

## Finite Element Analysis for the Treatment of Proximal Femoral Fracture

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**Abstract:** Dynamic hip screw and gamma nail have been widely used to treat the patients with proximal femoral fractures, but clinical failures of those implants are still to be found. This study developed three-dimensional finite element models to investigate the biomechanical performances of the implants. Two kinds of commercially available implants (dynamic hip screw and gamma nail) and one newly designed implant (double screw nail) under three kinds of the proximal femoral fractures (neck fracture, subtrochanteric fracture, and subtrochanteric fracture with gap) were evaluated. Double screw nail showed better biomechanical performances than dynamic hip screw and gamma nail. Two commercially available implants might provide good biomechanical performances if their designs were modified by using the suggestions of the reports. The finite element models developed in this study could provide the selection information of those implants to surgeons and offer the improved implant designs to engineers.

**Keywords:** finite element analysis, femur, double screw nail, dynamic hip screw, gamma nail.

### 1 Introduction

Hip fracture, which includes fracture of the proximal femur and pelvic ring, is among the most common injuries necessitating operative fixation [Lauritzen (1996); Parker (2006); Pearse, Redfern, Sinha, and Edge (2003); Willig, Luukinen, and

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Jalovaara (2003)]. This kind of fractures is usually caused by direct trauma to the bone which includes: blows, collisions, falls, and severe twists. An operation should be done as soon as possible to insert the implant on the fracture bone to make it become stable and avoid complications during the fracture healing.

Dynamic hip screw (DHS) and gamma nail (GN) are the most commonly used devices to treat the proximal femur fractures. DHS is a metal plate with locking screws system, and it is designed to provide strong and stable internal fixation for a variety of intertrochanteric fracture, subtrochanteric fracture, and basal neck fracture. The major advantage of DHS is that sliding of the lag screw in the barrel of the side plate facilitates fracture impaction and healing and prevents lag screw cut-out [Buchholz, Heckman, and Court-Brown (2006); Lorch, Geller, and Nielson (2004); Schipper, Steyerberg, and Castelein (2004)]. However, excessive sliding of the lag screw may result in limb shortening, lag screw cut-out, and significant functional impairment [Lin (2006)]. GN, which is an intramedullary device, has been used to treat proximal femoral fracture. It provides a better biomechanical performance with a shorter nail length to reduce the risk of implant failure and offers an effective control of lag screw sliding to prevent femoral shortening and hip deformity. However, GN has the disadvantages of intraoperative splintering due to the bulky proximal part and postoperative femoral shaft fracture via the nail tip due to stress concentration [Pervez, and Parker (2001)].

A newly designed intramedullary device, double screw nail (DSN), was presented [Lin (2006)]. This specially designed nail has several advantages: a smaller diameter on proximal nail to avoid intraoperative splintering, and a longer nail length to avoid postoperative femoral fracture. However, there are still few clinical reports investigating this kind of implant [Al-yassari, Langstaff, Jones, and Al-Lami (2002); Krastman, Welvaart, Breugem, and van Vugt (2004); Lin (2006)]. Moreover, some studies were focused on the investigation of DHS and GN [Butt, Krikler, Nafie, and Ali (1995); Haynes, Poll, Miles, and Weston (1997); C J Wang, Yettram, Yao, and Procter (1998)]. However, there is no study to investigate the biomechanical performances of those three kinds of the implants on different kind of fractures. In addition, computer modeling and simulations have been applied to reduce the experimental efforts [Daian, Taube, Torgovnikov, Daian, and Shramkov (2009); Panthi, Ramakrishnan, Pathak, and Chouhan (2007); L. Wang, Zhang, Gao, and Wang (2007)]. Therefore, the purpose of this study was to evaluate the biomechanical performances of two kinds of commercially available implants (DHS and GN) and a newly designed implant (DSN) on different type of proximal femoral fractures by using finite element analyses. The strength of the implants, the stability of the fracture fixations, and the risk of the lag screw cut-out were evaluated and discussed in this study.

## 2 Materials and Methods

### 2.1 Femur models with fracture

Femur model, which is an improvement of standardized femur model, is constructed by Marco Viceconti in 1996. Because the original femur model only consists of cortical bone tissue, this original femur model was modified and re-constructed by using SolidWorks 2008 (SolidWorks Corporation, Concord, MA, USA). The modified femur model consisted of the cortical bone and the cancellous bone. Moreover, in order to simulate the real condition of the treatment, three types of the proximal femoral fractures were considered including the neck fracture, the subtrochanteric fracture, and the subtrochanteric fracture with gap (Figure 1).

