A Novel Anatomical Locking Guide Plate in Treating Acetabular Transverse Posterior Wall Fracture: A Finite Element Analysis Study

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Abstract

Background: The acetabular transverse posterior wall fracture (ATPWF) is a classic type of associated acetabular fracture with an increasing prevalence worldwide. The optimal treatment for this complex facture remains a formidable challenge in orthopedics trauma. Our self-designed locking plate used to show a promising potential in treating acetabular fracture, but no direct comparison between our novel plate with traditional fixations are available.

Materials and methods: The ATPWF model was constructed by the Mimics software using the volunteer's cloud point data, and three internal devices were used to fix this model: the posterior-column locking plate with acterior-column screws (PCLP), double-column locking plates (DCLP), and the novel anatomical locking guidance plate (NALGP) with anterior-column screws and Magic screws. Then series of increasing downward vertical force (200N, 400N, and 600N) were loaded on above models. The stress distribution and peaks, and maximum displacements at two sites were assessed via a finite element analysis.

Results: We found that the major stress concentrated on the middle and lower sections of the posterior plate and lag screws in all three groups after the fixation on the ATPWF. And the NAGLP with its screws stood the bigger stress under all loading force when compared with other two groups. Then the maximum displacement of three groups were evaluated, and NAGLP group were found to have less fracture fragment displacements than PCLP and comparable results to DCLP at both sites.

Conclusion: Though our newly-designed plate with its screws showed larger stresses after fixation on the ATPWF, it also showed superiorities on the fracture stabilization over PCLP and comparable stability to DCLP, which might make the DCLP unnecessary for the treatment of ATPWF since DCLP would undoubtedly result in bigger surgical trauma and blood loss.

Introduction

The acetabular transverse posterior wall fracture (ATPWF) is a classic type of associated acetabular fracture according to the Letournel and Judet classification[1] with an incidence of approximately 24-32% [2]. As ATPWE is usually caused by high-energy violence and involved in the acetabular articular surface, open reduction with internal fixation is required in most cases[1-3].

Previously, the classic treatment for ATPWF was posterior column reconstruction plate with anterior column lag screws and posterior wall lag screws[4, 5], which was reported to provide adequate biomechanical stability for ATPWF. However, due to the complicated anatomical structure of acetabulum and its deep anatomical position, the lag screws implantation had high risks of screws insertion into the hip joint. How to minimize the surgical trauma, reduce the postoperative complications, and improve functional recovery have become the central to orthopedist's efforts on the treatment of ATPWF.

In recent years, since the locking plate is of high angular stability and could be fixed unicortically, it was becoming increasingly popular in the treatment of limb fractures, and gradually adopted in the fixation of ATPWF. On this basis, we previously, for the first time, have designed a novel anatomical locking guide plate (NALGP), which was totally based on the Chinese anatomical characteristics of acetabulum using our collected cloud data from 171 computed tomography models[6, 7]. Besides, two kinds of screws—anterior column screws and Magic screws— were also used with NALGP, therefore forming an inverted Y-shape structure and then providing firm fixation for both columns simultaneously.

Nonetheless, studies on the locking plates in treating ATPWF remain scant so far, let alone the comparative researches on the efficacy between our newly-designed locking plates and traditional locking plates. To this end, this study focused on the ATPWF and performed a finite element analysis on NALGP and two types of fixation that are currently commonly-used: the posterior-column locking plate with anterior-column screws (PCLP) and double-column locking plates (DCLP) so as to determine which treatment is more conducive to the anatomical reduction and fixation for ATPWF.

Materials And Methods

Three-dimensional modeling of the acetabular transverse posterior wall fracture

This study was approved by the ethnical committee of the hospital. A 48-year-old Chinese male volunteer's computed tomography scanning images with a slice width of 0.5mm were obtained from our hospital database and then used to create the three-dimensional finite element model of the half pelvis via the Mimics software 16.0 (Fig.1A).

On the basis of the Judet and Letournel classification for acetabular fractures[1, 8], the ATPWF was reconstructed as previously stated[9, 10]. In brief, since ATPWF includes two types of simple acetabular fracture: transverse fracture and posterior wall fracture, we reconstructed these two fractures, respectively. For transverse fracture, the fracture line started from the upper margin of iliopubic eminence to the top of the greater sciatic notch[11]. For another, the acetabular posterior wall was manually divided into 3 parts along the acetabular center-margin vertical and horizontal lines, and the lateral 2/3 of the acetabular posterior wall ranging from 40 to 90 degrees from the vertical line was marked as the posterior fracture area[12]. Then, the ATPWF finite model was successfully created (Fig.1B).

