

Effect of Ultrasonic Cutting Blade Orientation on Cutting Temperature

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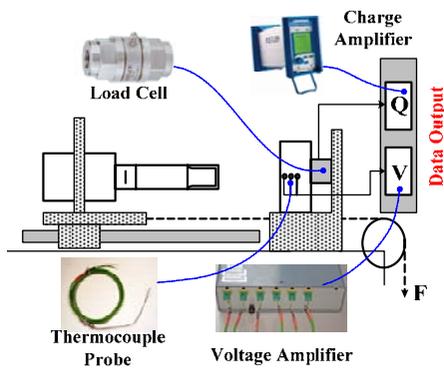


Figure 1: Diagram of the ultrasonic cutting rig used for cutting under constant applied loads

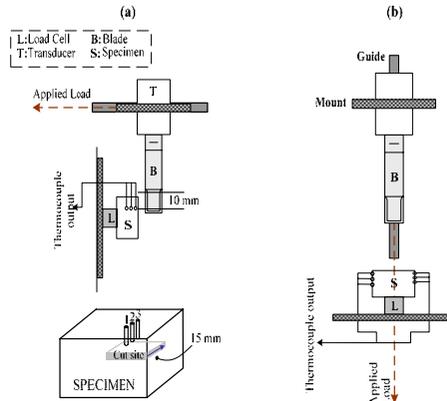


Figure 2: Experimental rig and blade orientation during (a) ultrasonic slicing (b) ultrasonic guillotining

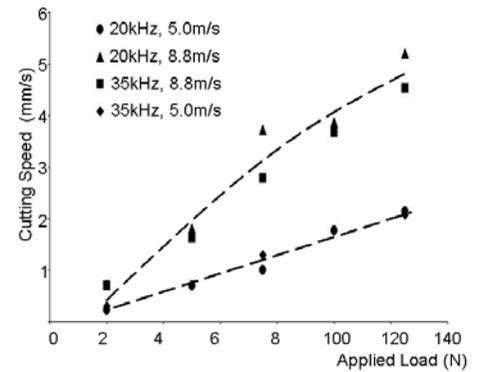


Figure 3: Effect of applied static load on cutting speed

ABSTRACT

Ultrasonic cutting of bone offers advantages compared with orthopaedic devices that rely on a reciprocating action, including the elimination of swarf, improved cut quality and precision, and reduced reaction forces. The technology has become accepted as an alternative cutting procedure for use in surgical operations on soft tissue. Recent studies conducted on bovine bone and a bone substitute material have shown that ultrasonic cutting results in a precise and fast operation using relatively low forces. Previous work by the authors highlighted the significance of frictional heating during ultrasonic cutting, a phenomenon that can lead to material degradation and excessive burning of the cut surface. The work presented a method of reducing cutting temperature by controlling ultrasonic cutting parameters and also presented a method of further reducing cutting temperature by incorporating blade geometry modifications that reduce friction between the blade and the specimen. Such studies have been concerned with uni-axial cutting blade orientations, known as guillotining cutting, and opportunities exist to enhance orthopaedic ultrasonic cutting by developing blades that can operate in more than one cutting direction.

This paper investigates the relationship between cutting parameters (such as cutting speed, applied load and blade tip vibration velocity) and temperature at locations around the cut site for a synthetic bone material during guillotine and slicing mode cutting.

INTRODUCTION

There are only a few documented studies into the abilities of ultrasonic cutting instruments to make maximally invasive operative incisions in bone [1]. Previous work by the authors has highlighted that parameters such as the applied load, cutting speed, vibration velocity and vibration amplitude have a direct effect on the instrument's cutting performance [2]. It is the aim of this investigation to report on the ability of ultrasonic cutting blades to make deep incisions in a synthetic bone material, and to study the effect of ultrasonic blade orientation on the cutting temperature. Hence, two ultrasonic cutting blades have been designed to resonate in a longitudinal mode at 20 and 35 kHz whilst maintaining an identical cutting tip profile and tip vibration velocity.

Performance of the blades is quantified as a relationship between cutting time, applied load and temperature measured at different frequency and blade tip vibration velocity. Temperature has been found to be critical in all cutting procedures performed on bone. Cell necrosis is assumed to occur if specimens are exposed to a temperature of 50°C for 30 seconds or more, and necrotic damage is deemed irreparable if prolonged temperatures exceed 70°C [3].

EXPERIMENTAL SET UP

Cutting under constant applied load was achieved using the test rig detailed in Figure 1. A specimen is secured in a holding device above a horizontal guide. The piezoelectric transducer is structurally mounted, at its nodal position, on a slider which is free to move with minimal friction along the guide. Cutting is initiated by applying a static load, F , as shown in the figure. Each specimen is cut to a depth of 15 mm which is monitored by a dial clock gauge and a trigger system, and the cut duration is recorded.

A load cell with a range of ± 10 kN is used to monitor the load applied to the specimen during cutting. The load cell is attached to an aluminium plate on which the specimen is pre-loaded. The position of the specimen, and the direction of cutting, were aligned with the blade longitudinal axis. K-type thermocouple probes were used to measure the temperature within the specimen.

