Will the Strength of the Clavicle Plate be Increased by Inserting Small Screws into the Empty Holes above the Fracture Site?

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Research article

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Abstract

Background: Open reduction and plate fixation is the standard surgery for displaced midshaft clavicle fractures because of biomechanical stability. Implant failure like plate breakage or deformation is the most serious complication of plate fixation. Several plate designs for midshaft clavicle fractures have been introduced, but traditional superior plate has been mostly used.

Methods: We generated the clavicle 3D image using the computed tomography (CT) of the left normal clavicle of a 54-year-old female, and then made the comminuted midshaft clavicle fracture model with 10-mm fracture site gap. The fracture model was fixed with 7-hole superior locking compression plate. Finite element analysis (FEA) was performed between the presence (model B) and absence (model A) of screws above the fracture site.

Results: The average peak stress from the cantilever bending force was much greater than the peak stress from the axial compression and axial torsion force. This means that the cantilever loading force is the main force which could cause plate breakage or deformation. The maximal stress of the model B was lower than the one of the model A. Therefore, model B showed superior biomechanical property than model A under all loading conditions, especially cantilever bending force.

Conclusions: The peak stress of the superior clavicle plate could be decreased just by inserting a small screw into the screw hole above the fracture site.

Background

Clavicle fracture is the most common trauma of the scapular girdle and occurs about 81% at the midshaft [1, 2]. Non-displaced clavicle fractures are usually managed conservatively [3, 4], but open reduction and plate fixation is the standard treatment for displaced midshaft clavicle fracture to reduce risk of shortening, nonunion, malunion and so on [5-7]. Actually, displacement and comminuted pattern are 48% and 19% in the midshaft clavicle fracture [8].

Among the surgical procedures, plate fixation provides biomechanically stable strength for early mobilization and gives good clinical outcomes [9, 10]. Major complication associated with plate fixation is implant failure due to plate breakage or deformation. A previous study demonstrated two risk factures for plate breakage: the use of reconstruction plate and the bridging plate technique [11, 12].

According to the study which was a FEA about clavicle fracture fixation, the maximum stress in the precontoured superior reconstruction plate fixation without lag screws occurred at the edge of screw holes above the fracture site [13]. Also other study revealed that the weakest point of the superior clavicle locking compression plate in comminuted midshaft clavicle fracture is the screw holes above fracture zone, especially in the cantilever bending force and therefore recommended a new design which is a superior locking plate without screw holes above fracture zone to prevent metal failure [14]. However, in mass production of metal plates, it is practically impossible to remove a hole only in the fracture area.

We considered placing small screws in the holes above the fracture area on the actual metal plate to remove empty holes and give similar effect as the previously described new design. Our hypothesis is that the strength of the plate could be increased by inserting small screws into the holes above the fracture zone in the clavicle fractures.

Methods

Finite element model

A computed tomography (CT) of the left normal clavicle of a 54-year-old female volunteer was used to generate the clavicle 3D model. The axial images were obtained with 1.0mm slice thickness and then a 3D model was created by using a free medical software which is InVesalius (Center for Information Technology Renato Archer, Campinas, Brazil); the 3D model was imported into ANSYS mechanical simulation (ANSYS, Inc., Canonsburg, PA, USA) for FEA. The finite element meshes were generated as a tetrahedral 0.5mm size for bones, plates, and screws. The average mesh element quality was 0.83861 and the orthogonal quality was 0.85907. The total generated mesh nodes were 1,843,793 EA and elements were 1,258,688 EA.

There was 5-mm transverse gap between a medial and a lateral fragment, which means a comminuted midshaft clavicle fracture. The fracture was fixed with 7-hole superior locking plate which was modeled by a 2.5-mm, 7-hole titanium superior locking compression clavicle plate system (AO Synthes, Solothurn, Switzerland). To simplify the simulation, just locking holes were used instead of combi holes.

There were two models: one is the fracture model which was fixed with six 2.5-mm locking screws on both medial and lateral fragment without screw fixation above the fracture site (model A) ; on the other hand, a small screws was inserted to fill the empty hole, not into the bone in the other model (model B) in Figure 1.

The contact interface between all items was set as a totally bonded condition for the bone-plate interface with high contact angle, the plate-screw and screw-bone interfaces. The material properties of cortical bone, cancellous bone and titanium alloy were applied as literature references in Table 1 [15].