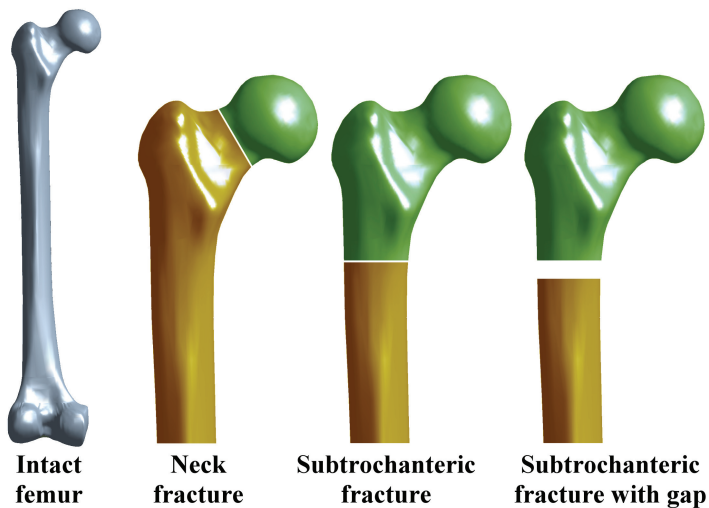


Figure 1: Three kinds of the proximal femoral fractures

### 2.2 Proximal femoral implants

DHS was manufactured by *Smith & Nephew* (Memphis, Tennessee, USA), and it consisted of three major components including plate, lag screw, and distal locking screws (Figure 2A). The plate was firstly implanted into the femur, and most of the plate's body was located outside the bone. Then, the lag screw was inserted through the center of femoral head. Finally, four distal locking screws were tightened to fix the fractured femur and the plate. GN was manufactured by *Stryker* (Miami, Florida, USA), and it consisted of four major parts including nail, lag screw, distal screws, and pin (Figure 2B). The nail was firstly inserted into the proximal femoral

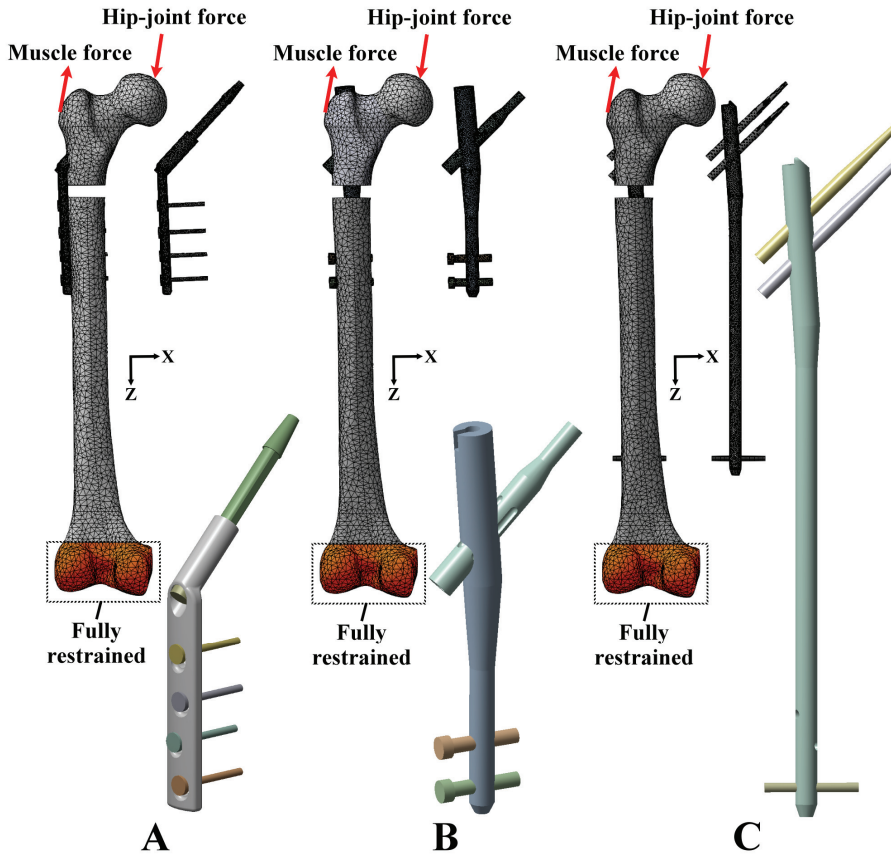


Figure 2: Proximal femoral implants and the boundary and loading conditions of the finite element models: (A) Dynamic hip screw; (B) Gamma nail; (C) Double screw nail

