Comparison of Fragment Removal Versus Internal Fixation for Treatment of Pipkin I Femoral Head Fractures: A Finite Element Analysis

Dong Dong¹, Yingnan Li², Dong Zhu³, Mingyang Yu⁴, Guishan Gu³

¹Department of Radiology, The First Hospital, Jilin University, Changchun, Jilin, China
²Department of Orthopedics, The Fourth Hospital, Jilin University, Changchun, Jilin, China
³Department of Orthopedics, The First Hospital, Jilin University, Changchun, Jilin, China
⁴Department of Orthopedics, Zhongshan Hospital, Dalian University, Dalian, Liaoning, China

Fragment removal and internal fixation are the principle treatments for Pipkin type I femoral head fractures. The aim of this study was to compare, using a finite-element method, changes in stress on the femoral head after 2 different operation types. A three-dimensional (3D) finite-element model of a Pipkin type I femoral head fracture was generated with MIMICS and ABAQUS software. A 3D numerical screw model was reconstructed based on data from BIOFIX and using SOLIDWORKS software. The screw was implanted in the fragment and femoral head to reconstruct the implantation. Stress changes on the femoral head after removal of the fragment and internal fixation were investigated. Mean stresses along 13 points were 16.94 ± 16.79 MPa in the fragment removal group and 14.17 ± 14.08 MPa in the internal fixation group ($P < 0.05$). Random tests indicated that the mean stresses along 50 randomly determined points were 25.41 ± 12.12 MPa in the fragment removal group and 19.45 ± 14.62 MPa in the internal fixation group ($P < 0.05$). Compared with internal fixation, fragment removal led to greater stress that was more concentrated in the femoral head.

Key words: Femoral head fracture – Finite element – Three-dimensional – Pipkin
Femoral head fracture is a severe, rare hip injury. These fractures occur in approximately 10% of traumatic posterior dislocations of the hip joint.\(^1,2\) The classification originally proposed by Pipkin in 1957 is the most commonly used classification system. It categorizes femoral head fractures into 4 types increasing in severity.\(^3\) Pipkin type I fractures occur inferior to the fovea in the non-weight-bearing portion of the femoral head. Because this is a rare injury, patient treatment and outcome data are limited. The aims of treatment are to reposition the fracture and to restore articular congruency. Often, these aims are accomplished nonsurgically by limiting weight-bearing activities and by physical therapy. Outcomes are good if the fracture is displaced less than 2 mm after reduction and no intra-articular fragments remain. In fractures that require surgery, there is controversy regarding whether to perform femoral head fragment excision or internal fixation.\(^4\)

Epstein et al suggest that all traumatic dislocations of the hip require surgery to remove fragments.\(^1\) In contrast, studies conducted by Hougaard and Thomsen indicate that internal fixation of fragments leads to better outcomes compared with fragment excision.\(^2\) More recent studies have shown that internal fragment fixation could achieve positive results and early mobility. Studies comparing conservative treatments, fragment resection, and internal fixation with limited cases have shown controversial results.\(^5-7\) Hence, there is no universally accepted treatment strategy.

Finite element (FE) methods can perform complex biomechanical analyses better than traditional methods.\(^8-10\) This technique has gained in popularity because mechanical properties of the body can be modeled under different experimental conditions. In this study, we built a three-dimensional (3D) FE model of a Pipkin type I femoral head fracture. Our aim was to compare stresses on the femoral head after fragment excision and internal fixation. Results of these analyses may provide biomechanical information that surgeons can use to make treatment decisions. To our knowledge, this is the first biomechanical report to compare the 2 treatments for Pipkin type I fractures.

Materials and Methods

**Reconstruction of the FE models**

Numerical data of 3D FE models of the hip were based on the computed tomography (CT) images of a 28-year-old healthy male volunteer. He was scanned by a Siemens Dual-Source CT scanner (Siemens Medical Solutions, Berlin, Germany). A slice thickness of 0.5 mm was used with an image matrix of 512 × 512 pixels. Images were obtained from the acetabulum to the upper part of the femur. Sequential cross-sectional images of the human femoral neck were extracted from the CT data by MIMICS software (Materialise, Leuven, Belgium). Three-dimensional images of the femoral head were reconstructed after meshing was performed by ABAQUS (Simulia, Johnstown, Rhode Island).