Mechanical loading test

Like the previous study, three common loading modes with boundary condition were applied at the lateral end of the clavicle: 100N of cantilever bending, 100N of axial compression and 1Nm of counterclockwise axial torsion for case of raise hand in Figure 2.

The stress distributions in the plate were measured on the seven points same as seven locking holes of superior clavicle plates: medial (M) 1, 2, 3, fracture site (FS), lateral (L) 1, 2, 3 in Figure 1. The peak stresses on each point and maximal stress of both plate models in all three forces were analyzed as the von Mises stress.

Results

The von Mises stresses for each plate are shown in Table 2. In cantilever bending force, the average stress of M1, 2, 3 and L1, 2, 3 in the both plates are similar that average ratio (M/L) is 1.108, but the stress of FS was dramatically lowered just by insertion of small screw from 1000.800 MPa in model A to 438.560 MPa in model B. The peak stress point in the model A were at the FS point, and the peak stress of the model A (1027.400 MPa) was larger than one of the model B (582.050 MPa) in Figure 3. This similar trend was shown in the axial compression loading. As shown in Figure 4, the stress of FS was much lowered from 279.810 MPa in model A to 123.930 MPa in model B, and peak stress of the model A (297.690 MPa) was larger than one of the model B (181.220 MPa) in Table 2. On the other hand, this tendency about the FS stress was not found in the counterclockwise axial torsion load in Figure 5. The von Mises stress of FS point was higher even though small screw was inserted (model A: 31.100 MPa, model B: 67.845 MPa), but the peak stress of the model B was slightly lower than the one of the model A (model A: 131.920 MPa, model B: 127.960 MPa).

Discussion

The management of displaced midshaft clavicle fractures remains challenge. According to the recent meta-analysis study [7], surgical treatment for displaced clavicle fractures led to a greater possibility of union at 1 year of follow-up. Patients who hesitate to have surgery for acute displaced midshaft clavicle fractures could have the possibility of nonunion more than 10% of patients. Also, these nonunion would be more difficult to treat compared with acute fractures. Therefore, acute displaced clavicle fractures are recommended surgery to reduce risk of nonunion and malunion.

Open reduction and plate fixation are the standard surgery for displaced midshaft clavicle fractures. Plate fixation provides biomechanically stable strength for early mobilization and then are more used rather than intramedullary fixation. The holes above the fracture site are not usually filled with screws to prohibit nonunion, and just remain empty. However, implant failure is one of the complications in plate fixation. Some FEA studies recommend various type of plates such as anterior plate, spiral plate, superior plate without screws holes above fracture zone and so on [14-17].

According to the FEA comparison between superior locking plate with and without screw holes above fracture zone [14], the biomechanical property of superior clavicle locking plate without screw holes above fracture zone is superior to the standard locking plate with screw holes above fracture zone, with a significantly lower peak stress on the screw holes above fracture zone in all loading conditions. The reason why we pay attention to this study is that locking plates is the same as a manufactured superior locking plate used nowadays, so we don't need to develop a new design and set equipment for manufacture. However, it is practically impossible to remove holes only in the fracture area in mass production of clavicle superior locking plates. We wondered that if inserting small screws into an empty hole above the fracture site would have the same effect as superior locking plate without screw holes above fracture zone.

We set a comminuted midshaft clavicle fracture model fixed with 7-hole titanium locking compression superior clavicle plate and did FEA comparison between superior clavicle plate with (model B) and without a screw (model A) above the fracture site. According to the result in Table 2, the FS stress of model A from the cantilever bending force (1000.800 MPa) was much greater than the peak stress from the axial compression (279.810 MPa) and axial torsion force (31.100 MPa). This result means that the cantilever loading force is the force that has the greatest impact on implant failure.

The model B reduced the peak stress on the FS point with 56.179% decrease in cantilever bending force and 55.709% decrease in axial compression loading compared to the model A, whereas the model A's peak stress was higher approximately 1.765 times rather than the model B. Nevertheless, the maximal stress received by the superior plate under all three loading conditions was low overall in model B with screw inserted, and the biggest difference was the cantilever loading condition.

