Int J Clin Exp Med 2017;10(5):7867-7874
www.ijcem.com /ISSN:1940-5901/IJCEM0047129

Original Article

Biomechanical comparison of dynamic hip screw and Gamma nail for the treatment of unstable trochanteric fractures: a finite element study

Xiaowei Huang[2*], Baoqing Yu[1*], Yong Gu[2], Zexiang Li[1]

[1]*Department of Orthopedic Surgery, Shanghai Pudong Hospital; Fudan University Pudong Medical Center, 2800 Gongwei Road, Pudong, Shanghai 201399, China;* [2]*Department of Orthopedic Surgery, The First Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215000, China.* [*]*Equal contributors.*

Received December 22, 2016; Accepted February 7, 2017; Epub May 15, 2017; Published May 30, 2017

Abstract: Objectives: To investigate the biomechanical behavior of the femur with two different implant configurations, namely dynamic hip screw and Gamma nail, in the treatment of two types of unstable intertrochanteric femoral fracture. Methods: A 3D finite element model of the intact proximal femur was constructed, from which two types of fractured models (AO classification 31-A2 and 31-A3) were produced. Then the fracture models were loaded with the peak force during a single gait cycle. The effect of stress and displacement of femurs with three different implant configurations were recorded and analyzed. Results: The stress induced on the two different implants demonstrated a similar pattern; stress concentration was mainly located in the intersection area between lag screw and the nail or between lag screw and the lateral plate. Gamma nail in both types of fractures shared the smaller displacement. The displacement of femurs fixed by Gamma nail showed smaller displacement. The stress in the calcar region which was the main load-bearing area of the intact femoral neck was decreased markedly in all of the models, especially in model fixed with Gamma nail. Conclusions: In conclusion, for the 31-A3 fracture, DHS may be not suitable because it failed to maintain the integrity of the calcar region and showed larger displacement of fractured fragment. Generally, the Gamma nail has mechanical superiority over DHS, but the shielding effect accompanied may increase the risk of intra-operative and later fracture around or below the implant. When the integrity of the calcar region fails to maintain, the Gamma nail is preferred.

Keywords: Finite element analysis, intertrochanteric fracture, comparative study

Introduction

Fractures of the hip are common injuries. And approximately 50% of hip fractures occur in the intertrochanteric region, the prevalence of which increases exponentially with age [1]. It is also associated with a high rate of morbidity and mortality [2]. Beyond preventing avoidable deaths, the goal of the treatment is to restore patients to their pre-injury level of mobility. In order to allow immediate return to unrestricted weight-bearing, secure fixation is often required [3]. The implants chosen for the operative intervention are mainly categorized into two types, namely extra-medullary and intramedullary. For the treatment of stable intertrochanteric femoral fracture, dynamic hip screw (DHS) has been proven to be the most widely acceptable implant [4]. But, there still exist controversies over the choice of treatment for unstable intertrochanteric femoral fractures [5-7]. The usage of DHS is restricted due to the relatively high rate of failure and complication [6]. Although intramedullary fixation, such as Gamma nail, has an advantage in mechanics and clinical practice, other implants such as dynamic hip screw and dynamic condylar screw are also under consideration in certain circumstance. In this study, we intended to investigate the biomechanical behavior of two different implants, namely dynamic hip screw (DHS), and Gamma nail, via finite element analysis, for the treatment of two types of unstable intertrochanteric femoral fracture (AO classification 31-A2 and 31-A3), with the intention to provide more information for clinical practice.

