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Degeneration Exists along the Entire Length of the Supraspinatus Tendon in Patients with a Rotator Cuff Tear

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Background: The purposes of the study were to examine rotator cuff tendon degeneration with respect to harvesting location, to determine a rationale for debridement of the torn end, and thus, to determine adequate debridement extent.

Methods: Twenty-four patients with a full-thickness rotator cuff tear were included in the study. Tendon specimens were harvested during arthroscopic rotator cuff repair from three locations; from torn ends after minimal regularization of fraying (native end group, NE group), from torn ends after complete freshening of the frayed end (freshened end group, FE group), and from the macroscopically intact portion just distal to the musculotendinous junction (musculotendinous junction group, MTJ group). Control samples were harvested from patients admitted for surgery for proximal humerus fracture. Harvested samples were evaluated using a semi-quantitative grading scale.

Results: Mean total degeneration scores in the NE group (13.3 ± 3.21), the FE group (12.5 ± 2.30), and in the MTJ group (10.8 ± 3.10) were significantly higher than those in the normal control group (5.0 ± 2.87; all $p<0.001$). Mean total degeneration score in the NE group was significantly higher than that in the MTJ group ($p=0.012$), but was not from that of the FE group. Mean total degeneration score in the FE group was not significantly different from that of the MTJ group.

Conclusions: Tendon degeneration exists throughout the entire tendon to the macroscopically intact portion of full-thickness rotator cuff tear. Therefore, aggressive debridement to grossly normal appearing, bleeding tendon is unnecessary for enhancing healing after repair.
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Key Words: Rotator cuff tendon; Rotator cuff tear; Degeneration; Histology; Rotator cuff repair

Introduction

Rotator cuff disease is one of the most common sources of shoulder pain seen by physicians.[1] The prevalence of symptomatic rotator cuff disease increases with age and the disease is present in 2.8% of those older than 30 years and in 21% of those older than 70.[1,2] In the United States, rotator cuff disease is responsible for more than 4.5 million physician visits annually, and over 300,000 rotator cuff repairs are performed annually at a cost exceeding US $3 billion.[3,4] Thus, rotator cuff disease poses high socioeconomic costs and burdens.

Several theories have been proposed to explain the etiology of rotator cuff tear. These theories could be categorized as extrinsic or intrinsic.[5] Extrinsic theories include impingement, overuse, and multifactorial, whereas intrinsic theories include hypoperfusion, degeneration, degeneration-microtrauma, apoptosis, and extracellular matrix modifications. Nonetheless, the actual etiologies of rotator cuff tears remain to be elucidated.

A number of histological studies have emphasized the importance of degeneration. Kannus and Józsa[6] demonstrated characteristic histological changes in tendons that rupture spontaneously. In this study, degenerative changes were evident in 865 of 891 cases (97%) and included features of hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis, or calcifying tendinopathy, which were either present in isolation or combination. Nirschl[7] described changes in rotator cuff tendons,

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such as, disorganization and fragmentation of collagen architecture and infiltration of fibroblasts and vascular tissue. Hashimoto et al.[8] described different patterns of degenerative change in partial and full thickness rotator cuff tears. Longo et al.[9] reported histological characteristics with respect to tear size, and concluded that small-sized rotator cuff tears have greatest healing potential. However, few studies have investigated the extent of degeneration along the whole length of rotator cuff tendons.

The purposes of the present study were to investigate degeneration of the supraspinatus tendon histologically in patients with a full-thickness rotator cuff tear with respect to harvest location, to determine a rationale for torn end debridement, and thus, to determine an adequate extent of debridement. Our hypothesis was that degeneration scores would be dependent on harvesting location.

Methods

Study Design and Patients

This study was approved by our institutional review board, and all patients provided informed consent. The inclusion criteria were a full-thickness rotator cuff tear treated by arthroscopic surgery and the availability of tissue samples of rotator cuff tendon harvested at time of surgery. The exclusion criteria applied were inflammatory arthritis (including rheumatoid arthritis), a history of acute trauma or infection, a subacromial injection within the previous 3 months, systemic conditions associated with chronic pain, isolated subscapularis tear, rotator cuff arthropathy, calcific tendinitis, and retear. The normal control group included patients admitted for surgery of a proximal humerus fracture with no history of shoulder injury or disease.

