Short Stems Promote Positive Bone Remodeling; A DEXA And FEA Study

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Disclosures: A. Ercan: None. A. Traynor: 3A; Corin Ltd. D. Simpson: 3A; Corin Ltd. J. Jerosch: 1; Corin, Implantcast. 2; Sanofi, Orthomol, ÖSSUR.

Introduction: Short stem hip implants were introduced in an attempt to better replicate physiological loading, to minimize bone loss and improve the long term survival of the implant. Radiological response with respect to bone responses depends on proximal and distal stem design¹². Several short term DEXA studies¹²³⁴ have supported the use of short-stem design prostheses. This study aimed to predict the bone remodeling around a short stem implant by using Finite Element Analysis (FEA), and comparing the results to short term Dual Energy X-ray Absorptiometry (DEXA) analysis. Since bone resorption is often seen in Gruen zone 7, this was the focus of the study.

Methods: Two physiological load cases, stair climbing and gait, were simulated in finite element models of a short hip stem (MiniHip). Magnitudes and directions of the muscle forces and joint reaction force were obtained from Heller et al⁵⁶ and Duda et al⁷. The three dimensional geometry of the femur was constructed from computed tomography (CT) data of a donor (female, 44 years old, right side). Elemental bone properties were assigned from the Hounsfield Unit values of the CT scans. The elastic modulus (E) of the bone was assumed to be isotropic and was determined using a cubic relationship to the apparent bone density⁸, and the following E = cρ³. The Poisson’s ratio for the bone regions varied between 0.2 and 0.32 depending on the apparent density of the bone⁴. A size 2 short stem device was modeled and implanted into a cadaveric femur model (Figure 1). Frictional contact was used to represent the immediate postoperative period, where there is little bone integration. A coefficient of friction of 0.615 was used between the coated parts of the stem and the bone. Bonded contact was used to represent the point at which bone integration with the stem had occurred and frictionless contact was used to represent bone contact with the polished tip of the short stem.

Strains along the medial and lateral aspect of the femur were analysed for the stem and compared to the unimplanted femur. Strain energy density (SED) has been shown to be a predictor of bone remodeling through the mechanical environment therefore SED was compared in established Gruen zones⁹.

A short term DEXA study was completed using the MiniHip stem (Corin Ltd, UK). Thirty three patients aged 25 -76 years (average age 56 years; 20 women, 13 men) were enrolled in the study between 2011 and 2012. Periprosthetic bone mineral density in each of the 7 Gruen zones was measured by DEXA method with the Lunar Prodigy ™ (GE Healthcare, Madison, WI). Measurements were made postoperatively within the first 2 weeks as a baseline measurement. Follow-up measurements were performed at 3, 6 and 12 months post-operatively.

Results: The results of the FEA are shown in Figure 2 for the size 2 implanted case compared to the unimplanted case. The FEA model predicted no adverse remodeling in Gruen zone 7, when considering the lazy zone required to initiate any change. The DEXA data showed a slight decrease in bone mass in the first 3 months in Gruen Zone 7 (-12%, Figure 3). However, 12 months post-operatively, there was an increase in the bone mineral density in Gruen zone 7 (+0.65% Figure 3).
Discussion: The FEA analysis predicted little to no remodeling in Gruen Zone 7 and this was verified by the DEXA analysis at 3 and 12 months. The short stem transfers load physiologically into the bone and resulting in favorable remodeling. This study has shown that a generic FEA model is able to predict the mechanical loading environment around a short stem implant. Further work is required to create a patient specific model to more accurately predict the mechanical environment.

Significance: This study shows the possibility of using finite element analysis studies to predict the bone remodeling of different stem designs and the results are encouraging for the remodelling of bone around a short stem.