In axial torsion load condition, peak stress position was changed to another point because counterclockwise moment moved force vector to different direction in Figure 6. As shown in Figure 6, the peak stress position moved to L1 point of rear side plate, it shows same result on both models.

The study had several limitations. First, actual clavicle fracture is not as simple as the model constructed in this study and is very complex, and the number of fracture cases varies greatly in practice. Second, there's are some considerations such as micromotion between bone and plate, variation of clavicle anatomy, bone quality and quantitative and the stress riser effect of the screws. To simplify simulation, the authors excluded these considerations. Third, the magnitude of the applied forces is not reflected in the magnitude of the force actually acting in the body, but rather the relative nature of the force's direction.

Further studies will require analysis according to various form of bone and fracture. In addition to the shape of plates, studies on the location, number, size and orientation of screws will also have to be conducted simultaneously.

Conclusions

As previous studies [13, 14], the screw hole above the fracture site is the weakest point in the superior clavicle locking plate for comminuted midshaft clavicle fracture, especially in the cantilever bending force. B model showed superior biomechanical property than A model under all loading conditions. Therefore, we can reduce the peak stress using a small screw insertion into the screw hole above the fracture site.

Abbreviations

CT: Computed Tomography

FEA: Finite Element Analysis

M: medial; FS: fracture site; L: lateral

Declarations

Ethics approval and consent to participate

This study was conducted following approval by the Institutional Review Board of Soonchunhyang University Gumi Hospital and the written informed consent of volunteers has been obtained.

Consent for publication

Not applicable.

Availability of data and materials

The data analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors have no conflict of interest to disclose.

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Not applicable.

Authors' contributions

Kim DG contributed to the conception and design of the study, and was a major contributor in writing the manuscript. Kim SM analyzed and interpreted numerical calculation and 3D modeling. All authors read and approved the final manuscript.

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Tables

Table 1. Material properties adopted in numerical simulation models

Materials	Young's modulus [MPa]	Poisson's ratio	Density [g/cm3]	Bulk modulus [MPa]	Shear modulus [MPa]
Cortical bone	17,000	0.3	1.19	14,167	6,539
Cancellous bone	1,000	0.3	1.19	833	385
Titanium alloy	186,400	0.3	4.62	155,330	71,692

Table 2. Stress analysis results on numerical simulation model						
Points	Cantilever bending load [MPa]		Axial compression load [MPa]		Axial torsion load [MPa]	
	Model A	Model B	Model A	Model B	Model A	Model B
M1	22.228	22.268	1.633	1.641	7.204	7.222
M2	47.740	47.827	7.698	7.721	16.494	16.539
M3	131.550	131.410	32.535	32.492	35.413	35.451
FS	1000.800	438.560	279.810	123.930	31.100	67.845
L1	104.790	104.430	32.844	32.725	45.499	45.526
L2	50.685	50.761	15.660	15.684	34.420	34.461
L3	26.453	26.378	8.255	8.233	15.758	15.769
Average M	67.173	67.168	13.955	13.951	19.704	19.737
Average L	60.643	60.523	18.920	18.881	31.892	31.919
Average ratio (M/L)	1.108	1.110	0.738	0.739	0.618	0.618
Maximum	1027.400	582.050	297.690	181.220	131.920	127.960

