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PŮVODNÍ PRÁCE

Biomechanical Comparison of Dynamic Hip Screw, Proximal Femoral Nail, Cannulated Screw, and Monoaxial External Fixation in the Treatment of Basicervical Femoral Neck Fractures

Biomechanické porovnání dynamického skluzného šroubu, proximálního femorálního hřebu, kanylovaného šroubu a monoaxiální zevní fixace při léčbě bazicervikálních zlomenin krčku femuru

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ABSTRACT

PURPOSE OF THE STUDY

The objective of this study was to establish relative fixation strengths of proximal femoral nail (PFN), dynamic hip screw (DHS), monolateral external fixator (EF), and cannulated screw (CS) in basicervical hip fracture model.

MATERIAL AND METHODS

The study involved four groups of implanted composite proximal femoral synthetic bones of eight specimens per group; nailing with PFN, DHS, fixation with three cannulated screws, and EF. 70˚ osteotomy was performed to simulate a Pauwels Type 3 basicervical fracture. Minimum preload of 100 N was applied before loading to failure. The constructs were subjected to cyclic loading with 16˚ to midline from 100 N to 1,000 N for 10,000 cycles at 3Hz. Axial loading was applied at 10 mm/min until failure. Failure load, failure mode, and displacement were documented.

RESULTS

Mean failure load was 2182.5 ± 377.9 N in PFN group, 2008.75 ± 278.4 N in DHS group, 1941.25 ± 171.6 N in EF group, and 1551.6 ± 236.2 N in CS group. Average displacement was 15.6 ± 4.5 mm, 15.5 ± 6.7 mm, 11.7 ± 1.9 mm, and 15 ± 1.7 mm, respectively. No significant difference was noted among groups for fixation strength except CS group. All CS constructs failed during cyclic loading.

CONCLUSION

Our findings suggest that PFN, DHS and EF achieved higher fixation strengths than CS in basicervical fracture. PFN has higher failure loads and possesses biomechanical benefits for fixation of unstable basicervical fractures compared with DHS and EF.

Key words: basicervical fracture, internal fixation, biomechanics.

INTRODUCTION

Proximal femoral fracture through the basis of femoral neck at junction with intertrochanteric region is defined as basicervical fracture (7). Due to its anatomical location, it represents a transitional zone between femoral neck and intertrochanteric line (19). Because these extracapsular fractures biomechanically behave like intertrochanteric fracture, they are often fixed with sliding hip screw systems. Although surgical outcome of basicervical neck fractures were thought to be similar to those of intertrochanteric fractures, the incidence of complications such as nonunion and avascular necrosis of femoral head were reported to be higher in basicervical fractures (6, 7, 19). Several surgical modalities have been proposed such as proximal femoral nail, monolateral external fixation, and cannulated screws for basicervical fracture management (4, 5, 7, 19, 20).

The purpose of this study was to evaluate the biomechanical properties and stabilities of proximal femoral nail, dynamic hip screw, monolateral external fixator, and cannulated screw in synthetic basicervical femoral neck fracture model under mechanical load to compare their initial stiffness, failure loads, displacement at the fracture site under cyclic loading for each implant system.

MATERIAL AND METHODS

Specimens

Synthetic composite bones were tested for cyclic loading, load to failure and displacement at the fracture site to construct the main scenario of the study. For the experimental procedure, standard artificial model of proximal femur bone (Synbone no: 2220, AG Malans, Switzerland) was cut at 20 cm higher to distal end of the bone by an adjustable saw, thereby forming a standard Pauwels type 3 basicervical femoral neck fracture with an angle of 70° osteotomy (Fig. 1). Power analysis was performed from data obtained in the pilot study and necessitated to use a minimum of 5 models in each group to detect a statistical significance with a 10% difference among groups and a calculated standard deviation of 5%. Cyclic loading amplitude was 75% of the load to failure value of pilot studies to ensure a high-level stress condition on the implanted system (13, 22).

In all groups, the surgical technique was performed by a single surgeon. For precise anatomical reduction, osteotomies were performed after the implants were applied to the bone. Loading tests were also inspected visually and behaviors against applied forces, conformity between bone implant units, loosening and mobilizations of screws or pins, and types of fracture within different groups were observed and recorded. Radiographs were taken in all groups to confirm the ideal position of the test materials.

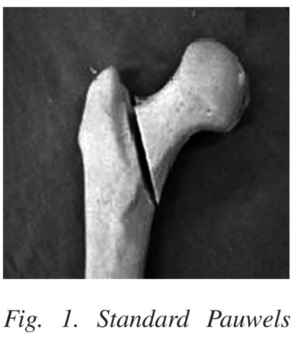

Fig. 1. Standard Pauwels type 3 basicervical femoral neck fracture with an angle of 70º osteotomy in synthetic bone model.

