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Impaction Force Influences Taper-Trunnion Stability in Total Hip Arthroplasty

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ABSTRACT

Background: This study investigated the influence of femoral head impaction force, number of head strikes, the energy sequence of head strikes, and head offset on the strength of the taper-trunnion junction.

Methods: Thirty titanium-alloy trunnions were mated with 36-mm zero-offset cobalt-chromium femoral heads of corresponding taper angle. A drop tower impacted the head with 2.5J or 8.25J, resulting in 6 kN or 14 kN impaction force, respectively, in a single strike or combinations of 6 kN + 14 kN or 14 kN + 14 kN. In addition, ten 36-mm heads with −5 and +5 offset were impacted with sequential 14 kN + 14 kN strikes. Heads were subsequently disassembled using a screw-driven mechanical testing frame, and peak distraction force was recorded.

Results: Femoral head pull-off force was 45% the strike force, and heads struck with a single 14 kN impact showed a pull-off force twice that of the 6 kN group. Two head strikes with the same force did not improve pull-off force for either 6 kN ($P = .90$) or 14 kN ($P = .90$). If the forces of the 2 impactions varied, but either impact measured 14 kN, a 51% higher pull-off force was found compared to impactions of either 6 kN or 6 kN + 6 kN. Femoral head offset did not significantly change the pull-off force among −5, 0, and +5 heads ($P = .37$).

Conclusion: Femoral head impaction force influenced femoral head trunnion-taper stability, whereas offset did not affect pull-off force. Multiple head strikes did not add additional stability, as long as a single strike achieved 14 kN force at the mallet-head impactor interface. Insufficient impaction force may lead to inadequate engagement of the trunnion-taper junction.

Femoral component modularity allows joint arthroplasty surgeons to intraoperatively modify femoral articular bearing material, offset, and size to maximize joint stability [1,2]. The femoral head is connected to the femoral stem via a morse taper connection between the femoral head female taper and femoral stem male trunnion. This design is reliant on a friction fit to stabilize the trunnion-taper junction and prevent micromotion during hip range of motion. To cold-weld the components, surgeons are suggested to impact the femoral head onto the trunnion using 1, 2, or multiple impacts without a specified impaction force level. These instructions have led to variable surgeon techniques in terms of strike energy and the number of strikes employed [3–5].

It is critical to achieve a secure connection between the femoral head and stem to minimize micromotion. In prior publications, it was found that the first strike determines 90% of the head pull-off force with subsequent hits minimally affecting stability [6]. Inadequate impaction force has been correlated with inferior head stability on the taper junction [3–6], which may lead to motion between the 2 surfaces resulting in trunnion damage and adverse local tissue reactions [1,5,7].

Few studies have investigated the factors influencing trunnion-taper stability. One study using finite element analysis testing demonstrated that increasing femoral head size directly intensifies the contact stresses between the trunnion and taper [8]. Similar

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trends have been noted in larger femoral heads, and one study demonstrated 20% lower pull-off force in 36-mm heads compared with 28-mm heads [9]. This connection may be further weakened if the junction is contaminated by blood, fat, debris, or other fluid, which significantly decreases the strength of the interface [1,6]. One variable that has not yet been investigated is the influence of femoral head offset on head stability.

Thus, the purposes of this study were to investigate how the trunnion-taper mating is influenced by (1) femoral head impaction force; (2) the number of head strikes; (3) varied energy sequence for 2 head strikes; and (4) femoral head offset. It is hypothesized that increased head impaction force, 2 high-energy head impacts, and neutral or decreased head offset is associated with stronger pull-off force.

Material and Methods

Forty titanium alloy trunnions (Ti6Al4V, Stryker, Mahwah, NJ) that were machine surface finished with an attached rectangular base were used in this study. The rectangular base (Fig. 1) facilitated attachment of the heads into the testing apparatus. The trunnion design was a taper angle 5°40', and this was matched to a 36-mm cobalt chrome femoral head (LFIT Anatomic, Stryker Mahwah, NJ) with corresponding taper design. Thirty heads were size zero offset, 5 were size −5 offset, and 5 were size +5 offset. Taper dimensions were confirmed with a gage (Wenzel LH87 Coordinate Measuring Machine, Wenzel America, Wixom, MI) with a servo controller and touch probe (Renishaw Group, Wotton-under-Edge, Gloucestershire, UK), confirming that the taper was within the tolerance of the equivalent clinical product. Before testing, all heads and tapers were cleaned in an ultrasonic cleaner with deionized water and micro90 detergent, then washed with alcohol and allowed to dry.