* M: medial, FS: fracture site, L: lateral

Figures

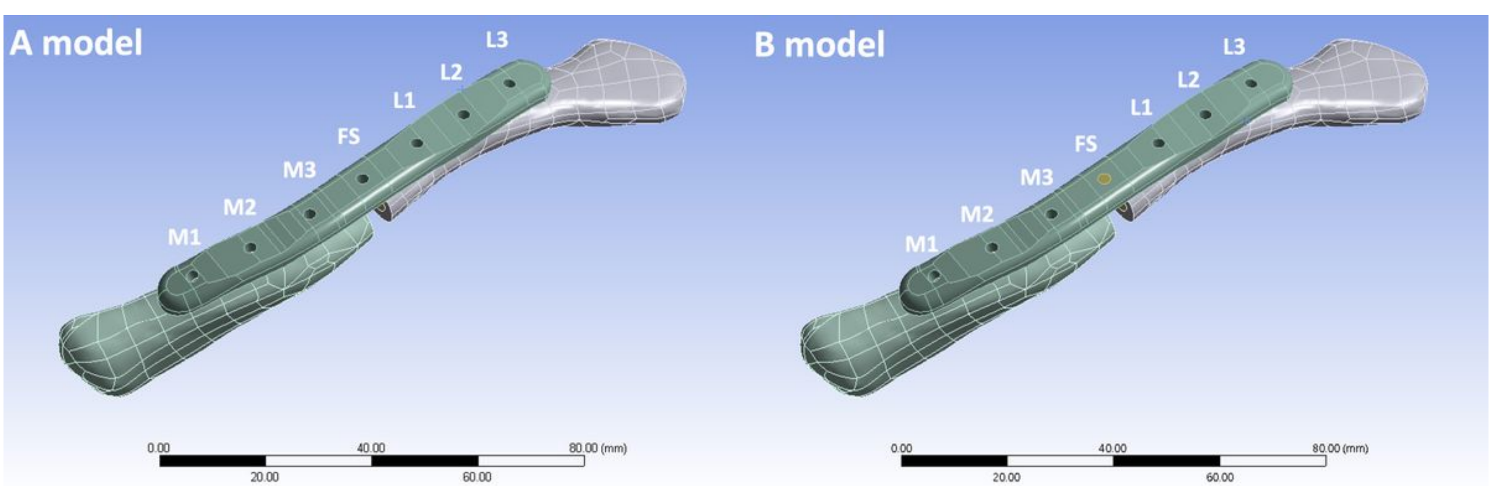

Figure 1

Simulation model structure (left) A model: FS point bolt missing, (right) B model: All bolts contact

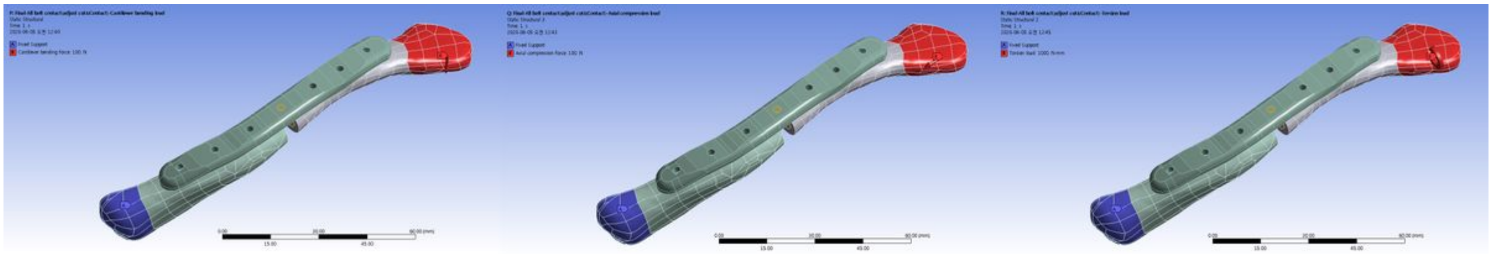

Figure 2

Boundary conditions of clavicle simulation model, (left) cantilever bending load, (mid) axial compression load, (right) axial torsion load with count clockwise

