THERMOGENICS IN CAVITY PREPARATION WITH AIR-TURBINE HANDPIECES: THE RELATIONSHIP BETWEEN RATE OF TOOTH STRUCTURE REMOVAL AND RATE OF HEAT TRANSFER

by

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A Thesis

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

The development of air-turbine and multiple-belt-drive dental handpieces which operate in the 100,000 rpm-and-over range has created much new interest in the thermal hazards which may accompany use of these instruments in dental practice. As a result, recent dental literature contains many reports of temperature production and effects of temperature upon the dental organ.[1-18] Virtually all reports, recent and old, have been concerned either with measurement of temperatures at some point within the tooth or with various tissue responses which might be observed following dental cutting procedures. In view of the considerable interest which has been shown in the qualitative aspects of thermogenics, it is surprising how little interest has been given the quantitative, or caloric aspects of the problem. In reviewing the dental literature only one paper, that of Henschel, published in 1943,[19] was found which dealt with caloric aspects of dental thermogenics.

Although most workers agree that thermal insult may result in damage to vital teeth, adequate knowledge of the specific nature or degree of thermal stimulation necessary to produce damage is still lacking. In view of this, it was reasoned that a study of the heat or caloric transfer involved in dental cutting procedures might be of considerable value in the evaluation of many aspects of dental thermogenics.

It was the purpose of this investigation to determine, under a single set of carefully controlled conditions, the relationship of the rate of heat transferred to the rate of tooth structure removal during dental cutting with an air-turbine handpiece.

GENERAL PROCEDURE

The general procedure followed in this investigation was to cut prepared dentin specimens with a dental bur driven by an air-turbine handpiece; then to determine the amount of heat which was transferred to and which remained within each specimen following the cutting procedure. Heat determinations were made with a simple calorimeter device which was constructed for use in this study. Amounts of material removed from each specimen by the cutting procedure were determined, as were the rotational speeds of the dental bur under all conditions of cutting.

EXPERIMENTAL DESIGN

Because rigid control of the variables involved would be extremely difficult, if not impossible to achieve *in vivo*, it was decided that an *in vitro* approach to this problem would be necessary.

Following is a brief discussion of those factors which were considered in the design of this experiment, and over which control was deemed necessary.

A. *Air supply to the handpiece*. The potential power obtainable from a dental bur driven by an air-turbine handpiece has been shown to be directly related to the magnitude of the air pressure which drives the handpiece.[21] It was deemed necessary, therefore, to control the magnitude of the driving air pressure. A pressure of 25 pounds per square inch (psi) was selected for this investigation because: (1) It has been shown by Semmelman, Kulp and Kurlansik that, under certain operating conditions, maximum cutting efficiency of a similar air-turbine handpiece was realized when 25 psi air pressure was supplied to the handpiece;[20] and (2) This pressure is one which is easily obtained in dental practice.

B. *Bur sharpness*. Unpublished work done in this laboratory has suggested that a relationship between temperature rise within tooth structure and bur sharpness exists. Although a complete understanding of the nature of this relationship has not been realized, it seemed advisable to attempt some control of the sharpness of the cutting instruments. Therefore, a new #557 carbide bur was utilized for each three test cuts performed. Thus, each bur was replaced with a new one (of the same manufacturer) after approximately 45 seconds of actual cutting time.

C. *Cutting load.* Because air-turbine handpieces are low torque devices, the lateral cutting load which is applied to the dental bur has a marked effect upon cutting performance. Application of only a few ounces of load to these instruments results in complete stall-out of the revolving bur. In view of this, it was necessary to carefully control the force or load applied to the cutting instrument. The loading device utilized to achieve this control is described in detail in a later section of this paper.

D. *Hardness and state of hydration.* In addition to the factors mentioned above, it was expected that certain characteristics of the specimens utilized might significantly influence the results to be obtained. For example, the state of specimen hydration might affect cooling characteristics or sample hardness; hardness, in turn, might be expected to influence the rate of cutting and/or rate of heat generation and transfer. Therefore, some effort was expended to control these factors and to evaluate the effect of hardness on rate of cutting and heating.

E. *Depth of cut.* The depth of bur cut affects: (1) the area of contact of the bur with the specimen while cutting; (2) the total frictional area; (3) the area of the site of heat generation and heat entrance into the tooth; and (4) the rotational speed of the bur. The expected net effect of uncontrolled variation of depth of cut among samples would be uninterpretable variation of the rate of removal, heat generation, and rate of heat transfer. Depth of cut, therefore, was maintained constant (2.5 ± 0.1 mm.) for each specimen.

