Orthopaedic Surgery

RESEARCH ARTICLE

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

Ming Li, PhD[1,2†], Junhao Deng, PhD[1,2,3†], Jiantao Li, PhD[1,2], Zhirui Li, PhD[1,2], Hao Zhang, PhD[1,2], Yanpeng Zhao, PhD[1,2], Licheng Zhang, PhD[1,2], Peifu Tang, PhD[1,2]

[1]*Department of Orthopaedics, Chinese PLA General Hospital,* [2]*National Clinical Research Center for Orthopedics, Sports Medicine and Rehabilitation and* [3]*Medical School of Chinese PLA, Beijing, China*

Objective: To improve the treatment of the acetabular transverse posterior wall fracture (ATPWF), a novel anatomical locking guidance plate (NALGP) was designed and compared with traditional fixations using finite element analysis.

Methods: The ATPWF model was constructed using the three-dimensional finite element model of the half pelvis via the Mimics software and three internal devices were used to fix this model: the posterior-column locking plate with anterior-column screws (PCLP), double-column locking plates (DCLP), and NALGP. Next, mesh division was conducted by solid 187 tetrahedral elements in the workbench software. After defining the boundary condition and material properties, each assembly model was loaded in an increasing manner with a downward vertical force of 200, 400, and 600 N, respectively. The loading force was directed at 45 degrees upward in the coronal plane and 25 degrees backward in the sagittal plane. Finally, the stress distribution and stress peak of plates and screws were measured and evaluated, and the displacement of fracture fragments under different loading force was assessed among the three groups.

Results: For stress distribution, it was found that the stress mainly acted on the posterior-column plate, especially concentrated at the middle and lower section of the plate in all three groups after fixation on the ATPWF. In addition, most stresses of screws appeared on the lag screws instead of the common screws. The common screws in the NALGP group experienced larger stresses under all loading force, while those in the DCLP group withstood less stresses compared to those in the PCLP group. For the displacement of fracture fragments, the NALGP group were found to have less fracture fragment displacements than the PCLP group, but had comparable results to DCLP at both the transverse fracture and the posterior wall fracture sites.

Conclusion: The newly-designed fixation device showed superiorities on fracture stabilization over PCLP, but had comparable stability to DCLP. This suggests that the DCLP might be unnecessary for treating ATPWF in some instances because it might cause bigger surgical trauma and blood loss.

Key words: Acetabular transverse posterior wall fracture; Finite element analysis; Fragment displacement; Novel anatomical locking guide plate; Stress distribution

Introduction

Associated acetabular fractures, a typical type of severe high-energy injury involving the pelvis and lower limbs, is a serious hazard for patients all over the world.[1] Over the years, the incidence of acetabular fractures has increased dramatically largely due to the rapid development of transportation,

Address for correspondence Licheng Zhang and Yanpeng Zhao, Department of Orthopaedics, Chinese PLA General Hospital, No. 28 Fuxin Road, Beijing 100853, China Email: zhanglcheng301@163.com and zhaoyanpeng301@163.com
[†]These authors should be considered co-first authors as they contributed equally to this paper.

Grant sources: This research was supported by the major project of military logistics research–Development, Application, and Clinical Evaluation of Equipment for War-Trauma Acetabular Fractures (No. AWS17J004).
Disclosure: There is no conflict of interest between authors.
Received 23 November 2021; accepted 26 June 2022

construction, and industry. The situation is compounded by the fact that the treatment for these fractures remains a big challenge for orthopedic surgeons because of the deep position and difficulties in decent exposure of the acetabulum.

According to the Letournel and Judet classification,[2] the acetabular transverse posterior wall fracture (ATPWF) is a classic and main type of associated acetabular fracture, which accounts for approximately 24%–32% of all acetabular fractures.[3] Similar to acetabular fracture, ATPWF is usually caused by high-energy violence and is involved in the acetabular articular surface, in which open reduction and firm internal fixation are required in most cases to achieve anatomic reduction as well as minimum complications.[2–4]

Although significant progress has been achieved in understanding the ATPWF, there is still no elaborate surgical treatment to date. Considering the involvement in both the anterior and posterior columns, the classic treatment for ATPWF in the past was posterior column reconstruction plate with anterior column lag screws and posterior wall lag screws,[5,6] which was reported to provide adequate biomechanical stability for ATPWF. However, given the complicated anatomical structure of the acetabulum and its deep anatomical position, the implantation of lag screws posed high risk of screws penetrating into the hip joint. Consequently, orthopedists have focused on exploring mechanisms of minimizing the surgical trauma, reducing the postoperative complications, and improving functional recovery, with the overall goal of developing new strategies for treating ATPWF.

