

A Comparison of Past, Present and Future Bone Surgery Tools

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ABSTRACT

The ability to cut and shape bone is a requirement for orthopaedic and maxillofacial surgery. Modern tools are just powered versions of traditional instruments. New methods of cutting have potential benefits that are difficult or impossible to achieve with existing tools, such as miniaturisation or an inherent protection against cutting soft tissues. However, these new cutting technologies must still prove to be successful in cutting mineralised tissues. An amputation saw, powered sagittal saw (commonly used for arthroplasty procedures) and new ultrasonic bone scalpel, representing the last 200 years of bone surgery, were compared in a standardised fashion. Cutting time, temperature and cell death were evaluated. The amputation saw was found to cut with the lowest temperature and the least cell death but required the greatest bone exposure. The sagittal saw cut the fastest but also resulted in the greatest cell death. The ultrasonic powered blade created the greatest temperature and was also the slowest, but caused less cell death than the currently used sagittal saw. However, temperature and cell death were significantly reduced by the application of a cooling spray. It was concluded that current ultrasonic devices are not suitable for thick cortical bone, but may be useful for cutting thinner bones, especially those close to critical soft tissues.

INTRODUCTION

Cutting and shaping bone is an integral part of orthopaedic surgery. The science of cutting has advanced continuously over the last two centuries, yet the instruments in standard orthopaedic operating theatres still use techniques developed from several millennia ago for cutting and shaping stone and wood. These techniques can broadly be divided into two categories; sawing (i.e. abrading) and splitting. Figure 1a demonstrates a method of drilling stone used by the Ancient Egyptians. The tools used are comparable with the 17th Century bone surgery tools shown in figure 1b). The method of cutting by drilling a series of holes, creating a path for a crack to travel is still in use today. Figure 1c) shows surgical instruments discovered during the excavation of Pompeii which show startling similarities to those in use today, shown in figure 1d).

Cutting tools are required to cut cleanly through the desired tissue while causing minimum damage to surrounding tissues. With an increasing number of procedures being performed with minimal access techniques, it is also advantageous for this cutting tool to require limited exposure. The cutting devices should be able to perform the task quickly so as to reduce the duration of surgery, and by causing minimal damage to the remaining and surround tissues provide the optimum conditions for healing. Additionally the greater the cutting precision that a tool can offer allows for increasingly complicated forms of surgical procedure to be undertaken.



Figure 1 Cutting tools through the ages.

The devices used for cutting and manipulating bone have remained relatively unchanged throughout the centuries. The advancement of this technology was limited by the available power source, i.e. hand power. The advent of new power sources has created the opportunity for alternative surgical devices. To evaluate these developments we evaluate three bone surgery tools from the last two centuries. The tools evaluated were an 18th Century amputation saw, a sagittal saw and an experimental ultrasonic device.

METHODS

The era of hand powered cutting devices was represented by an 18th Century amputation saw (kindly supplied by the Royal College of Surgeons, Surgeons Hall, Edinburgh). A similar implement can be seen on the crest of that institution, in the top right of the shield, as shown in Figure 2. Modern bone surgery is conducted with a variety of tools, often specialised to the type of surgery performed. A battery powered sagittal device was used to represent the modern era of bone surgery (Stryker, Stryker Co, USA). The near future of cutting tools was represented by an ultrasonic scalpel, designed and manufactured by the University of Glasgow (Glasgow, UK), shown in Figure 3. All tools used in this study were assessed by the following clinically relevant metrics; percentage cell death occurring over a range of distances from the cut surface, maximum temperature and duration of cut.

Ovine bones were used to examine the effectiveness for each tool when cutting through bone. The femurs were removed from sheep immediately post mortem and the bones were cleaned of any remaining soft tissue before being stored in Phosphate Buffered Saline (PBS) and transported under refrigeration to the laboratory for testing.

The bones were held in a rubber tipped vice during cutting to hold the bone securely without causing damage. Approximately half thickness cuts were made with each device, ensuring that the machined region travelled fully through the cortex. The machining process was recorded by a FLIR thermal camera (FLIR Systems Inc, Oregon, USA) to determine heat generation during cutting. After testing, the bone was cut into sections using a multipurpose hacksaw approximately 10mm either side of the test cut. These

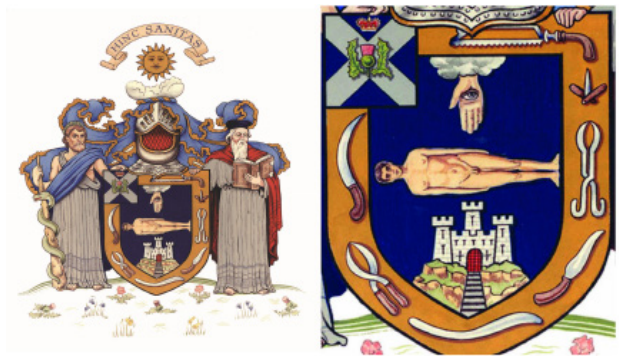


Figure 2 Crest of Royal College of Surgeons - Detail of surgical instruments.