Geometric modeling of three types of internal fixation in the ACPHTF

The Unigraphis software (Unigraphis Solutions of EDS, USA) was applied to establish these kinds of internal fixation models (PCLP, DCLP, and NALGP, Fig.2). Mesh division was conducted by solid187 tetrahedral elements in the workbench software (Ansys, USA).

Computation and loading parameters

All the definitions of boundary condition, material properties, and loading mode were defined as follows by the Abaqus6.11 software (Dassault Systemes, Velizy-Villacoublay, France).

3. The definition of boundary condition: the contact surfaces between the bone and internal fixation, or between devices were set as binding, while the contact surface between fracture fragments was defined as friction and its friction coefficient was 0.2
4. Material properties: for model construction purpose, we assumed that all the cortical bones, cancellous bones, fixation plates and screws were homogeneous and isotropic.
5. Loading mode: to facilitate the computations, we fixed the pubic symphysis and sacroiliac joint firmly. Since patients with ATPWF were usually required to perform early partial or complete weight-bearing, each assembly model was loaded in an increasing manner with a downward vertical force of 200N, 400N and 600N, respectively. The loading force directed at 45 degrees upward in the coronal plane and 25 degrees backward in the sagittal plane.

Assessment

The stress distribution and stress peak of plates and screws were measured and evaluated, and the fracture fragments displacement under different loading force was also assessed among three groups.

Statistical analysis can be unavailable for the finite element analysis, for the motion and stress were created at the identical loading force and vectors, which effectively eliminated the sample differences.

Result

Stress distribution and stress peak of internal fixations

The rigidity of both plates and screws were firstly assessed in our study and found significant differences among three groups. The stress distributions of plates and screws were demonstrated in Fig.3 and Fig.4. For the plate's stress distribution, stresses mainly act on the posterior-column plate, especially concentrated at the middle and lower section of the plate in all three fixations. For another, most stresses of screws appeared on the lag screws (and Magic screws in the NAGLP group) instead of the common screws. Compared with those in PCLP group, the common screws in the NAGLP group experienced larger stresses and those in the DCLP group withstood less stresses.

For the Von Mises stress peak of plate in three groups, they were tested under the increasing loading force of 200N, 400N, and 600N. The stress peak of posterior plate of PCLP was 32.241Mpa, 67.126Mpa, 114.115Mpa, and the stress peak of anterior and posterior plate in the DCLP were 11.361and 14.521Mpa, 34.083Mpa and 43.54Mpa, 68.219 and 82.294Mpa, and the stress peak of novel plate in NALGP was 42.398Mpa, 91.547Mpa, 156.824Mpa (Tab.1). As for the screws of three groups, the Von Mises stress peak of anterior and posterior screws of PCLP were 70.208 and 27.471Mpa, 126.426 and 57.359Mpa, 198.157 and 92.107Mpa, and in the DLP were 12.066 and 10.906Mpa, 36.205 and 38.222Mpa, 72.419 and 67.472Mpa, and in the NALGP was 38.509Mpa, 79.843Mpa, and 132.769Mpa, respectively (Tab.2).

Table 1 The Von Mises stress peak of plate under different loading force among three groups.

	Stress (Mpa)		
Loading force Model	200N	400N	600N
PCLP (posterior plate)	32.241	67.126	114.115
DCLP (anterior plate)	11.361	34.083	68.219
DCLP (posterior plate)	14.521	43.54	82.294
NALGP (posterial plate)	42.398	91.547	156.824

Table 2 The Von Mises stress peak of screws under different loading force among three groups.

	Stress (Mpa)		
Loading force Model	200N	400N	600N
PCLP (anterior screw)	70.208	126.426	198.157
PCLP (posterior screw)	27.471	57.359	92.107
DCLP (anterior screw)	12.066	36.205	72.419
DCLP (posterior screw)	10.906	38.222	67.472
NALGP (posterior screw)	38.059	79.843	132.769

Fracture fragments displacement

The displacement of the fracture fragment was next evaluated at two sites: the transverse fracture site, and posterior wall fracture site.

