Published in final edited form as:

J Am Acad Orthop Surg. 2019 January 01; 27(1): e41–e48. doi:10.5435/JAAOS-D-17-00155.

A Biomechanical Analysis of Fixation Devices For Basicervical Femoral Neck Fractures

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Abstract

Introduction—Basicervical femoral neck fractures are challenging fractures in geriatric populations. The goal of this study was to determine if compression hip screw (CHS) constructs are superior to cephalomedullary constructs for the treatment of basicervical femoral neck fractures.

Methods—Thirty cadaveric femurs were osteotomized and received either a CHS with derotation screw, a long cephalomedullary nail (LG) or a short cephalomedullary nail (SG). All constructs were loaded dynamically in compression until dynamic failure.

Results—All failed CHS constructs demonstrated superior femoral head cut out. In the LG and SG groups, constructs failed by nail cut out through the medial wall of the trochanter or rotationally. Normalized fluoroscopic distance was found to increase significantly with increasing cycle count when considering all treatment groups.

Conclusions—Given our results and those of previous studies, we could not determine superiority of one implant and recommend that surgeons select fixation constructs based on the individual patient's anatomy and the surgeon's comfort with the implant.

Dr. Johnson or an immediate family member serves as a board member, owner, officer, or committee member of the Orthopaedic Trauma Association. Dr. Cassidy or an immediate family member serves as a board member, owner, officer, or committee member of the American Association for Hand Surgery. Dr. Born or an immediate family member serves as a paid consultant to Illuminoss and Stryker; serves as an unpaid consultant to Biointraface; has stock or stock options held in Biointraface and Illuminoss; has received research or institutional support from Stryker; serves as a board member, owner, officer, or committee member of the American Academy of Orthopaedic Surgeons and the American College of Surgeons. None of the following authors or any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article: Dr. Deren, Dr. Chambers, and Mr. Koruprolu.

Introduction

Basicervical femoral neck fractures are typically seen in geriatric populations after low energy falls. In 1992, Cooper et al estimated that 250,000 hip fractures occurred in the United States alone.¹ Given the increasing age of the United States population, they estimated that by 2032 the number of these fractures would increase to 500,000 per year.¹ The goal of fixation of these fractures within 48 hours has become widely accepted allowing for early mobilization and weight bearing to prevent post-operative complications and allow maximal return to function remains constant.^{2,3,4,5}

Basicervical femoral neck fractures are a challenging fracture in geriatric populations. Data regarding their fixation is limited because these fractures are less common than intertrochanteric fractures and are often misdiagnosed⁶. Failure rates for these fractures are thought to be higher than intertrochanteric hip fractures, with implant cut out, nail breakage and failure rates reported as high as 54%.^{7,8,9} The goal of this study is to determine the biomechanically optimal construct for fixation of basicervical femoral neck fractures using human cadavers.

Prior studies have examined the role of various implants in the treatment of these fractures. Recently, studies have focused primarily on compression hip screws (CHS) and cannulated screw constructs, showing CHS devices with derotation screws to have a biomechanical advantage.^{10,11} One recent study using sawbones compared intramedullary and extramedullary implants for treatment of basicervical femoral neck fractures, and while it showed an increased load to failure for the intramedullary fixation device, due to multiple modes of failure in the treatment groups, this study lacked sufficient power to detect differences in groups.¹² The cephalomedullary nail is a reliable implant for treating unstable intertrochanteric fractures and may be a better alternative for basicervical fractures.¹³ There have been several small case series describing the use of cephalomedullary nails to treat basicervical fractures despite the lack of basic science research to support its use.^{8,14}

The goal of this study is to determine if a CHS construct with a derotation screw is superior to long and short intramedullary constructs with regards to cycles to failure and implant migration for the treatment of basicervical femoral neck fractures in a cadaveric model.

Methods and Materials

Specimen Preparation

Thirty female femur samples over the age of 75 years (mean age = 88.2±7.4 years; 15 matched pairs) were used. Fresh frozen cadaveric tissue is an appropriate medium for evaluating biomechanical properties because it most closely approximates *in vivo* biomechanical characteristics.¹⁵ Computed tomography (CT) and quantitative CT (QCT) Mindways (Mindways Software Inc, Austin, TX) analysis were used to quantify bone density (BMD) across the proximal femur for each sample.¹⁶ The specimens were screened for gross anatomical defects and were excluded if present. Specimens were maintained at -20 degrees Celsius until approximately 24 hours before testing. The samples were thawed, and all residual soft tissue was carefully removed. A basicervical femur fracture was then

created with the use of a thin bladed straight sagittal saw as described by Stafford, et al via a cut at the base of the femoral neck.¹⁷ Throughout preparation and testing, the specimens were kept moist with saline-soaked gauze.