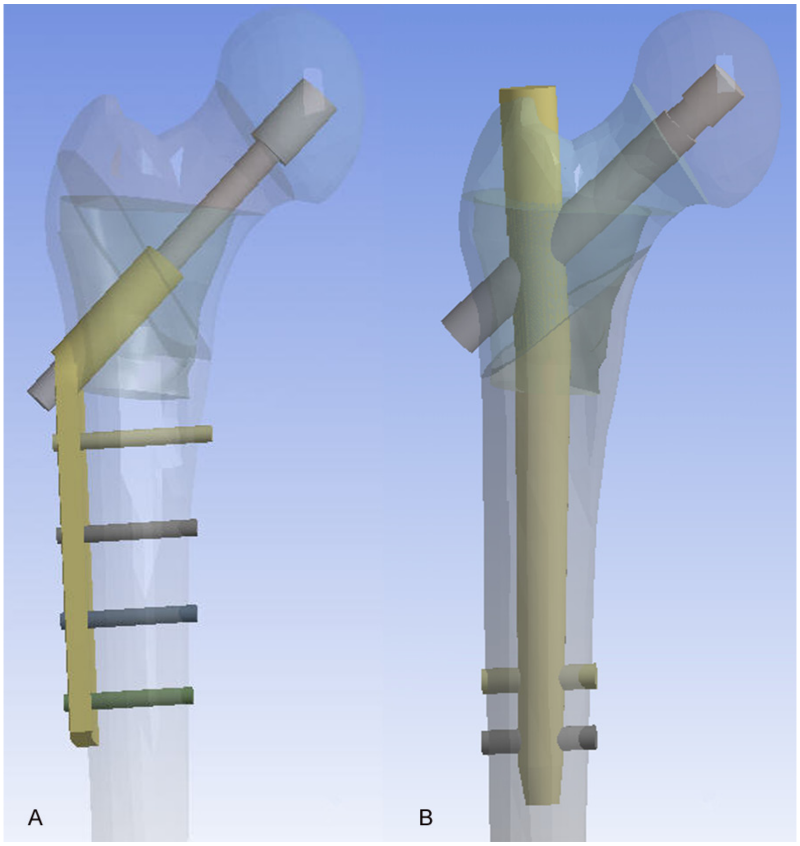

Figure 1. A: CAD model of AO 31-A2.1 fracture fixed with DHS. B: CAD model of AO 31-A3.1 fracture fixed with Gamma nail.

Table 1. Material properties assigned

Materials	Tensile moduli (MPa)	Poisson's ratio
Cancellous bone in femoral head	900	0.29
Cancellous bone in femoral neck	620	0.29
Cancellous bone in intertrochanteric region	260	0.29
Cortical bone	17000	0.30
Implants	200000	0.30

Materials and methods

This study was approved by the local institution. One of the co-authors (a 29-year-old male with a weight of 70 kg and a height of 170 cm) volunteered to be the subject of this study. Pelvic and lower extremity fractures, osteoarthritis and other bone diseases were excluded by X-ray before undergoing a CT scan of his right lower extremity.

Experimental model

Three dimensional (3D) model of the right proximal femur was reconstructed from CT images, using efilm software (MERGE Co., Milwaukee, WI, USA), with 1 mm cuts and in the form of the DICOM format. After the procedures of segmentation, refining and rendering, non-uniform rational B-spline (NURBS) surface reconstruction was performed via Pro/Engineer2001 software (PTC Co., MA, USA), to build the entire CAD model. Then the CAD model of the proximal femur was imported to ANSYS software (version 8.0, Ansys, Inc., Canonsburg, PA, USA) which was employed to establish the finite element model with 1.0 mm sized tetrahedral mesh of both the bones and implants. AO classification 31-A2.1 femoral fracture and 31-A3.1 fracture were created respectively on the basis of the intact femur model [8, 9]. Given the data provided by manufacturers, CAD and finite element models of dynamic hip screw (DHS) and Gamma nail (asian type) were also created, as shown in **Figure 1**.

Material properties

In this study, the material of either the bone or the implant was regarded as isotropic, linear, elastic material [10]. Elastic moduli and Poisson's ratios of cortical and cancellous bone and implants were obtained from published literatures [8, 11], as listed in **Table 1**.

Nomenclature

In this study, AO classification 31-A2 and 31-A3 were designated as "S" and "R" respectively. Arabic numerals "1", "2" stood for DHS and Gamma nail respectively. For example, 31-A2 fracture fixed with DHS was labeled as 'S1'. And 31-A3 fracture fixed with Gamma nail was labeled as 'R2'.