We firstly measured the displacement under the loading force of 200N, 400N, and 600N at the transverse fracture site. The maximum displacement in the PCLP was 0.138mm, 0.216mm, and 0.315mm, and in the DCLP was 0.119mm, 0.157mm, and 0.204mm, and in the NALGP was 0.124mm, 0.179mm, and 0.257mm, respectively., while at the posterior wall fracture site, the maximum displacement in the PCLP was 0.095mm, 0.157mm, and 0.236mm, and in the DCLP was 0.076mm, 0.09mm, and 0.107mm, and in the NALGP was 0.083mm, 0.107mm, and 0.142mm, respectively (Tab.3 and Fig.5).

Table 3 The maximum displacement of fracture under different loading force at two sites among three groups.

	The maximum displacement (mm)					
Site	Transverse Fracture			Posterior Wall Fracture		
Force Model	200N	400N	600N	200N	400N	600N
PCLP	0.138	0.216	0.315	0.095	0.157	0.236
DCLP	0.119	0.157	0.204	0.076	0.09	0.107
NALGP	0.124	0.179	0.257	0.083	0.107	0.142

Discussion

The acetabular transverse posterior wall fracture, a classic type of associated acetabular fractures and complex intra-articular fractures[1, 3], is usually caused by strong violence, which would inevitably involve both anterior and posterior column. Therefore, timely open reduction and firm fixation are required to restore the integrity of the articular surface and the matching relationship between the acetabulum and femoral head. Previous studies[13-16] have tried varieties of internal fixations, double-column plates or plates combined with lag screws, etc., to treat the acetabular fractures. However, the optimal treatment remained controversial. Some of them[13, 14] showed that double-column plates were superior to the single-column plate with lag screws in terms of the biomechanical stability, while one study[16] demonstrated that plate combined with lag screws seems non-inferior to the double plates with regards to the biomechanical stability, and could significantly reduce the surgical trauma and blood loss compared with double plate fixation.

In recent years, though sparse research, the locking plate has emerged as a novel way in the treatment of acetabular fracture due to its superiorities in angular stability and unicortical screw fixation. On this basis, we previously have designed a novel anatomical locking guidance plate based on the acetabular morphology of Chinese patients, which was reported to show promising efficacy in the treatment of acetabular fracture from a small sample[6]. But no direct comparison is available between our newly-designed plate and traditional plate in treating the ATPWF so far.

In this study, we aimed to simulate the mechanical behavior of the APTWF and compare two traditional fixations with our novel plate for fracture stabilization using a finite element analysis. Moreover, series of increasing loading force (200N, 400N and600N) were applied to better mimic the early partial or full weight-bearing loading.

We firstly evaluated the stress distribution and rigidity of plates and screws in three groups. As we described aforementioned, the major stress concentrated on the middle and lower sections of the posterior plate and lag screws in all three groups after the fixation on the ATPWF. Therefore, regardless of the type of internal fixation, the stiffness of these sites of the device should be enhanced so as to avoid

the material break. For the rigidity of the plate, the NAGLP and DCLP seemed to experience larger stresses, whether it be the loading force of 200N, 400N or 600N, when compared with the DCLP. For the rigidity of screws, anterior screws in the PCLP group and screws in the NAGLP group showed highest stress concentration. Plates and screws in the DCLP group stood the minimum stresses as there were two plates in the fixation, which could efficiently disperse the stress. Namely, the plate and screws in the NAGLP and PCLP group were more likely to be broken when the loading force increased, which put a higher demand on the rigidity of the NAGLP and PCLP with its screws.

We then assessed the maximum displacement at two sites—transverse fracture and posterior wall fracture. Generally, the maximum displacement at the site of transverse fracture was larger than that at the site of posterior wall fracture. And there is no significant difference in the displacement of fracture fragment among three groups under the loading force of 200N. Nonetheless, as the loading force increased, the maximum displacement in the PCLP group was far larger than that in other two group, whether it be the transverse fracture site or posterior wall fracture site. And the NAGLP group demonstrated a slightly larger but comparable displacement to DCLP group. Namely, both NAGLP and DCLP offered a better stability in the treatment of ATPWF.

Taken together, DCLP group experienced the least stress and provided the firmest stability in treating the ATPWF from our data, which was consistent with the previous studies[17-20] about the treatment of acetabular fractures. However, as previously stated[16, 21], DCLP fixation would inevitably induce many complications like enlarged surgical trauma, and heavy blood loss. These shortcomings could be overcome by the single-column plate fixation. However, PCLP not only showed larger stress concentration, but worse biomechanical stability in our study, which was also in line with the previous study[22]. Notably, our newly-designed plate not only had the advantages of single plate fixation, but showed promising results in the displacement after fixation, which might emerge as an ideal device for the ATPWF treatment.