Figure 3 Ultrasonic Scalpel Blade.

sections of bone were fixed using 4% formalin for 18 hours before decalcification in Ethylenediaminetetraacetic acid (EDTA) for 6 weeks. The specimens were then embedded in wax and sectioned for Picro-sirious Red (PSR) staining to assess collagen damage and Haematoxylin and Eosin (H&E) staining to facilitate cell death assessment (Figure 4 a, b & c).

Temperature at the point of cutting was extracted from the thermal camera data and the cutting duration was measured by stopwatch (Table 1). Cell death was assessed by examination under 20x magnification, a feature location algorithm (Image J) was used to locate and count the micro-cavities (i.e. lacunae) within the bone where the bone cells (osteocytes) reside. Empty lacunae indicated that the cells had died, while the presence of a nucleated cell categorised the cell as alive (Figure 4 d & e). Zones of 50 μ m from the cut surface were used to collate the live/dead data and the results were expressed as a percentage of live cells within each zone (Figure 5).

After analysis of these results, additional experiments were carried out to evaluate modifications to the ultrasonic cutting device. These modifications included changes to the cutting profile and the inclusion of a Phosphate Buffered Saline (PBS) cooling spray. Full thickness cuts through freshly excised rat femurs were used for these experiments and the same method of analysis outlined above was used evaluate the effectiveness of these modifications.

Table 1 Temperature and cutting duration of Ovine Bone Experiments.

Tool	Peak temp	Duration of Cutting	Extent of 50% cell death
18 th Century	54 °C	20 sec	50-100 μ m
Sagittal	107 °C	7 sec	200-250 μ m
Ultrasound	150 °C	68 sec	150-200 μ m

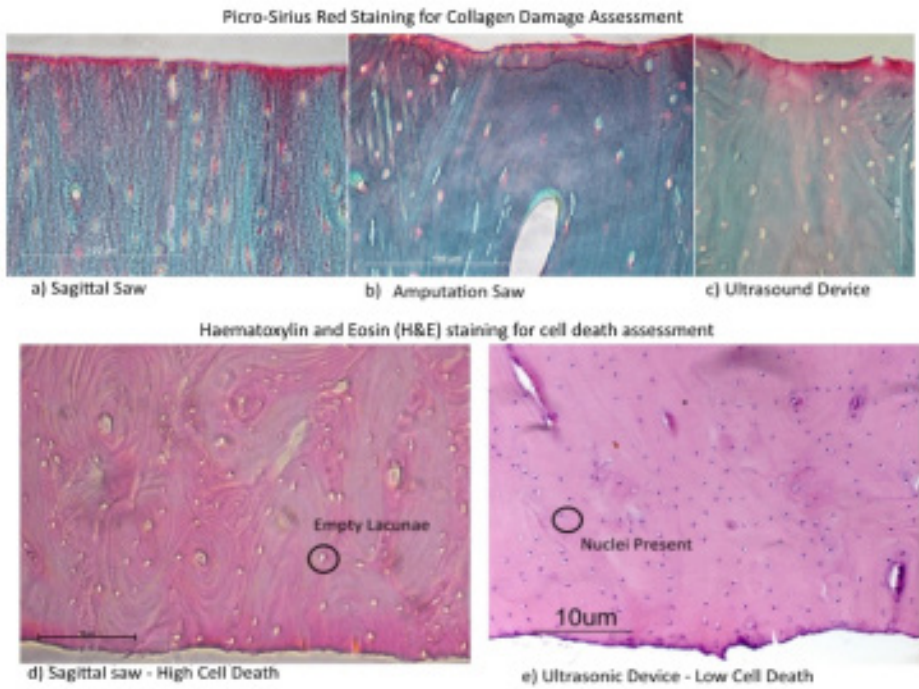


Figure 4 Histological examination of cut surface.

