Quantitating the Effect of Prosthesis Design on Femoral Remodeling Using High-Resolution Region-Free Densitometric Analysis (DXA-RFA)

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Introduction: Our current understanding of the effect of prosthesis design on periprosthetic bone remodeling after total hip arthroplasty (THA) is limited. This is, in part, because the technology used, dual energy x-ray absorptiometry (DXA) has low analysis resolution and makes limited use of the available scan data. The sensitivity of the method is also confounded by the use of pre-defined analysis regions of interest (ROIs) that may not best fit the areas of most dynamic bone mineral density (BMD) change. We recently developed and validated a novel DXA analysis solution that allows tracking of periprosthetic BMD at the individual pixel-level from existing DXA scans, shedding the limitations of ROI-based DXA analysis methods (1). This tool, termed DXA-Region Free Analysis (DXA-RFA), has a median pixel-level accuracy error of within 1.9% (interquartile range -7.2 to 3.5%), and a median pixel-level precision, expressed as CV%, of 1.4% (IQR 1.2 to 1.6) (1). The aim of this study was to compare the effect of different implant geometries and fixation methods on proximal femoral bone remodeling using DXA-RFA. DXA data from 2 randomized trials were studied; one of composite beam versus sliding-taper cemented femoral prosthesis designs (2), and the other of a cementless proximally coated femoral design versus a hip resurfacing (3).

Methods: Effect of cemented stem design on bone remodeling: 120 subjects randomized at a ratio of 1:1:1 to receive a cemented composite-beam femoral prosthesis, a double-tapered, polished prosthesis, or a triple-tapered, polished prosthesis were studied. BMD was measured at post-operative baseline within 1 week of surgery, and at 3, 6, 12 and 24 months using a Hologic QDR4500A densitometer (Hologic Inc, Bedford, MA). Hip resurfacing versus total hip replacement: 30 subjects randomized at a ratio of 1:1 to receive a cemented resurfacing head of the ASR brand or a cementless, proximally plasma-coated, titanium Bi-metric femoral component were studied. BMD was measured at post-operative baseline within 1 week of surgery, and at 2, 12 and 24 months using an Hologic QDR4500A densitometer. The acquired DXA scans were quantitated using DXA-RFA. Heat-maps were generated to show the baseline post-operative BMD distribution at pixel-level for each prosthesis type and the change in BMD at each time-point. The P-value of the overall change at 24 months versus baseline within each group was calculated using a paired t-test and is presented here.

Results: Baseline scans for all prosthesis groups showed a pattern of BMD distribution consistent with proximal femoral architecture. Over 2 years the greatest BMD changes occurred in the metaphyseal region with relatively less change at the diaphysis for all designs (Figures 1 & 2). BMD change events occurred in discrete focal areas that mapped poorly to established ROI models. An increase in bone mass was consistently observed across all prosthesis designs in the area of the greater trochanter (P<0.001), and was most intense adjacent to the interface with the lateral border (shoulder) of the
prosthesis (up to P<0.0001). Many remodeling features varied with prosthesis design. Cemented stemmed prostheses showed a spatially-complex pattern of BMD change in the area medial to the proximal half of the prosthesis. Significant bone loss (P<0.001) occurred in the femoral cortex immediately central to the lesser trochanter (the femoral calcar), however more radially in the region of the tendinous attachment no bone loss occurred. These inter-regional differences in the pattern and direction of BMD change were more focal and statistically significant for the sliding-taper prostheses (P<0.0001) than the composite-beam prosthesis. A similar trend towards an increase in bone mass in the periosteal region of the medial femoral cortex was found in the cementless, proximally coated prosthesis, but no significant calcar bone loss was found. In contrast, the hip resurfacing prosthesis showed a widespread increase in metaphyseal BMD (P<0.001), but no significant areas of bone loss.
**Discussion:** The increased spatial resolution of DXA-RFA allowed the architectural detail of proximal femoral bone mass distribution to be examined around all the prosthesis designs studied, with quantitation of cortical and cancellous bone remodeling events independently. Our finding that remodeling events occurred in small but spatially discrete ‘quanta’ rather than as a diffuse continuously-graduated process is consistent with the biology of bone remodeling that occurs in discrete multicellular bone remodeling units. These BMD changes were spatially-complex and prosthesis-specific, with central to radial differential distribution that is unresolved using conventional ROI analysis. These findings suggest that high-resolution region-free analysis approaches are required to identify subtle differences induced by different prosthesis designs.

**Significance:** Analysis at pixel-level enhances the sensitivity of DXA in detecting local remodeling events and better facilitates in-vivo comparisons of the post-operative bone remodeling characteristics associated with different prosthesis designs.

ORS 2015 Annual Meeting  
Poster No: 1118