Apart from the advantages mentioned above, our self-designed plate, the inverted Y-shaped NAGLP, could match the inverted Y-shaped structure acetabulum very well. And on the basis of the acetabulum morphology of Chinese patients, this novel plate was anatomically precontoured to match the acetabular surface, therefore minimizing the surgical time and trauma. Moreover, NAGLP also have guide holes in the plate, facilitating the anterior-column screws and Magic screws implantation and therefore ensuring the safer and easier surgical process. After this direct comparison between two traditional fixations and our novel plate, we further confirmed its superiority in the fracture stabilization.

This study also has some limitations. First, all the results were based on the computer programs rather than the real environment, so some unknown information was lost in that case. A large clinical trial is in progress to further determine its superiorities and inferiorities. Second, we found NAGLP group experienced the highest stress concentration in the study. Therefore, future researches are required to address how to enhance its stiffness to avoid the plate breakage.

Conclusion

In conclusion, the major findings of this finite element analysis were: 1. the stress mainly acted on the on the middle and lower sections of the posterior plate and lag screws in all three groups after the fixation on the ATPWF. 2. though NAGLP demonstrated bigger stress on the plate and screws, it also displayed a better stability to PCLP and comparable one to DCLP in terms of the maximum displacement. The study further encouraged us that NAGLP should be taken into consideration in treating ATPWF.

Abbreviations

ATPWF: acetabular transverse posterior wall fracture; PCLP: posterior-column locking plate with acterior-column screws; DCLP: double-column locking plates; NALGP: novel anatomical locking guidance plate;

Declarations

Acknowledgement

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Contributions

The experiment was performed by Ming Li and Junhao Deng, and the initial manuscript was written by Junhao Deng. Jiantao Li, and Zhirui Li, and Hao Zhang participated in the data analysis and helped in the manuscript revise. Peifu Tang, Yanpeng Zhao, Licheng Zhang insturcted this study and offered us many constructive suggestions. All authors have read and approved the final manuscript.

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Data statement

The data would be provided by requesting the corresponding author.

Conflict of interest

There is no conflict of interest between authors.

Informed consent

Although there is no experiment on humans, all the processes were strictly abided by the regulations of Ethics Committee of Chinese PLA General Hospital. The written informed consent was offered to the CT

data contributor.