In recent years, the novel therapeutic approaches and new internal fixation devices have been widely studied for the treatment of APTWF. Among them, the locking plate has become increasingly popular in the treatment of limb fractures. Considering that the locking plate has high angular stability and can be fixed unicortically, it has been gradually adopted in the fixation of ATPWF. For instance, Zhang *et al.*[7] used the locking plate to treat 27 patients with associated acetabular fractures and reported that it exhibited superiority in the angular stability of cancellous bone and lower incidence of screw penetration into the hip joint. Lan *et al.*[8] also found that the posterior column locking plate demonstrated similar biomechanical performance to the posterior reconstruction plate combined with anterior acetabular transverse screw and posterior wall tension screw fixation. Based on this, our research group designed a novel anatomical locking guidance plate (NALGP), which was totally based on the Chinese anatomical characteristics of the acetabulum, using cloud data collected from 171 computed tomography models.[9,10] In addition, two kinds of screws, anterior column screws and magic screws, were used alongside the NALGP. Notably, the magic screw, first proposed by Starr et al.,[11] is a type of screw which is used to fix fractures involving the posterior column of the acetabular quadrilateral. Therefore, by virtue of these two types of screws, NALGP could form an inverted Y-shape structure, thereby providing firm fixation for both columns simultaneously.

However, although comparative studies on the efficacy between our newly-designed locking plates and traditional locking plates have not been done, it is worth noting that there are only a handful of studies that have explored the impact of the locking plates in treating ATPWF. To this end, this study performed a finite element analysis of NALGP and two types of fixation that are currently commonly-used: the posterior-column locking plate with anterior-column screws (PCLP) and the double-column locking plates (DCLP). The aims of the study were: (i) to explore the stress distribution and stress peak of the novel NALGP in treating ATPWF; (ii) to compare the fracture fragments displacement after the internal fixations on ATPWF; and (iii) to determine whether NAGLP is conducive to the anatomical reduction and fixation for ATPWF.

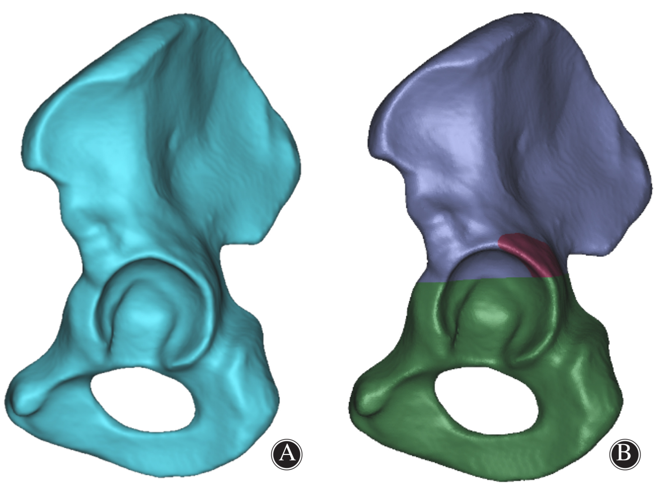

Fig. 1 The 3D acetabulum and the ATPWF model reconstruction. (A) Showed the normal acetabular model based on a 48-year-old volunteer CT data. (B) Showed the ATPWF model as well as its fracture lines. Different colors were used to distinguish bone after ATPWF.

Materials and Methods

Three-Dimensional Modeling of the ATPWF

This study was approved by the ethical committee of the Chinese PLA General hospital (No. S2020-114-04). Computed tomography scanning images, with a slice width of 0.5 mm, of Chinese volunteers were obtained from the hospital database and then used to create the three-dimensional finite element model of the half pelvis via the Mimics software 16.0 (Materialise Company, Leuven, Belgium) (Fig. 1A).

On the basis of the Judet and Letournel classification for acetabular fractures,[2,12] ATPWF was reconstructed as previously described.[13,14] Briefly, given that ATPWF includes two types of simple acetabular fractures: transverse fracture and posterior wall fracture, we respectively reconstructed these two fractures. For the transverse fracture, the fracture line started from the upper margin of iliopubic eminence to the top of the greater sciatic notch.[15] For the posterior wall fracture, the acetabular posterior wall was manually divided into three 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.[16] The ATPWF finite model was then successfully created (Figure 1B).

Geometric Modeling of the Three Types of Internal Fixation in the ATPWF

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

Computation and Loading Parameters

All definitions of boundary condition, material properties, and loading mode were defined as follows by the Abaqus 6.11 software (Dassault Systems, Velizy-Villacoublay, France):

1. The definition of boundary condition: the contact surfaces between the bone and internal fixation, or between devices were set as binding, whereas the contact surface between fracture fragments was defined as friction and its friction coefficient was 0.2.
2. Material properties: for model construction purpose, we assumed that all the cortical bones, cancellous bones, fixation plates, and screws were homogeneous and isotropic.
3. Loading mode: to facilitate the computations, we firmly fixed the pubic symphysis and sacroiliac joint. Considering that 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 200, 400, and 600 N, respectively. Notably, the loading force was 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 displacement of fracture fragments under different loading force was also assessed among the three groups.