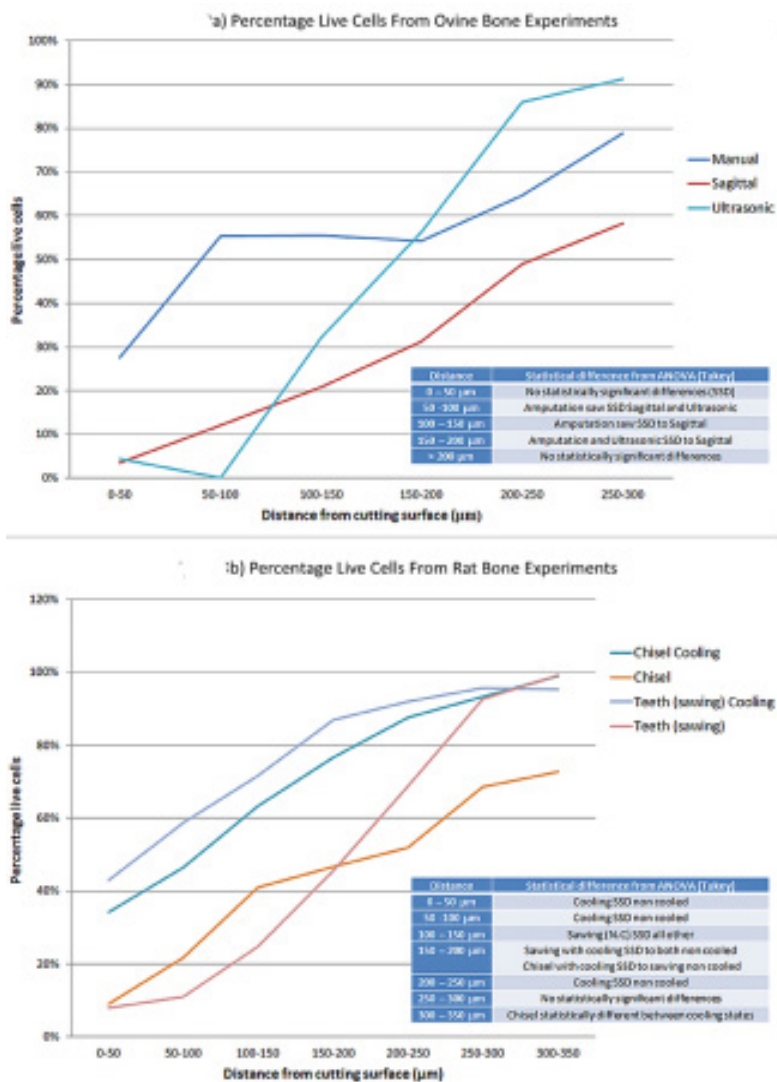


Figure 5 Percentage cell death from cut surface.

RESULTS

The 18th century amputation saw took 20 seconds to make the cut, with a peak temperature of 50°C. The battery powered sagittal saw took 7 seconds, reaching a peak temperature of 107°C and the ultrasonic device took 68 seconds, reaching a peak of 150°C.

The PSR staining indicated areas of collagen damage.

Percentage of live cells from the ovine bone experiments are presented in Figure 5a. An ANOVA was used to check for statistically significant differences (SSD). The results of this analysis are included in the figure. The percentage of live cells from the rat bone experiments are presented in figure 5b. The statistical analysis for this data is also included in the figure.

DISCUSSION

The cutting tool that provided the optimum between minimising cell death and rapid cutting time was found to be the 18th century amputation saw. While this result may appear surprising, one must bear in mind the design purpose of this tool; i.e. amputation. In an era when anaesthetic did not exist, speed was a priority, rather than accuracy or minimal access. With the advent of anaesthesia, which was advocated by various pioneers such as Crawford Long^[2] (Ether 1842), William Morton^[3] (Nitrous Oxide 1845, Ether 1846)^[5] and James Young Simpson (Chloroform 1847) and antiseptic techniques proposed by Lister^[1], safe surgery on bone became feasible and accuracy rather than speed became the priority. The ultrasonic device performed better, with respect to cell death, than the widely used sagittal saw, despite the higher cutting temperatures. It was considered that the heat produced was highly localised, and could be minimised by the addition of a cooling spray.

The ultrasonic blade designs used in this study demonstrated a continuation of the drive towards increased accuracy from bone cutting devices. As these devices can cut using both a reciprocal sawing motion and via direct action of the longitudinal micro-motion, it is possible to use far smaller cutting heads using this power source than are found with the oscillating (sagittal) saw.

One of the features that enhance the appeal of ultrasonic devices for cutting bone is their ability to transfer energy to hard tissues but not to soft tissues. The soft tissue can deform/oscillate with the vibrations of the ultrasonic cutting tip, while the stiffer bone tissue is unable to do this and is therefore cut by the device^[4]. This should minimise the damage to surrounding soft tissues, improving rehabilitation post-surgery. Additionally, these devices can be made very small, facilitating their use in a variety of minimal access

procedures, including those conducted arthroscopically.

The experiments conducted on ovine bone led to two design improvements: namely, the addition of a cooling spray and the addition of micro-teeth on the sides of the tool head of the instrument. The next set of experiments (on the rat tissue) demonstrated that these changes resulted in very low cutting temperatures. The measured temperature was maintained at the temperature of the spray, approximately 25°C. Additionally, there was significantly less cell death closer to the cutting surface as is shown in figure 5b.

In summary, current novel ultrasonic devices are not suitable for cutting the diaphyseal cortex of adult long bones. However as they use a splitting rather than sawing action they cause less cell death at small depths. Cell death can be reduced by the application of a cooling spray. Ultrasonic devices may be particularly advantageous in procedures on areas where there is a thin cortex, such as metaphyseal bone, facial bones and osteoporotic bones, and where it is important that the cut removes minimal bone.

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CONFLICT OF INTERESTS

There are no conflicts of interest with regard to the present study.

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