canal. Then, the lag screw was implanted through the center of femoral head. Finally, two distal locking screws were tightened to fix the fractured femur and the nail, and the pin was inserted into the proximal nail to lock the lag screw. DSN was manufactured by UOC (Taipei, Taiwan, ROC), and it consisted of three major components including nail, lag screws, and distal locking screws (Figure 2C). Firstly, the nail was inserted into the femoral canal. Then, two lag screws were implanted through the center of femoral head. Finally, two distal locking screws were tightened to fix the fractured femur and the nail. Those implants were also created with use of SolidWorks 2008.

### 2.3 Finite element analyses

Three-dimensional finite element models were developed and analyzed by using ANSYS 10 Workbench (ANSYS, Inc., Canonsburg, PA, USA). For the material properties of the implants, all of the implants were made from 316L stainless steel. The elastic modulus and the Poisson's ratio of those implants were 230 GPa and 0.3, respectively. For the material properties of the femur, the linear elastic isotropic material was assumed in this study. The elastic modulus was 17 GPa for the cortical bone and 0.36 GPa for the cancellous bone. The Poisson's ratio of the bones was 0.3. The fractured femurs with the implants were free-meshed with use of 10-node tetrahedral elements (SOLID 187). The interfaces between the fractured femur and the implant were assumed to be contact, and the contact elements which included CONTA 174 and TARGE 170 were used. In the loading and boundary conditions, the hip-joint force and the Glutius Medius muscle force were considered [Stolk, Verdonschot, and Huiskes (2000)], and the magnitude of those forces was referred by Wang et al. [C J Wang, Yettram, Yao, and Procter (1998)] (Table 1) (Figure 2). The convergent study was conducted by adjusting the element size on the regions which the highest von Mises stress was occurred.

Table 1: The hip-joint force and the Glutius Medius muscle force applied in the finite element analyses

	Hip-joint force	Glutius Medius muscle force
X-direction (N)	-320	310
Y-direction (N)	-170	0
Z-direction (N)	2850	-120

### 2.4 Biomechanical performances of implants

In the postprocessing, three kinds of the outcomes would be used to evaluate their biomechanical performances including the maximal von Mises stress of the implant, the maximal deflection of the femur, and the strain energy density of the proximal femur. The maximal von Mises stress of the implant was used to assess the mechanical strength of the implant. The implant with the smaller von Mises stress represented the greater mechanical strength. The maximal deflection of the femur was used to evaluate the stability of fracture fixation. The femur with the smaller deflection represented the higher fixation stability. The strain energy density of the proximal femur was used to assess the risk of the lag screw cut-out. The proximal femur with the smaller strain energy density represented that the proximal femur is hard to be cut-out.

### 3 Results

In this study, the total element number ranged from 100,000 to 230,000, the total node number ranged from 160,000 to 360,000, and the computational time ranged from 8 to 36 hours. The convergent analysis for each implant with different fracture was done, and the variation of the results between two sequent finite element models was within 5%.

#### 3.1 Strength of implants

The strength of the implants could be used to assess the risk of the implant failure. In this study, the implants with a lowest von Mises stress were expected and required. The maximal von Mises stress of the implants under different kind of the fractures was showed (Figure 3). The maximal von Mises stress was occurred on the distal locking screw for DHS, and that was found on the distal nail hole for GN. Besides, the maximal von Mises stress of DSN was occurred on either the lag screw or the nail hole. For the neck fracture and the subtrochanteric fracture with gap, DSN had a lowest von Mises stress as compared with DHS and GN. For the subtrochanteric fracture, DSN had a smaller von Mises stress than DHS, and it was similar to GN (Figure 4A). Moreover, the subtrochanteric fracture with gap would result a highest von Mises stress of the implants.

#### 3.2 Stability of fracture fixations

A good stability of the fracture fixations meant that the fracture site would not be distracted and the fracture healing could be accelerated. In this study, a smallest maximal deflection of the femur was also expected and required. The maximal deflection of the femur for all of the situations was found at the tip of proximal femoral head. For the neck fracture and the subtrochanteric fracture, there was no significant difference between the implants. However, DHS had a weakest stability of the fracture fixations for the subtrochanteric fracture with gap as compared with GN and DSN (Figure 4B).