Instrumentation

The treatment groups investigated were the CHS (Omega3, Stryker Inc, Kalamazoo MI) with derotation screw, long Gamma nail (LG) or short Gamma nail (SG) (Stryker Inc, Kalamazoo MI) with a center-center lag screw position as previously described by Baumgartner et al.¹⁸ A balanced incomplete block design was used to randomly assign the specimens to one of three comparison groups: CHS with derotation screw versus long cephalomedullary nail (CHS vs LG), CHS with derotation screw versus short Gamma nail (CHS vs SG), and long Gamma nail versus short Gamma nail (LG vs SG). A paired t-test was used to test for differences in BMD between matched pairs. Additionally, a one-way analysis of variance (ANOVA) was used to test for BMD differences between the three different comparison groups (LG vs SG, SG vs CHS, CHS vs LG). There were no differences found in BMD between contralateral sides for the same matched pair or for the three different comparison groups ($p=0.991$ and $p=0.891$, respectively). All instrumentation was performed in general accordance with the Instructions for Use Guidelines. Specimens from different groups were randomly selected for instrumentation to prevent any learning curve bias. To ensure anatomic reduction, all specimens were predrilled prior to osteotomy. The basicervical fracture in the CHS cohort was fixed with an appropriately measured lag screw, 130-degree side plate and a 6.5mm ASNIS III partially threaded screw of appropriate length (Omega3/ASNIS, Stryker Inc, Kalamazoo MI) (Figure 1). The plate was secured distally with two 4.5-millimeter cortical screws. Intramedullary nail length and lag screw length was measured for each femur and a 120 degree cephalomedullary nail was used (Figure 1). The proximal set-screw was placed to allow sliding of the lag screw while preventing lag screw rotation as per the manufacturer's technical manual. A single distal interlocking screw in the dynamic position was placed for each nail to simulate clinical practice and allow any additional fracture compression. Anterior to posterior and lateral radiographs were obtained before dynamic testing to ensure proper implant placement, and measure tip apex distance. Prior to loading, all fractures were compressed either using a compression screw in the CHS group, or the compression handle on the Gamma nail guide.

Dynamic Compression Testing

After instrumentation, the distal condyles were potted in a urethane compound and mounted on a double gimble fixture facilitating uncontrolled motion in the sagittal and coronal planes.¹³ The femurs were potted such that loading vector applied to head of the femur was in line with the intercondylar fossa. The potted femoral condyles were rigidly mounted to the base of an Instron 8521S servohydraulic load frame (Instron, Norwood MA). Proximally, the head of the femur was coupled with the actuator using a custom concave indenter (Figure 2). For all tests the loading vector was oriented in the center of the femoral head passing through the inter-condylar notch in the coronal plane and the femoral epicondyles in the sagittal plane. Samples were loaded dynamically in compression at 700N (one times body weight of 70 kg) with a loading profile of 70–700N (R ratio of 10) with a test frequency of 1 Hz (sinusoidal wave) for a total of 500 cycles.^{19,20} Upon the completion of 500 cycles, the

loading magnitude was increased by 350N (1/2 times body weight) and retested for an additional 500 cycles (R ratio of 10 sustained throughout testing). This ramping load sequence was repeated every 500 cycles until dynamic failure, reported as greater than 15 mm of height loss (plastic and elastic deformation) from the start of dynamic testing at 700N.^{13,21} Load and displacement data were recorded digitally at a frequency of 300 Hz. Displacement was observed in real time as actuator travel to assess deformation of the constructs and to determine if functional failure was reached. A displacement change of >15 mm from the beginning of testing was deemed a functional failure. Catastrophic failure was defined as the device clearly cutting out of the femoral head or the construct no longer functioning structurally.

X-ray: Device Failure Tracking

A fluoroscope was oriented around the test frame, such that X-ray could be acquired in the anterior-posterior direction for each femur in real time during mechanical testing. X-ray videos were captured at the beginning of testing (700 N load profile) and at every 500 cycle increment until failure or 3000 cycles. For the cephalomedullary and CHS constructs the perpendicular distance between the tip of the lag screw and the superior femoral head cortical wall was measured at each 500 cycle increment (Figure 3). All distances measured between the device and the superior femoral head cortex were normalized (subtraction) to their initial measurement at the beginning of the 700 N loading segment or 10 cycles. This normalized fluoroscopic distance represents change in device distance to superior femoral head wall over the course of the dynamic testing.

Cycles to Failure

All specimens that reached 3000 cycles were deemed run out. A generalized estimation equation for log normal distributions was used to access cycles to failure as the majority of specimens failed during testing (2 specimens of 30 were censored at 3000 cycles, 1 LG and 1 SG). The predictive factors of treatment group (CHS, LG, and SG), and BMD were used to assess cycles to failure in the model and the interaction between treatment group and BMD was included to allow for differences in treatment with increasing BMD.

