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Infrared thermal imaging during ultrasonic aspiration of bone

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Abstract

Ultrasonic surgical aspirator tips target removal of bone in approaches to tumors or aneurysms. Low profile angled tips provide increased visualization and safety in many high risk surgical situations that commonly were approached using a high speed rotary drill. Utilization of the ultrasonic aspirator for bone removal raised questions about relative amount of local and transmitted heat energy. In the sphenoid wing of a cadaver section, ultrasonic bone aspiration yielded lower thermal rise in precision bone removal than rotary mechanical drills, with maximum temperature of 31°C versus 69°C for fluted and 79°C for diamond drill bits. Mean ultrasonic fragmentation power was about 8 Watts. Statistical studies using tenacious porcine cranium yielded mean power levels of about 4.5 Watts to 11 Watts and mean temperature of less than 41.1°C. Excessively loading the tip yielded momentary higher power; however, mean thermal rise was less than 8°C with bone removal starting at near body temperature of about 37°C. Precision bone removal and thermal management were possible with conditions tested for ultrasonic bone aspiration.

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Keywords: Ultrasonic Surgical Aspirators; Ultrasonic Aspiration of Bone; Ultrasonic Bone Removal; Infrared Thermal Imaging of Bone

1. Introduction

Ultrasonic surgical aspirators have been used in removal of tumors and diseased tissue in neurosurgery and general surgery for more than 30 years, Balamuth et al. [1] and Wuchinich et al. [2]. A continuous circuit of cooling saline irrigation liquid dilutes blood and further wets aspirated tissue to prevent occlusion of the central suction channel. Small diameter (0.38 mm) preaspiration holes are used axially near the distal end of the surgical tip to further ensure cooling, prevent occlusion, and capture mist. The distal end of the surgical tip vibrates at ultrasonic frequencies with high amplitudes (e.g., 24 kHz and 305 µm p-p).

More recently developed ultrasonic surgical tips enable broader neurosurgical uses including endonasal and neuroendoscopic applications, [3-7] fine removal of bone adjacent to critical neural and vascular structures, [8-16]

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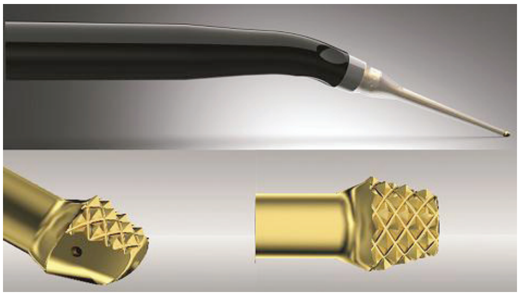

Fig. 1. Developmental Ultrasonic Aspirating Bone Tip. A 24 kHz Bone Tip and piezoelectric transducer are shown, along with magnified illustrations.

and debulking of fibrous, calcified tumors. The lack of rotational forces and low profile angled tips provide increased visualization and safety in many high risk surgical situations that commonly had been approached using a high speed drill. However, the utilization of the ultrasonic aspirator for bone removal raises as of yet unanswered questions about the relative amount of local and transmitted heat energy from the cavitating tip compared to that generated by various drill bits.

2. Methods

Herein, thermal effects of ultrasonic bone aspiration are investigated with an initial study using development surgical bone tips, shown in Fig. 1, removing bone in a human cadaveric section and more statistical analysis in representative porcine cranium. Temperatures in precision bone removal in the sphenoid wing are compared for ultrasonic surgical bone tips and high-speed mechanical fluted and diamond drills. Non-contact Infrared Thermal Imaging is utilized.

The developmental surgical bone tip is a 24 kHz ultrasonic horn (Integra LifeSciences, Plainsboro, NJ, USA, U.S. Patent No. 8,092,475 and 8,142,460) driven by the transducer. The design intent follows:

- Protruded working surface for improved visibility
- Relief angles to avoid resistance to plunge cutting
- A 45° helical lay of pyramids
- Surgical tip stroke of 250 µm p-p, exceeding cavitation threshold in saline, measured to be 208 µm p-p
- Pyramidal structure to enable varying angled refracted longitudinal waves and stress concentration
- Reduced frictional heating
- Improved efficacy, visibility, and geometry

A comparison of ultrasonic bone removal and mechanical fluted and diamond drills was conducted. The sphenoid wing of a cadaveric section was targeted. Maximum temperature readings were taken manually during bone removal in the field of view with a FLIR Infrared Camera, ThermaCAM P45HSV. Electrical power data were acquired continuously under Labview control via a Yokogowa WT-210 Digital Integrating Power Meter. Acoustic or fragmentation power was calculated based on the electrical power measured in removing bone less the quiescent power needed to establish surgical tip stroke. This was the fragmentation power supporting work done in removing bone tissue.

Infrared thermal imaging and emissivity were validated in advance of testing for tissue, specifically for bovine muscle, liver, and bone. Validation included comparing infrared measurements to miniature thermocouples placed at the surface and embedded near-surface within the tissue. Emissivity was characterized as materials were removed from a thermal bath and cooled, such that data were obtained over the range of temperature of interest. We reference ASTM Standard (E1933-99a) for IR (Infrared) emissivity compensation which indicates use of single point contact