**Reconstruction of a 3D numerical model of a Pipkin type I femoral head fracture**

A 3D sphere model with a diameter of 10 cm was reconstructed after meshing by using MIMICS software. A 3D sphere was used to cut the 3D femoral head to mimic a Pipkin type I femoral head fracture. Fracture anatomy was strictly consistent with the definition provided by Pipkin in 1957. We performed Boolean calculations at the overlapping

---

**Fig. 1** Reconstruction of a 3D numerical model of a Pipkin type I femoral head fracture. (A) A 3D sphere was used to cut the 3D femoral head based on a Pipkin type I femoral head. (B) Intersection was set at the fragment. (C) Lateral view of the fragment. (D) Portion remaining distal to the fracture.
parts of the two 3D models. The intersection set was fragmented as illustrated in Fig. 1.

**Reconstruction of a 3D numerical screw model**

A 3D numerical screw model was reconstructed using SolidWorks software (Dassault Systemes, Waltham, Massachusetts) and data from the absorbable self-tapping BIOFIX screw (Bionx, Espoo, Finland) (Fig. 2). The 3D numerical screw model was identical in size to the actual screw. The external diameter was 3.5 mm, and the length was 45 mm. The 3D numerical screw model was transferred in stereolithography format to MIMICS and was remeshed.

**Reconstruction of implantation**

Implanted points of the screws were determined based on the Campbell principle. The implantation points on the fragment were acquired after Boolean calculations between the fragment and the screw. Another calculation was done between the remaining femoral head and the screw to determine the implantation point on the femoral head, which was based on the size of the screw. The screw was implanted manually (Fig. 3).

All models and material properties were transferred to ABAQUS in input format. Every planar mesh was transformed to a 3D mesh by using MESH software (Altair Inc, Troy, Michigan), and every model was a tetrahedral element. A total of 880,377 elements for the femur, 895,022 elements for the remaining femur, 17,007 elements for the fragment, and 10,471 elements for the screw were used.

**Material properties and interfaces**

Material properties of the bone were provided by MIMICS. Bone density was calculated based on the CT Hounsfield (HU) units and the equation: \( \rho \text{ (kg/mm}^3) = 1.067 \times \text{HU} + 131 \). The relationship between elastic constants and density was described by \( E \text{ (MPa)} = 0.09882 \rho^{1.56} \). The Poisson ratio was assumed to be 0.3. Material properties of the screw were based on the screw instructions from BIOFIX. The elastic modulus was 8 to 15 GPa. We used the mean elastic modulus (12 GPa) and assumed that the Poisson ratio was 0.3.

In the ABAQUS system, the contact force was not set automatically because there was an interface between 2 elements in space. The bone-to-bone friction coefficient was set at 0.3, and the bone-to-screw friction coefficient was infinity, which assumed successful surgical placement.

---

**Fig. 2** Reconstruction of a 3D numerical screw model.

**Fig. 3** Reconstruction of implantation. (A) Implanted points of the screws on the fragment. (B) Implanted points of the screws on the remaining femoral head. (C) Implantation of screws on the fragment. (D) Implantation of the fragment on the femoral head.
The load on the femoral head in 1 gait cycle was calculated as 4 times the body weight. The joint reaction forces of an adult male weighing 700 N in 1 gait cycle were 0.616 (X), −2.8 (Y), and 0.717 (Z), which totaled 2.872 kN. Because the femoral head was observed in the study, freedom of motion for the distal part of the femur was set to zero. Stress changes on the femoral head after 2 treatments were analyzed by ABAQUS. Stress distribution maps were created by the software automatically.

**Statistical analysis**

All data were analyzed with SAS statistical software, Version 9.0 (SAS Inc, Cary, North Carolina). The significance level of $P$ was set to 0.05. Data were expressed as the mean ± SD. Between-group differences were analyzed by $t$ test. Random points were compared by the Kruskal-Wallis test. This study was approved by the Institutional Review Board of the First Hospital of Jilin University.