Table 2. Decomposition of loading forces

Loading forces	Decomposition of loading forces in three axises (N)			Resulant force (N)
	X	Y	Z	
Joint reaction force	616	2800	171	2872
Abductor force	430	1160	0	1237

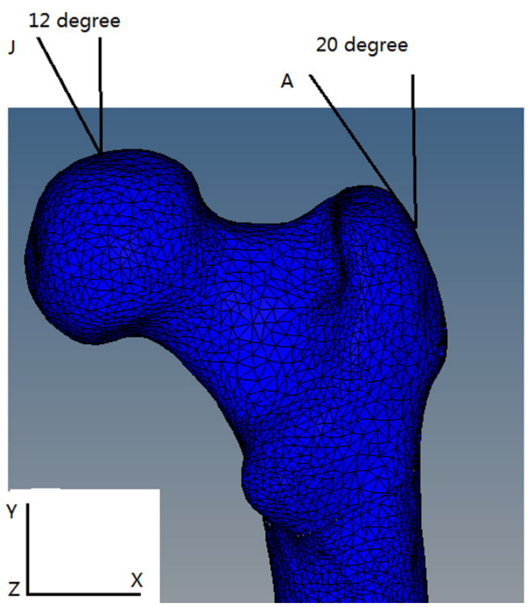

Figure 2. Loading of Joint reaction force (J) and abductor force (A).

Loading and boundary condition

The distal end of the femur was fixed in all degrees of freedom to prevent rigid body motions during the analysis. Forces were loaded to simulate the maximal loading in a single gait cycle of a 70 kg weight man, as shown in **Table 2** and **Figure 2**, which included joint reaction forces and abductor forces [11, 12]. For the screw part of DSH, it was assumed that they were completely bonded by femoral head without possible motion, while in the other part, they were partially fixed with a friction factor of 0.3 [13, 14]. The contact of distal locking screws for Gamma nail with femoral cortex was regarded as completely fixed without movement. And the effect of load sharing between the lag screws and sleeves was simulated by linking the screw and sleeve with virtual mechanical rigid links.

Analysis

The analysis was done using ANSYS software (version 8.0, Ansys, Inc., Canonsburg, PA, USA) with the equivalent Von Mises stress (EVMS) [15-17], displacement of the model relative to the intact femur used as the output measures.

Results

Stress distribution on implants

The stress induced on the two different implants demonstrated a similar pattern, as shown in **Figure 3**. The maximum stress regions of the devices were located in the intersection area between lag screw and the nail or between lag screw and the lateral plate. Both in model S1 and S2, the stress concentrated at the middle part of the lag screw. As for 31-A3.1 fracture, the stress distribution in R1 and R2 were similar to those in S1 and S2, which indicated that, for DHS and Gamma nail, the stress distribution basically remained the same, as showed in **Table 3**.

Stress distribution on femurs

The peak stress of femurs in two types of fracture was listed in **Table 3**. It was found that the stress concentration was mainly located where the distal part of the lateral plate or distal lock screw was contacted. As demonstrated in **Table 3**, the peak stress decreased by 24.27% from S1 to R1. The decreasing ratio was larger than that in S2 (16.33%). As shown in **Table 3**, stress in the calcar region which was the main load-bearing area of the intact femoral neck was decreased markedly in all of the models, especially in model R2 and S2.

Displacement pattern on proximal femurs

The maximal displacement of the proximal femur was compared. The displacement of femurs fixed by Gamma nail showed smaller displacement. As demonstrated in **Table 3**, the displacement of femurs decreased by 9.5% from S1 to R1, and decreased by 25% from S2 to R2.

Displacement pattern on implants

The displacements of two types of implants were compared in **Table 3**. The displacement

