Stress Distribution within the Rotator Cuff Tendon with a Crescent-shaped and an L-shaped Tears

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INTRODUCTION:
There are various shapes of full-thickness rotator cuff tears, but they are mainly categorized into two types: crescent-shaped and L-shaped tears. Although it is widely accepted that the tear often propagates with time, the exact propagation pattern in each type of tear is still remains unknown.

In the present study, we attempted to clarify the stress distribution in the tendons with a full-thickness rotator cuff tear using three-dimensional finite element (FE) method. Particularly, we compared the stress distribution pattern between a crescent-shaped and an L-shaped tears to clarify the differences of their propagation patterns.

MATERIALS AND METHODS:
Geometric data of the Specimen
A normal cadaveric shoulder (69-year-old male) was used for the current study (Fig. 1-a). All soft tissues except the rotator cuff tendons were removed and the specimen was examined with CT scan to obtain its DICOM-format data. Then, the data were imported to a workstation to develop a three-dimensional model of the rotator cuff tendons attached to the humeral head using software designed for the finite element analysis. Mechanical Finder (version 6.0, extended edition, Research Center of Computational Mechanics Inc., Tokyo, Japan). The specimen was modeled with 1.0-mm tetrahedron solid elements (Fig. 1-c).

Design of full-thickness rotator cuff tears
To simulate various size of full-thickness rotator cuff tears, a semicircular tendon defect (diameter: 2 cm) was created in the supraspinatus tendon close to its attachment (crescent-shaped tear model, Fig. 2-a). An L-shaped tear model was also created around the supraspinatus tendon attachment. The width and the length of the tear were determined as 2.0 cm and 1.0 cm, respectively (L-shaped tear model).

Fig. 2-a, b: Simulated full-thickness tears (a: crescent-shaped tear model, b: L-shaped tear model).

Yellow arrows indicate the lateral margin of tear and a white arrow indicated a longitudinal tear.

Material properties
The material properties of bone were calculated using its CT number based on the data proposed by Keyak, et al.10. For rotator cuff tendons, the Young\& modulus and the Poisson\& ratio were determined as 305.5 MPa and 0.497, respectively. Articular cartilage of the humeral head (Young\& modulus: 35 MPa, Poisson\& ratio: 0.495) was also modeled in the current study. GAP elements were inserted between the articular cartilage of the humeral head and the deep surface of rotator cuff tendons to control their contact. The friction coefficient was determined as 0 in the present analyses.

Loading and constraint conditions
The position of the shoulder joint was determined as 0-degree abduction with neutral rotation. The force generated by each rotator cuff muscle at this position were estimated based on a previous report by Kronberg, et al.11, which were then applied to the proximal end of the tendons. Tensile loads applied to the proximal ends of the supraspinatus, infraspinatus, and subscapularis tendons were determined as 50.5 N, 22.5 N and 63.3 N, respectively. Both the distal end of the humeral shaft and the humeral head facing to the glenoid at the 0-degree abduction and neutral rotation was constrained in all directions.

Data interpretation
In each model, elastic analysis was performed and the distribution of von Mises equivalent stress was calculated. Then, the stress distribution pattern in the tendon was compared between the two models.

RESULTS:
In the crescent-shaped tear model, a high stress concentration was observed both at the anterior and the posterior edges of the torn tendon stump. The area with high stress concentration extended both in anterior and posterior directions (Fig. 3-a, b). In the L-shaped tear model, a high stress concentration was observed not only at the lateral margin of torn tendon stump but also at the bottom of the longitudinal tear (Fig. 4-a, b).

Fig. 3-a, b: Stress distribution in the tendon with a crescent-shaped tear. The areas with high stress concentration were observed both at the anterior and posterior margins of the tear site.

Fig. 4-a, b: Stress distribution in the tendon with an L-shaped tear. The area with high stress concentration was also observed at the bottom of the longitudinal tear (arrow).

DISCUSSION:
The tendon strain is reported to increase at the edge of the full-thickness rotator cuff tears.12 In the present study, the FE models showed the concentration of the equivalent stress both at the anterior and the posterior edges of the torn tendon stump, which extended both anteriorly and posteriorly. Moreover, since a high stress concentration was observed at the bottom of the longitudinal tear in the L-shaped tear model, we assumed that the tear would also propagate proximally in an L-shaped tear.

SIGNIFICANCE:
The present study may explain why the zipper phenomenon is observed in the propagation of a full-thickness tear of the rotator cuff tendon.

REFERENCES