**Results**

Stress distribution maps were created to model the stresses experienced by the femoral head after fragment excision (Fig. 4) or internal fixation (Fig. 5). Colors indicative of high stress (i.e., gray, red, and orange) were more evident on the femoral head in the fragment-excision group compared with the internal-fixation group, suggesting that stress on the femoral head was higher in the fragment-excision group. Colors indicative of high stress in the fragment-excision group were most prominent along the fracture line.

To test stresses along the fracture line, 13 fixed points were selected every 15 degrees in a semicircular pattern from 3 to 9 o’clock, and stress calculations were performed for each point. Differences between the models of fragment removal and internal fixation were compared. Table 1 shows the SD, 50th percentile, and range (maximum and minimum) values of the stress in the 2 groups. The mean stress values in the fragment-removal and internal-fixation groups were 16.94 and 14.17 MPa, respectively ($P = 0.027$). Stress tests were also performed along the fracture line at 50 distinct points, which were selected randomly from a cloud distribution stress diagram. Results were analyzed by the Kruskal-Wallis test. Table 2 reports the mean, SD, 50th percentile, and range (maximum and minimum) values of the stress in the 2 groups. The mean values of stress in the fragment-removal and internal-fixation groups were 16.94 and 14.17 MPa, respectively ($P = 0.027$).

**Table 1** Mises stress after loading on fixed points

| Group               | N  | Mean (MPa) | SD (MPa) | 50th Percentile (MPa) | Minimum (MPa) | Maximum (MPa) |
|---------------------|----|------------|----------|-----------------------|---------------|---------------|
| Fragment removal    | 13 | 16.94      | 16.79    | 9.02                  | 2.36          | 46.81         |
| Internal fixation   | 13 | 14.17      | 14.08    | 7.60                  | 1.45          | 39.89         |

*Paired $t$ test, $P = 0.0266$; the difference is statistically significant, $P < 0.05$ (SAS software).
internal-fixation groups were 25.41 and 19.45 MPa, respectively ($P = 0.002$).

**Discussion**

Patient outcomes after femoral head injuries need to be improved. Considerable controversy exists regarding treatment protocols for these injuries. There is insufficient data to support treatment by fragment excision versus internal fixation.11–15 Most orthopedic surgeons treat only a few cases in their professional careers, and data on the best treatment could improve patient outcomes. Fractures of the femoral head are of interest because they are frequently accompanied by additional complications, such as avascular necrosis and posttraumatic osteoarthritis.5,16

FE is a convenient and effective method for biomechanical research under normal and pathologic conditions.17,18 Mechanical behaviors of biological systems can be understood more accurately and sensitively with modeling owing to precise control over the experimental design.19 There are many FE models of femoral head injuries and biomechanical studies on femoral load transfer and distribution.

In this study, we compared 2 different operative treatments for Pipkin type I femoral head fractures using FE analyses. Three-dimensional models were built, and stress changes were detected under defined loads. To our knowledge, this is the first FE model of a Pipkin type I fracture and the first treatment comparison study using biomechanical methods. Stress differences between the 2 treatment groups occurred along the fracture line. Stress distribution maps showed that stresses were greater and more concentrated in the fragment-removal group compared with the internal-fixation group. For type I femoral head fractures, stresses on the femoral head were distributed relatively uniformly in the internal-fixation group, which may help maintain correct anatomic structures. In contrast, the concentration of stress on the femoral head in the fragment-removal group may increase the risk of severe complications, including femoral head necrosis and traumatic arthritis.20–23

Our biomechanical results are consistent with other clinical studies,4,5 which achieved positive results after internal fixation. Prokop et al5 treated 9 patients with Pipkin type I fractures, using biodegradable polylactide pins for internal fixation. They obtained positive results and few adverse reactions 54.2 months after the procedures. Henle et al4 treated 12 patients with digastric trochanteric osteotomies and removed fragments accurately under direct visual inspection. Patients were monitored for 2 to 96 months, and the outcomes were favorable.4 Retrospective analyses of the 12 patients showed long-term good or excellent results in 10 patients (83.3%). Although other factors, such as age, sex, and time between injury and treatment, may influence the outcomes of femoral head fracture, our findings suggest that the different stresses and stress distributions may be one biomechanical explanation for the different results of the treatment approaches.