Tendon Harvest and Histological Assessments

Rotator cuff tendons were harvested during arthroscopic rotator cuff repair using a basket forceps. Specimens of 3×3 mm were taken from three locations, that is, from torn ends after minimal regularization of fraying (native end group, NE group), from torn ends after complete freshening of the frayed end (freshened end group, FE group), and from the macroscopically intact portion just distal to the musculotendinous junction (musculotendinous junction group, MTJ group). In the control group, specimens were harvested from the middle portion of the supraspinatus tendon after opening the rotator cuff interval for biceps tenotomy using a basket forceps.

Harvested tendon samples were fixed with 5 ml of 10% formalin in plastic pathology containers, dehydrated, embedded in paraffin, sectioned at 4 μm, and stained with H&E. Three sections were prepared per tendon, and one of these three was randomly selected and examined under a light microscope. Whole areas of sections were examined and the most severely degenerated area with the worst degeneration score was selected for analysis.[10] The examination was performed by a fellowship trained orthopedic surgeon and a pathologist, and results were assessed for inter-observer reliability by having the orthopedic surgeon re-assess slides one week after first examinations.

Each slide was evaluated using the semi-quantitative grading scale originally devised by Aström and Movin and modified by Maffulli (requoted from reference).[10-12] The parameters included in the scale were fiber structure, fiber arrangement, rounding of nuclei, regional variations in cellularity, increased vascularity, decreased collagen stainability and hyalinization. A 4-point scoring system was used, where 0 indicated a normal appearance, 1 slightly abnormal, 2 moderately abnormal, and 3 markedly abnormal. The following scheme was used: fiber structure (0=linear, no interruption, 3=short with early truncation); fiber arrangement (0=well ordered and regular, 3=no pattern identified); appearance of nuclei (0=flat, 3=rounded); regional variations in cellularity (0=uniform; 3=marked regional variations); vascularity (0=absent, 3=high); collagen stainability (0=vivid, 3=pale); and hyalinization (0=absent, 3=high).[10] Total tendon degeneration scores for a given slide could vary from 0 (normal) to 21 (severely degenerated).

Statistical Analysis

Scale values of histological parameters and total degeneration scores were compared using the t-test or analysis of vari-

Table 1. Baseline Characteristics of Patients

Characteristic	Value
Age (yr)	60.2 ± 7.0
Sex (male:female)	8:16
Symptom (mo)	14.6 ± 17.6
Cofield (small:medium:large:massive)	0:18:6:0
Boileau (stage I:II:III:IV)	11:7:6:0
Visual tendon grade (A:B:C)*	7:16:1
Goutallier grade of the supraspinatus (0:1:2:3:4)	0:11:10:2:1
Tangent sign (1:2:3)†	20:4:0
Occupation ratio (1:2:3)‡	16:7:1

Values are presented as mean ± standard deviation or number only.
*Tendon grade assesses rotator cuff quality using three gross tendon criteria; (1) fraying over half of the tendon thickness; (2) delamination of the supraspinatus tendon, and (3) thinning of less than half of the normal thickness. A, none of these criteria were met; B, fraying or delamination was identified; and C, both fraying and delamination or thinning were present (regardless of other criteria). †The tangent sign assesses muscle atrophy of the supraspinatus. Grade 1 (negative) means that the superior border of the supraspinatus was superior to the line tangential to the coracoid and scapular spine; grade 2 (borderline) means that the superior border was located about the tangential line; grade 3 (positive) means that the superior border was inferior to the tangential line. ‡Occupation ratio means the ratio of the cross-sectional area of the supraspinatus to the fossa. Grade 1, 0.6 to 1; grade 2, 0.4 to 0.6; and grade 3, <0.4.

ance (ANOVA) with Bonferroni tests for multiple comparisons. To validate the tendon histopathology grading system used, we assessed its intra- and inter-observer reliabilities using kappa statistics. Kappa values were interpreted according to convention: excellent when κ was between 0.81 and 1.0; high between 0.61 and 0.80; moderate between 0.41 and 0.60; fair between 0.21 and 0.40; and poor 0.20 or less. The analysis was performed using SPSS ver. 13.0 (SPSS Inc, Chicago, IL, USA), and significance was accepted for *p*-values of <0.05 throughout.

Results

Patients

Twenty-four patients with a full-thickness rotator cuff tear were included in the study (Table 1). Mean patient age was 60.2 ± 7.0 years, and there were 8 males and 16 females. The majority of the patients had a medium-sized tear of Goutallier grade 1 or 2 and a Tangent sign of 1. The normal control group contained nine patients of average age 62.8 ± 17.7 years. At surgery, no patient in the control group showed any evidence of rotator cuff tear in bursal or articular sides.

