

# In vitro study of heat production during power reduction of equine mandibular teeth

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**Objective**—To measure the amount of heat generated during 3 methods of equine dental reduction with power instruments.

**Design**—In vitro study.

**Sample Population**—30 premolar and molar teeth removed from mandibles of 8 equine heads collected at an abattoir.

**Procedure**—38-gauge copper-constantan thermocouples were inserted into the lingual side of each tooth 15 mm (proximal) and 25 mm (distal) from the occlusal surface, at a depth of 5 mm, which placed the tip close to the pulp chamber. Group-NC1 (n = 10) teeth were ground for 1 minute without coolant, group-NC2 (10) teeth were ground for 2 minutes without coolant, and group-C2 (10) teeth were ground for 2 minutes with water for coolant.

**Results**—Mean temperature increase was 1.2°C at the distal thermocouple and 6.6°C at the proximal thermocouple for group-NC1 teeth, 4.1°C at the distal thermocouple and 24.3°C at the proximal thermocouple for group-NC2 teeth, and 0.8°C at the distal thermocouple and -0.1°C at the proximal thermocouple for group-C2 teeth.

**Conclusions and Clinical Relevance**—In general, an increase of 5°C in human teeth is considered the maximum increase before there is permanent damage to tooth pulp. In group-NC2 teeth, temperature increased above this limit by several degrees, whereas in group-C2 teeth, there was little or no temperature increase. Our results suggest that major reduction of equine teeth by use of power instruments causes thermal changes that may cause irreversible pulp damage unless water cooling is used. (*J Am Vet Med Assoc* 2004;224:1128–1132)

Dental care and dentistry have long been recognized as important components of horse health management programs. Because it is not uncommon for horses to live 30 years or longer, proper dental care becomes even more important for horses as nutritional requirements change with the different phases of life. In North America, dentistry was the third most common medical call for veterinary services encountered by large animal practitioners,<sup>1</sup> and 80% (400/500) of horses examined at a mid-west abattoir had oral lesions

of some form.<sup>2</sup> Sharp enamel points were most commonly associated with horses < 10 years of age, whereas older horses had more advanced changes. Abnormal wear patterns such as wave (a condition resulting in excessively long and short teeth in the same arcade), shear, and step mouth (an exceptionally long tooth, usually caused by lack of an opposing tooth) were all found in older horses.<sup>2</sup> In a study of 400 horses in the United Kingdom, 349 (87%) horses had abnormalities of the premolars or molars.<sup>3</sup>

Technological improvements from the introduction of power dental instruments have been welcomed by equine practitioners. The advantages of power instruments include increased speed and ease of operation, and they may be the best tools for removing abnormalities such as hooks and overgrowths or steps, and creating bit seats. In addition, power instruments reduce the risk of tooth fracture and pulp exposure that may result from the use of dental shears or percussion cutters. However, there may be some drawbacks to certain systems that should be considered. It has been speculated that the production of excessive heat, resulting in thermal damage to dental pulp, may be an important problem. This can occur as a result of using power instruments without the aid of proper cooling mechanisms. It has been reported that it is easy to expose the pulp unexpectedly when using power instruments for these procedures.<sup>4</sup>

Five pulp horns project from the pulp chamber to slightly above the gingival margin in a normal equine mandibular tooth. As the reserve crown erupts and is worn, the odontoblasts lining the pulp chamber and horns respond to chemical and physical stimuli to produce secondary dentin within the endodontic system. This secondary dentin prevents exposure of the pulp as teeth progress through their normal wear patterns. Continuous growth and proper dental management will expose the 3 calcified layers without creating pulp disease. This production of secondary dentin is facilitated by reception of stimuli through the dentinal tubules.

Tubules penetrate the predentin and travel through the dentin layer to terminate just below the enamel. Within each tubule is the odontoblastic process, which rarely contains major organelles. Many coated vesicles are present in these processes.<sup>5</sup> In the odontoblastic layer, cells are arranged to provide intercellular junctions that are impermeable, adhering, or communicating. A 5.5°C temperature increase causes protein denaturation in the pulp and irreversible damage in 15% of tested human teeth,<sup>6</sup> and an increase of 16.7°C results in pulp necrosis in 100% of human teeth.<sup>7</sup>

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Our hypotheses were that uncooled power reductions in equine mandibular premolar and molar teeth can generate heat in excess of the commonly accepted 5°C maximum safe limit and water-cooling would substantially reduce the amount of heat generated. The purpose of the study reported here was to measure the amount of heat generated during 3 methods of equine dental reduction with power instruments.

