Stress distribution of osteoporosis and normal bone on humeral short stem implantation: Finite Elements Analysis

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INTRODUCTION: Reverse total shoulder arthroplasty (RTSA) aims to relieve pain and restore shoulder joint function caused by chronic disease or trauma. The stress shielding effect is one of the major postoperative problems for RTSA, which is mainly appears in the humeral part. To minimize the stress shielding and preserve the bone, short stem has been used more and more recently. However, short stem might lead to malalignment due to its short length and wider metaphysis of proximal humerus. When it comes to the curved short stem, the probability of malalignment would be higher. It could result in another stress shielding on the medial or lateral side of proximal humerus. And this stress shielding in malaligned short stem could be more aggressive especially in the osteoporotic bone. However, there are lack of studies regarding biomechanical consequence of malaligned short stem in osteoporotic bone. Therefore, the current study aims to analyze the biomechanical aspects of the humeral bone, when the humeral short stem is located in the neutral-varus-valgus position on normal BMD and osteoporosis states. The hypothesis is that the osteoporotic bone will show more severe stress shielding compared to normal bone density in malalignment.

METHODS:
Image Segmentation and 3D Model Reconstruction: One humerus with normal BMD (BMD -1.2) and one osteoporotic humerus with low BMD (BMD -2.8) were selected for this study. Image segmentation was performed on the humerus containing both cortical and trabecular parts and Tornier Perform Humeral Stem (Stryker, United States) was chosen for short stem. The humeral head was cut according to anatomical standards, and the humeral stem was aligned into neutral, varus, and valgus axis respectively.
Finite Elements Model Settings: Bone density was calculated through the HU value of the CT DICOM image, and an experimental formula can be also followed to calculate the elastic modulus through the density. All Degrees of Freedom (DOFs) was fixed for the surface of the most distal part of the humerus. Force and moment were set considering surface contact force and sum of all periscapular muscle forces in the shoulder joint.
Analysis: The stress distribution was analyzed by selecting Von-mises stress. Sections, which were defined as 'slice 10' to 'slice 80', were set at 10 mm intervals from the most proximal part. For each section, average stress values of medial and lateral part were divided into cortical and trabecular. The average stress value differences between the state without implant placement and each alignment condition were expressed as percentage.

RESULTS SECTION: In the varus state in normal BMD, stress shielding was reduced in both medial and lateral parts. In the normal BMD varus state, the percentages of 339, 500, and 464 for the proximal 10 to 30mm lateral part of bone were all greater than the percentages of 260, 415, and 337 in the neutral state. In the medial part, the same trend was observed, where the percentages of 248, 383, and 313 in the varus state were greater than the corresponding percentages of 130, 248, and 215 in the neutral state. In the neutral and varus states, the osteoporotic bone exhibited relatively lower percentages compared to normal bone density. Notably, the disparity was more pronounced in the lateral portion when compared to the medial part. In the valgus state, for both normal BMD and osteoporosis, the stress to the bone is greatly reduced, maximizing proximal stress shielding. However, in the valgus condition, it was difficult to find a difference according to the presence or absence of osteoporosis compared to other conditions. In the lateral part of the valgus state, all values showed minus percentages. For the medial region spanning the proximal 10 to 30mm, normal bone mineral density exhibited percentages of -65, -63, and 15, whereas osteoporotic bone displayed percentages of -77, -55, and -9. The distal region in the valgus position exhibited a notably more negative value compared to other conditions, reaching a maximum of -75 percent.

DISCUSSION: With the curved short stem, varus malalignment was more beneficial in terms of proximal stress shielding. Regardless of BMD, in the valgus state, the stress to the bone is greatly reduced and proximal stress shielding is maximized. Thus, it will be better to avoid valgus implantation especially in the osteoporotic bone. In addition, stress shielding in the distal part was more remarkable for the valgus malalignment. Our results can be emphasized based on previous clinical studies showing that valgus malalignment was more common than varus malalignment. Stress shielding in osteoporosis was much greater than in normal BMD, and regardless of osteoporosis, stress shielding was found to be large in case of valgus state. Unlike in normal BMD, implant insertion to osteoporosis needs to be careful because a stress shielding effect in the proximal region may occur in neutral and varus conditions. In conclusion, our hypothesis that stress shielding would be much more sever in osteoporosis could be approved.

SIGNIFICANCE/CLINICAL RELEVANCE: Although further research needs to be conducted, our results suggested that osteoporosis shown more stress shielding effect compared to normal BMD and especially for the valgus position of curved short stem implantation seemed to be severe by stress shielding effect regardless of BMD.

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IMAGES AND TABLES:

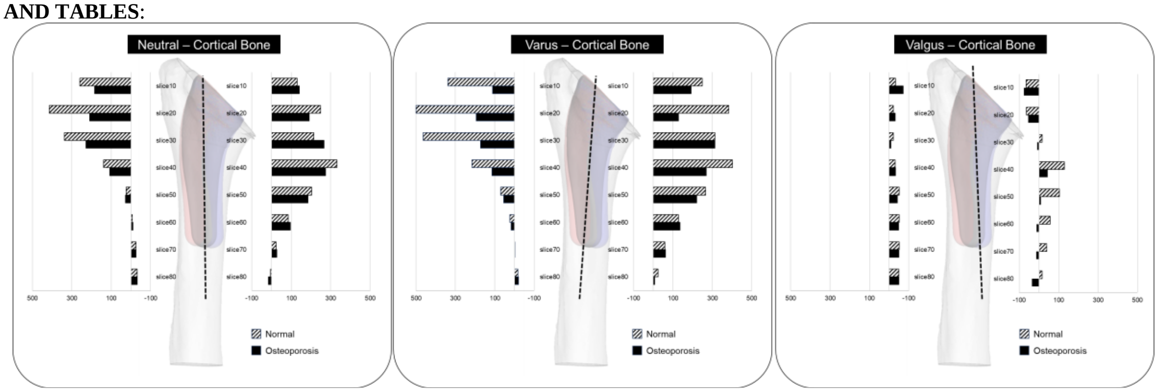

Figure. Average stress value differences between non-implantation and different implantation axis bone state into percentage