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Figures

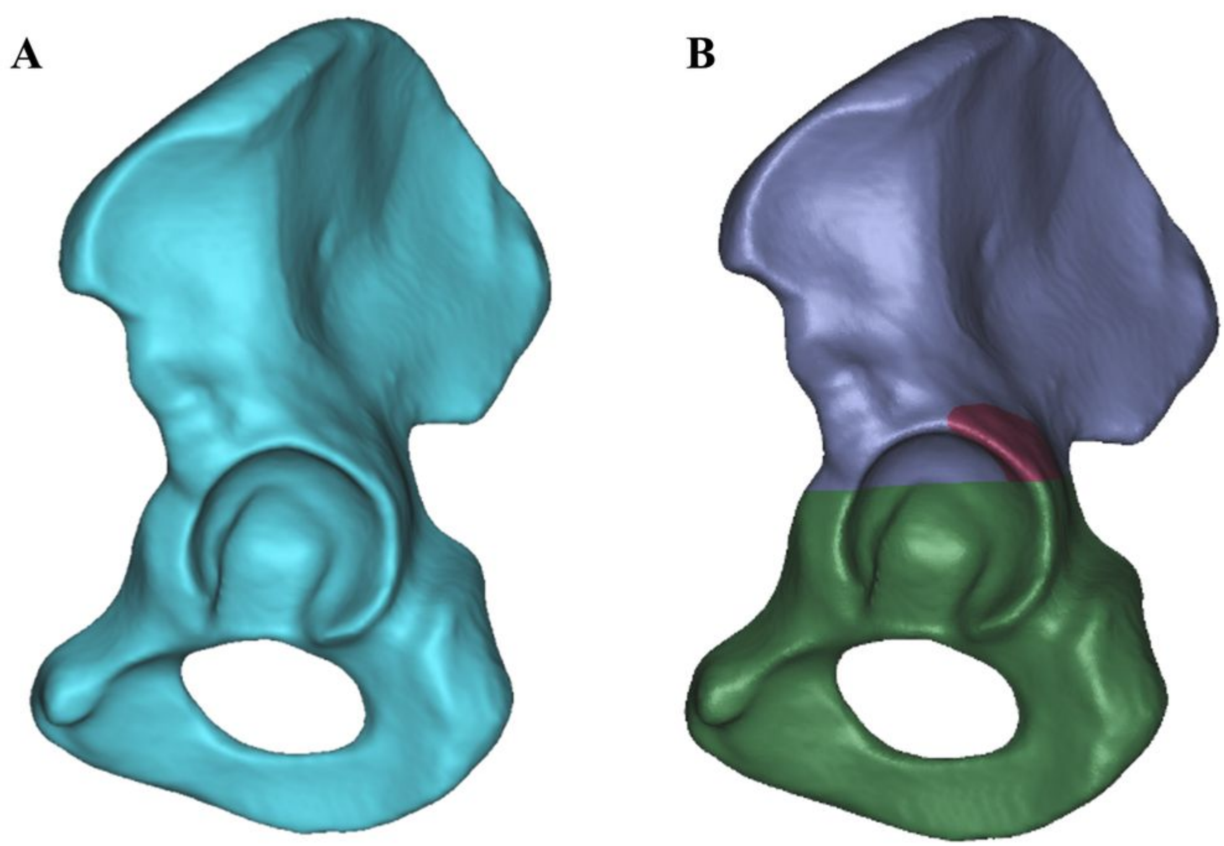

Figure 1

The 3D acetabulum and the ATPWF model reconstruction. A showed the normal acetabular model based on a 48-year-old volunteer CT data. B showed the ATPWF model as well as its fracture lines. Different colors were used to distinguish bone after ATPWF.