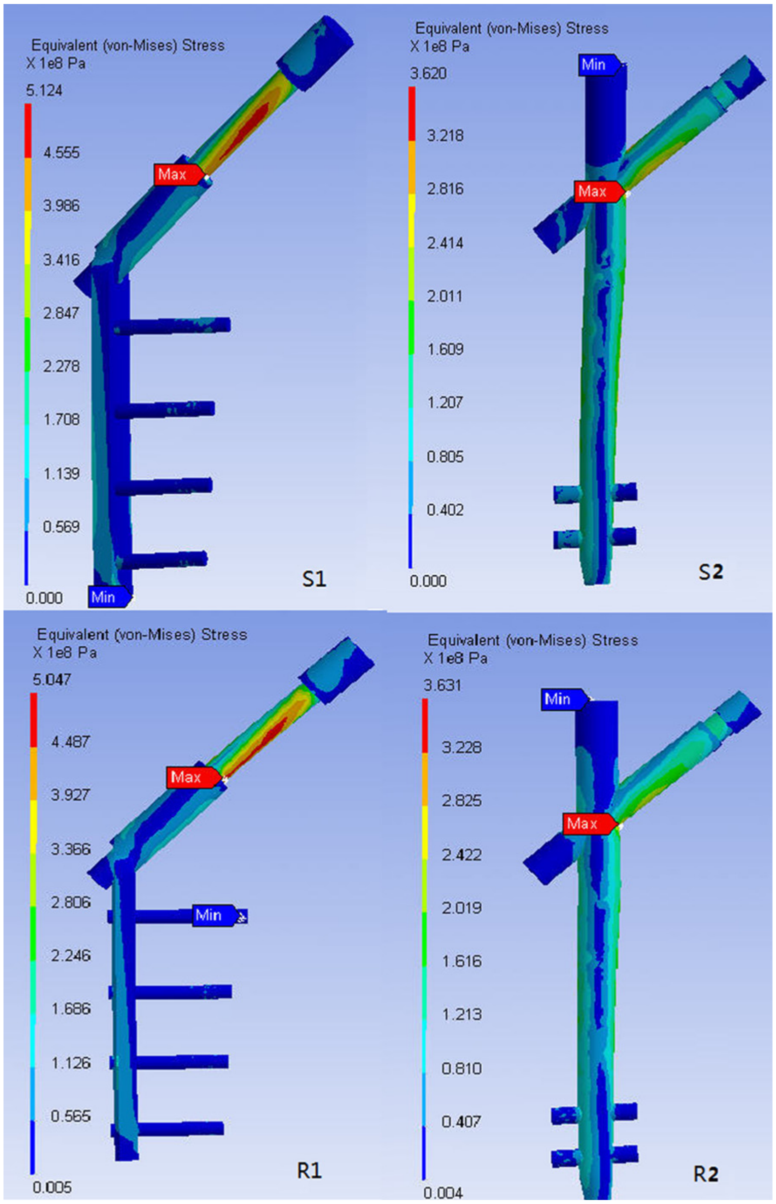

Figure 3. Stress distribution of implants in different models.

patterns were similar in two implants. Gamma nail in both types of fractures shared the smaller displacement. This is consistent with displacement pattern of femurs aforementioned.

Discussion

Intertrochanteric fractures have been treated with numerous implants, intramedullary or extra-medullary. However, the optimal management of intertrochanteric fractures is still controversial. Fracture patterns, osteoporosis, and aging process make the selection of implants a difficult problem [1, 2], especially in unstable intertrochanteric fractures. To facilitate the decision making process for choosing the most appropriate implant, we used one of the computational methods, finite element analysis (FEA), to analyze the stress and displacement pattern of DHS and Gamma nail in the treatment of 31-A2.1 and 31-A3.1 fractures.

As illustrated in **Figure 3**, the stress distribution of implants in model S shared the similar tendency. The maximum stress regions of the devices were located in the intersection area between lag screw and the nail or between lag screw and the lateral plate, which can be attributed to the intrinsic design of the implants. However, Gamma nail undertook relatively small stress, for the Gamma nail was inserted in the center of medullary cavity, close to the axis of the loading force, with relatively small bend moment. In R model, as the medial supporting structures (calcar region and lesser trochanter) and lateral supporting structure (greater trochanter) were both impaired, the stress distribution of the implants was different. In model R1, DHS undertook the highest stress of 504 MPa, which concentrated where the lateral plate contacted the fracture line, which can be explained by the anti-sliding effect of DHS to prevent the proximal fractured fragment from moving laterally and the distal fractured fragment from moving medially. The stress concentration also occurred at the intersection area between the most distal screw and the plate, which indicated potential implant failure in this region, as illustrated in **Figure 3**.

Comparing with the intact femur, unlike S1, the stress distribution of femur in S2 was similar to that of the intact femur. And in both S2 and R2,

Table 3. Stress and displacement pattern on the femurs and implants

Model	Maixmal stress on implants (MPa)	Maximal stress on femurs (MPa)	Maximal displacement on implants (mm)	Maximal displacement on proximal femurs (mm)	Stress on the medial cortex of fracture end (MPa)	Stress on the anterior cortex of fracture end (MPa)	Stress on the posterior cortex of fracture end (MPa)	Stress on the calcar region (MPa)
S1	512	128	3.85	10.5	49	31	36	66
S2	362	57	3.15	9.6	30	20	32	32
R1	504	103	3.53	9.5	18	17	5	62
R2	363	49	2.53	7.22	22	27	22	26
Intact femur	N/A	105	N/A	6.2	N/A	N/A	N/A	105