### Materials and Methods

Thirty mandibular premolar or molar teeth were removed from 8 horses within 30 minutes of slaughter at a regional abattoir. Ages were estimated on the basis of dental development<sup>a</sup> and ranged from 2 to 13 years with median age of 8.5 years. Five horses were female, 2 were male, and sex of 1 horse was unknown. Three-dimensional measurements were recorded for each tooth before storage at -18°C until data collection.

Thirty-eight gauge polytef-coated copper-constantan<sup>a</sup> thermocouples were constructed by removing the polytef coating on each end. The copper and constantan wires were connected by twisting the free ends together and soldered to make a permanent connection. When the tips had cooled, excess solder was removed and discarded. Construction of the thermocouples in this manner reduced the thermal measurements to the tip region. Each thermocouple had a measuring temperature range of -270° to 400°C.

One data collection site was drilled 15 mm (proximal site, with reference to the surface to be ground) from the highest point from the occlusal surface and another 25 mm (distal site) from the same reference point, by use of a dental burr.<sup>b</sup> In general, the more proximally placed site was at or close to the gingival margin. Each thermocouple was inserted 5 mm into the lingual side of each tooth in a horizontal direction. This procedure placed the tip of the thermocouple within the dentin close to the pulp chamber and deep to the dentino-enamel junction (Fig 1).

Three groups of 10 teeth were prepared with temperature-measuring devices and mounted in polymethylmethacrylate and stabilized in a vice. A power float grinding system<sup>c</sup> with a 26-mm-diameter circular carbide blade and a maximum rotational speed of 4,000 revolutions/min was used for each reduction. All procedures were performed at maximum revolutions per minute by the same individual (MLA) for consistency. Group-NC1 teeth were ground for 1 minute without cooling, group-NC2 teeth were ground for 2 minutes without cooling, and group-C2 teeth were ground for 2 minutes with water cooling. Coolant was delivered at a consistent temperature of 20.3°C (tap water monitored with a copper-constantan thermocouple) and a rate of 20 mL/min by use of a roller pump delivery system.<sup>d</sup>

For group C2, the more distal portions of the tooth, including the thermocouple leads, were shielded to prevent false data collection because of conductive cooling along the wire leads. Each tooth and thermocouple were covered with a surgical water-impervious drape and wrapped tightly with a rubber band. The tooth was placed through a small hole in an equine rectal examination sleeve and wrapped tightly with polymeric silicone tubing to form a watertight seal. As each water-cooled experiment was taking place, water was allowed to drain away from the tooth to prevent fluid accumulation.

A validation experiment was performed to test the integrity of the design by pouring heated water (70°C) over the occlusal surface of teeth. The increased temperature curve was compared with equine teeth reduction curves to check for sudden increased temperatures that would result from a leak in the system and thermoconductivity in the region of the polytef coating of the thermocouples. Heated water was applied to the polytef surface of the thermocouples

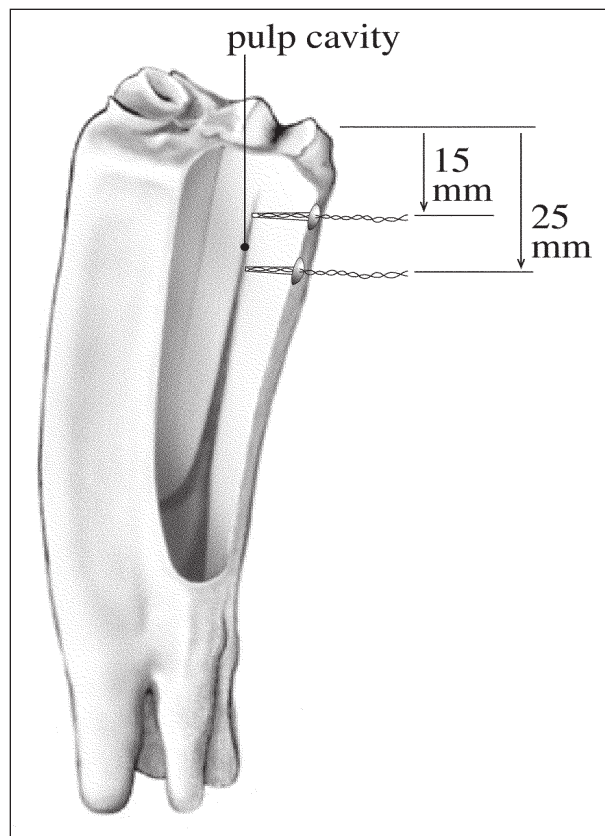


Figure 1—Illustration of thermocouple placement in equine mandibular molar and premolar teeth.

to test the conductivity of the thermocouple wires. Examination of the data proved that the sealing procedure prevented water contact directly on the thermocouple. The protocol was proven to be valid and repeatable.

