

Björkenheim (1989) observed a decrease in the percentage share of the muscle fiber in the middle part of the rabbit supraspinatus muscle after detachment of its bone insertion in comparison with the normal side after 4, 6 and 9 weeks . After 12 weeks, the differences had disappeared. In our CT study, fatty degeneration developed mainly in the distal part of the muscle and did not disappear during 6 months of observation.

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