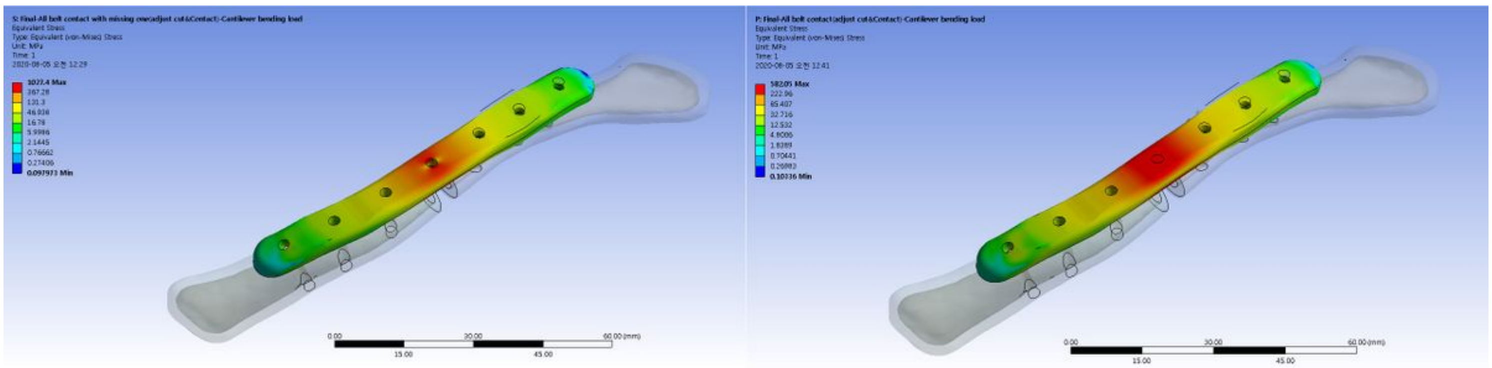

Figure 3

Von Mises stress distribution of cantilever bending load condition, (left) A model, (right) B model

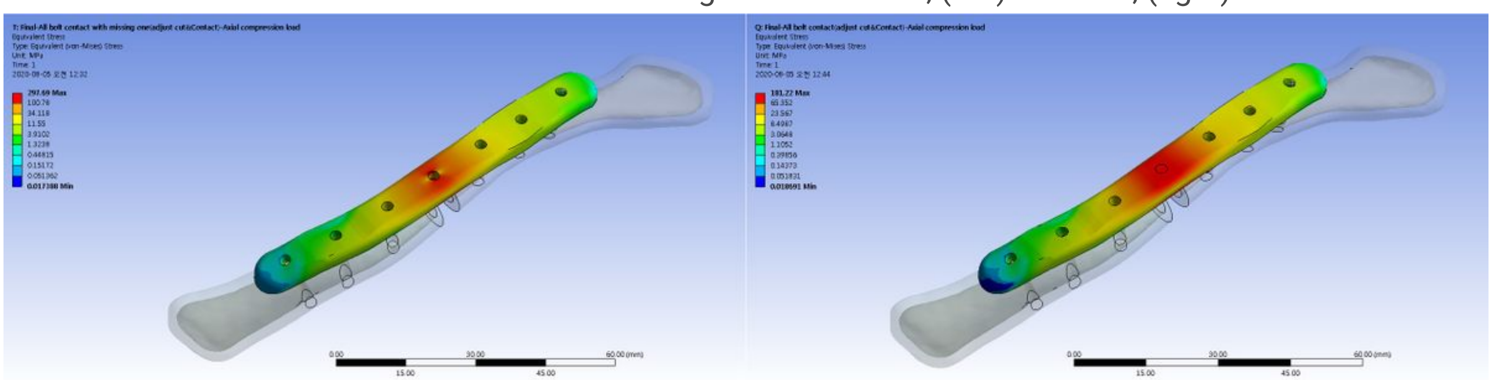

Figure 4

Von Mises stress distribution of axial compression load condition, (left) A model, (right) B model

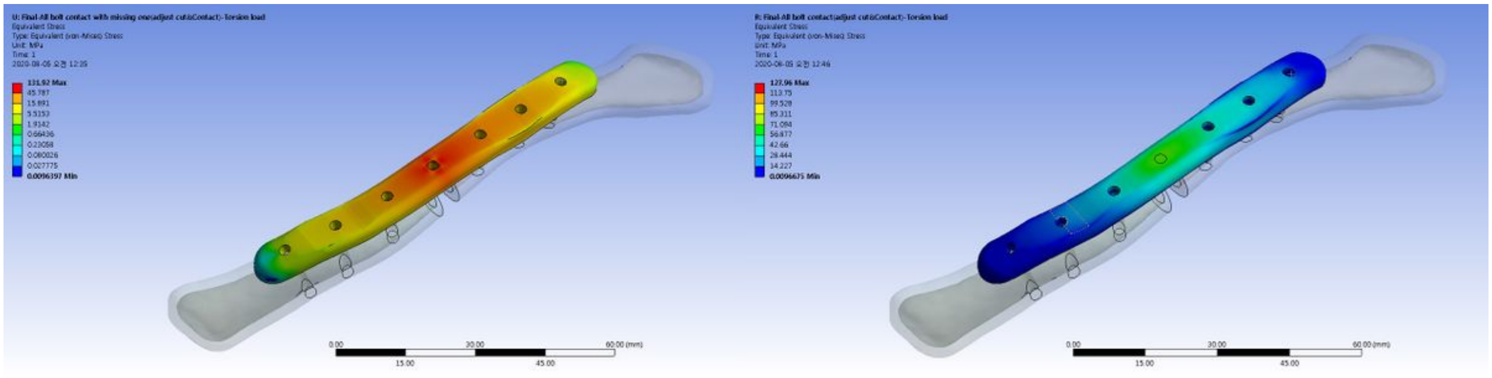

Figure 5

Von Mises stress distribution of axial torsion load condition, (left) A model, (right) B model