Temperature measurements were collected by use of a self-correcting thermocouple reference computer program.<sup>e</sup> A temperature measurement was recorded before grinding and at 0.5-second intervals for 2 minutes after completion of grinding.

**Statistical analyses**—Temperatures obtained before grinding were subtracted from each temperature taken at 0.5-second intervals after grinding to yield a relative temperature change for each tooth. Least square mean temperature changes were calculated and plotted for both the proximally and distally positioned thermocouples for each group and compared by use of repeated measures ANOVA, with repeated measures on time and horse nested within group. The physical characteristics of the teeth (age, surface area, and buccal and lingual length of the teeth) were compared by use of ANOVA, with horse nested within group. The association between group and sex of the horse was tested by the use of the Fisher exact test. Computer software<sup>f</sup> was used for all analyses, and a value of  $P < 0.05$  was considered significant.

### Results

The initial design of the study involved recording temperature measurements from the beginning of grinding to measure temperature increases during tooth reduction. However, because of the severe vibration caused by the motorized carbide blades, steady meaningful temperature readings could not be obtained. As a result, it was possible only to record tooth temperature immediately before and after grinding.

There were significant main effects for treatment ( $P < 0.001$ ), time ( $P < 0.001$ ), and the interaction between treatment and time ( $P < 0.001$ ) at both thermocouple sites. In group NC1, the more distally positioned thermocouples (25 mm from the occlusal surface) revealed mean peak thermal change of 1.2°C (range, 0.4° to 1.7°C; Fig 2). The temperature increases were all within the recommended limit (ie, 5°C) for the full duration of testing. In general, mean and individual temperatures increased steadily throughout the period, although mean temperature only slightly exceeded 1°C after 1 minute of grinding.

The more proximally placed thermocouples (15 mm from the occlusal surface) revealed mean peak thermal change of 6.6°C (range, 3.8° to 11.8°C; Fig 3). Mean temperature of the more proximally positioned thermocouple in this group exceeded the recommended 5°C safety limit by 1.6°C. Of the 10 teeth that were tested in this group, in only 1 tooth did temperature not increase above the 5°C limit and several exceeded the safety limit by several degrees.

In group NC2, the more distally positioned thermocouples revealed mean peak thermal change of 4.1°C (range, 3.0° to 5.9°C; Fig 2). Of the 10 teeth test-

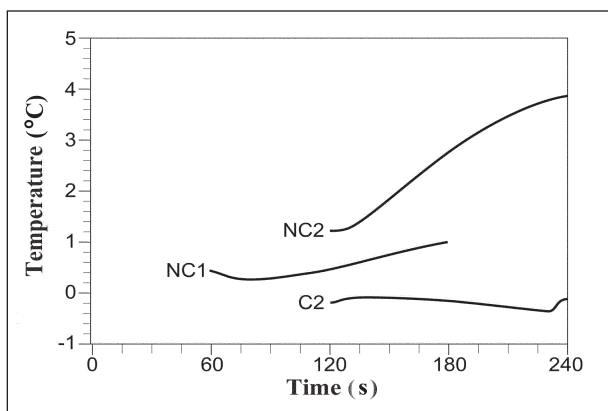


Figure 2—Mean changes in temperature measured at the distal thermocouple in equine mandibular molar and premolar teeth after 1 minute of power grinding without cooling (NC1), 2 minutes of power grinding without cooling (NC2), or 2 minutes of power grinding with water cooling (C2).

