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CONVENTIONAL AND ULTRASONICALLY ASSISTED BONE CUTTING: FINITE ELEMENT STUDY

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ABSTRACT

Bone cutting is one of the oldest and most frequent surgical procedures in the history of medicine. One of the principal methods of repair and reconstruction of a bone fracture is achieved by cutting the bone and fixing its separate parts together using screws, wires and plates. Modern bone cutting techniques aim at minimizing the invasiveness and improving the safety of the operation.

Surgical instruments that employ ultrasonic vibrations of the blade/drill bit are becoming popular in clinical practice. These instruments allow easy separation of perosium and coherent mass such as calcium from the bone. Also better penetration control of the cutting tool can be achieved to avoid unnecessary damage to the soft tissues. A temperature increase in bone cutting can cause thermal necrosis that is associated with irreversible changes in its structure and physical properties reducing the stability and strength of the fixation.

In this study a thermo-mechanical finite element model of cortical bone cutting is presented based on ABAQUS. Bone is modelled as a unidirectional-fibre reinforced composite material. To predict cutting forces and temperatures, the properties of fibre and matrix are used to obtain an equivalent homogeneous anisotropic material that is used in initial simulations (Fig. 1).

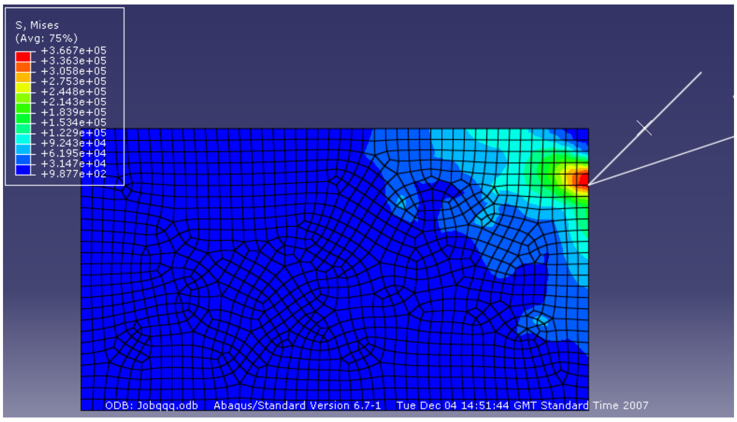

Figure 1. FE cutting model of equivalent homogeneous anisotropic bone material

The next stage of the study is based on presentation of the bone tissue in terms of a two-phase micro-mechanical composite model with osteons modelled as fibres and interstitial bone material serving as matrix (Fig. 2). The geometrical parameters of the model (e.g. average osteon diameter, tool dimensions) are acquired by microscopic examinations. Nanoindentation is used to measure mechanical parameters (e.g. hardness, elastic modulus) of the bone tissue. The obtained parameters are mapped onto the modelled composite structure to mimic the nature of bone at the micro scale. Fibres and matrix are assumed to be elastic and elasto-plastic, respectively.

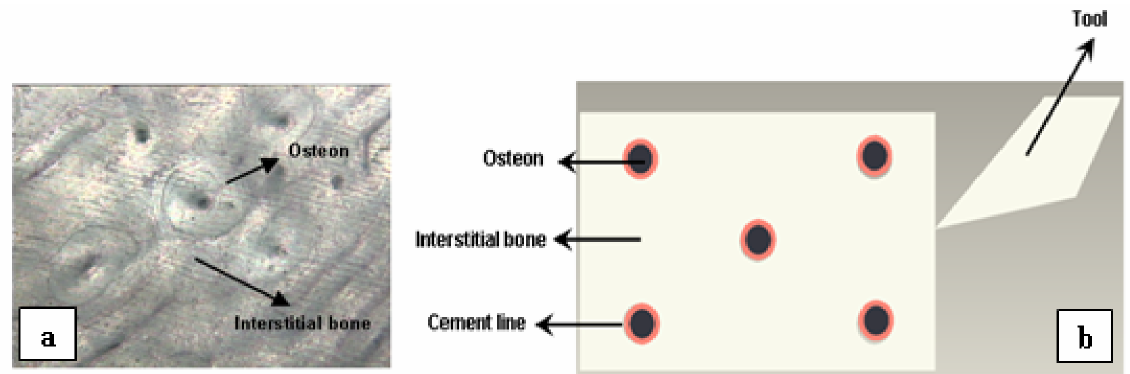

Figure 2. Bone microstructure (a) and FE model of cutting (b)

The cutting tool penetrating into the bone is modelled with a constant penetration rate or vibrating with frequency 20 kHz to represent conventional and ultrasonically-assisted cutting techniques, respectively. The tool surface temperature, measured experimentally for free vibration of the tool (i.e. when the tool is not in contact with the bone), is applied as an additional boundary condition in ultrasonic cutting simulations. No irrigation (cooling environment) is modelled in the simulations. Cutting forces exerted on the cutting tool modelled as a rigid body are predicted for both penetration modes as well as temperatures and thermal damage (necrosis) in the bone.

Crack propagating ahead of the tool is monitored in the FE model; cohesive elements are utilized to simulate this process. Advantages and limitations using a vibrating tool for cutting of bone tissue are also discussed. The results obtained in numerical simulations are compared with the experimental data for forces and temperatures.