F. Heat loss to the environment. In planning these experiments, it was recognized that some heat loss to the environment during cutting and transfer procedures would be unavoidable. In order to minimize variations of this heat loss among samples, such factors as size and shape of the specimens, starting temperature of the specimens, and time required for specimen transfer to the calorimeter were held constant throughout. In this way, heat losses to the environment were, it was felt, quite comparable for each specimen studied.

It was also recognized at the outset that some heat loss would occur in the calorimeter between the time of sample introduction and the time at which equilibrium temperature was reached. Utilization of uniform volumes and starting temperatures of water within the calorimeter for each test specimen allowed use of a single correction factor for this source of heat loss. A description of the method of determination of this correction factor is presented in Appendix 2.

G. Cutting time. Another factor which, if not controlled, might affect the consistency of the data obtained was that of cutting time. Under the conditions of this experiment, the temperature of each specimen would be expected to increase with time after the cutting procedure was initiated. Although the rate of heat input to the specimen would probably remain essentially constant throughout the cutting procedure, the rate of heat loss would be expected to vary—increasing with time as the specimen temperature increased. Thus, the net heat realized during the first second of cutting would be expected to be greater than the net heat realized during the later seconds of cutting. Possible factor variation in this respect was minimized by limiting each test cut to fifteen seconds duration.

H. <u>Additional factors</u>. Although the measurement of rotational speeds of the bur during cutting was not necessary to the determination of heat or removal rates, it was felt that inclusion of such data might be of considerable help in evaluating the findings of this and subsequent investigations. Accordingly, observations of rotational speeds during cutting were obtained and are presented herein.

An outline of the variables which were controlled and those which were measured by the experiment is presented in Table 1.

MATERIALS AND METHODS

A. Specimen preparation and handling. One-hundred and eight sections of dentin, as nearly uniform dimensionally as was feasible*, were cut from extracted human posterior teeth with a DiMet diamond-blade cutting machine. Knoop hardness determinations were made on these specimens to allow placement into one of three hardness groups—hard, medium, or soft. Each hardness group contained 36 specimens.

Small starting cuts were carefully placed in each specimen to allow rapid orientation of the bur at the time of experimental cutting. The starting cuts also served to make all experimental cutting more uniform in that each cut was then initiated with a half-circumference contact of the bur with the specimen.

Specimens were marked for identification and stored in distilled water until used.

B. Cutting tool and handpiece. One bur type (#557 cross-cut fissure bur) and one air-turbine handpiece (Borden) were utilized in the study. Choice of this bur type was based upon recently published work by Semmelman, et. al.,[20] in which determinations of cutting efficiency with this bur type, driven by an air-turbine handpiece, were made. It was felt that this work might serve somewhat as a guide, or standard, with which cutting efficiency data obtained in this study could be compared.

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* 5 mm. X 5 mm. X 2.5 mm.

C. Loading device and method of cutting. The handpiece was clamped tightly in a heavy vertical stand containing a facility which allowed some vertical adjustment for easy orientation of the bur prior to cutting. The specimen was clamped in a wooden vice which was securely mounted on a wheeled platform. The platform wheels rode on tracks which were securely mounted on a heavy, flat piece of brass. Thus, the platform and specimen mounting vice were free to move forward or backward under the fixed dental handpiece and bur. A pulley system attached to the wheeled platform allowed application of known weights, and thereby, known lateral loads, to the bur during cutting. Figure 1 is a diagrammatic representation of this device.

Although no auxiliary coolant was used during the cutting procedure, air escaping from around the bur tube of the handpiece undoubtedly effected some cooling of the specimen during cutting. This, however, was essentially constant for all observations since cutting time and handpiece air supply were held constant throughout.

D. Speed measurement during cutting. A small photocell, mounted on the head of the handpiece, was used to detect changes in light intensity reflected from the bur shaft as it turned. One half of the circumference of the bur shaft was painted black. Thus, for each revolution of the bur, a pulse of electric current was generated by the photocell. This signal, after suitable manipulation*, was fed to the input of a pulse counter. In this way the total number of revolutions made by the bur during cutting or free running conditions was recorded. An accurate timer clock operated as an integral part of the scaler

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* A detailed description of the speed measuring apparatus appears in Appendix 2.

system. Thus, determination of cutting time and average rotational speed could be made.

E. Rate of removal. Pre- and post-cut weights of each specimen were determined with an analytical balance. Rate of removal was determined by dividing the specimen weight loss by the cutting time.

Hydration effects on weight were minimized by conditioning of the samples as described in a following section of this paper.

F. Measurement of heat transferred to the specimen during cutting. Determination of heat transferred to the specimens was accomplished utilizing a simple calorimetry method; i.e., by measuring the temperature change of a known volume of distilled water after introduction of the sample immediately after it had been cut. The water was contained within a small, plastic, silvered vessel which was suspended within a larger vacuum bottle container. The vacuum bottle served to stabilize the environment and thus, to minimize heat loss via conduction and convection. The silvered covering of the water container reduced radiation losses. Temperature of the water and specimen within the container was continuously monitored by a small, sensitive thermister which was permanently mounted within the container, and which was connected as one leg of a sensitive Wheatstone Bridge circuit. The calorimeter is illustrated in Figure 2.