Histologic Assessments

1) Intra- and inter-observer reliabilities

Intra- and inter-observer reliability testing showed high to excellent reliability, except for the assessment of hyalinization (Table 2).

2) General morphology

The microscopic appearances of tendons from patients differed from those of controls (Fig. 1). In specimens from controls,

Table 2. Intra- and Inter-observer Reliabilities

Parameter	Intra-observer	Inter-observer
Fiber structure	0.836	0.860
Fiber arrangement	0.913	0.854
Rounding of the nuclei	0.612	0.712
Variations in cellularity	0.731	0.759
Increased vascularity	0.742	0.773
Decreased stainability	0.884	0.808
Hyalinization	0.538	0.412
Total	0.796	0.746

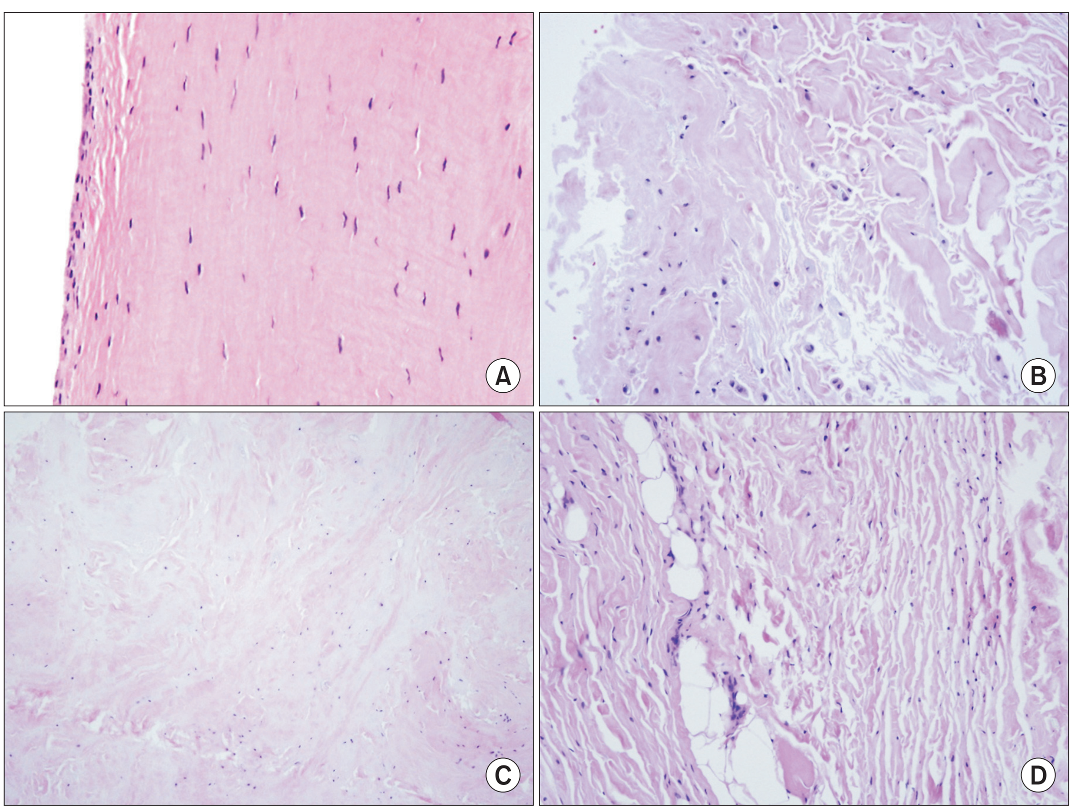

Fig. 1. Histology of a torn rotator cuff tendon from a normal control (A), the native end (B), the freshened end (C), and from near the musculotendinous junction (D). (A) Fiber structure, 0; fiber arrangement, 0; rounding of the nuclei, 1; regional variation in cellularity, 0; increased vascularity, 0; decreased collagen stainability, 0; hyalinization, 0; total degeneration score 1. (B) Fiber structure, 3; fiber arrangement, 3; rounding of the nuclei, 2; regional variations in cellularity, 2; increased vascularity, 3; decreased collagen stainability, 2; hyalinization, 2; total degeneration score 17. (C) Fiber structure, 3; fiber arrangement, 3; rounding of the nuclei, 2; regional variations in cellularity, 3; increased vascularity, 0; decreased collagen stainability, 2; hyalinization, 2; total degeneration score 15. (D) Fiber structure, 2; fiber arrangement, 2; rounding of the nuclei, 2; regional variations in cellularity, 2; increased vascularity, 1; decreased collagen stainability, 2; hyalinization, 2; total score 13 (A–D: H&E, ×200).