Results

Stress Distribution on the Internal Fixations

After assessing the rigidity of both plates and screws, it was found that there were significant differences among the three groups. Figs 3 and 4 show the stress distributions of plates and screws. With regard to the distribution of the plate's stress, it was evident that stresses mainly act on the posterior-column plate, especially concentrated at the middle and lower section of the plate in all three fixations. For the distribution of screw's stress, most stresses appeared on the lag screws (and magic screws in the NALGP group) as opposed to the common screws. The common screws in the NALGP group experienced larger stresses, while those in the DCLP group withstood less stresses compared to screws in the PCLP group.

Magnitudes of the Maximum Von Mises Stress on the Internal Fixations

The magnitudes of the maximum Von Mises stress on the internal fixations in the three groups were tested under the increasing loading force of 200, 400, and 600 N. As for the plate in three groups, there was no significant difference in the posterior plate among the three groups when under the loading force of 200 N. When the loading force increased to 400 N, the posterior plate in the NALGP showed a little higher stress when compared with that in the PCLP and DCLP, and there was no significant difference between the plate in the PCLP and DCLP. When under the loading force of 600 N, the posterior plate in the NALGP had the highest stress, followed by the plate in the PCLP and DCLP. Notably, the anterior plate in the DCLP

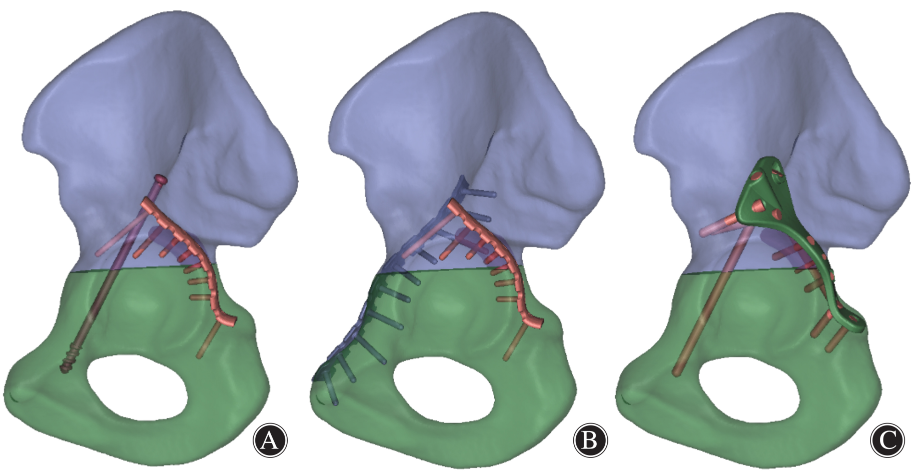

Fig. 2 The 3D modeling of three kinds of internal fixation on ATPWF. (A, B, and C) Showed the PCLP, DCLP, and NALGP, respectively.