G. Data acquisition. For each test specimen the following procedures were carried out: (1) Twenty four hours prior to test cutting the sample was removed from water storage, wiped with a clean dry towel, and placed on a wooden table top in the room in which cutting was to be carried out. Room temperature was maintained at 23°C.. (2) Immediately prior to cutting, each specimen was weighed to the nearest 0.5 mg. on an analytical balance. All specimens were handled with wood insulated tweezers to minimize heat exchange with the sample. (3) The specimen was carefully placed and oriented in the wooden vice which was mounted on the loading device, and the air-turbine was turned on and allowed to achieve its maximum free running speed at 25 psi.. (4) The specimen was carefully brought into contact with the revolving dental bur, care being taken to avoid any jarring impact at the time of initial contact. Cutting time was limited to fifteen seconds, measured from the time of initial contact of the bur with the specimen. (5) Immediately after cutting, the specimen was transferred (using the insulated tweezers) to the measured volume of room temperature water contained within the calorimeter. Care was taken to effect this transfer in not less than 5, nor more than 8 seconds after termination of cutting. (6) The temperature of the water within the calorimeter was continuously monitored while the entire calorimeter was gently agitated by hand to aid in heat dispersion throughout the water. (7) When equilibrium temperature of the water and specimen was achieved the temperature value was recorded. Equilibrium temperature was determined, by prior experimentation, to be that temperature at which no further change in temperature could be noted during fifteen seconds of gentle agitation of the calorimeter. (8) Total revolutions of the bur during the timed cutting period were read directly from the scaler and recorded. (9) Following a twenty four hour room temperature reconditioning period of the cut sample, post-cut weights were taken on the analytical balance. The difference between pre- and post-cut weights was taken as the amount of dentin removed by the cutting procedure.

In Table 2 the various categories for which data were obtained are shown. Within each of the hardness groups, six sets of observations (as described previously) were obtained for each of six different conditions of bur loading.

Statistical design for evaluation of the data was that of a completely randomized block, with six loads, three hardness categories within each load, and six observations within each hardness category.

Tables 7 and 8 are the analysis of variance tables for rate of removal and rate of heat transfer.

RESULTS AND DISCUSSION

The data are summarized in Table 3. The analysis of variance of this data showed that there were significantly different rates of removal and rates of heat transfer among the applied cutting loads at the 5% level. It was also concluded from this analysis that neither rate of removal nor rate of heat transfer differed significantly among the three specimen hardness groups. No significant interaction between loads and hardness was detected for either rate of removal or rate of heat transfer. Accordingly, all hardness values within each load group were pooled for purposes of further evaluation and to facilitate illustration.

The mean values of the pooled data for rate of removal and for rate of heat transfer in the various load categories were broken into linear, quadratic and cubic components. Tests of significance revealed that the second degree (parabolic) components were significant at the 5% level. Correlations between observed and calculated values in this analysis were 0.987 for rate of removal, and 0.998 for rate of heat transfer.

Best-fitting parabolic curves were fitted to the data and are shown in Figure 3. The formulae for these parabolas were determined, and the maximum point of each was determined using the First Derivative Method. Maximum rate of tooth structure removal occurred at 63.3 grams applied cutting load, and maximum rate of heat transfer occurred at a load of 49.0 grams.

The finding that maximum heat transfer occurred under different conditions of loading than did maximum removal rate may be of practical significance. It can be seen in Figure 4 that applied loads near 50 grams resulted in relatively high rates of heat transfer, but only moderate to high rates of removal. Loads approaching 70 grams, on the other hand, resulted in much reduced rates of heat transfer while yielding equal or only slightly reduced removal rates. In view of this, the use of the heavier cutting loads, especially during the rough-out phase of cavity preparation, might be desirable from a clinical point of view.

The effect on rotational speed of increased cutting loads is shown in Figure 5. It can be seen that, within the range of approximately 50 to 80 grams applied load, slight alterations of the load resulted in relatively great changes in the speed of rotation. For example, increasing the cutting load from 50 to 60 grams reduced rotational speed by almost 100,000 revolutions per minute.

Since such large changes in rotational speed of air-turbine handpieces are accompanied by marked alteration of the pitch of the sound emitted by the handpiece, it may be possible, in the future, for the trained clinician to determine when he is operating under conditions which present the least thermal hazard to the tooth upon which he is working.

Additional studies utilizing different driving air pressures, different handpieces, and different bur types should be undertaken to determine whether the relationships demonstrated under the conditions of this experiment hold under other operational conditions.