Individually, each femoral head was seated on the designated trunnion to ensure an equivalent baseline across all groups. Each head/neck combination was preloaded with 10N force (Chatillon DFS Series Digital Force Gauge, Ametek, Largo, FL). No sample was reused in this study. Each was securely mounted below a drop tower (Instron Dynatup 9250G; Instron Corp, Norwood, MA) with an 89 kN load cell, used for axial impaction of the femoral head. The samples were fixed in an alignment fixture, so that the locking taper analog and head were axially aligned in the center of the impaction load (Fig. 2). A modular surgical impaction handle with a polyethylene impaction pad was mounted above the femoral head. The samples were then impacted with an impaction energy of either 2.5J or 8.25J, resulting in approximately 6 or 14 kN impaction force at the drop tower-femoral head impactor interface, respectively. These impaction energy levels were previously studied by Scholl et al after studying average impaction force among 8 orthopedic surgeons [4]. Six different femoral head assembly protocols were then trialed with each comparison group comprising 5 femoral heads. Multiple head strikes, if utilized, were consecutively performed. Groups were assembled as follows: group 1 (6 kN impact), group 2 (14 kN impact), group 3 (6 kN + 6 kN impacts), group 4 (6 kN + 14 kN impacts), group 5 (14 kN + 6 kN impacts), and group 6 (14 kN + 14 kN impacts). Five femoral heads in group 7 (+5 offset) and 5 femoral heads in group 8 (−5 offset) were impacted with 14 kN + 14 kN impacts, and outcomes were compared to data from group 6 (+0-offset) with the same impaction protocol. The maximum force values were recorded in a controlled assembly test model.

Each construct was subsequently disassembled utilizing a screw-driven mechanical testing frame (Instron 5582; Instron Corp, Norwood, MA) at a rate of 0.008 mm/s (Fig. 3) [10]. Head disassembly was defined as a decrease in pull-off force of more than 1 kN. Peak distraction force was collected and compared between samples.

A power analysis demonstrated that a minimum of 3 samples per group would provide adequate power to identify a difference in femoral head pull-off force, using a $\beta = 0.8$ and $P < .05$, similar to protocols in prior studies [4,6]. To maximize study power, we utilized 5 samples per group. Test data for the taper assembly and disassembly tests were determined to be normally distributed and

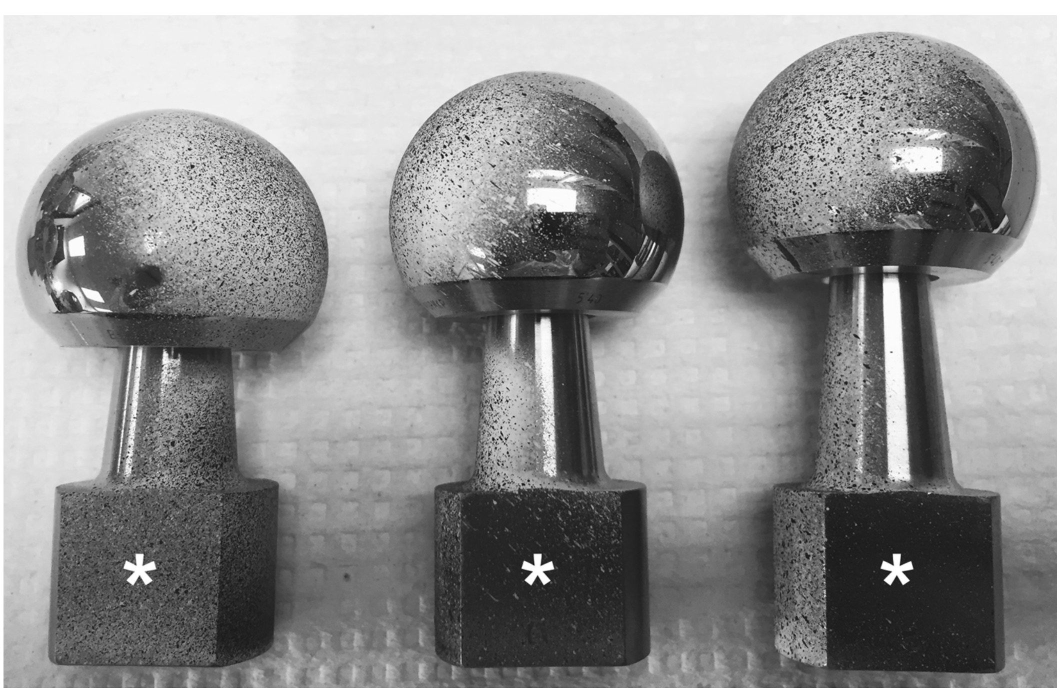

Fig. 1. Thirty-six millimeter cobalt chrome femoral heads of −5, 0, and +5 offset (left to right). *Depicts the rectangular base attached to the trunnion which facilitated attachment to the testing apparatus.