



# Biomechanical study of extramedullary and intramedullary fixation in the treatment of unstable intertrochanteric reversed-tilt fractures of the femur

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**Background:** To investigate the efficacy of the 135° hip screw, 95° intramedullary hip screw (IMHS) and 95° hip screw in the treatment of intertrochanteric reverse dip fracture of the femur.

**Methods:** We retrospectively analyzed 125 matched pairs of human femurs (median age 64 years) which were osteotomized at a 33° angle in the left femur and extended downward from the minor trochanter to simulate a reverse oblique intertrochanteric fracture. The right femur served as a control. The left femur (n=4) was implanted with a 135° hip screw, 95° hip screw, or IMHS. A strain detector was placed distal to the fracture site to monitor fragment strain. The lateral displacement of the proximal femur was measured by a linear variable differential transformer. An Instron tester measured stiffness, strain, and lateral displacement at 25° adduction, and 90° adduction with vertical loads on the femoral head. A 2 cm gap was then formed at the fracture site to simulate comminution and the mechanical test was repeated.

**Results:** Before the formation of the gap, there was no significant difference in stiffness among different bone structures ( $P>0.05$ ), but after the formation of the gap, the stiffness of all the adduction structures decreased ( $P=0.03$ ), and the difference in adduction was statistically significant (135° hip screw:  $46.6\% \pm 3\%$ ; 95° hip screw:  $22.9\% \pm 2\%$ ; IMHS:  $53.7\% \pm 7.8\%$ ;  $P<0.05$ ). Similar results were found for the abduction and buckling positions. There was no significant difference in the lateral displacement of the gap before ( $P=0.92$ ) and after ( $P=0.26$ ), but a significant difference in the failure load was found (135° hip screw:  $1,222 \pm 560$  N; 95° hip screw:  $2,566 \pm 283$  N; IMHS:  $4,644 \pm 518$  N;  $P=0.02$ ).

**Conclusions:** There was no statistically significant difference in stiffness among different structures ( $P>0.05$ ). However, in the presence of gaps, IMHS bone implant structures are much stiffer than 135° and 95° structures and have a greater destructive load.

**Keywords:** Hip screw; biomechanics; intramedullary nail; intertrochanteric reverse dip fracture; retrospective study

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## Introduction

Intertrochanteric fractures of the femur are common, leading to significant morbidity and mortality. The functional outcomes of patients with intertrochanteric fractures are surprisingly poor, with significant limitation of mobility (1-3). Interfemoral rotor fractures have a very high incidence in the elderly population, especially in the elderly patients with osteoporosis. Due to its high disability rate and case fatality rate, it poses a serious threat to the life and health of elderly patients (4). The epidemiological trends suggest that the incidence of interrotor fractures will increase further in the future, which also poses a serious challenge to the global healthcare system. Standardizing the treatment of femoral interrotor fractures with different types is also a hot topic for orthopedic doctors today. Timely surgery as well as early postoperatively functional exercise are key to reducing high mortality (5). Interfemoral rotor fracture refers to the fracture from the base of the femoral neck to the area of the small rotor level (6). It belongs to the hip capsule fracture. It is a common hip fracture and is often seen in elderly patients (7). In this study, a reverse dip intertrochanter fracture was defined as a two-part fracture extending downward from the lower direction of the lesser trochanter.

The best fixation device for reversibly inclined intertrochanteric fractures is an internal fixation device that can resist the tendency of proximal fracture to transition, rotation, and varus (8). Intramedullary fixation has gradually replaced dynamic hip screw (DHS) for its advantages of strong stability, simple operation, less damage and less bleeding. Hemoglobin (Hb) decreased after surgery, and Hb could not be restored to normal level soon after blood transfusion, resulting in large unplanned blood consumption. The best way to fix a reverse-inclined intertrochanteric fracture is to use an implant that the proximal pronation and rotation of the fracture. As the global population ages, the incidence of interfemoral rotor fractures is increasing, accounting for more than half of hip fractures, and over 90% of patients with clinical interfemoral rotor fractures are over 65 years. Patients with such fractures are often accompanied by severe osteoporosis, minor trauma can cause interrotor fractures, and interrotor fractures have a high disability rate and case fatality rate (9). A recent retrospective clinical study by Baral *et al.* (10) intertrochanteric reverse dip fracture of the femur concluded that 95° extramedullary fixation was superior to other fixation devices. Luo *et al.* (11) conducted

a prospective, randomized clinical study which found that intramedullary devices were superior to 95° extramedullary devices. However, there are still few studies comparing the biomechanical properties of different fixation devices inclined intertrochanteric fractures (12). It can be divided into stable and unstable fractures in Evans typing, which is mainly based on the integrity and continuity of the posterior inner wall cortex. After the stable interrotor fracture, the internal wall is intact or with a very small displacement, and the unstable interrotor fracture after the internal wall is comminuted (13). There is also a special classification in this classification. Type R, whose fracture line is antioblisque, also known as inter-rotor fracture.