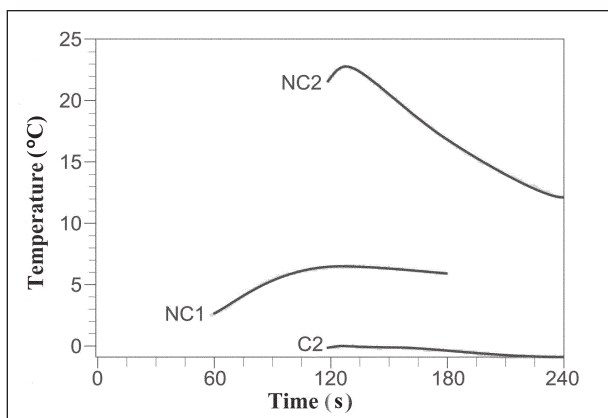


Figure 3—Mean changes in temperature measured at the proximal thermocouple in equine mandibular molar and premolar teeth after 1 minute of power grinding without cooling (NC1), 2 minutes of power grinding without cooling (NC2), or 2 minutes of power grinding with water cooling (C2).

ed in this group, in only 3 did distally placed thermocouples reveal an increase  $> 5^{\circ}\text{C}$ . The more distally positioned thermocouples of group NC2 also revealed greater mean temperature increase, compared with corresponding measurements in group NC1, although the temperature increase did not exceed 5°C. Similar to the group-NC1 measurements, results suggested that temperatures were increasing beyond the end of the recording period. The more proximally placed thermocouples revealed mean peak thermal change of 24.3°C (range, 16.9° to 36.7°C; Fig 3).

In group C2, the more distally positioned thermocouples revealed peak thermal change of 0.8°C (range,  $-1.1^{\circ}$  to 3.0°C; Fig 2). The proximally positioned thermocouples revealed mean peak thermal change of  $-0.1^{\circ}\text{C}$ , (range,  $-1.2^{\circ}$  to 2.4°C; Fig 3). Both thermocouples revealed a decrease in temperature in most of the teeth. Only 2 of the 10 teeth had more than a 2°C increase in temperature, and in most teeth, similar temperatures were recorded by both thermocouples. In contrast to groups NC1 and NC2, the proximally positioned thermocouples at the gingival level at some point during the recording period revealed temperatures less than those recorded by the distally positioned thermocouples. This was in stark contrast with the temperatures measured at these locations in groups NC1 and NC2.

There was no difference in the physical dimensions or age of the teeth in the 3 groups ( $P > 0.50$  for main effect of group). In addition, there was no association ( $P = 0.21$ ) between group and sex of the horse.

## Discussion

Group NC1 represented teeth subjected to basic molar reduction that would be performed at a regular interval health examination. One minute of dry power grinding reduced the tooth by an amount that would not be considered excessive for this purpose. The carbide burr was angled in a manner to contact only the sharp lingual portion of the tooth.

Groups NC2 and C2 were intended to represent specialized dentistry associated with creating bit seats, perform hook reductions or wave mouth corrections, or treat other abnormal conditions. In these 2 groups, the lingual edge and occlusal surface were reduced. It is important to note that tooth temperature was determined after 2 minutes of reduction and that time is now considered to be conservative for more advanced pathologic conditions. Many situations will require more extensive occlusal reduction than could be accomplished in 2 minutes.

The more proximally positioned (gingival level) thermocouples in group NC2 all recorded very high levels of heat production. Essentially all of the peak readings for this group exceeded the safety limit by a factor of 3 or more. In addition, none of the teeth returned to safe temperatures before the end of the recording period. The risk for iatrogenic damage in this group was considered to be very high.

It is important to remember that the generated heat does not need to penetrate the full depth of the dentin into the pulp chamber. The presence of odontoblastic processes extending from the pulp chamber to



the dentino-enamel junction is well documented.<sup>9</sup> Thermal energy need only reach beyond the dentino-enamel junction into the dentin to damage the odontoblastic processes and ultimately the tooth's capability to generate reparative dentin.<sup>5,9</sup> Because there are many intercellular communications,<sup>9</sup> seemingly minor injuries can have widespread results.

Another important aspect to consider is the possible effect blood flow may have in cooling the pulp chamber. Several dynamic changes can occur. Normally, pulp blood flow exceeds muscle blood flow on a per volume basis, although it is not as great as that in vital organs. However, pulp has high anaerobic cellular capacity. Because of sympathetic nerve stimulation, blood flow in teeth decreases to 0 during the first 30 seconds of general anesthesia and remains low for the following 60 minutes<sup>10</sup>; an intrapulpal pressure increase of 2.5 mm Hg is correlated with each degree Celsius of increasing temperature. Increasing temperatures result in complete hemostasis. Many procedures on human teeth leave a pink hue to the dentin that represents vascular stasis in the subodontoblastic plexus. However, dark purple discoloration indicates thrombosis and poorer prognosis. All of these conditions will obviously prevent or diminish the capability of blood to aid in convective cooling.