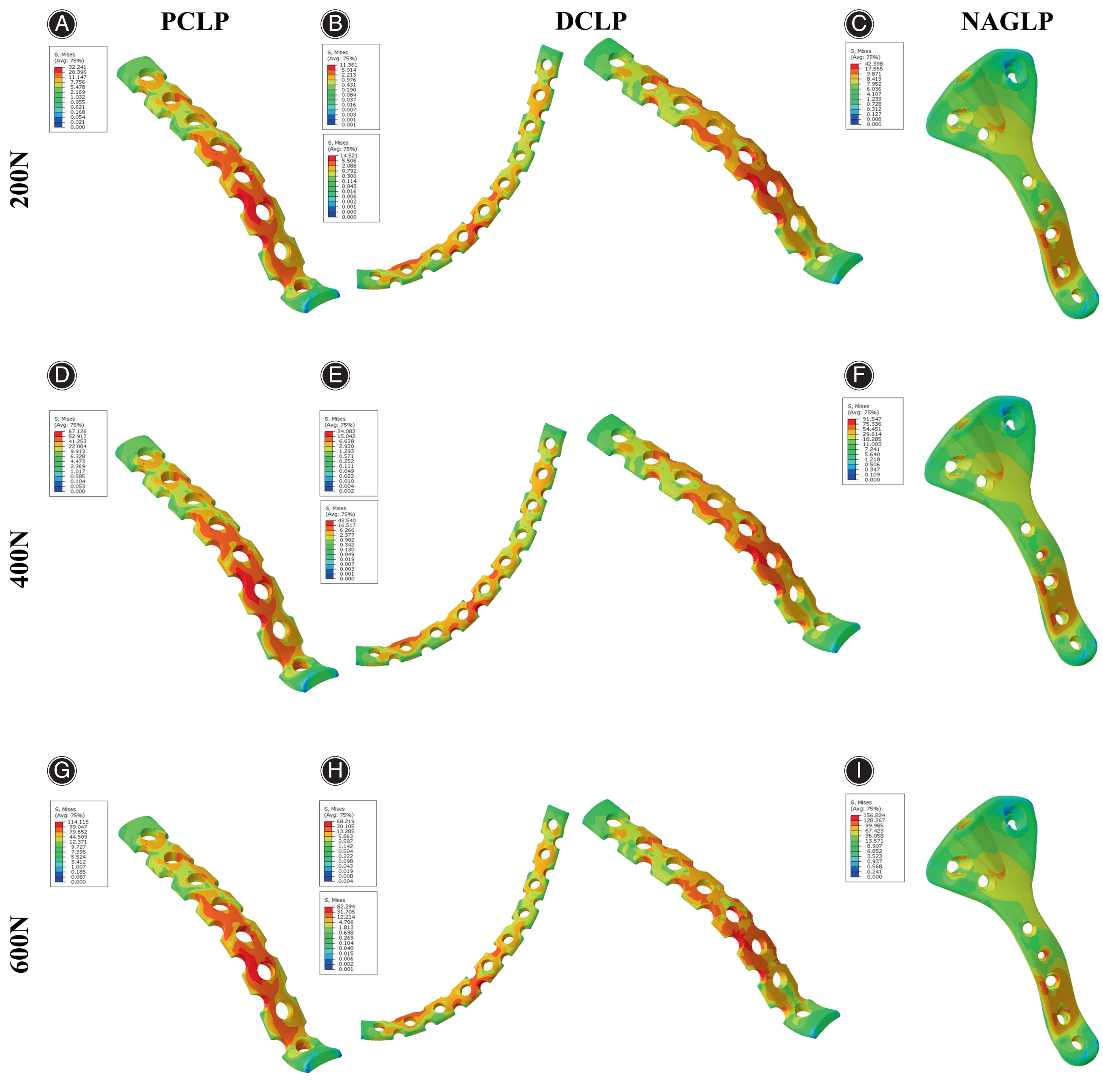

Fig. 3 The stress distribution of plates among three groups. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, F, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, 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.

showed the lowest Von Mises stress compared with the posterior plate in the three groups, be it under the loading force of 200, 400 or 600 N (Table 1).

Similarly, the magnitudes of the maximum Von Mises stress of anterior and posterior screws in three groups were under the increasing loading force of 200, 400, and 600 N. Under the loading force of 200, 400 or 600 N, the anterior screws in the PCLP showed the highest stress, followed by the posterior screws in the NALGP and PCLP, and both anterior and posterior screws in the DCLP. Particularly,

