Introduction: Potential advantages of short-stem cementless femoral prostheses include preserving bone, avoiding proximal-distal mismatch, and less invasive surgery1-3. Proponents of distal contacting (routine-stem) prostheses advocate axial stability, reduced subsidence, and clinical record. Best design criteria for femoral hip prostheses include initial stability; normal proximal bone strains, and good bone-prosthesis contact. One underlying hypothesis is that normal proximal bone strain maintains the mechanical and physiological proximal bone environment and subsequently distal bone, eliminating detrimental remodeling and outcomes. The purpose of this study was to test for differences in prosthesis stability, proximal femoral surface strain, and cortical-bone prosthesis contact between short and standard-length femoral prostheses.

Materials and Methods: Eight fresh femur pairs were individually aligned in a holder, submerged in a water bath, and high resolution volumetric CT performed. Titanium 6/4 alloy short- and routine-stem femoral prostheses were custom manufactured, using the CT data for each femur pair (Stryker, Malwah, NJ). Short stems were inserted into one femur and routine-stems into the contralateral femur. Short stems had no bone contact distal to one centimeter below the lesser trochanter. Fig 1a. Standard-length stems had bone contact from the mid portion of the prosthesis until the distal tip where circumferential contact was attempted with a cylindrical distal tip matching the femur anterior-posterior diameter. Fig. 1b. Proximal femurs were surgical prepared using conventional curettes and a custom manufactured broach. To eliminate metal-artifact a methyl-methacrylate prosthesis replica was inserted prior to a second CT scan.

Bone Prosthesis Contact
Femurs were potted in aluminum channel replicating loading for mid-phase stance, aligned in a water bath, re-CT imaged, and data transferred to a workstation. Prosthesis circumference was measured in four zones: medial, posterior, lateral, and anterior. Prosthesis-bone contact was defined as a distance of less than 0.75mm. Medial, posterior, and anterior contact was calculated superior to the lesser trochanter. Contact for all 4 zones was calculated around routine-stem distal tips. Student t-tests tested for differences.

Proximal Femur Surface Strains
Following CT scanning, prosthesis replicas were exchanged for titanium prostheses. Photoelastic coating was applied to each femur (Measurements Group, Raleigh, NC). Coatings extended from the proximal femoral neck osteotomy to at least eight centimeters below the tip of the routine-stem, even for the short-femur stem. Fig. 1c. Surface strain measurements were made using a reflection polariscope and null-balance indicator (Measurements Group, Raleigh, NC). Surface strains were measured at forty-eight (short-stem) or fifty-two points (routine-stem) for each femur. Femurs were placed in a materials-testing machine, compressive loading was applied vertically to the prosthesis head center, a preload applied, and then loaded up to 2000 Newtons. Bone surface strains were measured on each femur during the 2000 Newton loading. Student t-tests tested for differences.

Torsional Stability
After surface strain measurement prosthesis torsional movement relative to the proximal femur was measured. Fig. 1d. Following preloading, a steadily increasing load up to 668 Newtons was applied for ten minutes, followed by increasing stepwise retroverting torque. Each retroverting torque was followed by a 3 Newton-meter anteverting torque. The retroverting torques ranged from 0 to 18 Newton-meters and were increased in 3 Newton-meter increments. Two thousand retroversion cycles were performed for each femur. Student t-tests tested for differences.

Results: Short stem lengths ranged from 80 to 110 mm. One centimeter below the lesser trochanter the stem tapered and did not have contact with the femur. Length of the proximal contacting portion ranged from 50 to 70 mm. Standard stem lengths ranged from 140 to 170 mm. Routine-stems were 40 to 65 mm longer overall (mean difference 51 mm).

Bone Prosthesis Contact
Bone-prosthesis contact in medial, posterior, and anterior portions of the femur proximal to the lesser trochanter ranged from 34 to 74 (mean 58) percent for short stems and 32 to 70 (average 54) percent for standard length stems. There was no statistical difference between the percent contact of the short stems and standard length stems (paired, one- and two-tailed t-tests).

Proximal Femur Surface Strains
Proximal bone strains were within published values and showed no significant difference between short- or standard length stems (paired t-test). Proximal strains ranged from 1257 to 1573 (mean 1188) microstrain for short stems and 1003 to 1425 (average 1027) microstrain for routine-stems. Distal strains were significantly higher for the standard length stems (p=0.01). Distal strain at the level of the routine stem tip region ranged from 625 to 791 (average 729) microstrain for short stems and 695-1057 (average 879) microstrain for the standard length stems.

Torsional Stability
Torsional micromotion increased with increasing torque, was less than 30 microns for all prostheses, and overall was not significantly different between the stem types (p>0.05). Micromotion for the short-stems ranged from 3 to 23 microns, versus 2 to 19 microns for standard length stems. Micromotion differences decreased as applied torque increased.

Discussion: In this study, there were no statistically significant differences between short and standard length femoral stems with regards to proximal bone-prosthesis contact, proximal femoral surface strains, and overall torsional stability. Femoral surface strains were higher adjacent to distal stem tips. Torsional stability for both stem types was appropriate for ingrowth and expected long term success. Study limitations include custom proximal design of both stems to optimize bone-prosthesis contact for each femur and minimize the effect of individual bone – off the shelf prosthesis fit mismatch. We wanted to study whether having a distal contacting standard length stem would lower proximal bone-prosthesis contact and whether a short stem would lower torsional stability. Another caveat is that a cylindrical distal tip and not a taper tip was used on the standard length stem.

Significance: Proximal femoral bone strains were not significantly increased with the use of short femoral stems. Based on this data, the proximal bone remodeling around tapered short and standard length stems should be similar. Both stem designs had initial rotational stability (less than 30 microns) to allow bone ingrowth. Thus, we would not expect a higher rate of failure to osseointegrate with the use of short stems.