We present the following article in accordance with the STROBE reporting checklist (available at <https://atm.amegroups.com/article/view/10.21037/atm-22-93/rc>).

## Methods

### *Patients enrolled in the study*

The patient medical records of 125 pairs of matched femurs (median age: 64, 55–82) were collected from the Dongying Hospital of Traditional Chinese Medicine. None of the enrolled patients had a history of femur malignancy, fracture, or internal fixation. Bone quality was determined by radiographs of the femur using Singh's index. The included medical records detailed the efficacy of different graft materials in three groups of 125 patients with different treatment regimens. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of the Dongying Hospital of Traditional Chinese Medicine (No. 2021-038). Individual consent for this retrospective analysis was waived.

### *Surgical procedure*

This study used an appropriate implant to fix the left femur, fluoroscopic assistance to implant the implant, and ensured that the lag screw was in the best position within the femoral head. The bone graft structure was examined to ensure that the implant was placed correctly. The lag screw was placed in the center of the head, and using cyanoacrylate adhesive, the uniaxial strain gauge (EA-06-125AC-350) was bonded to the lateral side of the control and implant diaphysis in several locations.

**Table 1** Measurement data of fixed structure before clearance

| Position location | Implant materials | Average stiffness (%) | Average error (SEM) | P    |
|-------------------|-------------------|-----------------------|---------------------|------|
| 25° adduction     | 135° hip screw    | 67                    | 8                   | 0.32 |
|                   | 95° hip screw     | 76                    | 11                  |      |
|                   | (IMHS)            | 53                    | 12                  |      |
| 25° outreach      | 135° hip screw    | 80                    | 4                   | 0.68 |
|                   | 95° hip screw     | 97                    | 8                   |      |
|                   | (IMHS)            | 93                    | 5                   |      |
| 25° bend          | 135° hip screw    | 60                    | 4                   | 0.69 |
|                   | 95° hip screw     | 67                    | 4                   |      |
|                   | (IMHS)            | 71                    | 8                   |      |
| 90° bend          | 135° hip screw    | 79                    | 10                  | 0.49 |
|                   | 95° hip screw     | 98                    | 13                  |      |
|                   | (IMHS)            | 86                    | 17                  |      |

SEM, standard error of mean; IMHS, intramedullary hip screw.

### Data sorting

All data were reported as mean  $\pm$  standard error of mean (SEM), and the results of the bone graft structure were calculated by dividing. All the specimens of the pre-clearance stiffness test and post-clearance stiffness test remained within the online elastic range, and the average linear coefficients were  $R^2 > 0.95$  and  $R^2 > 0.90$ , respectively. Strain was reported as a non-normalized value that distinguishes tension from compression. For any significant differences identified in each analysis of variance (ANOVA) ( $P < 0.05$ ).

### Statistical analysis

SPSS 21.0 software (IBM) was used for statistical analysis of all data in this study. The measurement data were expressed as mean  $\pm$  standard deviation. *T*-tests were used for comparisons between two groups, and one-way ANOVA was used for comparisons between multiple groups.  $P < 0.05$  was considered to be statistically significant.

## Results

### Stiffness measurement

For the intact control femur group, the stiffness results (SEM) for the 135° hip screw were 25° adduction

1,535.81 $\pm$ 111.68 N/mm, 25° abduction 315.29 $\pm$ 6.71 N/mm, 25° forward bend 564.20 $\pm$ 28.26 N/mm, and 90° flexion 44.94 $\pm$ 2.39 N/mm. The stiffness results for the 95° hip screw were 25° adduction 1,864.01 $\pm$ 185.05 N/mm, 25° forward bend 581.96 $\pm$ 95.59 N/mm, and 90° forward bend 45.02 $\pm$ 5.02 N/mm. The stiffness results for intramedullary hip screw (IMHS) were 25° adduction 1,678.19 $\pm$ 192.86 N/mm, 25° abduction 282.70 $\pm$ 21.90 N/mm, 25° forward bend 477.99 $\pm$ 27.85 N/mm, and 90° forward bend 41.78 $\pm$ 2.34 N/mm (Table 1). After the segmentation gap was formed, the stiffness of all implanted structures decreased ( $P = 0.03$ ), and the stiffness of different implanted structures was significantly different ( $P = 0.046$ ; Table 2). All 135° hip screw implants failed during pre-treatment after gap formation. Tests at 90° flexion showed significant differences in hardness between implants after fragmentation ( $P = 0.0004$ ), with 135° hip screws being stiffer than 95° hip screws ( $P = 0.002$ ) and 95° hip screws being stiffer than IMHS ( $P = 0.02$ ). See Figure 1.

