Propagation of Full-thickness Rotator Cuff Tears – An Analysis using Three-Dimensional Finite Element Method

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INTRODUCTION:
It is known that full-thickness rotator cuff tears gradually propagate with time. However, the pathomechanism of this propagation has not been fully clarified yet. The purpose of this study was to investigate the pathomechanism of the propagation of the full-thickness rotator cuff tears using three-dimensional finite element method.

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 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, Research Center of Computational Mechanics Inc., Tokyo, Japan). The specimen was modeled with 1.0-mm tetrahedron solid elements (Intact model, Fig. 1-c).

Material properties
The material properties of bone were calculated using its CT number based on the data proposed by Keyak, et al.11 For rotator cuff tendons, the Young’s modulus and the Poisson’s ratio were determined as 305.5 MPa and 0.497, respectively. Articular cartilage of the humeral head (Young’s modulus: 35 MPa, Poisson’s ratio: 0.495) was also modeled in the current study. Moreover, GAP elements were inserted between the articular cartilage of the humeral head and the deep surface of rotator cuff tendons to simulate their contact.

Loading and constraint conditions
The position of the shoulder joint was determined as 0-degree abduction with neutral rotation in the current study. The force generated by each rotator cuff muscle at this position were estimated based on the previous report by Kronberg, et al.12, which were then applied to the proximal end of the tendons. For shoulder abduction, tensile load applied to the proximal end of supraspinatus, infraspinatus and subscapularis were determined as 50.5 N, 22.5 N and 63.3 N, respectively. For external rotation, tensile load applied to those 3 tendons were determined as 10.5 N, 15.0 N and 94.9 N, respectively.

Both the distal end of the humeral shaft and the humeral head facing the glenoid at the 0-degrees abduction and neutral rotation was constrained for all directions.

Data interpretation
In each model, elastic analysis was performed and the distribution of von Mises equivalent stress was calculated. Stress distribution pattern inside the tendon as well as the highest value of the stress at the tearing site were compared among the models.

RESULTS:
In the abduction, high stress concentration was seen both at the anterior and posterior edges of torn tendon stump. The area with high stress concentration extended both anterior and posterior directions (Fig. 3). Interestingly, the stress distribution pattern in the external rotation was similar to that of the abduction (Fig. 4).

The highest value of the equivalent stress increased with the size of tears both for the abduction and for the external rotation (Table 1).

DISCUSSION AND CONCLUSION:
It has been reported that the tendon strain increased at the edge of the tendon in the full-thickness rotator cuff tears.10 The results of the current study clearly demonstrated that the concentration of the equivalent stress appeared both at the anterior and the posterior edges of the torn tendon stump in the full-thickness rotator cuff tears, which extended both anteriorly and posteriorly. These results may explain that the full-thickness rotator cuff tendon may propagate to both anterior and posterior directions with the zipper phenomenon.

REFERENCES

Table 1: Values of the highest equivalent stress at the site of full-thickness tear.

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<th>Abduction</th>
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<th>3 cm</th>
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<td>Ext Rotation</td>
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<td>0.22</td>
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<td>0.096</td>
<td>0.12</td>
<td>0.13</td>
<td>0.15</td>
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Fig. 1-a, b: Harvested cadaver humeral head, 1-c: Three-dimensional finite element model (intact model).

Fig. 2: Simulated full-thickness tears. Arrows indicate the simulated full-thickness tears.

Fig. 3: Distribution of the von Mises equivalent stress at the site of full-thickness tear in the abduction.

Fig. 4: Distribution of the von Mises equivalent stress at the site of full-thickness tear in the external rotation.