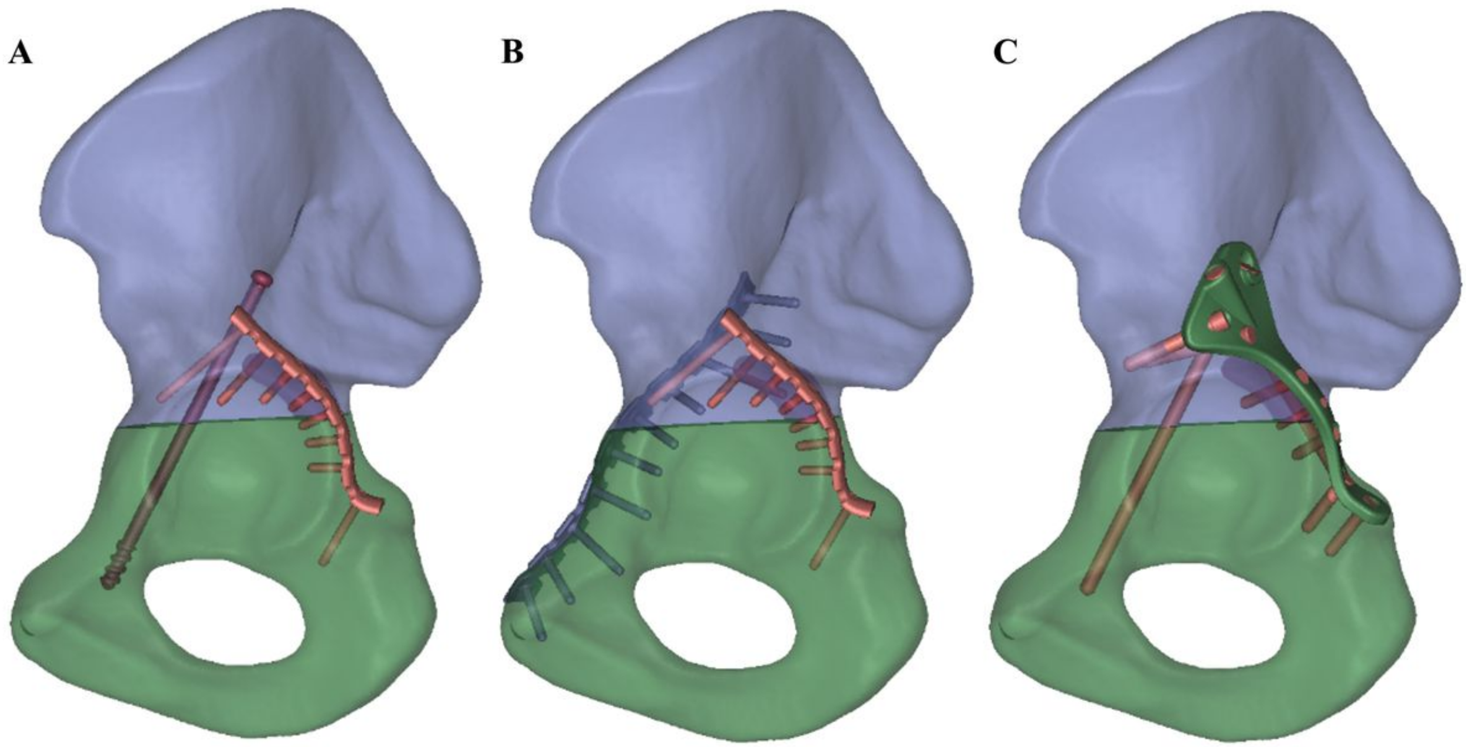

Figure 2

The 3D modeling of three kinds of internal fixation on ATPWF. A, B, and C showed the PCLP, DCLP, and NALGP, respectively.

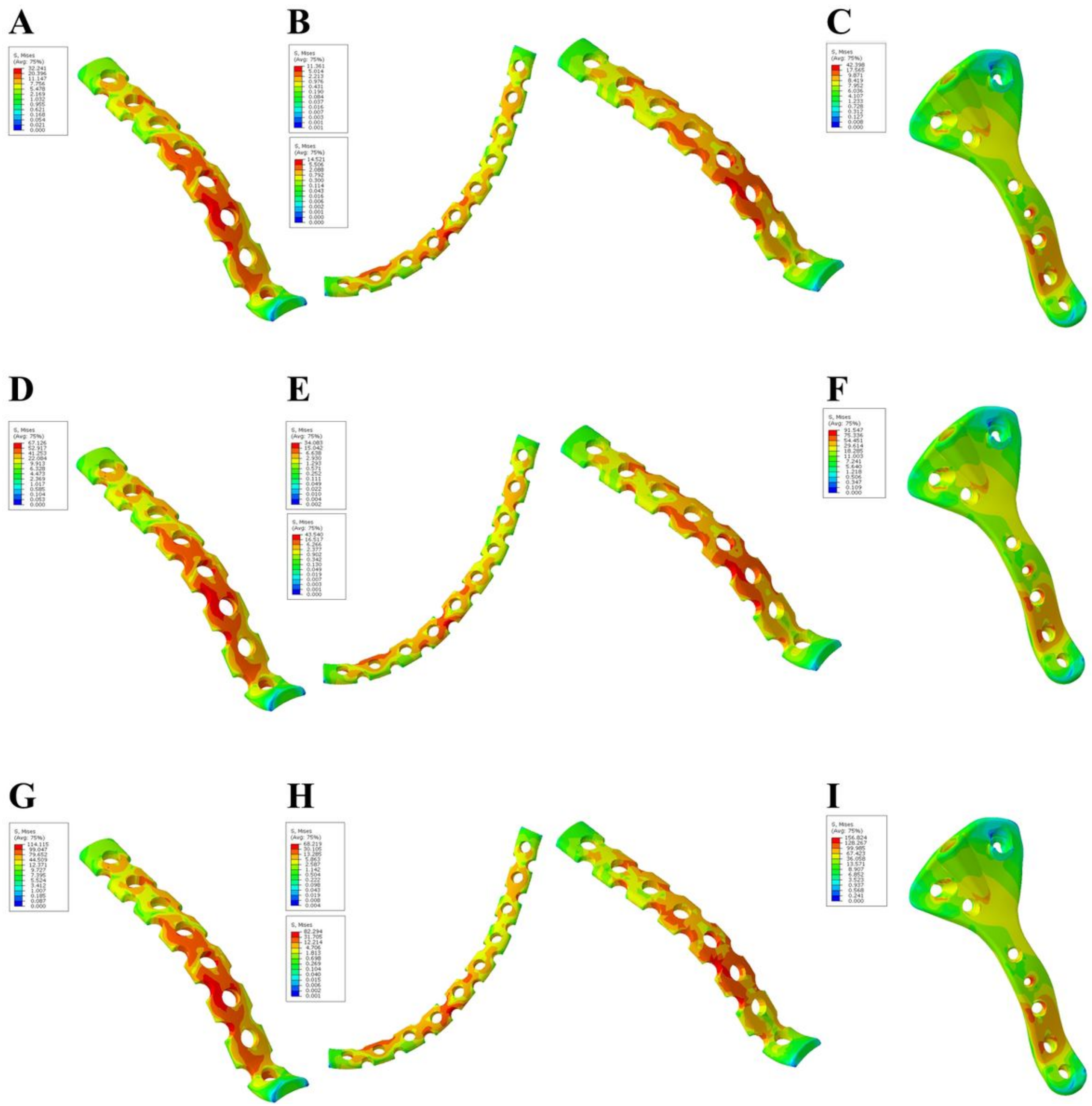

Figure 3

The stress distribution of plates among three groups. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, D, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, and 600N, respectively. The left and right of B, E, and H showed the anterior-column plate, and the posterior-column plate, respectively. The red areas in the plate experienced the maximum force, whereas the blue one experienced the minimum force.

