A biomechanical evaluation of the interprosthetic distance as a risk factor for periprosthetic fractures of the femur: does the gap distance matter?

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Introduction

The treatment of femoral fractures between a proximal and distal prosthetic stem is expected to become a major challenge because of the increasing life expectancy and the rising prevalence of osteoporotic fractures, Total Hip (THA) and Total Knee Arthroplasties (TKA). Although orthopedic surgeons intuitively consider a decreased interprosthetic gap distance as an important risk factor for a periprosthetic fracture of the femur, this has never been quantified.

It was our aim (1) to evaluate the effect of the interprosthetic gap distance on the biomechanical properties of the femur and (2) to evaluate whether this would also influence the stability of a subsequent lateral plate construct used to treat these fractures.

Material and Method

Twelve primary, cemented THA stems (C-stem, Depuy, &J&J) were cemented into a third generation and validated femoral sawbone specimen (Pacific Research Laboratories, Sawbones Europe, Sweden). The cement plug was inserted at a fixed distance from the greater trochanter and 1cm distal to the marked prosthetic tip position. Next, a 12mm diameter revision TKA stem (Profim, Smith & Nephew) of varying length was inserted. In group 1, a 10cm stem was inserted which resulted in an interprosthetic gap of 20cm. Likewise, groups 2 to 4 had an interprosthetic gap of 15, 10 and 5cm, respectively. There were 3 specimens in each group.

First, each individual specimen was mounted in a 250 kN Instron materials testing machine. The specimens were placed in a loading position of 15° of valgus inclination and a neutral position in the sagittal plane. Distally, they were placed in a V-shaped holder. Proximally, forces were applied on the femoral head through a socket that was potted in and fixed on the materials-testing machine with neutral anteversion with respect to the femoral neck. The femoral head could rotate freely in the cup. During application of a compressive force of 100 N preload followed by progressive compression of 8mm/minute, the force-compression curve was registered until failure of the specimen. The interprosthetic segment length was verified and the fracture pattern was documented with a high speed HD camera.

Second, the fractures of each group were fixed by 3 different devices with an anatomical fracture reduction. For construct A, a 20cm Accord cableplate (Smith & Nephew) was used and fixed with 5 cables to the femoral shaft. The specimens in group B were stabilized by a 43cm NCB plate (Zimmer) fixed with 2 screws in the greater trochanter, 3 bicortical screws around the THA stem, 2 screws in the butterfly fragment and 4 bicortical screws in the distal fragment. Construct C consisted of a fixation with a 39cm LCP plate (Synthes) with 2 screws in the greater trochanter, 3 cables around the proximal diaphyseal region and 3 bicortical and 2 locking screws distally. Plates in all constructs were placed laterally with the proximal end directly subtrochanterically. The specimens were tested again in the same setting. Failure of the constructs (defined as visual loss of fracture reduction) during compression was documented.

Results

All fractures occurred in the interprosthetic segment with a typical configuration of a butterfly fragment of the medial cortex. The mean force at which failure occurred (Fmax) was 7468 N (SD, 577 N). Statistical analysis did not show a variation of Fmax between different configurations (P-values, 0.702 to 0.997). Mean compression of the specimens at failure (Cmax) was 10mm (SD, 2.3mm). Although not statistically significant, we noted a trend of obtaining higher Cmax values in specimens with a larger interprosthetic gap. Similarly, the absorbed energy at failure, demonstrated by the area under the force-compression curve, could not be correlated to the interprosthetic gap length although a positive trend was seen.

After fixation, an average reduction of Fmax by 50% was noted with a mean Fmax of 3702N. No correlation could be found neither between Fmax of the construct and the length of the interprosthetic segment nor between Fmax and the type of construct. The best results were obtained with the NCB plate construct with a mean Fmax of 4434N, which was 62% of the original Fmax. The LCP plate-construct had a mean Fmax of 3760 N and the Accord plate of 2914N. These were reductions of the original Fmax of 50% and 62%, respectively.

Discussion

Although frequently intuitively thought otherwise, this experiment could not demonstrate any significant influence of the interprosthetic gap distance on the maximal compression force of a femur with a primary cemented THA and TKA revision stem for interprosthetic segments between 5 and 20cm. However, a trend towards higher energy absorption and more compressive bending before failure was noted for larger interprosthetic gaps. The specimens failed at a mean compressive force of 7468N. Bergmann¹ defined a set of in vivo loading conditions onto the hip joint by utilizing telemetered THA. For a 100kg individual, activities as walking (peak forces between 1800N and 3900N) and ascending stairs (peak forces between 1900N and 4200N) should be safely endured even with an interprosthetic segment as small as 5cm and in the presence of normal bone quality. However, during stumbling high peak force of up to 11000N were noted and patients can thus be at higher risk for a peri-prosthetic fracture with a decreased interprosthetic gap distance.

All plate constructs failed with a typical interprosthetic fracture with a butterfly fragment of the medial cortex which has been suggested to be a relative contra-indication for lateral plate constructs in Vancouver type B1 fractures³. This is also supported in the current study where none of the plate constructs could obtain an equal strength as the non-fractured femur and where 2 of 3 constructs where within the risk zone for failure during normal walking and stair ascent. Only with the NBC plate construct (Zimmer), all forces at maximal loading were higher than reference values for walking and ascending stairs.

This experiment utilized validated third generation sawbones. However, no other variables were taken into account such as bone quality, biometric parameters and the position of the interprosthetic segment relative in the femoral shaft.

Clinical relevance

This study suggests that up to a minimum 5cm distance, the length of the interprosthetic segment between two femoral stems does not alter the interprosthetic fracture risk. However, a trend towards more energy absorption was noted with a larger gap distance. A lateral, single plate construct significantly reduced the loading capacities of the femur and only 1 construct could resist loadings of normal walking and stair ascent.

References