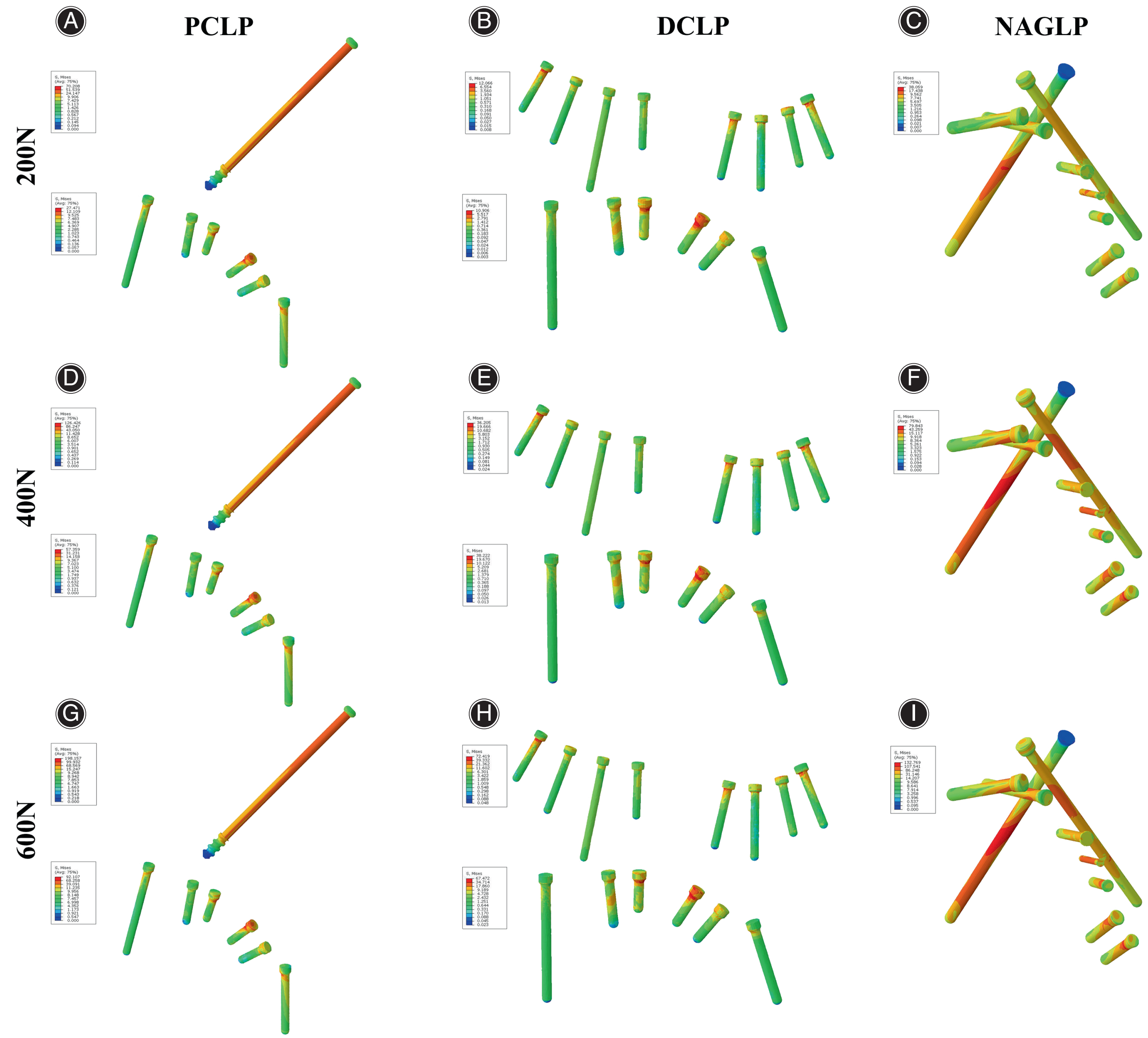

Fig. 4 The stress distribution of screws among three groups. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, F, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, 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.

when the loading force came to 600 N, the anterior and posterior screw in the PCLP had much higher stress than those in the DCLP and NALGP, and the screws in the DCLP still displayed the lowest stress (Table 2).

Taken together, the maximum Von Mises stress in the PCLP group was highest, followed by the NALGP and DCLP, regardless of plates or screws. And in the PCLP group, the higher stress was found in the anterior screws than in the posterior ones, whereas in the DCLP group, the similar stress was seen in the anterior and posterior screws.

Displacement of Fracture Fragments after Internal Fixations

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

TABLE 1 The Von Mises stress peak (MPa) of plate under different loading force among three groups

Model	200 N	400 N	600 N
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 (posterior plate)	42.398	91.547	156.824

DCLP, double-column locking plate; PCLP, posterior-column locking plate; NALGP, novel anatomical locking guidance plate.

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

	Stress (Mpa)		
Model	200 N	400 N	600 N
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

DCLP, double-column locking plate; PCLP, posterior-column locking plate; NALGP, novel anatomical locking guidance plate.

First, we measured the displacement under the loading force of 200, 400, and 600 N at the transverse fracture (TF) site. We found that there was no significant difference in the displacement at the TF site under the loading force of 200 N among three groups. However, as the loading force increased, PCLP group showed the much higher displacement, followed by the NALGP and DCLP group.

With regard to the posterior wall fracture (PWF) site, the trend of maximum displacement in the three groups was similar to that at the TF site. Specifically, there was little discrepancy in the displacement at the PWF site under the loading force of 200 N among three groups, and PCLP group had higher displacement with the growing loading force, followed by the NALGP and DCLP group. Of note, the maximum displacement in the NALGP group was more close to that in the DCLP group at the PWF site, signifying the better stability of NALGP at the PWF site compared to that at the TF site (Table 3 and Fig. 5).

Discussion

The ATPWF, a classic type of associated acetabular fractures and complex intra-articular fractures,[2,4] is usually caused by strong violence, which inevitably involves both anterior and posterior columns. 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. Several previous studies have explored various internal fixations, double-column plates, or plates combined with lag screws to treat the acetabular fractures.[17–20] However, the optimal treatment has been elusive. The present study aimed at simulating the mechanical behavior of the APTWF to compare two traditional fixations with our novel plate for fracture stabilization using a finite element analysis. Specifically, a series of increasing loading force (200, 400, and 600 N) were applied to better mimic the early partial or full weight-bearing loading.