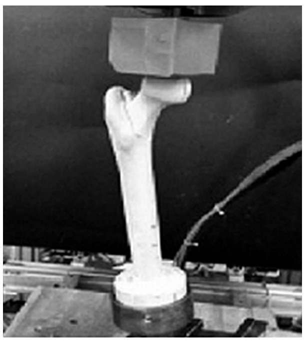

Fig. 2. Cyclic loading with servohydraulic universal testing machine.

Surgical technique

In PFN group, short proximal femoral nail (10x150 mm, *Smith & Nephew, London, UK*) advancing to the neck with a collodiaphyseal angle of 135° and an anteversion angle of 12° was locked by two 6.5 mm self-threading screws (95 mm, 100 mm) proximally, and two 4.5 mm self-threading screws (40 mm, 42 mm) distally after guided drilling upon the guide for screws to the system from lateral aspect.

In DHS group, a 135-degree, 3-hole DHS plate (TST, Istanbul, Turkey) was positioned with the central screw directed into the central region of the femoral head with tip-apex distance < 25 mm. The side plate was fixed to the femoral shaft with three 4.5 mm cortical screws.

In EF group, fracture was fixated by 4 Schanz screws of 6 mm in diameter, two of which were parallel to the neck proximally and others were perpendicular to the shaft distally over the trochanteric monolateral external fixator segment (TST, Istanbul, Turkey) having a head-neck angle of 135°.

In CS group, three 7.3-mm cannulated screws (100 mm, 100 mm, 95 mm; *TST, Istanbul, Turkey*) were inserted parallel into the femoral head in a triangle configuration. Inferior screws were positioned in the calcar region, above the lesser trochanter. The cephalad screw was inserted superiorly, 5 mm from the anterior and posterior cortices of the femoral neck and 5 mm from subchondral bone.

Biomechanical testing

Distal end of femurs were encrusted into plastic molds filled with polyester cement (DYO Chemical Inc., Izmir, Turkey). Two perpendicularly crossed Kirschner wires were inserted into the end of bones, which were buried into the cement, to augment the stability between the cement and bone model units. Specimens were positioned in the testing machine by putting the distal ends into fixed support of the stable base cylindrical metal plate and the femoral head into a custom made acetabular cup for loading tests.

Cyclical compression loads were applied to femoral heads with 16° to midline using a servohydraulic universal testing machine (MTS 858 Mini Bionix II Axial/Torsional universal testing machine, Eden Prairie, MN), (Fig. 2). Load and linear displacement values were collected using standard transducers of the MTS 858. An axial preload of 100 N was applied proximally to

Table 1. Biomachanical properties of four fixation techniques

Group	Construct	Initial stiffness (N/mm)	Load to failure (N	Displacement (mm)
1	proximal femoral nail	237.4 ± 12.9	2182.5 ± 377.9	15.6 ± 4.5
2	dynamic hip screw	230.7 ± 20.8	2008.75 ± 278.4	15.5 ± 6.7
3	external fixator	208.5 ± 6.8	1941.25 ± 171.6	11.7 ± 1.9
4	cannulated screw	153 ± 46.1	1551.6 ± 236.2	14.9 ± 1.7

stabilize the construct. Load-displacement data were collected and recorded initially (after 10 cycles) and at 1,000 cycle increments up to a total of 10,000 cycles. Failure load values were obtained after 10,000 cycles with a loading velocity of 10 mm/min for axial loading. Stiffness values were calculated using the linear portions of the load-displacement curves obtained at 1,000 cycle intervals with the units of N/mm. Failure was defined as a sudden decrease in the applied load, cut-out of implant from the femoral head, failure of fixation of any of the components, gross displacement at the osteotomy site, permanent hardware deformation, and complete collapse. Construct damage was assessed for mode of failure. The data were recorded on a compatible computer that used Vic 3D Correlated., USA Global Lab Software Data Translation, Inc., Marlborough, Ma).

RESULTS

The biomechanical characteristics of the four fixation techniques are shown in Table 1. All specimens completed cyclic loading in above-mentioned groups, except CS group where all specimens failed cyclic loading phase. Cyclic loading was terminated upon formation of either a fracture distal to the screw or a subtrochanteric fracture in all of CS models between cycles 150 to 170 of repetitive loading. Mean displacement ensued at the fracture line subsequent to cyclic loading was recorded as 15.6 ± 4.5 mm, 15.5 ± 6.7 mm, and 11.7 ± 1.9 mm in PFN, DHS, and EF group respectively.

