BONE REMODELING ANALYSIS AROUND FUNCTIONALLY GRADED AND FULLY METALLIC ORTHOPAEDIC SCREWS: CONSIDERING DISUSE AND OVERLOADING RESORPTION

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INTRODUCTION
Bone loss around orthopaedic screws due stress shielding and its consequent screw loosening and avulsion is one of the main concerns of orthopaedic surgeons. In this study, we are combining bone remodeling algorithm based on strain energy density stimulus with finite element approach to evaluate biocompatibility of two types of orthopaedic screws, i.e. functionally graded and fully metallic screws.

METHODS
A 2D axi-symmetric idealization of bone-screw geometry is modeled using the FE package of ANSYS [1] (Fig. 1). A dimensionless set of stress-transfer parameters (STP) and newly introduced strain energy density-transfer parameter (SEDTP) are developed to quantify the screw–bone load sharing, which are defined as follow [2]:

\[ STP_a = \frac{\sigma_{sl}}{\sigma_{f}} \]  \hspace{1cm} (1)

\[ STP_\beta = \frac{1}{N} \sum_{i=1}^{N} \frac{\sigma_{sl}}{\sigma_{f}} \]  \hspace{1cm} (2)

\[ SEDTP_a = \frac{\sigma_{sl} \times \sigma_{f}}{\sigma_{f} \times \sigma_{f}} \]  \hspace{1cm} (3)

\[ SEDTP_\beta = \frac{1}{N} \sum_{i=1}^{N} \frac{\sigma_{sl} \times \sigma_{f}}{\sigma_{f} \times \sigma_{f}} \]  \hspace{1cm} (4)

where \( \sigma_{sl} \) is the stress in the bone between consecutive screw threads, \( \sigma_{f} \) is the stress in the midpoint of screw threads, and \( N \) is the total number of screw threads. Lower values of STP and SEDTP indicate weak load transfer to bone, which is a sign of stress shielding. Bone properties are changed during the simulation using the following bone remodeling equations [3]:

\[ \frac{\delta \rho}{\delta t} = B \left( \frac{n}{\rho} - K_{Min} \right) \]  \hspace{1cm} if \( \frac{n}{\rho} < K_{Min} \) \hspace{1cm} (5)

\[ \frac{\delta \rho}{\delta t} = 0 \]  \hspace{1cm} if \( K_{Min} \leq \frac{n}{\rho} \leq K_{Max} \) \hspace{1cm} (6)

\[ \frac{\delta \rho}{\delta t} = B \left( \frac{n}{\rho} - K_{Max} \right) \]  \hspace{1cm} if \( K_{Max} < \frac{n}{\rho} < K_{Overloading} \) \hspace{1cm} (7)

\[ \frac{\delta \rho}{\delta t} = B \left( K_{Overloading} - \frac{n}{\rho} \right) \]  \hspace{1cm} if \( K_{Overloading} < \frac{n}{\rho} \) \hspace{1cm} (8)

where \( \rho \) and \( B \) are the apparent density and remodeling constant, respectively, and \( K_{Min} \), \( K_{Max} \), \( K_{Overloading} \) are strain energy density reference values for bone resorption, formation, and loading conditions.

In every iteration bone properties is updated via two separate density-elastic modulus relationships for cortical and cancellous bone, through the following equations [3]:

\[ E(MPa) = 2065 \times \rho^{3.09} \]  \hspace{1cm} Cortical bone \hspace{1cm} (9)

\[ E(MPa) = 1964 \times \rho^{1.64} \]  \hspace{1cm} Cancellous bone \hspace{1cm} (10)

In this study, the configuration of FGM follows the patterns from literature [4], and is governed by a power law based on mixture theory.

RESULTS
Results of this study indicate that STP and SEDTP values for a FGM screw are greater than those of a fully metal screw. Moreover, reducing the elastic modulus of the metal fraction and increasing the volume fraction of ceramic would decrease the stress shielding. Also, by increasing screw major diameter, thread numbers and decreasing minor diameter, pitch and elastic modulus, STP and SEDTP values will increase, which means a lower probability of screw loosening.

DISCUSSION AND CONCLUSIONS
By manipulating orthopaedic screws’ design parameters, many revision surgeries might be avoided. Employing bone-like material for orthopaedic screws can greatly decrease the risk of excessive resorption around screws’ threads, and thus decrease the probability of screw loosening. Future research can include the real configuration of cancellous bone, and an isotropic model for both cortical and cancellous bones.

REFERENCES
[1] ANSYS, v 11, Swanson Analysis Inc., Houston, PA, USA.