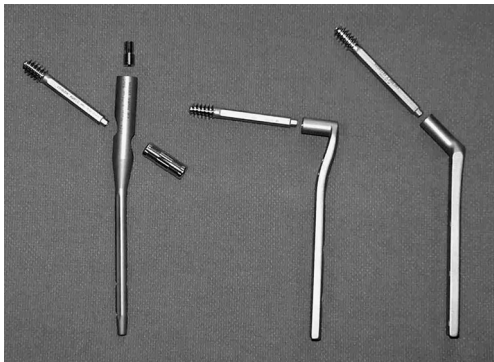
### Lateral displacement measurement

In this study, this was performed before and after the fragmentation gap was created in all implants at 25° adduction. There was no difference in proximal fracture segment displacement before and after fracture space formation ( $P = 0.92$ ; Table 3). After space formation, the

**Table 2** Measurement data of fixed structure after clearance

| Position location | Implant materials | Average stiffness (%) | Average error (SEM) | P      |
|-------------------|-------------------|-----------------------|---------------------|--------|
| 25° adduction     | 135° hip screw    | 47                    | 3                   | 0.046* |
|                   | 95° hip screw     | 23                    | 2                   |        |
|                   | (IMHS)            | 57                    | 8                   |        |
| 25° outreach      | 135° hip screw    | 73                    | 7                   | 0.020* |
|                   | 95° hip screw     | 39                    | 3                   |        |
|                   | (IMHS)            | 59                    | 3                   |        |
| 25° bend          | 135° hip screw    | 58                    | 8                   | 0.040* |
|                   | 95° hip screw     | 29                    | 3                   |        |
|                   | (IMHS)            | 57                    | 6                   |        |
| 90° bend          | 135° hip screw    | 114                   | 3                   | 0.004* |
|                   | 95° hip screw     | 67                    | 7                   |        |
|                   | (IMHS)            | 45                    | 4                   |        |

\*, P<0.05; SEM, standard error of mean; IMHS, intramedullary hip screw.



**Figure 1** The IMHS, 95° hip screw, and 135° hip screw devices. IMHS, intramedullary hip screw.

femurs of the 95° hip screw implants tended to shift laterally.

#### *Stress measurement*

Under the femoral head load of 1,000 N, the stress changes at all positions were recorded. It was no difference in the implant at 25° abduction, 25° buckling, or 90° buckling (P>0.05). Proximal strain gauge analysis at 25° adduction revealed a reduction in tensile strain after space formation. This resulted in a reduction of the implant was subjected to major gravity after the fragmentation gap had formed. The distal strain gauge of all implants was compressed during

**Table 3** Measurement data of lateral displacement along the fracture before and after fracture formation (%)

| Position location | Implant materials | Average stiffness (%) | Average error (SEM) | P    |
|-------------------|-------------------|-----------------------|---------------------|------|
| Before clearance  | 135° hip screw    | 53                    | 16                  | 0.92 |
|                   | 95° hip screw     | 79                    | 19                  |      |
|                   | (IMHS)            | 84                    | 25                  |      |
| After clearance   | 135° hip screw    | 41                    | 24                  | 0.26 |
|                   | 95° hip screw     | 183                   | 172                 |      |
|                   | (IMHS)            | 77                    | 28                  |      |

SEM, standard error of mean; IMHS, intramedullary hip screw.

the 25° adduction test. The distal strain gauge showed that the implant was exerting stress on the femoral shaft. But compressive stress increased with the crevices at the fracture site and at the distal end. Compared with extramedullary implants, the stress of IMHS at the distal end of the implant was not significantly increased, and there was no significant difference between the strain of IMHS at each position and the distal locking screw tip ( $P>0.05$ ). All the patients were followed up for 3 months.

## Discussion

Interfemoral rotor fracture is one of the most common fractures in orthopedic clinical work (14). Due to high disability and lethality rate, the treatment of such fracture needs early surgery. The purpose of the operation is: (I) to reduce the pain; (II) to enable the patient to recover as soon as possible; (III) to reduce the complications caused by long-term bed (15). Although a variety of implantable internal materials have been developed, none is available for all types of fracture. And orthopaedic surgeons should make reasonable choices based on individual patient differences and the different typing of the fracture. Of course, there are inevitable complications, clinicians should constantly improve the surgical skills and be familiar with the use of different internal fixation materials so as to minimize the occurrence of surgical complications, which is also the key to determine the success of the operation.