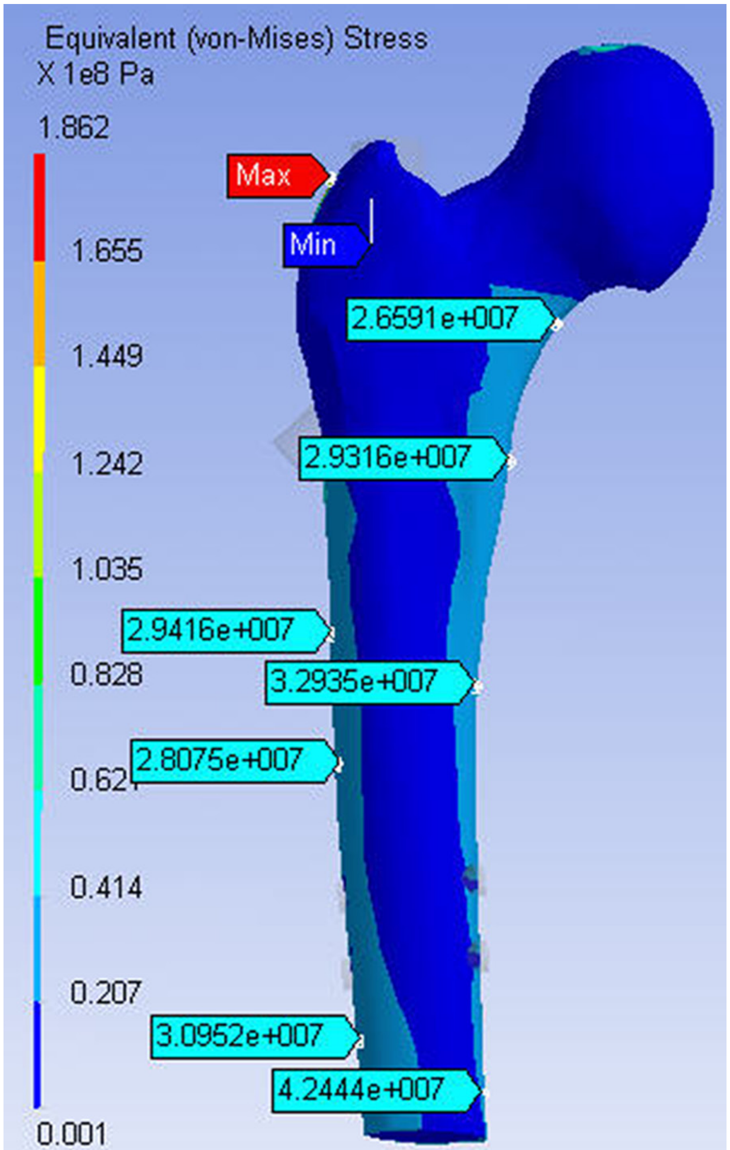

Figure 4. Stress of the inner side of femoral cortex contacted with Gamma nail.

the stress distribution of the femur was similar and the stress in the calcar area was much smaller than that in S1 and R1, which indicated that, for unstable fractures involving the calcar area, Gamma nail can maintain the loading transmission pathway similar to the intact femur and the fractured medial calacr region can be effectively protected in 31-A3.1 fractures. It also seemed that the stress distribution pattern was not dependent on fracture types but the inherent attributes of the Gamma nail. However, it should be noted that stress concentration occurred in the inner side of femoral cortex contacted with distal end of Gamma nail (**Figure 4**), which was twice as much as the stress in the proximal part of cortical bone, may increase the potential risk of fracture.

Interestingly, we found dramatical decrease of stress (5 MPa) on the posterior cortex of fracture end in R1, showing that the loading transmission failed to pass through the fracture line and the integrity of the calcar region failed to retain. This is because that the direction of compression effect produced by the lag screw was parallel to the fracture line and produced the shear force instead of compression force. As a result, we thought DHS may not be suitable for 31-A3.1 fracture.