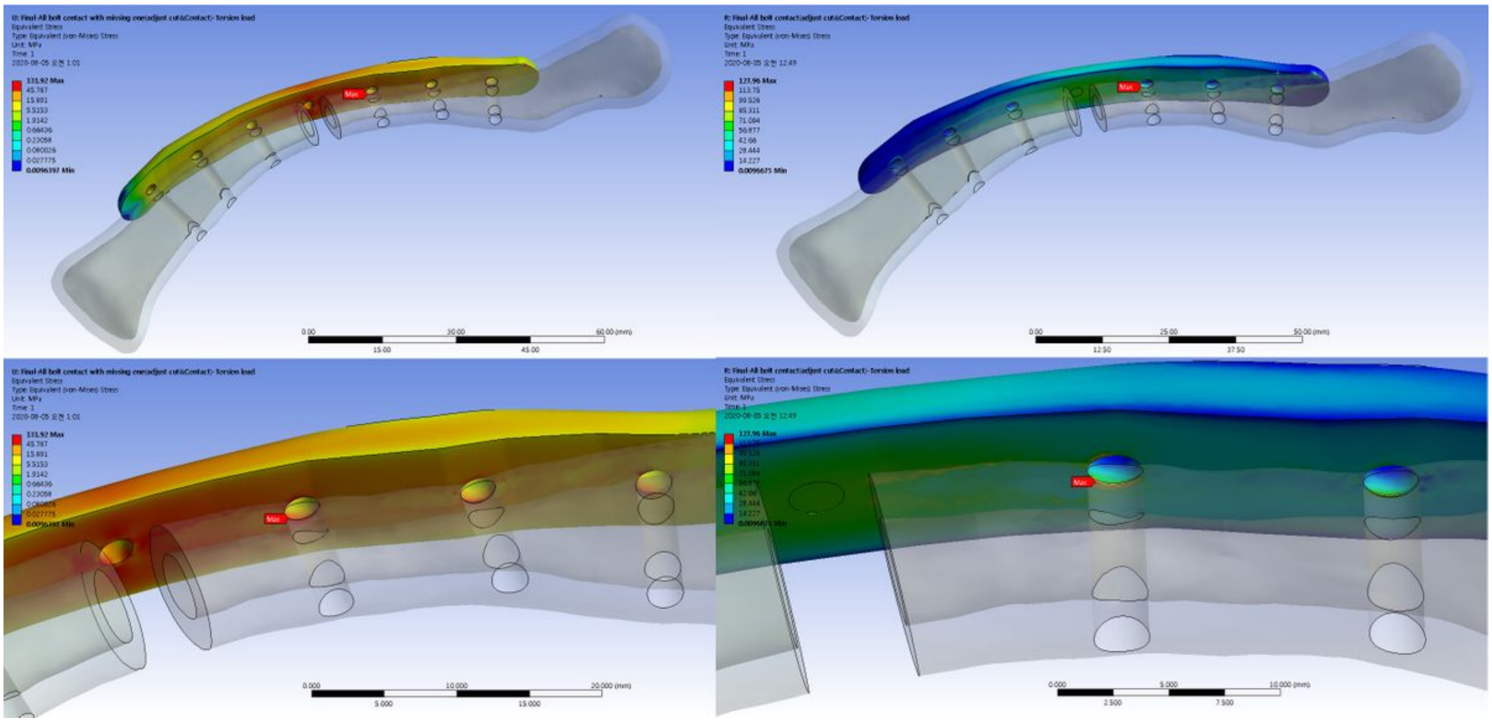

Figure 6

Von Mises stress distribution of axial torsion load condition at maximum peak stress position, (up-left) A model, (down-left) enlarge A model, (up-right) B model, (down-right) enlarge B model