Table 3. Parameters and the Total Degeneration Scores of Tendons Harvested from Normal Controls, Native Ends, Freshened Ends, and Musculotendinous Junctions

Parameter	Control	Native end	Freshened end	Musculotendinous junction	*p*-value*
Fiber structure	1.4 ± 0.53	2.0 ± 0.72	2.3 ± 0.74	2.0 ± 0.62	0.298
Fiber arrangement	1.2 ± 0.83	2.3 ± 0.44	2.3 ± 0.64	2.1 ± 0.50	0.262
Rounding of the nuclei	0.9 ± 0.60	2.0 ± 0.72	1.8 ± 0.56	1.3 ± 0.64	0.002
Variations in cellularity	0.6 ± 0.73	2.0 ± 0.83	1.9 ± 0.78	1.7 ± 0.87	0.353
Increased vascularity	0.4 ± 0.73	1.6 ± 0.78	1.8 ± 0.74	1.6 ± 0.88	0.434
Decreased stainability	0.2 ± 0.67	1.6 ± 0.88	0.9 ± 0.78	0.7 ± 0.69	0.708
Hyalinization	0.2 ± 0.44	1.8 ± 1.37	1.5 ± 1.22	1.4 ± 0.88	0.001
Total	5.0 ± 2.87	13.3 ± 3.21	12.5 ± 2.30	10.8 ± 3.10	0.012

Values are presented as mean ± standard deviation.
*p-values for comparisons between the native end, freshened end, and musculotendinous junction groups were calculated using analysis of variance with Bonferroni's *post hoc* adjustment.

