Introduction: In the surgical treatment of rotator cuff tears, repair technique has been shifted from the single-row (SR) or the double-row (DR) to the transosseous equivalent (TE) repair with the advancements of arthroscopic instrumentations including suture anchors. Previous biomechanical studies revealed that the TE repair provided a better initial fixation than other two techniques; i.e., higher ultimate tensile load, greater contact area as well as pressure, and smaller gap formation during cyclic loading. However, postoperative re-tearing still occurs in a considerable number of patients. Clinically, it was reported that the re-tearing pattern differs between the SR and the DR repairs, which could be explained by the difference of stress distribution in the repaired tendon (Hayashida, et al., 2012). Since the TE repair was first introduced on 2006 (Park, et al., 2006), no studies have yet been carried out that dealt with the stress distribution pattern inside the tendon in this technique. The purpose of the present study was to compare the stress distribution pattern both in the rotator cuff tendon and the bone between TE repair and SR or DR repairs using 3-dimensional finite element method.

Methods: A three-dimensional model of rotator cuff tendon as well as humeral head (bone-tendon model) was designed using computer graphics software, Metasequoia (version 3.1.4, tetrafase Inc., Japan). This model was simplified as having board-like shape to recreate supraspinatus tendon repair at hanging arm position. The STL (stereolithography) data of this model were imported to the software for finite element method, Mechanical Finder (Extended Edition, version 6.2, RCCM, Japan). Suture threads were also modeled, which were used in the typical SR, DR and TE repairs. (Fig. 1-a, b, c). Then, the STL data of suture threads for each repair technique was imported to the bone-tendon model to link these two materials together. In other words, the finite element models developed in the present study simulated the state immediately after surgical repair. Each model was divided into approximately 1,500,000 tetrahedron elements. Contact elements were inserted between each material to avoid penetrating tendon into bone as well as suture threads into tendon or bone. Both the Young’s modulus and the Poisson’s ratio for bone, tendon and suture thread were determined according to the previous studies (Sano, et al. 2007, Table 1). To simulate the suture anchor fixation, both ends of the suture thread were inserted and fixed to bone and a tensile force (20N) was applied to each suture thread along its direction to recreate a tension caused by knot tying. A tensile force (100N) was also applied to the proximal end of the supraspinatus to simulate muscle contraction force. The distal end of humerus was completely constrained during the analysis. To simplify the analysis, the influence of friction between each material was not considered in the present study. Then, the elastic analysis was performed and the distribution pattern of von Mises equivalent stress was compared among 3 models to investigate the possible re-tearing site. Moreover, the highest values of the equivalent stress in the repaired tendon and in the bone were also investigated.

Results: In the repaired tendon, the stress distribution pattern in each suture technique varied considerably. In SR model, a high stress concentration was seen around the site of suture thread penetration at the lateral aspect of footprint, which extended medially (Fig. 2-a). In DR model, a high stress concentration was seen in the medial side of medial-row threads (Fig. 2-b). A high stress concentration also appeared around the sites of suture thread penetration in TE model but at the medial aspect of the footprint (Fig. 2-c). The highest equivalent stress in the tendon for SR, DR and TE models was 41.6 MPa, 25.3 MPa and 37.0 MPa, respectively. In the humeral bone, the area with high stress concentration was seen around the sites of suture thread insertion. It was interesting to note that TE model represented a higher equivalent stress in bone than SR or DR models (SR: 212.5 MPa, DR: 170.0 MPa, TE: 380.3 MPa).

Discussion: To reduce the re-tearing rate after rotator cuff repair, it is important to minimize the stress concentration at the site of repair. This was the first study that focused on the stress distribution pattern after 3 representative repair techniques using 3-dimensional finite element method. In the present study, both SR and DR models demonstrated the same stress distribution pattern as those described in the previous study using 2-dimensional finite element method (Sano, et al., 2007). In TE model, a high stress concentration appeared around the medial side of footprint where suture threads penetrated tendon. In the clinical practice, it was reported that re-tearing of the tendon after TE repair was frequently observed near the musculotendinous junction (Cho, et al., 2010). Moreover, the TE models in the present study demonstrated the highest equivalent stress in the repaired tendon among three models. We believe that the results of the present study well explained why re-tearing frequently occur at the musculotendinous junction after this procedure. The other interesting finding of the present study was that TE...
model showed the highest equivalent stress in humeral head among three models. Since the highest equivalent stress was seen around the site of suture thread insertion, we assumed that the risk of anchor pull-out might be higher in TE repair than other two techniques. In conclusion, surgeons should pay attention to both the quality of tendon stump and bony strength around the footprint to avoid postoperative re-tearing after transosseous equivalent rotator cuff repair.

**Significance:** The transosseous equivalent repair caused higher equivalent stress concentration at the medial row area than the single-row or the double-row repairs.

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**References:**

<table>
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<tr>
<th>Material properties used in the present study</th>
<th>Young’s modulus (MPa)</th>
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<tr>
<td>Humeral head (bone)</td>
<td>2780</td>
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<tr>
<td>Supraspinatus tendon</td>
<td>168</td>
<td>0.497</td>
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<tr>
<td>Suture thread</td>
<td>591</td>
<td>0.45</td>
</tr>
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</table>
Figure 1-a, b, c: The finite element models developed in the present study (a: SR, b: DR, c: TE)

Figure 2-a, b, c: Stress distribution pattern in the repaired tendon (a: SR, b: DR, c: TE)