Distribution of load to failure by displacement values were observed to be similar in PFN, DHS and EF groups (Fig. 3). In CS group which failed to accomplish cyclic loading experiment, mean displacement at the fracture line secondary to fracture load in an axial loading setting was found to be 15 ± 1.7 mm.

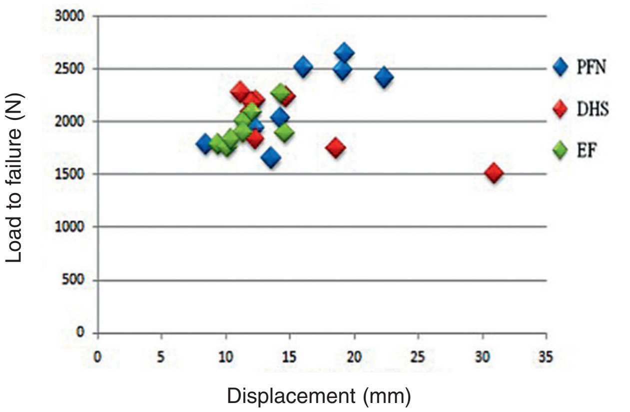

Fig. 3. Distribution of load to failure by displacement in group 1 to 3.

The experiments in group 1 were terminated due to pertrochanteric fractures in 6 of 8 models, a femoral head fracture with displacement on fracture line in a model, and a fracture at the level of distal screw in the remaining (Fig. 4A, B).

Experiments in group 2 were ended upon formation of distal fractures with cut-out of distal screws of the plate in five bone models. Two models showed > 20 mm displacement and rotation at fracture line, and the last model had collum femoris fracture accompanied with displacement at fracture line (Fig. 5A, B).

In group 3, experiments were halted upon formation of femoral fracture at the level of distal Schanz screw of the monoblock trochanteric EF system in all models, except one where a collum femoris fracture had developed (Fig. 6).

In CS group, where fractures occurred in cycles 150 to 170 of cyclic loading phase, six bone models had fractures at the level of distal screws constituting the base of triangular configuration, and the remaining two models were observed to have subtrochanteric femoral fractures (Fig. 7A, B).

DISCUSSION

Fractures of the proximal femur are very common (5, 6, 14, 15). Although various fixation devices have been designed, surgical management of these fractures still

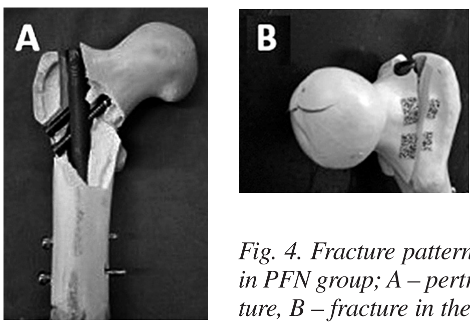

Fig. 4. Fracture patterns to end the test in PFN group; A – pertrochanteric fracture, B – fracture in the femoral head.

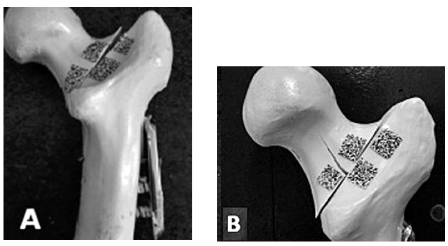

Fig. 5. Fracture patterns to end the test in DHS group; A – distal fracture with cut-out of distal screws of the plate, B – femoral neck fracture accompanied with displacement at fracture line.

Fig. 6. Fracture at the level of distal Schanz screw of the monoblock trochanteric EF.

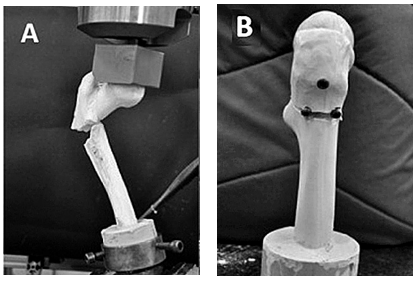

Fig. 7. Fracture patterns to end the test in CS group; A – subtrochanteric fracture, B – fracture at the level of distal screws constituting the base of triangular configuration.

remain a challenge (2, 5, 6, 9). The aim of surgical treatment is to provide a stable construct allowing for early ambulation. Known to be of extracapsular type, basicervical fractures were more often reported to have avascular necrosis than intertrochanteric fractures, rendering them to be evaluated as collum fractures with respect to the biological behavior and addressed under intracapsular fractures. Higher instability compared to trochanteric fractures may be explained by lack of relationship between proximal fragment and trochanteric region as well as no muscular insertion to this area. Furthermore, basicervical fractures are deprived of cancellous interdigitation observed in fractures of trochanteric region, which may unfavorably affect rotational and axial stability in particular (5, 9).

