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Basic Science

Thermal Damage Done to Bone by Burring and Sawing With and Without Irrigation in Knee Arthroplasty

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ABSTRACT

Background: Heat from bone resecting tools used in knee surgery can induce thermal osteonecrosis, potentially causing aseptic implant loosening. This study compared oscillating saws to burrs in terms of temperature generation and histologic damage. Use of irrigation to reduce bone temperature was also investigated.
Methods: Temperatures were recorded during sawing and burring with or without irrigation (uncooled or cooled). Histologic analyses were then carried out. Differences between groups were tested statistically ($\alpha = 0.05$).
Results: On average, burring produced higher temperatures than sawing ($P < .001$). When uncooled irrigation was used, bone temperatures were significantly lower in sawed bone than in burred bone ($P < .001$). Irrigation lowered temperatures and thermal damage depths and increased osteocyte viability ($P < .001$).
Conclusion: These results suggest that irrigating bone during resection could prevent osteonecrosis onset.

Total knee arthroplasty (TKA) operations are becoming increasingly common in developed countries because of an aging population and a rise in obesity prevalence [1-5]. Reducing the chances of or preventing the need for surgical reintervention is therefore essential to ensure that health care systems maintain the ability to cope with annual increases without negatively impacting on the quality of care offered [6,7].

Heat from high-powered orthopedic tools can irreversibly damage or kill bone cells—a process known as osteonecrosis [8-11]. Presently, it is agreed that bones exposed to temperatures of >47°C for 60 seconds or longer are at risk of osteonecrosis [9-14]. This leaves the implant exposed to necrotic tissue, reducing bone-implant incorporation, as well as healing processes [9,12].

Although thermal osteonecrosis has been well described in current literature, most studies are drill based [15-24]. as drills are the most commonly used tool in dentistry, a field where thermal osteonecrosis is a prominent problem [19]. Few studies have investigated the effects of sawing and burring in arthroplasty on bone health.

Robotic computer-assisted surgical devices favor the use of a burr over a saw blade for bone resection, as burrs provide more accurate bone preparation than saws. As these devices are newly developed, little research has been carried out into the effects of burring on bone.

The amount of heat generated by a tool has been found to be positively correlated with the extent of thermal damage done to bone [11]. However, most studies which have investigated thermal damage done to bone do not agree on the maximum temperatures generated by sawing and burring [18-24].

Another common controversy in the literature is the use of irrigation in orthopedic surgery. Based on previous studies, it is not clear whether using a cooling agent on the cutting surface can reduce the temperature enough to lessen the thermal damage done to bone [12,25-28].

To increase our understanding of the relationship between high-powered orthopedic tools and heat-induced osteonecrosis, we aimed to (1) compare the thermal damage done to bone by sawing and burring, (2) determine whether there were temperature differences between sawing and burring bone, and (3) investigate the effect on temperature of irrigation while cutting the bone.

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Materials and Methods

Bone Preparation and Resection

Bovine femora (n = 17) were sourced from an abattoir on the day of animal sacrifice and immediately prepared for resection. The diaphysis of each bone was fixed in a vice, with the anterior side of the femur orientated superiorly, exposing the medial and lateral condyles for cutting. The anterior and posterior facets of each condyle were cut, allowing temperatures from both sites to be recorded during resection.

Bones were burred with a NavioPFS handheld robotic device (Blue Belt Technologies Inc), which was connected to an Anspach console. Identical spherical burrs of 6-mm diameter were used throughout the duration of this study [28]. Burrs were renewed after 10 uses [23]. Tools with higher rotational cutting speeds generate less heat in bone than the same tools at lower speeds [16,21,29-32]. Based on this information and on advice given by an orthopedic surgeon who uses the device, burring speed was controlled with a foot pedal at 80,000 rpm, the maximum burring speed. Jaramaz and Nikou [33] found that it took surgeons approximately 4 minutes to burr a femoral condyle facet for implant placement; hence, burring time was controlled at 4 minutes.

An oscillating saw designed by Stryker Corporation sawed the bones in this study. Stryker Performance Series sagittal blades were used (cut edge: 25 mm, cut depth: 90 mm, thickness: 0.97 mm). Blades were renewed after 10 uses [23]. The anterior facet of the condyles was cut in the coronal plane, and bone from the posterior facet was resected in the transverse plane. Bone sawing was done in 2 minute sessions. This was intentionally shorter than burring, as the cutting process itself is faster. This time included the time it took to realign the saw between cuts.