Normalized Fluoroscopic Distance

Similarly, a generalized estimation equation for log normal distributions was used to access normalized fluoroscopic distance, with the predictive factors of treatment group (CHS, LG, and SG), cycle count, and specimen BMD. The interaction between treatment group and cycle count was included in the model to allow for differences in treatment with increasing cycle count. Tukey adjustment was used to maintain family wise alpha at 0.05 across multiple comparisons for both models (cycles to failure and normalized fluoroscopic distance). Sandwich estimation was used to adjust for any model misspecification for both models (unequal variances/covariances).²² In all cases, statistical significance was set to $p < 0.05$ *a priori*. SAS was used for all statistical analyses (version 9.4, Cary, NC)

Results

Bone Mineral Density Testing

All thirty samples were screened for anatomic defects and CT scanned from the most proximal point of the femur to below the lesser trochanter. This data was digitally analyzed by the QCT program to determine a T score and quantitative bone mineral density in mg/cc. The average T score was -2.27 (range: 0.25 to -4.51). The average quantitative bone mineral density was 252.32 g/cm^3 (range: 149.1 to 359.3). As defined by t score, 6 specimens were normal (T score >-1.0), 10 were osteopenic (T score -1 – -2.5) and 14 were osteoporotic (T score <-2.5).

Mode of Failure

Only two samples survived testing: one instrumented with a short cephalomedullary nail (SG) and one with a long cephalomedullary nail (LG). The mode of failure between the fixation constructs was different. In specimens instrumented with a CHS, all constructs failed by cutting out of the femoral head (Figure 4). While in specimens instrumented with the long cephalomedullary device, three constructs failed with the femoral head rotating around the lag screw, one failed with screw cut out of the femoral head, while the other five failed by nail migration through the medial wall of the trochanter (Figure 5). Similarly, in specimens instrumented with a short cephalomedullary device two constructs failed rotationally and seven failed with medial wall nail migration.

Cycles to Failure

Treatment group was not found to have a significant effect on specimen cycles to failure (p -value= 0.1469). BMD was found to have a significant effect on specimen cycles to failure where specimens with lower BMD had less cycles to failure (p -value= 0.024) (Figure 6). The interaction between BMD and treatment group was not found to be significant ($p=0.1910$).

X-ray: Device Cut Out Data

No difference was found for normalized fluoroscopic distance between treatment groups ($p=0.483$) when considering all cycle counts. Further, BMD was not found to have a significant effect on normalized fluoroscopic distance ($p=0.808$) across all cycle counts. Cycle count had a significant effect on normalized fluoroscopic distance ($p<0.0001$), where larger cycle counts were found to have larger fluoroscopic distances. Further, the increase of normalized fluoroscopic distance with increasing cycle count was found to be significant with the CHS and LG treatment groups but not the SG group ($p<0.0001$, $p=0.0001$, and $p=0.193$, respectively) (Figure 7). However, there was no difference between the increase of the normalized fluoroscopic distance between treatment groups (CHS vs LG, CHS vs SG, and LG vs SG; $p=0.064$, 0.138 , 0.628 , respectively) (Figure 7). Although, the difference between the increases of normalized fluoroscopic distance for the CHS and LG groups did approach significance. (Figure 7)

Discussion

Our testing was unable to demonstrate a difference in cycles to failure or implant motion in the femoral head associated with the method of fixation. However, mode of failure seemed to vary between treatment groups. In our study, all of the CHS failures occurred by the screw cutting out of the head, whereas the intramedullary constructs only had one cut out. The rest of our intramedullary constructs failed by having the nail migrate medially through the medial wall of the trochanter or by femoral neck rotational failure. This mode of failure may have been related to the amount of space between the intramedullary device and the cortices of the cadaveric femurs. This space may have allowed motion during load testing that results in cut out of the intramedullary device through the medial trochanteric border. Additionally, BMD had a significant effect upon cycles to failure, with lower BMD being associated with earlier failure.

Previous studies have been performed that demonstrate the biomechanical superiority of CHS constructs over cancellous screw constructs for basicervical femoral neck fracture fixation.^{10,11,12} However, only one such study attempted to compare CHS constructs to cephalomedullary constructs.¹² This study was performed in sawbones and due to sample size restrictions was unable to determine any differences between its CHS, intramedullary fixation and external fixation groups.¹² In contrast to the results of Imren *et al*, none of our CHS constructs failed rotationally, likely due to our use of a derotation screw.¹² We included a derotation screw in our CHS construct group based upon these rotational failures and the results of previous biomechanical analysis showing improved strength and rotational control with the addition of the derotation screw.^{10,11,12}

We were not able to establish the superiority of one construct in terms of cycles to failure or movement of the screw in the head of the femur. This study did however suggest that modes of failure may be different in each group. In the intramedullary groups, there were five rotational failures (3 LG and 2 SG), which limits our ability to interpret our data about motion of the lag screw in the head as detected by live fluoroscopy. This may cause us to over report the amount of motion seen in the intramedullary group, as rotational failure may be reported similar to superior migration.