#### 3.3 Risk of lag screw cut-out

Except for the strength of implants and the stability of fracture fixations, the risk of the lag screw cut-out was another important issue. This performance could be used to assess the risk of a second fracture caused by the lag screws. In this study, a highest strain energy density represented that the proximal femur is easy to be cut-out. For all of the fractures, DSN had a lowest strain energy density as compared with DHS and GN (Figure 4C). In addition, the subtrochanteric fracture with gap might lead to easy to be cut-out for three kinds of the implants.

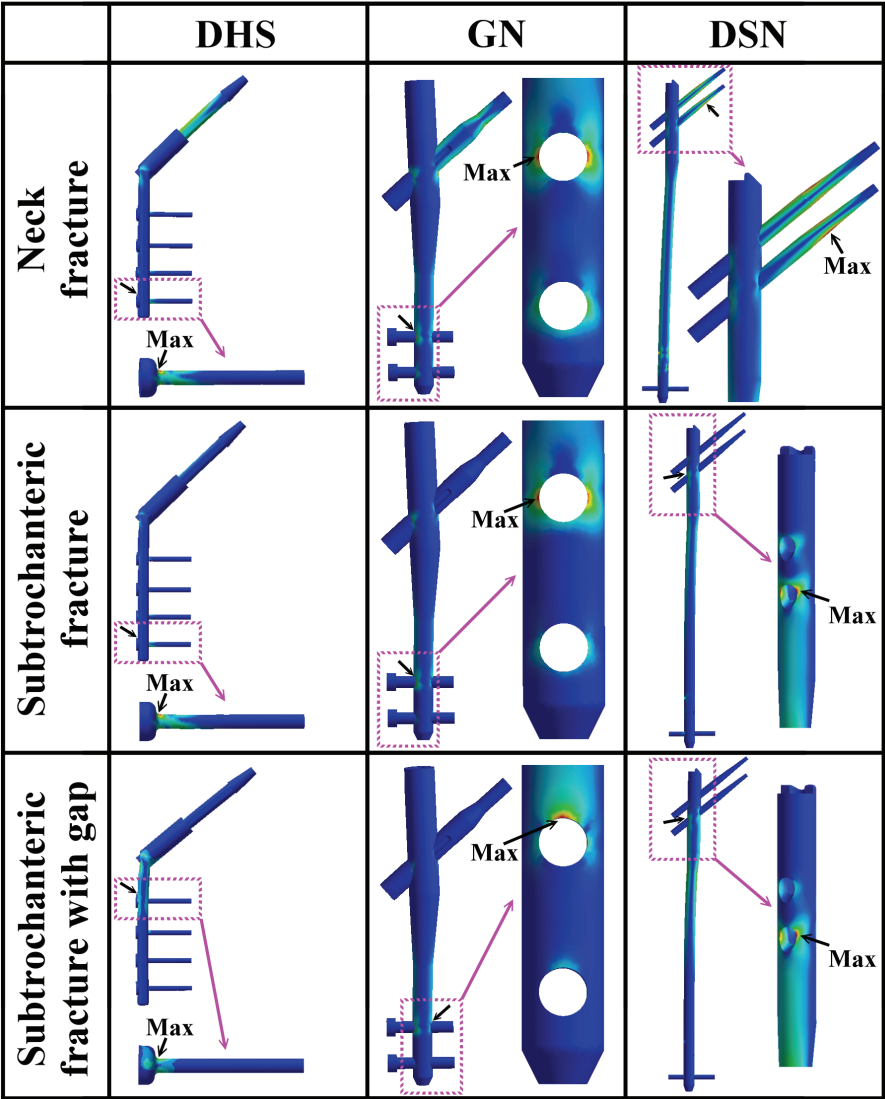


Figure 3: The von Mises stress distribution of the implants

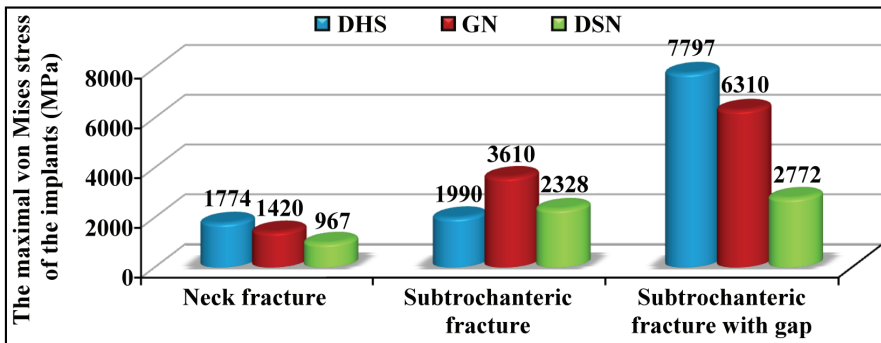
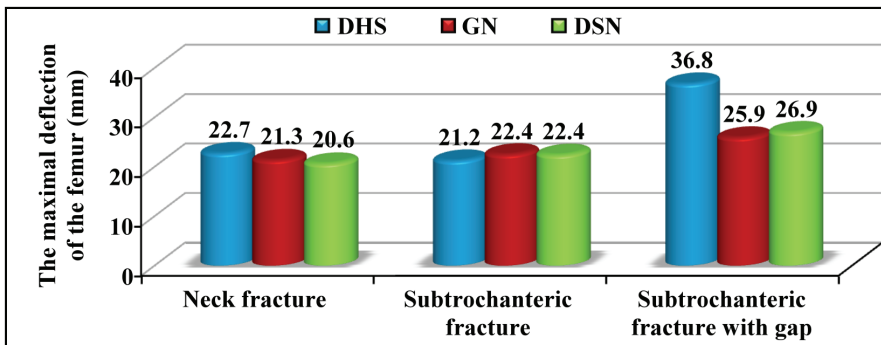
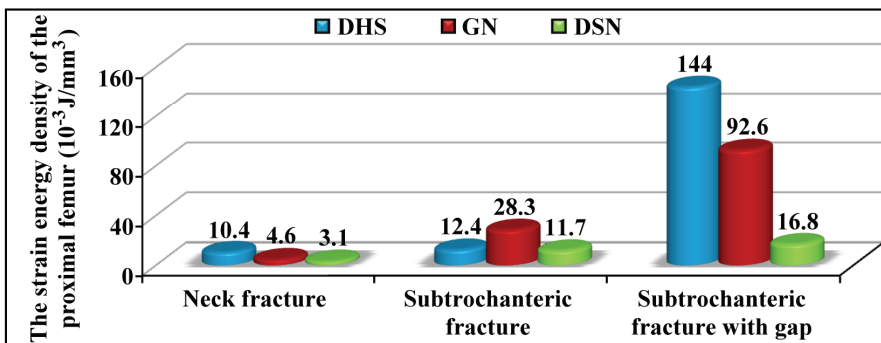
**A****B****C**

Figure 4: The results of the finite element analyses for different kind of the implants with different kind of the fractures: (A) The von Mises stress; (B) The maximal deflection; (C) The strain energy density



#### **4 Discussions and Conclusions**

The strength of the implants was closely related to the risk of the implant failure. Therefore, decreasing the maximal stress of the implant could decrease the risk of the implant failure and increase the life of the implants. In this study, DHS exhibited the highest maximal von Mises stress for the femur with the neck fracture and the subtrochanteric fracture with gap. This implied that DHS had a higher risk of the implant failure. In order to decrease the risk of the implant failure, the improved DHS design was proposed by the reports. Jewell et al. presented DHS with locking plate design to improve the implant strength. They concluded that DHS with locking plate design would reduce the risk of DHS failure [Jewell, Gheduzzi, Mitchell, and Miles (2008)]. Moreover, Parker suggested that using DHS with a long side plate would decrease its maximal stress [Parker (2006)]. The reason was that the contact area between the side plate and the femur was increased. This implied that DHS with a long side plate would share the body weight. Similarly, GN also exhibited the highest maximal von Mises stress for the femur with the subtrochanteric fracture. The improved GN design was also presented by the report. Sehat et al. reported long gamma nail (LGN) to increase the contact area between the nail and the femoral canal [Sehat, Baker, Pattison, Price, Harries, and Chesser (2005)]. This kind of the improvement would reduce the maximal stress of the implant and increase its mechanical strength. DSN, which had the advantages of a longer nail length and a smaller diameter on the proximal nail, was presented in this study. The results showed that DSN had a lower maximal von Mises stress for the treatment of the proximal femoral fractures.