All cutting procedures were performed by a single author after training from a consultant orthopedic surgeon. To best replicate the operative scenario, both anterior and posterior facets of each condyle were cut. This allowed temperatures generated from 2 sites per condyle to be recorded. The same surface area of bone was cut by both tools. Furthermore, the same cutting style was always used on the same condyle (eg, sawing on anterior and posterior facets of medial condyle and burring on anterior and posterior facets of lateral condyle). The condyles which were burred and sawed were alternated per specimen to ensure that results were recorded from both lateral and medial condyles by both tools.

It should also be noted that during training, the appropriate software was used to map the surfaces of specimens. This provided the user with surgical plans; thus, the areas of bone removed were equivalent to those adequate for implantation. During the testing, the user aimed to burr and saw a similar area of bone to that which was removed during training sessions.

Temperature Capture

Temperatures were recorded with a visual infrared thermometer (Fluke VT04 Model, measurement accuracy ±2°C or ±2%). To ensure both cutting styles were comparable, temperatures were recorded every 5 seconds when sawing and every 10 seconds when burring. Hence, 24 temperature readings were captured with each resection. Temperatures of samples at 0 seconds were also recorded to allow temperature elevations when cutting to be determined. A volunteer operated the camera as the author resected bone samples.

Irrigation

Plastic tubing and a hollow metal wire conveyed the cooling agent from a bag to the cutting site. Using sodium chloride and water, 0.9% saline solution bags were prepared. Flow rate was controlled by the Anspach console when burring and sawing. Six of the sawed and burred femora were not irrigated during cutting, another 6 were irrigated with room temperature saline, and the remaining 5 were irrigated with cooled saline (4°C).

Histomorphometric Analyses

On completion of bone sawing and burring, approximately 1 cm^3 samples were removed from the cut surfaces and immersed in tissue fixative. All samples were processed and sectioned perpendicularly to the cut made by the orthopedic tools. Control samples were also prepared. After this, hematoxylin and eosin standard staining protocol was used to stain the sectioned samples. Images of control, burred, and sawed tissue were taken with a microscope.

Twenty fields from histologic sections of control, sawed, and burred bone were randomly chosen, and the percentages of viable cells relative to lacunae were calculated for each field. Lacunae which had distinguishable osteocytes within them were characterized as living (viable) cells, whereas empty lacunae were classified as dead (nonviable) cells. In addition, the distance between the burred or sawed surface, and first visible osteocyte was calculated for all images.

Statistical Analyses

Two-way analysis of variance (ANOVA) tests were carried out to test differences between groups. Non parametric tests were carried out where appropriate. For the purposes of this study, the level of significance was set at $\alpha = 0.05$ (version 16; Minitab Inc, State College, PA).

Results

Temperature Generation

As the bovine femora were not at body temperature on arrival to the laboratory, temperature elevations from the initial readings were calculated for all measurements in each data set. Initial bone temperature was subtracted from each measurement. Average body temperature (37°C) was added to these values. These adjusted values were used to analyze the results as they are easier to interpret.

Mean temperature at the surface of the bone increased suddenly on initiation of burring and sawing (Fig. 1). After this, it increased at a slower rate toward a point where an apparent peak occurred. It took longer time for irrigated bones to reach mean temperatures of at least 47°C, with nonirrigated burred and sawed bones taking as little as 20 seconds to reach 47°C. Critically, mean temperatures remained beyond 47°C for >60 seconds in nonirrigated bone as well as in bone burred with room temperature irrigation (Fig. 1). With the use of cooled irrigation, a mean temperature of >47°C was not reached, regardless of the cutting tool used (Fig. 1).

On average, the mean temperature in burred bone was higher than sawed bone (Table 1). Examples of the temperatures reached during burring and sawing can be seen in Figure 2. A 2-way ANOVA with cutting modality and irrigation modality as factors identified that both factors significantly affected bone temperature (both $P < .001$).

Bonferroni-adjusted post hoc tests identified that, on average, burring bone resulted in temperature 1.2°C higher than sawing ($P < .001$), while the absence of irrigation led to a mean bone temperature 3.5°C higher than in bone irrigated by room temperature irrigation ($P < .001$) which, in turn, was 2.2°C greater than cooled irrigation ($P < .001$). The significant interaction effect between these factors warranted further examination. Without