The ideal fixation material for vertically oriented basicervical femoral neck fracture must stand to weightbearing loads and provide stability across the fracture site in order to reduce complication rates during healing process. Previously, several prospective studies have compared screws with traditional fixed-angle devices and concluded with mixed results (1, 6, 16). To the best of our knowledge, this is the first experimental study to compare the biomechanical properties of four instruments currently used to treat basicervical femoral neck fractures. The objective of surgical treatment of a basicervical fracture is the restoration of function and early pain-free mobilisation.

Several screw configurations have been described for the fixation of femoral neck fracture. Triangular configurations have explicitly provided higher peak loads, and less displacement than others (20). Therefore, fixation in CS group was performed with an apex-proximal triangular configuration.

In biomechanical studies assessing fixation strength of fractures in the vicinity of proximal femur, force loading of 1,000 to 1,400 N at 2–3 Hz. is usually preferred during force-controlled experiments where a mean of 10,000 cycles is chosen in repetitive loading phase (11, 18). Force applied to the hip joint is around 238% of the body weight in average (3, 18). The force applied to the hip joint of 70 kg person walking at a velocity of 4 km/h equals to 1,400 N approximately. The frequency of 2 to 3 Hz. is used simulate walking or jogging of a subject (3, 18). 10,000 cycles during repetitive loading corresponds to the postoperative period of six weeks, essential for healing process of fractures (3). In our study, a force of 1,000 N was applied to each specimen in axial loading, while 1,000 N/mm at 3 Hz. was applied in repetitive loading for 10,000 cycles. This was to ensure the simulation of the 6-week period of an operated patient who walks with almost complete weightbearing on affected hip joint.

Rupprecht et al. induced standard Pauwels type 3 unstable transcervical collum femoris fracture in their study, where they biomechanically compared intertan nail, DHS, and tricannulated screw with reverse triangular configuration in fixation with an applied force of 1,400 N at 2 Hz. The authors reported the method of fixation with nail to achieve greater fracture loads compared to fixation techniques. They also stated the failure rates of targeted cycles of 10,000 of cyclic loading to be 12.5, 50, and 75 per cent in PFN, DHS, and cannulated screw groups, respectively. In our experiment, PFN group similarly reached greatest fracture loads upon a force of 1,000 N at 3 Hz in fixation of Pauwels type 3 basicervical fracture elicited on artificial bone model. While all specimens in cannulated screw group failed to cyclic loading, the specimens of other groups resisted 10,000 cycles with various levels of displacement. Apart from PFN, DHS and EF tended to have similar fracture loads whereas fixation with cannulated screw was found to have both markedly lesser fracture load and fixation stability than other techniques. However, CS fixation without weight bearing may perform better in clinical practice than in this experiment.

Ideal test material concerning fixation of the fracture is suggested to be human cadaver bone (10, 13). Due to difficulties in access to cadaver bone and prohibition of handling of bone tissue materials for scientific researches in institution of forensic medicine, we conducted our experimental study on synthetic composite bone models. Usage of artificial bone models is a frequent method in biomechanical studies (10, 12). Though these models, manufactured from polyurethane foam having a cancellous inner part and a harder cortical part, may not thoroughly mimic biomechanical behaviors of human bone, they offer standard sizes and characteristics, minimizing the probable bias created by variations in bone models (10, 23). This ensured minimal impact of probable alterations of specimens' bone quality on our results. Furthermore, composite bone is easier to obtain and store, also it has been reported to have a modulus of elasticity similar to that of native bone (21).

One of the major limitations in this study is the exclusion of torsional stability testing. Since we had limited number of composite bone models, our study design did not include torsional stability testing. Nevertheless, axial load is suggested to be the major deforming force leading to failure of fixation at hip fractures (17).

Secondly, the experiments were carried out without the effect of surrounding hip muscle attachments (8). Since proximal femur is loaded by muscle forces that place the neck in compression during normal gait, axial stiffness and failure loads may have been underestimated in this study.

CONCLUSION

To conclude, our findings suggest that PFN, DHS and EF restored higher fixation strengths than CS in basicervical femoral neck fracture model. Although there is no significant difference among PFN, DHS, and EF, PFN has higher failure loads and possesses biomechanical benefits for fixation of unstable basicervical femoral neck fractures compared with DHS and EF.

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