Figure 2 shows the test rig and blade orientation in relation to the specimen for (a) slicing and (b) guillotining. Loads in the range of 20-80 N were used to allow comparisons to be made between slicing and guillotining. 15 mm cuts were made in all tests to investigate the effect of blade orientation on cutting temperature.

RESULTS AND DISCUSSION

Figure 3 shows the relationship between applied static load and cutting speed using the two blades tuned at 20 kHz and 35 kHz. Each blade has been used to cut bone samples using two different blade tip vibration velocities: 5 m/s and 8.8 m/s. The results in the figure show that the cutting speed, for a given blade tip vibration velocity, is independent of the blade tuned frequency. At the higher vibration velocity the cutting speed is higher for the same applied static load.

Figure 4 plots cutting speed against applied load for the 35 kHz blade in both cutting orientations and for blade tip vibration velocities of 5 and 8.8 ms^{-1} . Figure 5 illustrates that there is a near linear relationship between cutting speed and applied load and that a blade used in a slicing orientation cuts faster for the same applied load than a blade in a guillotining orientation. Cutting blades with the higher blade tip vibration velocities are also shown to cut faster. Initial cutting results on a synthetic material also show that ultrasonic slicing results in a faster cut for the same blade tip vibration velocity.

The cutting temperature measured by thermocouple 1 during guillotining and slicing under applied loads of 20 and 50 N using a 35 kHz blade at blade tip vibration velocities of 5 ms^{-1} and 8.8 ms^{-1} , are shown in Figures 5 and 6, respectively. The figures show that for both applied loads and at both tip vibration velocities, guillotine cutting results in a higher cutting temperature than slicing. These preliminary cutting results illustrate that cutting blade orientation can reduce the peak cutting temperature by up to 24°C.

CONCLUSIONS

Ultrasonic cutting blades have been designed which successfully cut synthetic and natural materials such as polyurethane and bovine bone. Previous work by the authors reported on the capabilities of maintaining cutting temperature within necrotic limits by controlling cutting parameters such as frequency, cutting speed, applied load and blade tip vibration amplitude. The blades were designed with a tip section which enables cutting in either a guillotine or slicing orientation.

The peak temperature measured during slicing ultrasonic cutting of a synthetic replica of human trabecular bone was found to be lower than for guillotine cutting, and was found to be maintainable within the necrosis threshold. Also, by examining the cut specimens, burning on the cut surface was found to be less evident after ultrasonic slicing.

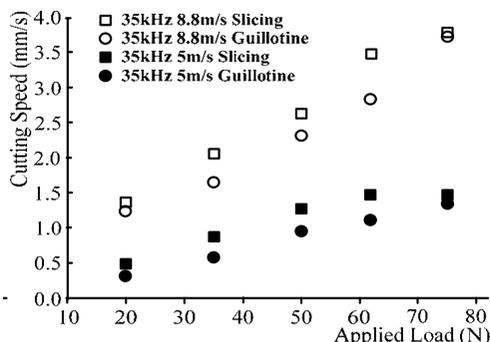


Figure 4: Cutting speed against applied load for a 15 mm incision during slicing and guillotine cutting

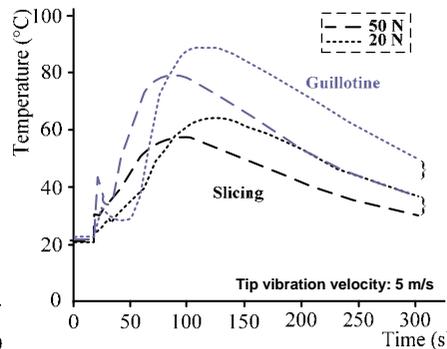


Figure 5: Temperature measured from thermocouple 1 during slicing and guillotine cutting using a blade tip vibration velocity of 5 ms^{-1}

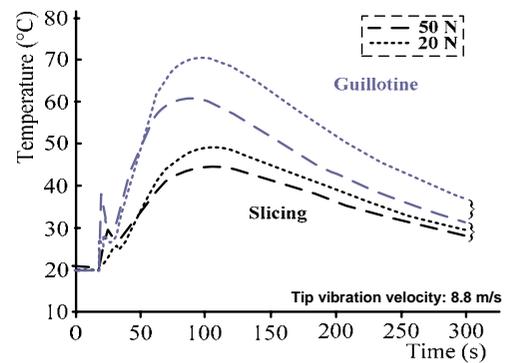


Figure 6: Temperature measured from thermocouple 1 during slicing and guillotine cutting using a blade tip vibration velocity of 8.8 ms^{-1}

[1] Polyakov V., A Precision Ultrasonic Tool, Contemporary Surgery, 1972;4 (3):58-60.

[2] Cardoni A, MacBeath A, Lucas M, Methods for reducing cutting temperature in ultrasonic cutting of bone, Ultrasonics, 2006 (in press).

[3] Lundskog J., Heat and Bone Tissue, PhD Thesis, University of Goteborg, 1972.