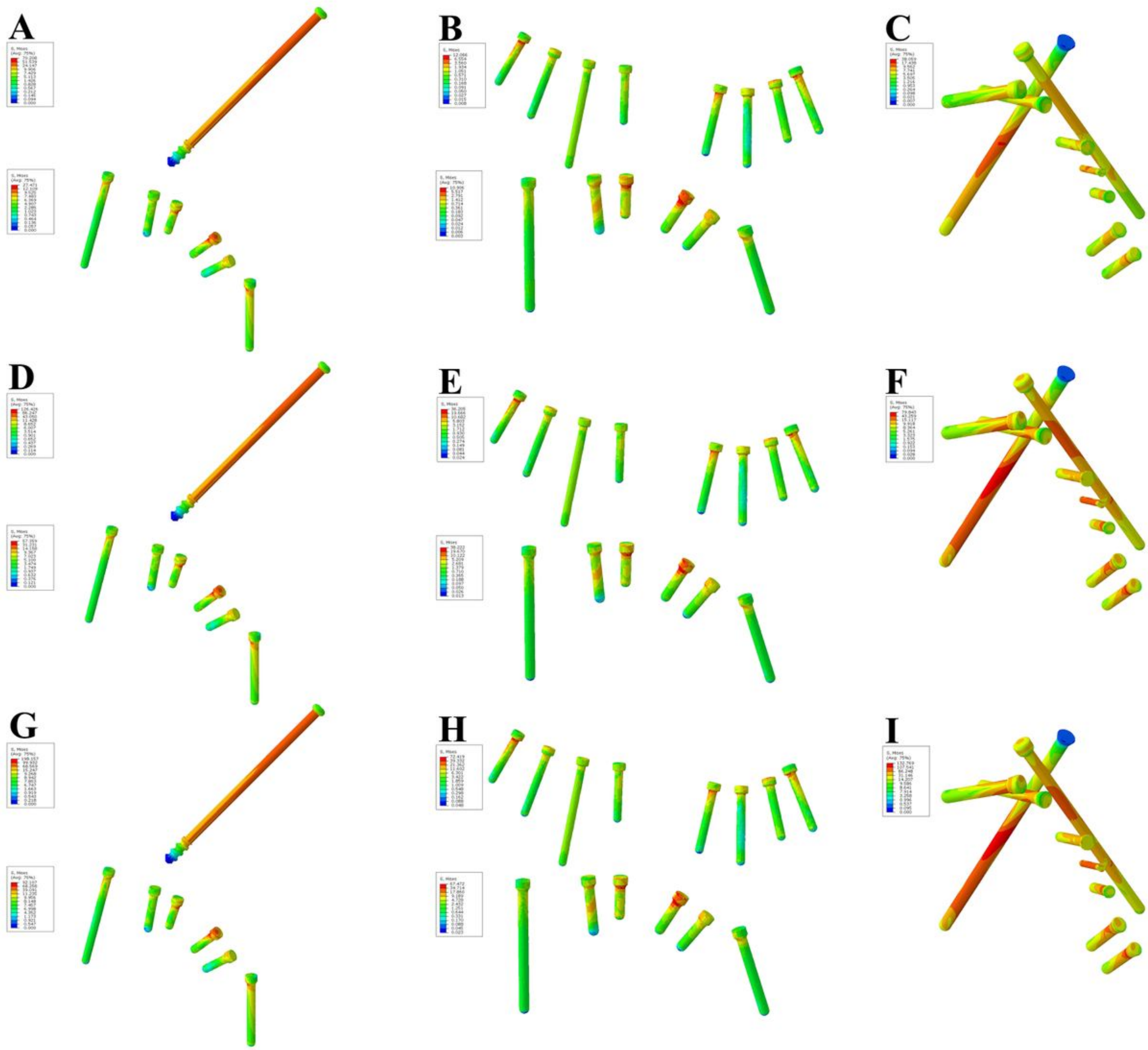

Figure 4

The stress distribution of screws among three groups. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, D, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, and 600N, respectively. The upper and lower of (A, D, G) and (B, E, H) showed the anterior-column screws, and the posterior-column scews, respectively. The red areas in the plate experienced the maximum force, whereas the blue one experienced the minimum force.