An implant with a highest stability of fracture fixations could protect the fracture sites and accelerate the fracture healing. In this study, the significant difference between three kinds of the implants was not found for the neck fracture and the subtrochanteric fracture based on the results of the fixation stability. This meant that any kind of the implants could be used to treat the femur with the neck fracture or the subtrochanteric fracture. However, DHS was not a good choice to treat the femur with the subtrochanteric fracture with gap as compared with GN and DSN. This result was similar to Parker's report [Parker (2006)]. This report concluded that there has been a greater use of intramedullary fixations for the fracture near the subtrochanteric area of the femur. In addition, an intramedullary fixation with a longer nail length could provide more mechanical support for the treatment of the proximal femoral fractures. Therefore, DSN could be selected to treat different kind of the proximal femoral fractures based on the results of the fixation stability. Fortunately, DHS and GN would provide a good stability of the fracture fixations if the designs of those implants were modified. For the modifications of DHS, Parker suggested that increasing the length of the side plate would obtain greater

fixation stability [Parker (2006)]. Jewell et al. found that DHS with a locking plate design would provide a stronger stability between the implants and the fractured femur [Jewell, Gheduzzi, Mitchell, and Miles (2008)]. For the modifications of GN, Sehat et al. concluded that LGN could provide sufficiently rigidity for immediate full weight bearing [Sehat, Baker, Pattison, Price, Harries, and Chesser (2005)]. Moreover, LGN could also eliminate the postoperative femoral shaft fracture via the nail tip due to stress concentration.

The lag screw cut-out from the proximal femur frequently occurred to the patients with osteoporosis. This failure mode would cause severe complications. Therefore, the risk of the lag screw cut-out should be as small as possible [Schipper, Steyerberg, and Castelein (2004)]. According to the results of the past studies, they reported that the lag screw cut-out was found from the patients with DHS as well as GN [Al-yassari, Langstaff, Jones, and Al-Lami (2002); Said, Farouk, El-Sayed, and Said (2006); Sehat, Baker, Pattison, Price, Harries, and Chesser (2005); C J Wang, Brown, Yettram, and Procter (2000)]. In addition, other studies even reported that the most common mode of failure of a DHS is cut out of the lag screw from the femoral head [Jewell, Gheduzzi, Mitchell, and Miles (2008)]. In this study, GN had a lower risk of the lag screw cut-out than DHS in the neck fracture. This result was the same as Haynes's report [Haynes, P oll, Miles, and Weston (1997)]. They used a cadaveric experiment to evaluate the risk of the lag screw cut-out. Their results showed that GN appeared to reduce the tendency to the lag screw cut-out as compared with DHS. Actually, DSN revealed a lowest risk of the lag screw cut-out for three kinds of the proximal femoral fractures in this study.

An excellent implant, which was used to treat the femur with the proximal femoral fracture, should consist of a higher strength of the implant, a greater stability of the fracture fixation, and a lower risk of the lag screw cut-out. After the evaluation of those implants, DSN had all of the necessary performances, but DHS and GN lacked some of the performances. Fortunately, those necessary performances could be retrieved by changing their designs. For instance, DHS with a longer side plate and a locking plate design would increase not only the strength but also the fixation stability. GN with a longer nail length would obtain the same improvements. Although three kinds of the implants had different advantages and disadvantages, a newly developed DSN, an improved DHS, and an improved GN might satisfy the requirements of the patients. Therefore, surgeons could select one of the implants to treat their patients with the proximal femoral fractures.

This study had following limitations. First, the screw thread for all of the lag screws and the locking screws was not considered, and the smooth rods were used in this study. This might underestimate the stress of the implants and the risk of the lag screw cut-out. Second, although the femur with a real geometry was developed and

considered, the material properties of the femur were assumed to be homogeneous, linear elastic, and isotropic. This might affect the applicability of the finite element models. Third, the material properties of the implants were also assumed to be homogeneous, linear elastic, and isotropic. This would lead to an unreasonable stress of the implants. Fourth, each kind of the proximal femoral fractures was perfectly cut by a flat surface. However, the fracture surface of the patient was irregular and complicated. This assumption might overestimate the contact force between two fragments of the fractured femur.

In conclusions, a newly developed DSN revealed a higher strength of the implants, a greater stability of the fracture fixation, and a lower risk of the lag screw cut-out than DHS and GN. DHS and GN might provide good biomechanical performances if their designs were modified and improved by using the suggestions of the reports. The finite element models developed in this study could provide the selection information of those implants to surgeons and offer the improved implant designs to engineers.

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