Stress Distribution Characteristics of Internal Fixations

First, we evaluated the stress distribution and rigidity of plates and screws in the three groups. Results showed that the major stress concentrated on the middle and lower sections of the posterior plate and lag screws in all groups after 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 material break. For the rigidity of the plate, the NALGP and PCLP experienced larger stresses than the DCLP at all loading forces. With regard to the rigidity of screws, anterior column screws in the PCLP group and screws in the NALGP group showed the 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. However, the plate and screws in the NALGP and PCLP groups were more likely to be broken

TABLE 3 The maximum displacement (mm) of fracture under different loading force at two sites among three groups

	Transverse fracture			Posterior wall fracture		
Model	200 N	400 N	600 N	200 N	400 N	600 N
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

DCLP, double-column locking plate; PCLP, posterior-column locking plate; NALGP, novel anatomical locking guidance plate.

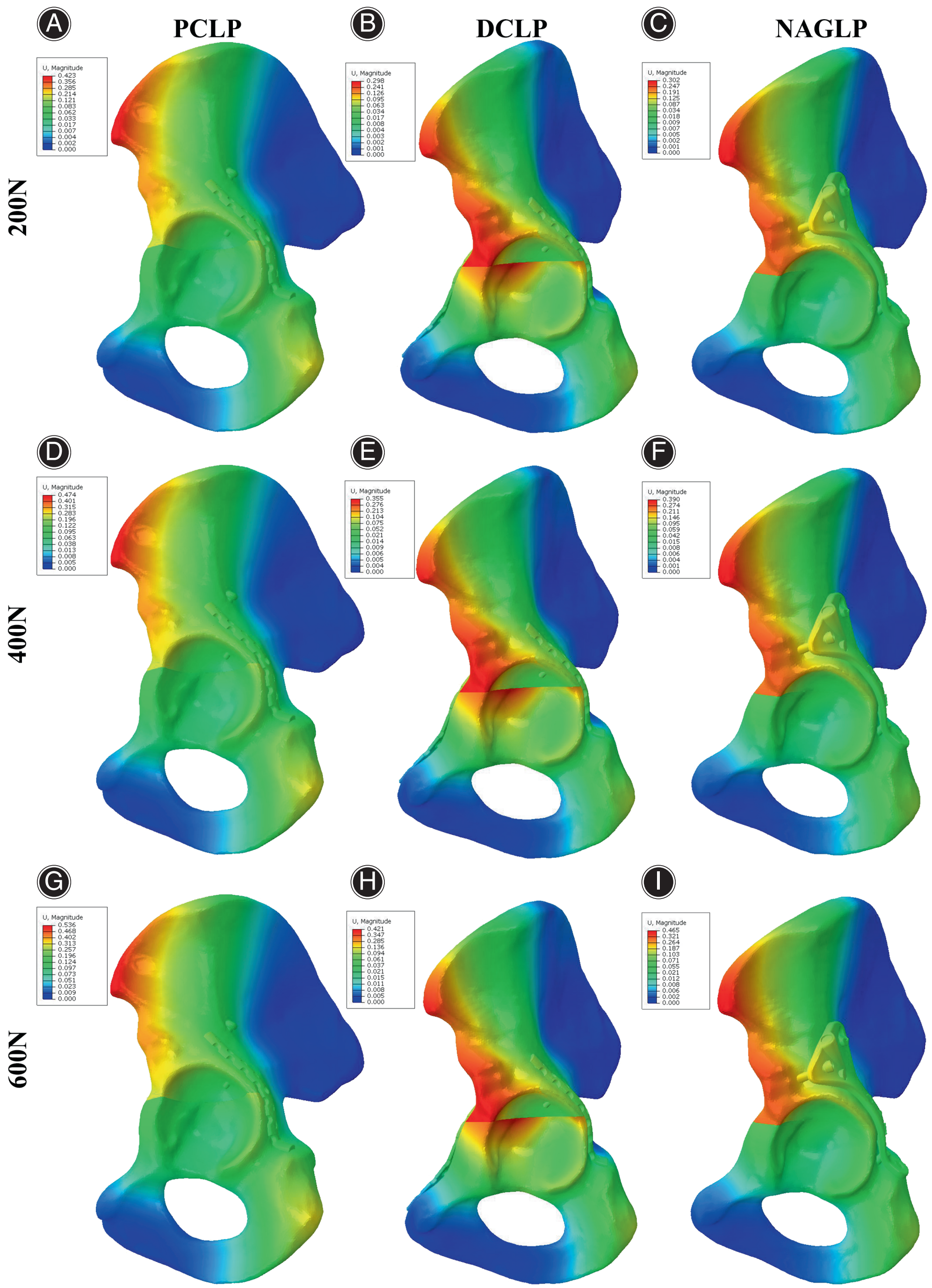

Fig. 5 The maximum displacement of fracture fragment at two sites. A, D, and G were representative of the PCLP group, B, E, and H were representative of the DCLP group, and C, F, and I were representative of the NALGP group. (A, B, C), (D, E, and F) and (G, H, and I) were under the loading force of 200N, 400N, and 600N, respectively. The red areas in the hip experienced the maximum deformation, whereas the blue area experienced the minimum deformation.

when the loading force increased, which put a higher demand on the rigidity of the NALGP and PCLP with its screws.

