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Wing-augmentation reduces femoral head cutting out of dynamic hip screw

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ABSTRACT

The dynamic hip screw (DHS) is commonly used in the treatment of femoral intertrochanteric fracture with high satisfactory results. However, post-operative failure does occur and result in poor prognosis. The most common failure is femoral head varus collapse, followed by lag screw cut-out through the femoral head. In this study, a novel-designed DHS with two supplemental horizontal blades was used to improve the fixation stability. In this study, nine convention DHS and 9 Orthopaedic Device Research Center (ODRC) DHSs were tested in this study. Each implant was fixed into cellular polyurethane rigid foam as a surrogate of osteoporotic femoral head. Under biaxial rocking motion, all constructs were loaded to failure point (12 mm axial displacement) or up to 20,000 cycles of 1.45 kN peak magnitude were achieved, whichever occurred first. The migration kinematics was continuously monitored and recorded. The final tip-to-apex distance, rotational angle and varus deformation were also recorded. The results showed that the ODRC DHS sustained significantly more loading cycles and exhibited less axial migration in comparison to the conventional DHS. The ODRC DHS showed a significantly smaller bending strain and larger torsional strain compared to the conventional DHS. The changes in tip-to-apex distance (TAD), post-study varus angle, post-study rotational angle of the ODRC DHS were all significantly less than that of the conventional DHS ($p < 0.05$). We concluded that the ODRC DHS augmented with two horizontal wings would increase the bone–implant interface contact surface, dissipate the load to the screw itself, which improves the migration resistance and increases the anti-rotational implant effect. In conclusion, the proposed ODRC DHS demonstrated significantly better migration resistance and anti-rotational effect in comparison to the conventional DHS construct.

1. Introduction

Femoral intertrochanteric fractures account for a large proportion of proximal femoral fractures in the elderly with osteoporosis. These fractures are one of the most important health care issues faced by orthopedic surgeons today. Many people who experience such fractures rapidly deteriorating in health status with a significant physical and functional impairment and require substantial financial resources during the perioperative and rehabilitative care [1]. In the 1950s, operative treatment for femoral intertrochanteric fractures was introduced to improve the functional outcome and reduce the complications associated with long-term immobilization and prolonged bed rest [2–4]. Later, a variety of different extra-medullary or intra-medullary implants have been developed since the 1950 s. The most commonly used extra-medullary implant is the dynamic hip screw (DHS) with side plate. Intramedullary nails may be used for the surgical fixation of extracapsular hip fractures in adults; however, there is limited

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evidence to date and it is insufficient to determine whether there are important differences in outcome between different designs of intramedullary nails used in the internal fixation of extracapsular hip fractures. Further studies comparing different designs of intramedullary nails are not a priority. DHS is still currently considered to be the gold standard for extra capsular hip fracture fixation as well as the implant that any new design should be compared to [5–8]. Since its introduction, the DHS has been shown to produce good results; however, complications are frequent, particularly in unstable fractures [9–11]. Post-operative implant-related complications have been reported in recent meta-analysis studies [7]. The most common cause of failure is reported to be varus collapse of host bone and cutting-out of the lag screw through the femoral head [9,12,13].

For the failure mechanisms about varus collapse and cutting-out of the lag screw through the femoral head, previous mechanical studies have relied on static or dynamic uniaxial loading regimens to induce construct failure. However, the hip is loaded in a multiplanar, dynamic manner during normal gait. In the insert-wearing study for prosthetic hip joints, the biaxial rocking motion (BRM) technology has been chosen to simulate dynamic multiplanar forces loading during level walking [14,15]. The hip implant performance simulator (HIPS) developed by Ehmke et al. can reproduce the dynamic multi-planar hip forces seen during level walking [16]. By using multi-planar forces with a loading protocol designed for hip ab-adduction, flexion–extension, and a double peak load history, BRM technology could simulate much closer to the normal physiologic hip joint motion. In this study, the biomechanical behavior and cut-out performance of a novel wing-augmented DHS and the conventional DHS implant were investigated under physiologic multi-planar loading model. Our hypothesis is that the additional wings would significantly dissipate the stress on the lag screw and enhance the anti-rotational effect. These factors would decrease femoral head cutting out incidence under cyclic load dynamic testing.