These rotational failures may have been related to lower bone mineral density; however due to the sample size this cannot be definitively stated. The implications for clinical use based on mode of failure are not clear. Lag screw cut out can result in significant acetabular bone damage while migration through the medial wall of the trochanter may have significant effect on the abductor muscle tension. Additionally, this failure results in the loss of the bony architecture of the femoral head, usually necessitating an arthroplasty revision procedure. While our study demonstrated an element of rotational instability of our cephalomedullary groups, there are cephalomedullary nail designs with multiple secondary sites of fixation into the femoral neck that may prevent some of these rotational failures. While cephalomedullary nails with multiple points of fixation into the femoral neck have not been studied in basicervical femoral neck fractures, they have been evaluated in intertrochanteric hip fractures. One biomechanical study found them to be more stable in a cadaveric intertrochanteric fracture model to axial loading, and rotational forces than

cephalomedullary nails with one point of fixation into the femoral neck.²³ The clinical superiority and importance of these nails have not been born out in the literature, however, it may provide a better solution to basicervical femoral neck fractures that have less bony contact and lower intrinsic stability.^{24,25,26}

Our study has several limitations. Specifically, this is an *in vitro* biomechanical study and does not provide clinical follow-up on these fractures. Thus, it is difficult to determine which, if any, of these failures would occur prior to healing. However, unlike previous studies, fresh frozen cadaveric bones were used as these are most biomechanically similar to living, *in vivo* human bone.¹⁶ Also, the rotational failures of cephalomedullary constructs limit the ability to interpret the fluoroscopic data on screw movement in the femoral head. However, to our knowledge, this is the only study in the literature evaluating the strength of fixation between CHS constructs, long cephalomedullary devices and short cephalomedullary devices. Additionally, some of the nail medialization seen in our LG and SG constructs may have been secondary to unidirectional loading, as we did not use a multidirectional loading system.²⁷

One recent study by Watson et al, reviewed 11 basicervical femoral neck fractures treated with cephalomedullary nails, six of which failed.⁹ Five of the six failed by screw cut out and collapse, causing the authors to caution against the routine use of cephalomedullary nails for treatment of these fractures.⁹ This rate of failure is much higher than the rate of failure reported for similarly treated intertrochanteric hip fractures reported in the literature, demonstrating the unique challenges posed by basicervical femoral neck fractures.^{7,18} These results differ from ours given that screw cut out was only noted in one intramedullary sample. We also note that head cut out was seen in all CHS samples. Based on the modes of failure seen in our study, it does not seem that CHS constructs provide a solution to the cutout seen by Watson et al in their cephalomedullary nail group. The mode of femoral head failure of our cephalomedullary nail constructs may allow for a bone sparing revision surgery, such as a valgus producing intertrochanteric osteotomy.²⁸ According to our data, BMD had a very strong correlation failure. While our specimens included normal, osteopenic and osteoporotic specimens; lower BMD was associated with earlier failure.

Further clinical evaluation of fixation constructs is warranted to determine optimal fixation in basicervical femoral neck fractures. However, given our results, and the rest of the body of literature regarding fixation of these fractures, there does not seem to be a clearly superior implant in the treatment of these fractures. Biomechanical data on cephalomedullary nails with multiple points of fixation into the femoral neck is promising with regards to treatment of intertrochanteric hip fractures.²³ However, further studies looking at these devices in basicervical femoral neck fractures are necessary, as are studies evaluating the clinical benefit of these devices.

Acknowledgements:

Dr. Born is a consultant to Stryker Orthopedics but received no compensation for this study. The authors have received funding in the form of implant donation for this study from Stryker Trauma (Mahwah, NJ). This study was supported in part by a grant from the National Institutes of Health; (2P20 GM104937) (COBRE Bioengineering Core).

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Figure 1:
Example of a compression hip screw with derotation screw and cephalomedullary nail constructs. Osteotomies marked with arrows.

Figure 2:
Testing apparatus with Instron and fluoroscopy testing machines.

10 Cycles**2320 Cycles**

Figure 3:
Example of x-ray device cutout measurement.

Figure 4:
Example of compression hip screw construction at moment of failure as captured by live fluoroscopy, with lag screw cutting out of the head.

Figure 5:
Example of cephalomedullary nail construct migrating through the medial wall of the trochanter at moment of failure as captured by live fluoroscopy. Arrows highlighting migration of the nail construct.

Figure 6:
The effect of BMD on cycles to failure stratified by treatment group.

Figure 7:
Cycle count vs normalized fluoroscopic distance stratified by treatment group.