Displacement Features of Fracture Fragments among the Three Groups

The study then evaluated the maximum displacement at two sites: transverse fracture and PWF. Generally, the maximum displacement at the site of transverse fracture was larger than that at the site of PWF. It was found that there was no significant difference in the displacement of fracture fragment among the three groups under the loading force of 200 N. Nonetheless, as the loading force increased, the maximum displacement in the PCLP group was significantly larger than that in the other two groups, whether at the transverse fracture site or PWF site. In addition, the NALGP group demonstrated a slightly larger but comparable displacement to the DCLP group. Overall, it was evident that both NALGP and DCLP offered a better stability in the treatment of ATPWF.

Recommendations on Choosing Optimal Fixation for APTWF Among the Three Groups

Taken together, the results suggested that the DCLP group experienced the least stress and provided the firmest stability in treating the ATPWF, which was consistent with previous studies about the treatment of acetabular fractures.[21–24] However, as previously stated,[20,25] DCLP fixation would inevitably induce many complications, such as enlarged surgical trauma and heavy blood loss. These shortcomings could be overcome by the single-column plate fixation. Moreover, it was evident that the PCLP not only showed larger stress concentration, but also worse biomechanical stability, which was in line with the findings of a previous study.[26] It should be noted that our newly-designed plate had the advantage of single plate fixation and also showed promising results in the displacement after fixation, and thus it might emerge as an ideal device for treating ATPWF.

In addition to the above-mentioned advantages, our self-designed plate, the inverted Y-shaped NALGP, could match the inverted Y-shaped structure acetabulum very well because its structure strictly conformed to the anatomical morphology of the acetabulum. Based on the acetabulum morphology of Chinese patients, this novel plate was anatomically pre-contoured to match the acetabular surface, thereby significantly minimizing the surgical time and trauma. Furthermore, the NALGP has guide holes in the plate, which facilitate implantation of the anterior-column screws and magic screws, thereby ensuring a safer and easier surgical process. Collectively, this direct comparison between two traditional fixations and our novel plate further confirms its superiority in fracture stabilization.

Limitations

This study also had some limitations. First, all results were based on the computer programs rather than the real environment, thus, some unknown information was lost. Notably, a large clinical trial is in progress to further determine its superiorities and inferiorities. Second, we found that the NALGP group experienced the highest stress concentration. Therefore, although the NALGP is rigid enough to avoid the plate breakage, future studies should address how to reduce the relatively-high stress concentration.

Conclusion

In conclusion, the major findings of this finite element analysis were: (i) the stress mainly acted on the middle and lower sections of the posterior plate and lag screws in all three groups after fixation on the ATPWF; and (ii) although NALGP demonstrated higher stress on the plate and screws, it also displayed a better stability to PCLP and was comparable to DCLP in terms of the maximum displacement. These findings suggest that NALGP should be taken into consideration in treating ATPWF.

Acknowledgment

We thank the instructive suggestions in data analysis from the National Clinical Research Center for Orthopedics, Sports Medicine, and Rehabilitation.

Ethical Approval and Consent to Participate

Although there was no experiment on humans, all procedures strictly abided by the regulations of the Ethics Committee of the Chinese PLA General Hospital. Notably, written informed consent was offered to the CT data contributor. All results were submitted to and approved by the Ethics Committee of the Chinese PLA General Hospital.