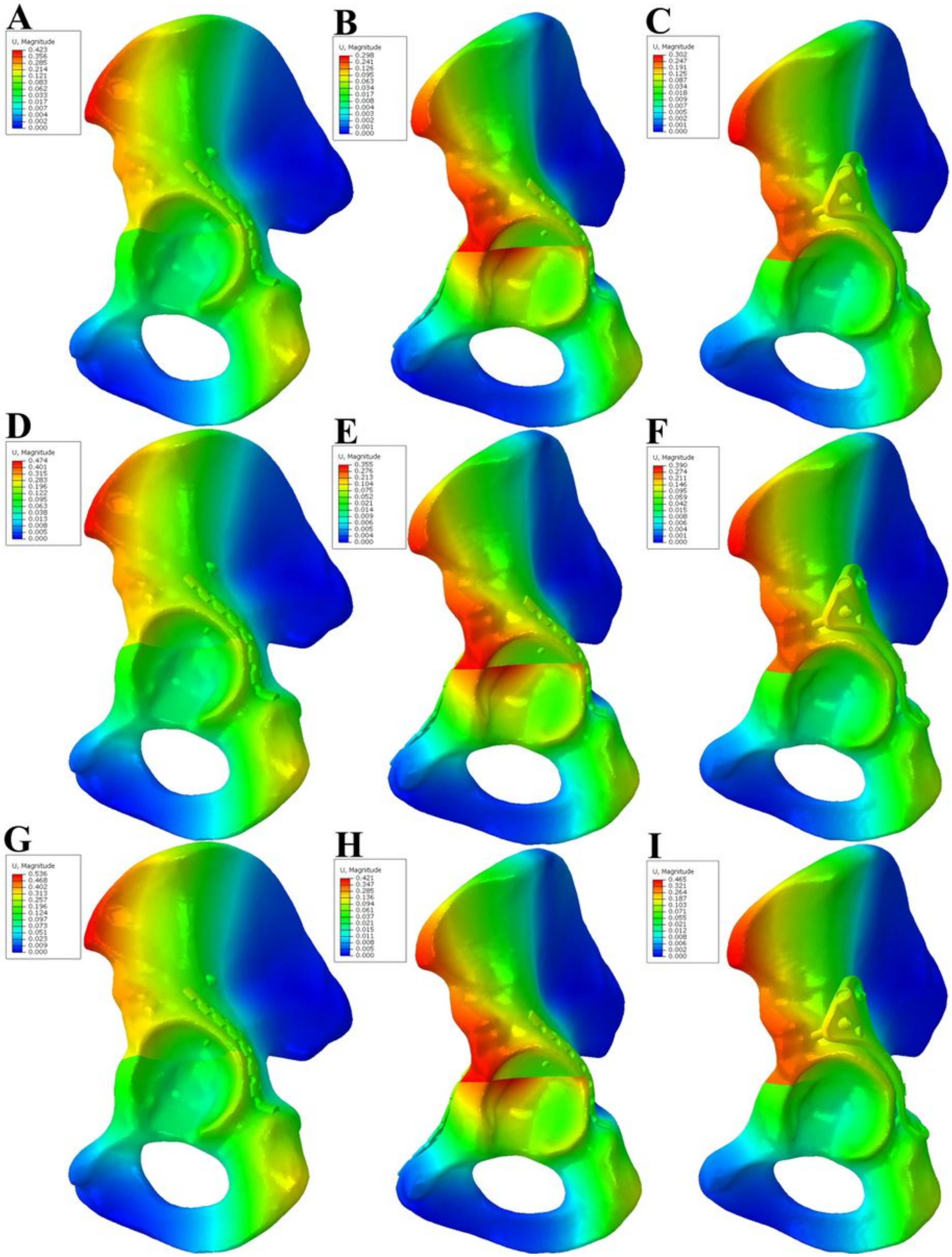

Figure 5

The maximum displacement of fracture fragment at two sites. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, D, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, and 600N, respectively. The red areas in the hip experienced the maximum deformation, whereas the blue area experienced the minimum deformation.