The Influence of Stem Taper Re-Use and Head/Stem Taper Mismatch on the Failure Load of Ceramic Heads

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Introduction: Modularity in Total Hip Arthroplasty (THA) is beneficial for patient and surgeon to reconstruct the patient specific anatomical situation. Despite of its advantages the additional interface of modular prostheses yielded in new problems. For couplings using ceramic heads, fracture of the head is rare but occurs [1]. In revision of those fractured heads, uncertainties arise whether or not to replace a well-fixed stem taper. Ceramic is a brittle material and even small damaged areas of the stem taper may lead to stress concentration causing premature failure of a new ceramic head. Clinically, ceramic heads placed on well-fixed used stem tapers at revision did not show overall increased re-fracture risk [2], but single incidents were reported [3]. Another problem with modularity is the possibility of mismatching components. Although strictly prohibited by the manufacturer, cases of mismatch resulting in catastrophic failure were reported [4].

The aim of this study was to directly determine the in-vitro fracture load of new ceramic heads paired with re-used tapers that have been subject to prior head fracture. Furthermore, the fracture load of new ceramic heads paired with mismatched stem tapers was investigated.

Methods: The fracture strength of Al2O3 ceramic heads (BIOLOX forte®; Ø 28mm, L) was measured by application of an axial force. Tests were performed on a custom-made test rig designed based on ISO 7206-10 with a Zwick Z400 test device (Zwick GmbH & Co. KG).

For investigation of stem taper re-use, five 12/14 tapers with matched heads (taper angle mismatch 0.09°) were subject to three subsequent fracture tests giving a total number of 15 fractured heads and two re-uses per stem taper. For investigation of mismatch between head and stem taper, five “Type 1” tapers were paired with five “V40” type heads (taper angle mismatch 1.7°) and loaded until failure. For both series, fracture loads were recorded and analyzed.

Before and after every fracture test, head and stem tapers were inspected visually and surface geometry was determined using a coordinate measuring device (Mitutoyo® Deutschland GmbH) and focus variation microscopy (FVM, Alicona® Imaging GmbH). The 3D coordinate data was used to determine the angular mismatch between heads and stems and macroscopic damages [5]. Additionally, a Finite Element (FE) model of the measured taper geometry was created from measured data and used to investigate changing contact conditions and stress distributions due to surface deformations in subsequent fracture tests (Figure 1).
Results: Taper re-use and mismatch both showed influence on the strength of the ceramic heads. For the subsequent re-use testing, no significant change of the mean fracture load was detected (Tamhane’s T2 Post hoc test, p≥0.77). The three group means (52.48kN, 47.40kN and 53.12kN) were above the required failure strength, but with every taper re-use, the standard deviation of the mean increased considerably (Figure 3A). For the first fracture test, standard deviation was 1.52kN, for the second 11.67kN and for the third 20.86kN. The fracture loads for the third test (twice re-use of taper) ranged from 17.8 to 70.4kN. Visible damages were found on all tapers independent from subsequent fracture load. Asymmetric deformations matching metal markings and points of crack initiation on the corresponding ceramic fragments were visible on some of the stem tapers. FE analysis indicated that deformations rising above the original taper surface caused stress concentrations resulting in early failure of the ceramic heads.

Evaluation of the fractured ceramic heads with the re-used stem tapers showed that the number of fragments positively correlated with the fracture loads (2-tailed Pearson correlation, r = 0.91, p≤0.01): Higher loads resulted in more fragments. Additionally, different patterns of metal markings were present on the fragments (Figure 2).
The mean fracture load for the mismatched heads (23.68kN±2.35kN) was significantly lower than the mean of the matched head - stem taper pairs (One-way ANOVA, p<0.001, Figure 3B). FE Analysis revealed increasing contact area and increasing contact stresses with decreasing taper angle mismatch.

Figure 3: Fracture loads of the ceramic heads. (A) Mean fracture loads and standard deviation of the three subsequent tests simulating stem taper re-use. No significant difference in mean fracture load, but standard deviation is increasing with every trial. (B) Comparison of fracture load of matched and mismatched head-stem taper pairs. Mismatched specimen had significantly lower fracture loads (p<0.001)
**Discussion:** The increasing deviation in fracture strength with re-use of stem tapers suggested a higher fracture risk for some of the specimens despite little variation in the mean fracture load. The lowest fracture strength observed (17.8kN) was close to reported in-vivo forces [6]. The FE model with measured geometry as input was capable of predicting the location of crack initiation.

For the mismatched pairs, fracture loads were much lower than expected. Metal markings indicated limited contact area and therefore stress concentrations in the ceramic head. This was supported by FE Analysis suggesting that a smaller taper angle mismatch was beneficial to increase contact area, preventing stress concentrations and thereby increase fracture loads.

Taper re-usage after ceramic head fracture as well as mixing and matching heads and stems that are not intended to be used together has to be avoided at all costs since failure could occur at dangerously low loads.

**Significance:** Stem taper re-use and mixing and matching of components did lead to failure of ceramic heads in the past but clinical evidence was controversial. Based on the results of this in-vitro study, it is strongly advised against taper re-usage or mismatching components with ceramic heads.

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