This may result in implant bone construction failure and neutralization of the distal fracture mass (16-18). This small area is subjected to considerable pressure (19). Failure of the 135° hip screw occurs in cortical fractures. Therefore, the success of 135° hip screw treatment for this fracture (20), and this type of internal fixation may be better for reverse dip fractures with greater distal extension. Therefore, it is necessary to select treatment and rehabilitation programs based on rapid post-admission risk assessment for elderly patients with intertrochanteric fractures. The patient's age, cardiopulmonary function, nutritional status, liver function, renal function, blood glucose and blood pressure levels, electrolyte balance, breath-holding tolerance and pre-injury activity state all directly affect the patient's anesthesia, operation tolerance and postoperative rehabilitation. Intramedullary nail has obvious biomechanical advantages in the treatment of intertrochanteric fracture of femur. The main nail and the screw in the femoral head and neck form a three-point fixation, which can share the load and reduce the bearing moment, thus reducing the bending

pressure of the intramedullary nail internal fixation and reducing the deformation or fracture of the intramedullary nail. However, there are still deficiencies in the treatment of osteoporotic fractures with intramedullary nail fixation. The main complications include nail tail shaft fracture, femoral head varus collapse, femoral neck shortening, etc. These complications are related to the design and placement of intramedullary nailing (21-24). After the intervertebral space was formed, the stiffness of the 95° hip screw at 25° adduction was significantly lower than that of the IMHS (25). This suggests that 95° hip screws and IMHS provide the same stable structure when anatomic reduction can be achieved, and IMHS may provide a more stable structure if the fracture construction and the talus breaks (26). IMHS is the hardest implant at 90° flexion.

In recent years, with the continuous optimization of endopplants and the improvement of doctors' surgical skills, the treatment effect of interrotor fractures has been significantly improved (27). The commonly used sliding hip screws, also known as compression hip screws or DHS, have evolved over the years. The early screw does not have the effect of compression on the broken end of hip fracture, because of the lack of compression on the broken end, it is very easy to appear the phenomenon of bone disunion and internal fixation failure. However, the advent of DHS makes up for this deficiency, and the compression effect of lag screws can make the fractured ends tightly stick together, reducing the occurrence of bone nonunion and internal fixation failure (28). The 95° hip screw was fixed to the lateral cortex, while the IMHS impinged on the lateral cortex within the intramedullary canal. Thus, when calcaneal support is lost at the fracture site, both implants change the physiological pull present near the femoral shaft into compression force. Moktar *et al.* (29) noted increased compression of the lateral cortex and increased fracture instability. The use of DHS requires the integrity of the large rotor lateral wall of the femur, which is an excellent implant for the complete and stable lateral wall. The nail plate structure can convert the shear force of the fracture into the axial force, which is consistent with the characteristics of human biomechanics. At the same time, the power hip screw can stably maintain the neck dry angle, which can effectively prevent the occurrence of hip valgus. Hiragami *et al.* (30) reported that IMHS distal fractures are ineffective treatment in biomechanical testing. The proximal abaxial intramedullary nail (PFNA) is a special and new intramedullary fixation system developed by AO. It is improved on the basis of PFN and has better biomechanical

and biomechanical effects than PFN. PFNA also has its own disadvantages. If the outer wall of the large rotor is heavily damaged, the support of the spiral blade, which can lead to internal fixation failure (31). In this study, it was found that the treatment of intertrochanteric reverse tilt fracture of the femur depends on the degree of fracture comminution and the angle of femur repair. In the absence of bone space, and IMHS hardness with bone space was significant (32). It also has a higher failure load than other structures.

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### Footnote

*Reporting Checklist:* The authors have completed the STROBE reporting checklist. Available at <https://atm.amegroups.com/article/view/10.21037/atm-22-93/rc>

*Data Sharing Statement:* Available at <https://atm.amegroups.com/article/view/10.21037/atm-22-93/dss>

*Conflicts of Interest:* All authors have completed the ICMJE uniform disclosure form (available at <https://atm.amegroups.com/article/view/10.21037/atm-22-93/coif>). The authors have no conflicts of interest to declare.

*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Ethics Committee of the Dongying Hospital of Traditional Chinese Medicine (No. 2021-038). Individual consent for this retrospective analysis was waived.

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