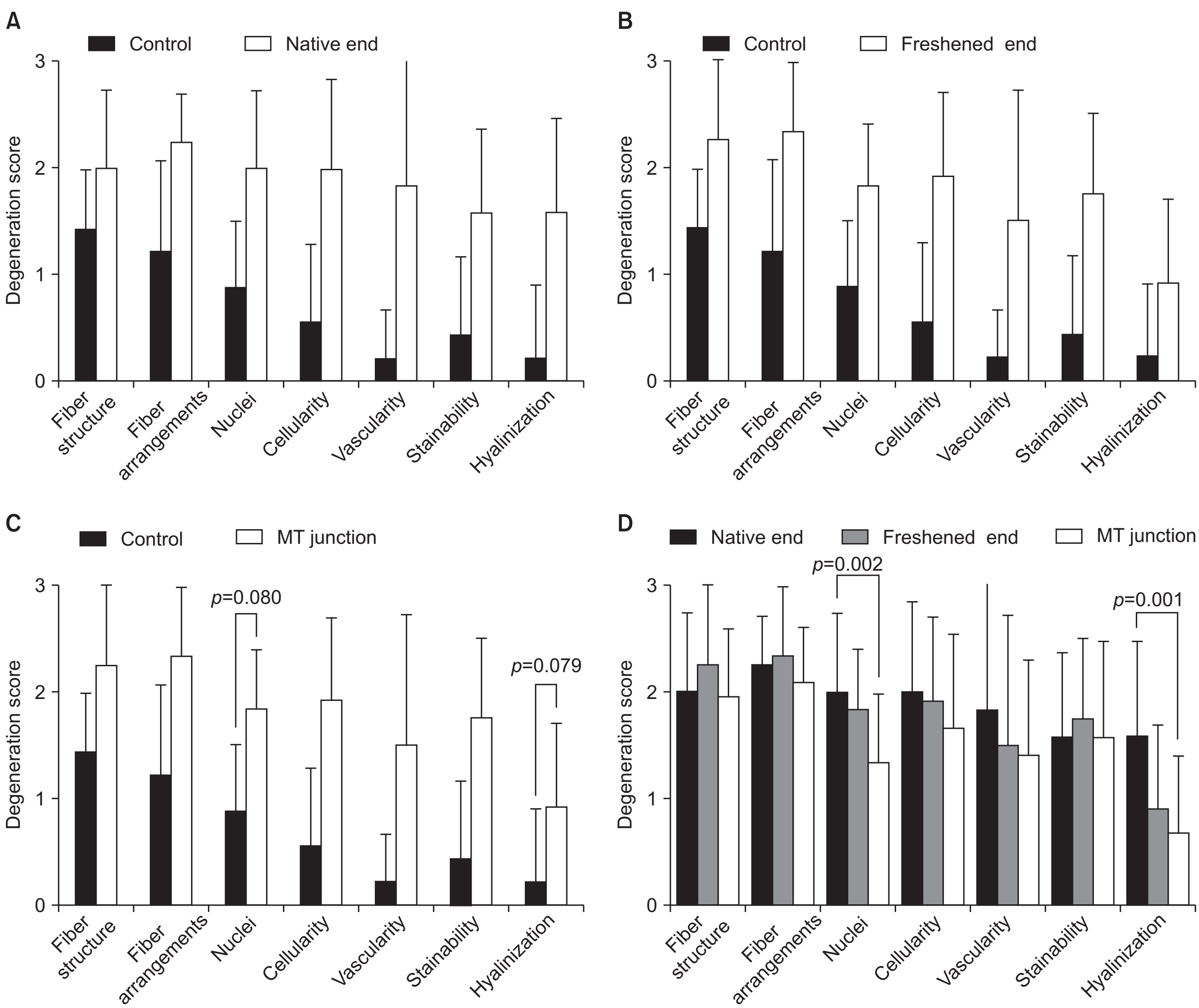

Fig. 2. Comparisons between the control group and the native end (A), freshened end (B), and musculotendinous junction (MT junction) (C) groups. Each parameter in these 3 groups had a significantly greater degeneration score than in the control group, except for nuclear rounding and hyalinization in the MT junction group. (D) Fiber structures, fiber arrangements, regional variations in cellularity, increased vascularity, and decreased collagen stainability were no different in these three groups, whereas nuclear rounding and hyalinization were significantly different (p=0.002 and 0.001, respectively).

collagen fibers were arranged close and parallel to each other with slight waviness (Fig. 1A).[13] Nuclei were flattened and spindle-shaped, sometimes arranged in rows between the collagen fibers, and distributed evenly. Vascular bundles were inconspicuous and usually ran parallel to and alongside collagen fibers. Colors of collagen fibers were deep pink-red after H&E staining. Hyalinization was rarely found.

Specimens from the NE, FE, and MTJ groups showed characteristics of degeneration, including loss of fine fiber structure and parallel arrangement, fewer and rounded nuclei, increased cellularity and vascularity, reduced and paler H&E staining, and some evidence of hyalinization (Fig. 1A–C).

3) Native ends

The degeneration scores of the 7 parameters were significantly higher in the NE group than in the control group (all $p<0.01$ except for fiber structure $p=0.044$; Table 3, Fig. 2A). Mean total degeneration score in the NE group (13.3 ± 3.21) was significantly higher than that of the control group (5.0 ± 2.87, $p<0.001$; Fig. 3A).

4) Freshened ends

Degeneration scores of all 7 parameters were significantly higher in the FE group than in the control group (all $p<0.01$ except for hyalinization $p=0.024$; Table 3, Fig. 2B). Mean total degeneration score in the FE group (12.5 ± 2.30) was significantly higher than that of the control group (5.0 ± 2.87, $p<0.001$; Fig. 3B).

5) Musculotendinous junctions

Mean degeneration scores of fiber structure, fiber arrangement, regional variations in cellularity, increased vascularity, and decreased collagen stainability were significantly higher in the MTJ group than in the control group, whereas nuclear rounding and hyalinization scores were not ($p=0.080$ and 0.078, respectively; Table 3, Fig. 2C). Mean total degeneration score was significantly higher in the MTJ group (10.8 ± 3.10) than in the control group (5.0 ± 2.87, $p<0.001$; Fig. 3C).