The immediate response to an inflammatory stimulus to the pulp is vasodilation. Increased intravascular pressure and capillary permeability results in a linear increase of 2.5 mm Hg in intrapulpal pressure for each degree increase in temperature.<sup>10</sup> With severe inflammation, the lymphatic system is totally occluded, which leads to continued increase in fluid and pulp pressure.

Researchers have studied blood flow patterns in rat incisors as models for other species. In 1 study, water was sprayed as a coolant onto the dentin from all directions during experimental reductions. By use of intravital microscopy, blood flow within teeth was determined to be unchanged. However, without the use of any type of coolant, blood flow was substantially decreased. The duration of response was approximately 1 hour, which indicated possible permanent damage to the pulp.<sup>8</sup> The reduction procedure resulted in an increase of flow through the distally positioned arteriovenous anastomosis and shunting of blood from the prepared side of the tooth to the unprepared side. Histologic studies revealed a burn lesion in the region of reduction, which caused alteration of the microvasculature. Pulp temperatures > 46°C cause irreversible stasis and thrombosis of the blood vessels.<sup>11,12</sup>

In human teeth, the least amount of damage occurs at rotational speeds from 150,000 to 250,000 revolutions/min if a coolant system is used.<sup>13,14</sup> These rotational speeds are presently well out of range of portable equine units, with or without cooling. At 300 to 500 revolutions/min, there were little or no odontoblastic reactions in the same studies when cooling was used. Rotational speeds from 3,000 to 30,000 revolutions/min were the most damaging to human pulp, regardless of cooling. In our study, tooth reductions were performed at 4,000 revolutions/min.

Thermocouples were placed 15 and 25 mm from the occlusal surface at a depth of 5 mm. The more

proximal measurement was at or near the gingival margin. In most teeth, this would be near the proximal extension of the pulp horn with the thermocouple tip deep to the dentino-enamel junction. As a result, measurements came from the area where odontoblast processes are found in the dentinal tubules. An inflammatory response is incited when these cells are injured or burnt, which will then result in a cascade of events that ultimately results in increased intrapulpal pressure. In addition, if odontoblasts are lost, reparative dentin will not be produced. This will ultimately result in exposed pulp at the occlusal surface as the tooth grows.

The concept of cooling with water has many merits. Not only does water reduce grinding temperatures, it also makes the procedure more efficient. Keeping the blades clean and free of dental debris may have been part of the reason for the lower thermogenic properties of the procedure. Subjectively, more material was removed from the group-C2 teeth than those in either of the other 2 groups. One negative aspect of the power instruments is the electrical hazard associated with water-cooling. At this time, the authors are unaware of any equine power equipment that is approved for use with water. Consequently, these devices should always use a circuit breaker plug-in to prevent electrical hazard to the operator and horse.

Research in humans indicates that there is no benefit to intermittent grinding if there is a lack of coolant. The pulp is simply burned a little at a time, and a temperature change of 28°C has resulted in dental cracks.<sup>15</sup> It has also been suggested that a hot dental burr may generate more heat in the pulp by radiation than conduction.<sup>16</sup> As grinding times increased, surface area contact between the burr and tooth increased, allowing a greater opportunity for both types of heat conduction.

Results of our study indicate that during routine dental prophylaxis, temperature changes at the dentino-pulpal junction do not increase above the thermal safety margin for pulp tissues extrapolated from humans. However, it is clear that power grinding of longer durations, equivalent to those required for removing major hooks, overgrown teeth, or creating a bit seat, is likely to create pulp necrosis from thermal trauma.

<sup>a</sup>Omega Engineering Inc, Stamford, Conn.

<sup>b</sup>Henry Schein, Melville, NY.

<sup>c</sup>D&B Equine Enterprises Inc, Calgary, AB, Canada.

<sup>d</sup>Masterflex, Cole-Palmer Instrument Co, Chicago, Ill.

<sup>e</sup>Industrial Computer Source, San Diego, Calif.

<sup>f</sup>SAS Institute Inc, Cary, NC.

<sup>g</sup>Kim S, Grayson A, Schacter W. Effects of tooth preparation on pulp flow in dogs (abstr). *J Dent Res* 1983;62:199-203.

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