There are some limitations of our model. First, the size of the fragment, shape, site of fracture, and location of the pins were not considered. Second, individual differences in collodiaphyseal angles or anteversion angles were not considered. Also, we did not include the effects of articular cartilage, which may influence the FE results. In addition, the material characteristics of the cortical and cancellate bone were not considered, and the interface of the bone and the screw was set to infinity. We used 4 times the body weight as the force of hip joint loading. This approximation was made according to the results of Bergmann et al24 and Davy et al,25 which show that hip joint loading during normal walking is 1 to 4 times the body weight. In addition, we considered Johnston and Smidt’s results, which reveal that median peak forces during walking are approximately 4 times the body weight.26 We assumed that the direction of the force was vertical and did not consider horizontal compressive forces.27,28

Finally, the numerical model was constructed based on data from 1 normal hip. Individual

| Table 2 | S Mises stress after loading on random points* |
|---------|---------------------------------------------|
| Group   | N   | Mean (MPa) | SD (MPa) | 50th Percentile (MPa) | Minimum (MPa) | Maximum (MPa) |
|---------|-----|------------|----------|-----------------------|---------------|---------------|
| Fragment removal | 50  | 25.41      | 12.12    | 23.24                 | 5.86          | 63.82         |
| Internal fixation  | 50  | 19.45      | 14.62    | 14.64                 | 3.00          | 62.71         |

*Kruskal-Wallis test, $P = 0.0024$; the difference is statistically significant, $P < 0.05$ (SAS software).
differences in sex, age, ethnicity, underlying pathologies, and activity level were not considered. For computational biomechanics, a very important restriction is the ability to model a population, with most studies using either a single or small set of bone models and extrapolating their findings. In this study, the sample size is too small to perform meaningful statistical analysis on the results obtained. Hence, these results need to be validated in a larger subject population size, which we plan to do next.

Taken together, this is the first time that FE modeling has been used to study the stress changes with different treatments for Pipkin I fractures. Our model data indicate that stresses on the femoral head are different after treatment by fragment removal or internal fixation. The stress was greater and more concentrated in the femoral head after fragment removal. This finding may improve our biomechanical understanding of the treatments and may help surgeons in making appropriate treatment plans for this type of injury. Further experimental and clinical studies should be undertaken to confirm the results generated by the FE model.

Acknowledgments

The authors declare that they have no conflicts of interest concerning this article.