6) Native ends, freshened ends, and musculotendinous junctions

Degeneration scores of fiber structure, fiber arrangement,

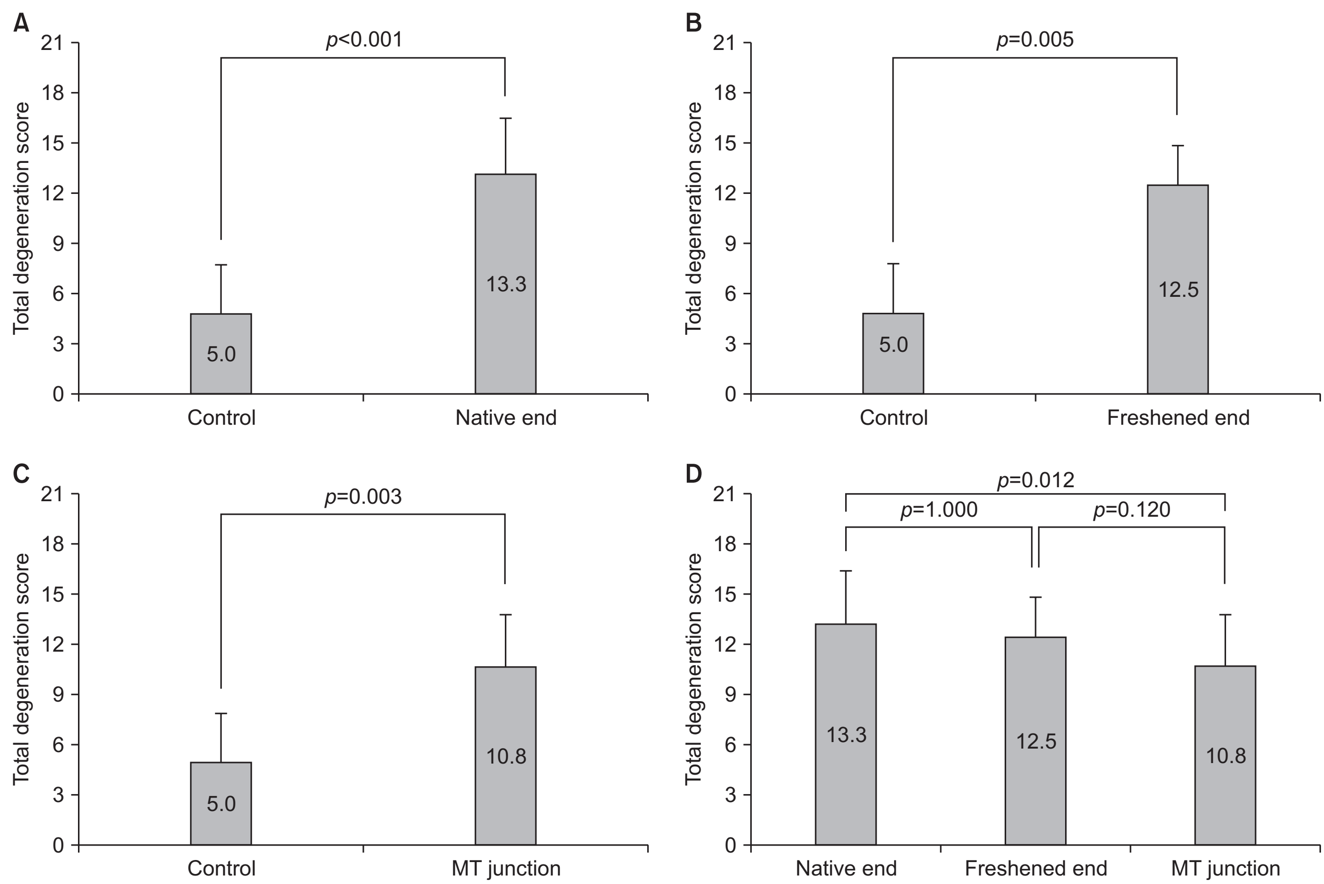

Fig. 3. Total degeneration scores in the native end (A), freshened end (B), and musculotendinous junction (MT junction) (C) groups as compared with the control group. All three groups showed significantly greater total degeneration scores than the control group. (D) Total degeneration scores in the native end group were no different to those of the freshened end group, but differed significantly from those of the MT junction group ($p=0.012$). Mean total degeneration scores of the freshened and MT junction groups were non-significantly different ($p=0.120$).

regional variations in cellularity, increased vascularity, and decreased collagen stainability were not significantly different in the 3 groups (all $p>0.05$; Table 3, Fig. 2D). However, scores for nuclear rounding and hyalinization were significantly different between the 3 groups ($p=0.002$ and 0.001, respectively). Furthermore, mean total degeneration scores of the 3 groups differed significantly ($p=0.012$; Fig. 3D). Mean total degeneration score in the NE group was significantly greater than in the MTJ group ($p=0.012$), but was not significantly different from that of the FE group. The mean total degeneration score of the FE group was not significantly different from that of the MTJ group.