Author Contributions

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

References

1. Yang Y, Sun J, Xiang Z. The short- and mid-term follow-up of single-column fixation in transverse and posterior wall acetabular fractures. Orthop Surg. 2022; 14(1):65–72.
2. Letournel E. Acetabulum fractures: classification and management. J Orthop Trauma. 2019;33:S1–2.
3. Giordano V, Pecegueiro do Amaral N, Franklin CE, Pallottino A, EAR P, Giordano M. Functional outcome after operative treatment of displaced fractures of the acetabulum: a 12-month to 5-year follow-up investigation. Eur J Trauma Emerg Surg. 2007;33(5):520–7.
4. Judet R, Judet J, Letournel E. Fractures of the acetabulum: classification and surgical approaches for open reduction. Preliminary report. J Bone Joint Surg Am. 1964;46:1615–46.
5. Wu XB, Chen W, Zhang Q, Su Y, Guo M, Qin D, et al. The study of plate-screw fixation in the Posterior Wall of acetabulum using computed tomography images. J Trauma. 2010;69(2):423–31.
6. Bogdan Y, Dwivedi S, Tornetta P, et al. A surgical approach algorithm for transverse posterior wall fractures aids in reduction quality. Clin Orthop Relat Res. 2014;472(11):3338–44.
7. Zhang QTH, Wang Q, et al. The application of locking-compression reconstruction plate in the surgical treatment of acetabular fractures. Chin J Joint Surg. 2008;2(2):14–7.
8. Lan HZZ, Jia C, Fu J. Biomechanical comparison of acetabular contact characteristics after acetabular transverse posterior wall fractures treated with three kinds of internal fixation. Chin J Tiss Eng Res. 2018;22(27):4375–9.
9. Xu M, Zhang LH, Zhang YZ, Zhang LC, He CQ, Wang Y, et al. Custom-made locked plating for acetabular fracture: a pilot study in 24 consecutive cases. Orthopedics. 2014;37(7):e660–70.
10. Xu M, Zhang LH, Zhang YZ, He CQ, Zhang LC, Wang Y, et al. Development of site-specific locking plates for acetabular fractures. Orthopedics. 2013;36(5): e593–600.
11. Starr AJ, Borer DS, Reinert CM. Technical aspects of limited open reduction and percutaneous screw fixation of fractures of the acetabulum. Oper Tech Orthop. 2001;11(3):218–26.
12. Beaule PE, Dorey FJ, Matta JM. Letournel classification for acetabular fractures. Assessment of interobserver and intraobserver reliability. J Bone Joint Surg Am. 2003;85(9):1704–9.

13. Hu T, Xu H, Jiang C, Ren G, An Z. Treatment of transverse with or without posterior wall fractures of acetabulum using a modified Smith-Petersen combined with Kocher-Langenbeck approach. Med Sci Monit. 2017;23:2765–74.
14. Gansslen A, Hildebrand F, Kretek C. Transverse + posterior wall fractures of the acetabulum: epidemiology, operative management and long-term results. Acta Chir Orthop Traumatol Cech. 2013;80(1):27–33.
15. Malkani AL, Voor MJ, Rennirt G, Helfet D, Pedersen D, Brown T. Increased peak contact stress after incongruent reduction of transverse acetabular fractures: a cadaveric model. J Trauma. 2001;51(4):704–9.
16. Olson SA, Bay BK, Pollak AN, Sharkey NA, Lee T. The effect of variable size posterior wall acetabular fractures on contact characteristics of the hip joint. J Orthop Trauma. 1996;10(6):395–402.
17. Kistler BJ, Smithson IR, Cooper SA, Cox JL, Nayak AN, Santoni BG, et al. Are quadrilateral surface buttress plates comparable to traditional forms of transverse acetabular fracture fixation? Clin Orthop Relat Res. 2014;472(11):3353–61.
18. Shazar N, Brumback RJ, Novak VP, Belkoff SM. Biomechanical evaluation of transverse acetabular fracture fixation. Clin Orthop Relat Res. 1998;352:215–22.
19. Moktar J, Machin A, Bougherara H, Schemitsch EH, Zdero R. Biomechanical analysis of transverse acetabular fracture fixation in the elderly via the posterior versus the anterior approach with and without a total hip arthroplasty. Proc Inst Mech Eng H. 2020;234(9):966–74.
20. Giordano V, do Amaral NP, Pallottino A, Pires e Albuquerque R, Franklin CE, Labronici PJ. Operative treatment of transverse acetabular fractures: is it really necessary to fix both columns? Int J Med Sci. 2009;6(4): 192–9.
21. Butterwick D, Papp S, Gofton W, Liew A, Beaule PE. Acetabular fractures in the elderly: evaluation and management. J Bone Joint Surg Am. 2015;97(9): 758–68.
22. Tian S, Chen Y, Yin Y, Zhang R, Hou Z, Zhang Y. Morphological characteristics of posterior wall fragments associated with acetabular both-column fracture. Sci Rep. 2019;9(1):20164.
23. Su K, Liu S, Wu T, Yin Y, Zhang R, Li S, et al. Posterior column acetabular fracture fixation using a W-shaped angular plate: a biomechanical analysis. PLoS One. 2017;12(11):e0187886.
24. Tosounidis TH, Giannoudis PV. What is new in acetabular fracture fixation? Injury. 2015;46(11):2089–92.
25. Fan Y, Lei J, Zhu F, Li Z, Chen W, Liu X. Biomechanical analysis of the fixation system for T-shaped acetabular fracture. Comput Math Methods Med. 2015;2015:370631.
26. Cahueque M, Martinez M, Cobar A, Bregni M. Early reduction of acetabular fractures decreases the risk of post-traumatic hip osteoarthritis? J Clin Orthop Trauma. 2017;8(4):320–6.