In order to study the displacement pattern of femurs, we chose the point with the maximal displacement of proximal femur other than load-bearing point to compare the displacement pattern in the proximal fractured segments of femurs in S1 and S2, since the displacement at the load-bearing site may be irreversible [18]. It was found that the femur in S1 had the larger displacement of proximal segment and the displacement pattern in R models shared the similar trend, which indicated Gamma nail seemed to have an advantage in mechanics over DHS.

There were many reports published comparing the utilization of DHS and Gamma nail for the fixation of intertrochanteric fractures. Pervez et al revealed that no significant difference was found in several parameters, such as length of surgery, pneumonia, thromboembolic complications and wound infection or hematoma, between Gamma nail and DHS [19]. However, in regard to blood loss, the fracture fixation with DHS led to more blood loss than with Gamma nail, as reported in several meta-analysis [20-22]. In addition, Liu et al found that DHS was associated with a higher risk of reoperation than Gamma nail. Although with superior biomechanical property over DHS, many studies indicated that Gamma nail can result in a higher risk of intra-operative and later fracture around or below the implant than DHS [22, 23], which in our study can be explained by multiple stress concentration on the femur fixed by Gamma nail, for example, the stress concentration occurred in the inner side of femoral cortex contacted with distal end of Gamma nail. However, Zeng et al reported that no significant difference was found in fixation failure, such as cutting-out or non-union, between Gamma nail and DHS [25].

A few limitations were inherent to this study. First, the FEA in our study is based on only one healthy subject. The results of our study should be verified by a larger cohort of patients with the same types of intertrochanteric fractures. In addition, the Proximal Femoral Nail Autorotation (PFNA) which has been widely used in intertrochanteric fractures, were not included in our comparison study. We plan to extend our further research to cover this implant. Furthermore, only a static load situation may be insufficient for representing a whole gait cycle. Finite element analysis of bone model considering the whole gait cycle leads to deviations in the mass loss and apparent bone density distribution in comparison with calculation of static loading alone [26]. Lastly, although the implants are subjected to an assumed normal human weight of 70 Kg, data obtained from higher amounts of loads may be necessary to prove the effectiveness of each implant during normal function. This is important considering that the daily human activity requires the keens to undergo stresses beyond that which is observed during standing.

Conclusion

For the 31-A3 fracture, DHS may be not suitable because it failed to maintain the integrity of the calcar region and showed larger displacement of fractured fragment. Generally, the Gamma nail has mechanical superiority over DHS, but the shielding effect accompanied may increase the risk of intra-operative and later fracture around or below the implant. When the integrity of the calcar region fails to maintain, the Gamma nail is preferred.

Acknowledgements

This study was Funded by the Outstanding Leaders Training Program of Pudong Health Bureau of Shanghai (PWR12013-01) and Program for Medical Key Department of Shanghai (ZK2015B17).

Disclosure of conflict of interest

None.

Abbreviations

DHS, dynamic hip screw; PFNA, Proximal Femoral Nail Autorotation; FEA, finite element analysis.

Address correspondence to: Dr. Zexiang Li, Department of Orthopedic Surgery, Shanghai Pudong Hospital, No. 2800, Gongwei Road, Huinan Town, Pudong New Area, Shanghai, China. Tel: +86138-62086284; E-mail: lzxsubmission@163.com

References

[1] Horowitz BG. Retrospective analysis of hip fractures. Surg Gynecol Obstes 1966; 123: 565.

[2] White BL, Fisher WD, Lauren CA. Rate of mortality for elderly patients after fracture of the hip in the 1980's. J Bone Joint Surg 1987; 69A: 1335-1340.

[3] Rogers FB, Shackford SR, Keller MS. Early fixation reduces mobility and mortality in elderly patients with hip fractures form low-impact falls. J Trauma 1995; 39: 261-265.

[4] Luitse J, Dunki J, Van H. The dynamic hip screw "Golden standard" in the treatment of pertrochanteric fractures. Proximal femoral fractures. Operative techniques and complications, vol 2. In: Marti R, Dunki J, editors. London: ED Medical Press; 1993. pp. 409-22.

[5] Kempf I, Grosse A, Beck G. Closed locked intramedullary nailing. J Bone Joint Surg 1995; 67A: 709-19.

[6] Willoughby R. Dynamic hip screw in the management of reverse obliquity intertrochanteric neck of femur fractures. Injury 2005; 36: 105-9.

[7] Honkonen S, Vihtonen K, Jarvinen M. Second-generation cephalomedullary nails in the treatment of reverse obliquity intertrochanteric fractures of the proximal femur. Injury 2004; 35: 179-83.