Discussion

This study shows that degeneration of the supraspinatus tendon in patients with a full-thickness rotator cuff tear is greater than that in patients without a rotator cuff tear, and that degeneration is present not only at tear ends, but also in macroscopically intact portions of musculotendinous junctions. Furthermore, degrees of degeneration were not significantly different between native ends before debridement and freshened ends after debridement ($p=1.000$) or between freshened ends and macroscopically intact portions just distal to musculotendinous junctions ($p=0.120$). However, degrees of degeneration were significantly different between native ends and musculotendinous junctions ($p=0.012$). These results suggest that aggressive debridement of frayed torn ends to macroscopically intact or bleeding tendon is unnecessary, because healthy tendon free of degeneration cannot be achieved in patients with a full-thickness rotator cuff tear. In addition, these results suggest that surgeons need a strategy to reverse or regenerate torn, degenerated rotator cuff tendons and achieve secure fixation of torn tendon ends at their anatomical locations.

One of strengths of this study is that it includes investigations of degeneration at three different locations, including a macroscopically intact location, in torn rotator cuff tendons. Whereas many histological studies have addressed rotator cuff degeneration and tears,[8,9,14-17] few studies have included specimens from a macroscopically intact portions.[13,18,19] Furthermore, it is worth mentioning that all of these studies demonstrated degeneration in macroscopically intact tendon. In addition, some authors have reported apoptosis, an important cause of rotator cuff tendinopathy,[20] in macroscopically intact tendons. In particular, Lee et al.[21] found no differences between apoptotic cell profiles in biopsy material from torn edges and a 1-cm-deep region proximal to the margins of torn supraspinatus tendons. The results of the present study concur with these findings, and also show that degrees of degeneration in grossly intact tendons do not differ significantly from those at freshened ends.

With respect to the extent of debridement of frayed torn ends, previous recommendations could be classified as; traditional, radical, and minimal. Surgeons have been customarily taught that they should resect the torn, frayed tendon end to bleeding, healthy looking tissue,[22] and attach it to a cancellous trough to enhance healing.[23,24] For rotator cuff repair, Neer[25] also recommended careful resection of the torn edge to increase the likelihood of tendon healing. However, these traditional procedures are not supported by solid scientific evidence, and some authors have suggested quite different treatment options.[13,21,26-29] Goutallier et al.[15] in a histological study, recommended radical debridement. In this previous study, histological lesions in tendinous stumps were found to correspond roughly to tendinous macroscopic lesions requiring resection. However, as this radical debridement would cause a large amount of tension, they also recommended use of special procedures called musculo-tendinoplasties. On the other hand, Uhthoff et al.[26] reported there is no scientific basis for unnecessary shortening of the tendon, because the tendon itself does not contribute to healing, and recommended that simple regularization of frayed ends is sufficient. In a histological study, Longo et al.[13] also suggested that it is not necessary to excessively freshen torn tendon to bleeding tissue because the macroscopically intact supraspinatus tendon is also degenerated and because the causes of healing failure are not limited to the ends of torn tendons. Recently, Fabiś et al.[19] reported that the expressions of caspases 9, 8 and 3, Bax, and tumor necrosis factor-alpha significantly diminished from the distal to the proximal parts of the torn edges of supraspinatus tendons, and suggested that resection 4 to 7 mm from torn edges may enhance the healing process by achieving a reasonable compromise between apoptotic and inflammatory processes and the mechanical aspects of rotator cuff reconstruction. The results of this study also confirmed that levels of degeneration in grossly intact locations of rotator cuff tendons were similar to those observed at more lateral torn ends. Taken these results together, we suggest that freshening of the torn end should be limited to the removal of most lateral fraying.

The limitations of this study include the small numbers of patients included, the lack of en bloc biopsy specimens, the use of a semi-quantitative grading system, the use of only H&E staining, no evaluation of myxoid, lipoid, or calcific degeneration, and potential rotator cuff problems in the control group.

Conclusion

The findings of this study demonstrate that tendon degeneration in patients with a full-thickness rotator cuff tear occurs throughout the entire rotator cuff tendon to macroscopically intact portions. Minimal freshening of lateral frayed ends, resulted in degrees of degeneration in freshened ends that were not significantly different from those observed in macroscopically intact portions, which suggests aggressive debridement to grossly normal looking, bleeding tendon is unnecessary.

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