References

1. Epstein HC, Wiss DA, Cozen L. Posterior fracture dislocation of the hip with fractures of the femoral head. Clin Orthop Relat Res 1985;201):9–17
2. Hougaard K, Thomsen PB. Traumatic posterior fracture-dislocation of the hip with fracture of the femoral head or neck, or both. J Bone Joint Surg Am 1988;70(2):233–239
3. Pipkin G. Treatment of grade IV fracture-dislocation of the hip. J Bone Joint Surg Am 1957;39-A(5):1027–1042 passim
4. Henle P, Kloen P, Siebenrock KA. Femoral head injuries: which treatment strategy can be recommended? Injury 2007;38(4):478–488
5. Prokop A, Helling HJ, Hahn U, Udomkaewkanjana C, Rehm KE. Biodegradable implants for Pipkin fractures. Clin Orthop Relat Res 2005;432:226–233
6. Kloen P, Siebenrock K, Raaymakers E, Marti R, Ganz R. Femoral head fractures revisited. Eur J Trauma 2002;28(4):221–233
7. Marchetti ME, Steinberg GG, Coumas JM. Intermediate-term experience of Pipkin fracture-dislocations of the hip. J Orthop Trauma 1996;10(7):455–461
8. Bagby GW, Janes JM. The effect of compression on the rate of fracture healing using a special plate. Am J Surg 1958;95(5):761–771
9. Pioletti DP, Rakotomanana LR. Can the increase of bone mineral density following bisphosphonates treatments be explained by biomechanical considerations? Clin Biomech (Bristol, Avon) 2004;19(2):170–174
10. Wei HW, Sun SS, Jao SH, Yeh CR, Cheng CK. The influence of mechanical properties of subchondral plate, femoral head and neck on dynamic stress distribution of the articular cartilage. Med Eng Phys 2005;27(4):295–304
11. Tripathy SK, Sen RK, Goyal T. Conservative versus surgical management of Pipkin type I fractures associated with posterior dislocation of the hip: a randomised controlled trial. Int Orthop 2011;35(12):1907–1908
12. Tonetti J, Ruatti S, Lafontan V, Loubignac F, Chiron P, Sari-Ali H, et al. Is femoral head fracture-dislocation management improveable: a retrospective study in 110 cases. Orthop Traumatol Surg Res 2010;96(6):623–631
13. Giannoudis PV, Kontakis G, Christoforakis Z, Akula M, Tosounidis T, Koutras C. Management, complications and clinical results of femoral head fractures. Injury 2009;40(12):1245–1251
14. Droll KP, Broekhuysse H, O’Brien P. Fracture of the femoral head. J Am Acad Orthop Surg 2007;15(12):716–727
15. Chen ZW, Lin B, Zhai WL, Guo ZM, Liang Z, Zheng JP, et al. Conservative versus surgical management of Pipkin type I fractures associated with posterior dislocation of the hip: a randomised controlled trial. Int Orthop 2011;35(12):1077–1081
16. McMurtry IA, Quaile A. Closed reduction of the traumatically dislocated hip: a new technique. Injury 2001;32(2):162–164
17. Gupta S, New AM, Taylor M. Bone remodelling inside a cemented resurfaced femoral head. Clin Biomech (Bristol, Avon) 2006;21(6):594–602
18. Radcliffe IA, Taylor M. Investigation into the effect of varus-valgus orientation on load transfer in the resurfaced femoral head: a multi-femur finite element analysis. Clin Biomech (Bristol, Avon) 2007;22(7):780–786
19. Ozan F, Yıldız H, Bora OA, Pekedis M, Ay Coşkun G, Göre O. The effect of head trauma on fracture healing: biomechanical testing and finite element analysis. Acta Orthop Traumatol Turc 2010;44(4):313–321
20. Wieding J, Souffrant R, Fritsche A, Mittelmeier W, Bader R. Finite element analysis of osteosynthesis screw fixation in the bone stock: an appropriate method for automatic screw modelling. PLoS One 2012;7(3):e33776
21. Lutz A, Nackenhorst U, von Lewinski G, Windhagen H, Floerkemeier T. Numerical studies on alternative therapies for femoral head necrosis: a finite element approach and clinical experience. Biomech Model Mechanobiol 2011;10(5):627–640
22. Eberle S, Bauer C, Gerber C, von Oldenburg G, Augat P. The stability of a hip fracture determines the fatigue of an intramedullary nail. *Proc Inst Mech Eng H* 2010; 224(4):577–584

23. Affolter C, Weisse B, Stutz A, Köbel S, Terrasi GP. Optimization of the stress distribution in ceramic femoral heads by means of finite element methods. *Proc Inst Mech Eng H* 2009; 223(2):237–248

24. Bergmann G, Graichen F, Rohlmann A. Hip joint loading during walking and running, measured in two patients. *J Biomech* 1993; 26(8):969–990

25. Davy DT, Kotzar GM, Brown RH, Heiple KG, Goldberg VM, Heiple KG Jr, et al. Telemetric force measurements across the hip after total arthroplasty. *J Bone Joint Surg Am* 1988; 70(1):45–50

26. Johnston RC, Smidt GL. Measurement of hip-joint motion during walking: evaluation of an electrogoniometric method. *J Bone Joint Surg Am* 1969; 51(6):1082–1094

27. Polgár K, Gill HS, Viceconti M, Murray DW, O’Connor JJ. Strain distribution within the human femur due to physiological and simplified loading: finite element analysis using the muscle standardized femur model. *Proc Inst Mech Eng* 2003; 217(3):173–189

28. Rudman KE, Aspden RM, Meakin JR. Compression or tension? The stress distribution in the proximal femur. *Biomed Eng Online* 2006; 5:12

29. Bryan R, Nair PB, Taylor M. Influence of femur size and morphology on load transfer in the resurfaced femoral head: a large scale, multi-subject finite element study. *J Biomech* 2012; 45(11):1952–1958