2. Materials and methods

2.1. Implants

Nine dynamic hip screws (DHS, Synthes, Oberdorf, Switzerland) made of stainless steel were tested as the gold-standard for single lag screw implants. The DHS lag screws had a shaft diameter of 7.8 mm, an outer thread diameter of 12.5 mm and a total length of 110 mm. The wing-augmented ODRC-DHS implants [ODRC: Orthopaedic Device Research Center, National Yang-Ming University, Taipei City, Taiwan] made of titanium were used for comparison. Besides the two grooved structure and the additional two horizontal wings, the ODRC DHS had the exact mechanical parameters derived from the control DHS implant (Fig. 1). To investigate if the newly designed implant can provide greater migration resistance and better biomechanical behavior, nine winged ODRC-DHS implants were tested for comparison.

2.2. Surrogate specimens

To yield higher reproducibility and consistent cutout failure, surrogate specimens were used as a cancellous bone substitute [16,17]. The stability of lag screw fixation was tested in surrogate femoral head and neck specimens machined from cellular polyurethane foam (50 mm in diameter, #1522-11, Pacific Research Inc., Vashon, Washington, USA). As validated in a previous study, these specimens had an elasticity modulus (E-modulus) of 48 MPa with 4 MPa compressive strength and a density of 12.5 pcf (0.2 g/cm^3) to simulate mildly osteoporotic bone [17]. These material properties correspond to the osteoporotic range of human cancellous bone, with 5–104 MPa E-modulus and 2–21 MPa compressive strength [18]. For delivery of dynamic loading, the surrogate specimens were placed in a 6 mm thick, polished steel shell to provide a rigid, spherical interface.

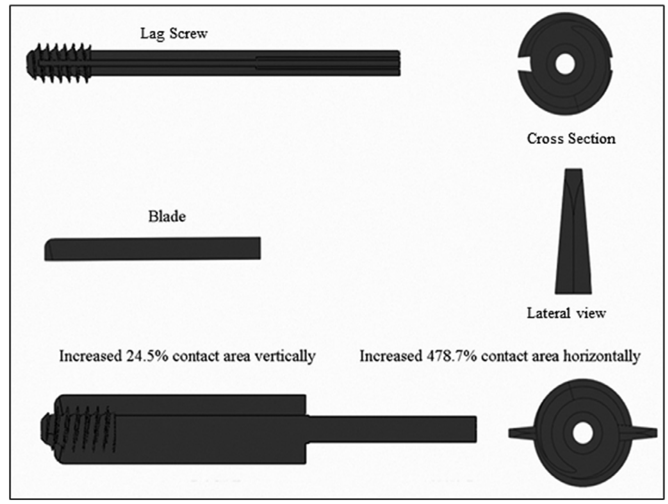

Fig. 1. Orthopedic device research center (ODRC) DHS design scheme. Upper: Lag screw profile and its cross section view. Middle: Blade profile and its lateral view. Lower: estimated increases in contact surface area both in the vertical and horizontal plane.

2.3. Implant insertion

In this study, DHS lag screw surrogate specimens were reamed but not tapped. The lag screw was placed centrally within the femoral head surrogate and advanced to a depth leaving 20 mm tip-to-apex distance (TAD) [19]. This measurement, the TAD, is the sum of the distance from the tip of the lag screw to the apex of the femoral head both on an anteroposterior radiograph and lateral radiograph, after controlling for magnification. This corresponds to a 10 mm distance of the screw tip to the femoral head apex in both views. The ODRC DHS were inserted using the same protocol as the control; after the lag screw was inserted to the intended depth, the ODRC-DHS blade trench was created to pre-determined length, and then the ODRC-DHS blade was inserted and fixed with compression screw. All implants were inserted according to the manufacturer's guidelines.

2.4. Experimental setup

The constructs were then tested in the HIPS-mode to reproduce the dynamic multi-planar hip forces during level walking. This model has been validated for simulation of lag screw migration and cut-out in a most serious clinical condition, that is, combination of an unstable femoral intertrochanteric fracture (OTA classification 31-A.2) in an osteoporotic bone and gait cycle loading [16]. The testing system is fixed at a solid base which simulated the physiologic situation that anatomic axis of femoral shaft aligned perpendicular to the horizontal plane. The proximal aspect of the base was fixed to simulate a pertrochanteric fracture with a fracture line inclination of 40° to the anatomic axis of the femoral shaft (Fig. 2). A bipolar-designed steel shell femoral head back plate with a 40 mm diameter hole was used to ensure unconstrained shear translation of the lag screw in the surrogate femoral neck. This back plate sit against a polyethylene bolster attached to the base plate to reproduce the constraints characteristic of a reduced, but unstable pertrochanteric fracture with deficient posteromedial neck support. This bolster construct simulated fracture