ULTRA-HIGH SPEED IMAGING FOR STUDYING ULTRASONIC CUTTING OF BONE & CARTILAGE

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Introduction

High-power ultrasonic surgery tools offer exciting opportunities for minimally invasive surgeries as their use requires low force while still providing high precision and preservation of critical biological structures such as nerves [1]. To understand the mechanics of ultrasonic cutting, a thorough understanding of blade-tissue interaction is necessary. This system is highly dynamic and depends on many factors such as properties of the tissue and the characteristics of the cutting device (type of blade, frequency, amplitude). In this study, we employ ultra-high speed imaging with imaging rates of over one million frames per second to temporally resolve deformation of bone and cartilage under ultrasonic cutting. We hypothesize that, by understanding the cutting process, it will be possible to optimize the cutting configuration leading to better outcomes for patients such as faster recovery and fewer complications.

Methods

In a preliminary study, a small cut was made in a piece of bovine cortical bone (from the femur) using a custom ultrasonic cutting device operating at 25 kHz and in chiseling configuration. The side surface of the specimen was prepared with a unique pattern, using a microcontact printing technique that is necessary to measure kinematics using Digital Image Correlation (DIC). The specimen was observed during the experiment with two high speed cameras (i-Speed 513, iX), capturing images at 75 kHz. The cameras were equipped with high magnification lenses (12x, Navitar), providing a field of view 8 × 4 mm^2 and the illumination was realized by means of a pulsed laser synchronized with camera acquisition. The gray scale images were processed with stereo DIC to measure relative motion of the bone specimen resulting from the interaction with the cutting tip.

Results

In this preliminary study displacements in bovine bone were measured resulting from the impingement of the ultrasonic tool vibrating with an amplitude of approximately 20 µm. The maximum displacement of the bone was measured as 2 µm (as seen in Figure 1), suggesting that the deformation is primarily concentrated close to the cutting site which cannot be resolved with the current state of high-speed camera technology.

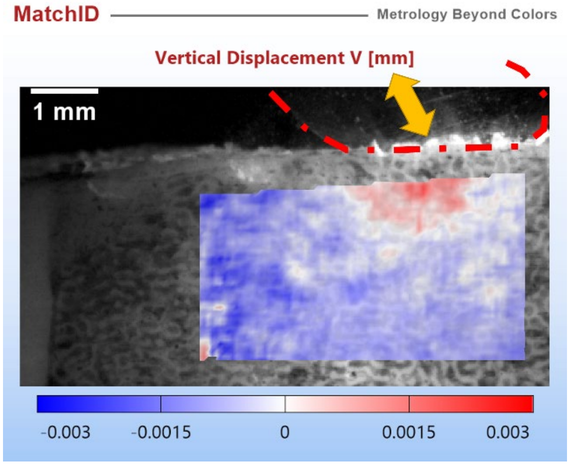

Figure 1: Ultrasonic tool impinging on the top surface of a bovine bone specimen. Digital image correlation was used to measure the deformation resulting from the tool-tissue interaction.

Discussion

The proposed method of imaging ultrasonic cutting is capable of providing insight into tool-tissue interaction and measuring deformation resulting from the mechanical contact between the two. Due to the stiffness of bone, the majority of deformation is concentrated in the cutting region, therefore a following study was performed on human cartilage samples. In this study, even faster cameras will be employed (Shimadzu HPV-X, 5 MHz) resulting in temporally resolved motion of the tissue. The proposed method enables study of the effects of process parameters, such as operating frequency, amplitude or blade geometry. These mechanical parameters can affect the amount of cell death at the cutting edge and therefore the biological outcomes of the surgical procedure.

References

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