[8] Sitthiseripratip K, Van Oosterwyck H, Vander Sloten J, Mahaisavariya B, Bohez EL, Suwanprateeb J, Van Audekercke R, Oris P. Finite element study of trochanteric Gamma nail for tro-

chanteric fracture. Med Eng Phys 2003; 25: 99-106.

[9] Haynes RC, Poll RG, Miles AW, Weston RB. Failure of femoral head fixation: a cadaveric analysis of lag screw cut-out with the gamma locking nail and AO dynamic hip screw. Injury 1997; 28: 337-41.

[10] Huiskes R, Chao E. A survey of finite element analysis in orthopedic biomechanics: the first decade. J Biomechanics 1983; 16: 385.

[11] Taylor ME, Tanner KE, Freeman M. Stress and strain distribution within the intact femur: compression or bending? Med Eng Phys 1996; 18: 122-131.

[12] Bohez E, Suwanprateeb J, Audekercke R. Finite element study of trochanteric gamma nail for trochanteric fracture. Med Eng Phys 2003; 25: 99-106.

[13] Chen WP, Tai CL, Shin CH, Hsieh PH, Leou MC, Lee MS. Selection of fixation devices in proximal femur rotational osteomy clinical complications and finite element analysis. Clin Biomech (Bristol, Avon) 2004; 19: 255-62.

[14] Mann K, Bartel DL. Coulomb frictional in modeling cemented total hip replacement: a more realistic model. J Biomech 2008; 9: 1067-78.

[15] Makar S, Joshi G. Analysis of a femoral hip prosthesis designed to reduce stress shielding. J Biomech 2000; 33: 1655.

[16] Terrier A, Rakotomananna RL, Ramaniraka AN, Leyvraz PF. Adaptation models of anisotropic bone. Comput Methods Biomech Biomed Engin 1997; 1: 47.

[17] Izaham R, Kadir M, Rashid A, Hossain G, Kamarul T. Finite element analysis of Puddu and Tomofix plate fixation for open wedge high tibial osteotomy. Injury 2012; 43: 898-902.

[18] Wang C, Yettram AL, Yao M, Procter P. Finite element analysis of a Gamma nail within a fractured femur. Med Eng Phys 1998; 20: 677-83.

[19] Pervez H, Parker M, Vowler S. Prediction of fixation failure after sliding hip screw fixation. Injury 2004; 35: 994-998.

[20] Shen L, Zhang Y, Shen Y, Cui Z. Antirotation proximal femoral nail versus dynamic hip screw for intertrochanteric fractures: a meta-analysis of randomized controlled studies. Orthop Traumatol Surg Res 2013; 99: 377-83.

[21] Bhandari M. Schemitsch E, Jonsson A, Zlowodzki M. Haidukewych GJ. Gamma nails revisited: Gamma nails versus compression hip screws in the management of intertrochanteric fractures of the hip: a meta-analysis. J Orthop Trauma 2009; 23: 460-4.

[22] Gu M, Yang Z, Pei F, Huang F, Chen S, Xiang Z. Meta-analysis of the Gamma nail and dynamic hip screw in treating peritrochanteric fractures. Int Orthop 2010; 34: 323-8.

[23] Ekstrom W, Karlsson-Thur C, Larsson S, Ragnarsson B, Alberts K. Functional outcome in treatment of unstable trochanteric and subtrochanteric fractures with the proximal femoral nail and the Medoff sliding plate. J Orthop Trauma 2007; 21: 18-25.

[24] Adams C, Robinson C, Court-Brown C, McQueen M. Prospective randomized controlled trial of an intramedullary nail versus dynamic screw and plate for intertrochanteric fractures of the femur. J Orthop Trauma 2001; 15: 394-400.

[25] Zeng C, Wang Y, Wei J. Treatment of trochanteric fractures with proximal femoral nail antirotation or dynamic hip screw systems: a meta-analysis. J Int Med Res 2012; 40: 839-51.

[26] Behrens B, Nolte I, Wefstaedt P, Stukenborg-Colsman C, Bouguecha A. Numerical investigations on the strain-adaptive bone remodeling in the peri-prosthetic femur: influence of the boundary conditions. Biomed Eng Online 2009; 8: 7.