SUMMARY AND CONCLUSIONS

An *in vitro* study of the relationships of rate of heat transferred to the tooth to the rate of removal of tooth structure has been completed. A single air-turbine handpiece, driven by a fixed air supply of 25 psi was used throughout the study.

Data obtained reveal that, under the conditions of this experiment:

1. Hardness of the tooth specimens had no significant effect upon either rate of heat transfer or rate of removal of tooth structure.

2. The rate of removal of tooth structure and the rate of heat transfer to the specimen during cutting were related to the magnitude of the applied cutting load. These relationships were not linear; rather, these functions were shown to be essentially parabolic in nature.

3. The magnitudes of applied load under which the rate of heat transfer and the rate of removal reached their maximum values were not the same. Maximum rate of heat transfer occurred with a lighter cutting load than did maximum rate of removal.

4. Rotational speed of the cutting instrument was observed to be a function of the applied cutting load and at loads greater than 50 grams, small alterations of the applied load resulted in marked alterations of the rotational speeds of the dental bur.

CLINICAL IMPLICATIONS

The results of this investigation suggest that the use of a cutting load which is only slightly less than that necessary to produce complete stall-out of the dental bur may be desirable in some phases of clinical cavity preparation. It was shown that, although the rates of removal of tooth structure were almost the same at applied cutting loads of approximately fifty grams and seventy grams, the rates of heat transfer realized within the tooth structure under these loading conditions differed markedly. Rate of heat transfer was approximately 50% less under the conditions of heavier loading.

It was observed that when the applied cutting load exceeded a certain magnitude (50 grams in these experiments) the rotational speed of the bur was markedly affected by slight changes in the magnitude of the cutting load. Because the pitch of the sound emitted by the handpiece varies with the rotational speed it may be possible, in the future, for the trained operator to determine (aurally) when he is operating under conditions which present minimum thermal hazards to the tooth upon which he is working.

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APPENDICES

APPENDIX 1

Table 1. Outline of Variables to be Controlled and to be Measured

Variables to be Controlled	Variables to be Measured
A. Cutting instruments	A. Cutting instruments
1. Air pressure to the handpiece.	1. Free running speed.
2. Bur type and sharpness.	2. Average speed of rotation during cutting procedure.
3. Cutting load applied.	
B. Specimen	B. Specimen
1. Material (human dentin).	1. Average rate of removal during cutting.
2. Size and shape of specimen.	2. Temperature of specimen at equilibrium in the calorimeter.
3. Hardness and state of specimen hydration.	
4. Depth of cut.	
5. Cutting time.	
6. Starting temperature.	
C. Calorimeter	C. Calorimeter
1. Starting temperature of water.	1. Temperature change of water after addition of cut specimen.
2. Volume of water in the calorimeter.	
3. Heat loss within the calorimeter.	

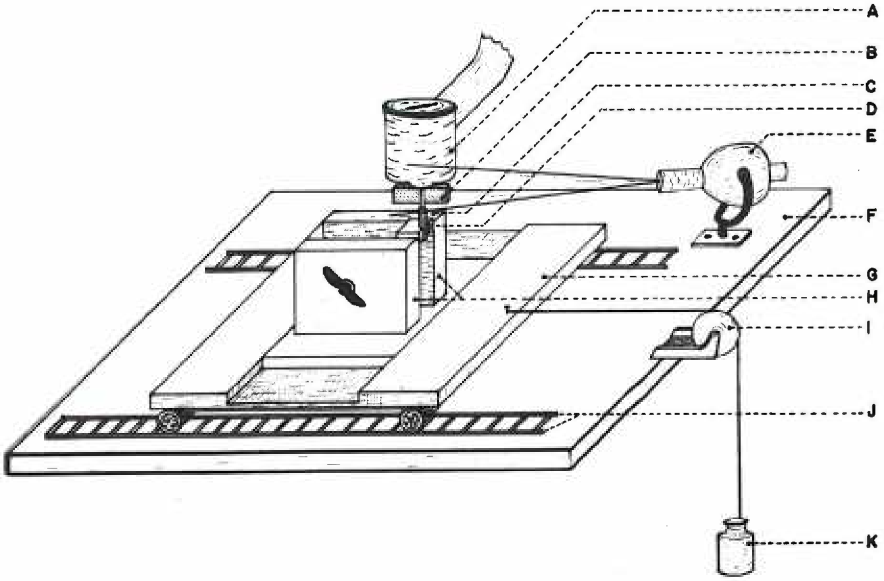
Table 2. Category Organization of the Data

Dentin Hardness					
Hard		Medium		Soft	
No. of specimens	Load (gm.)	No. of specimens	Load (gm.)	No. of specimens	Load (gm.)
6	30	6	30	6	30
6	40	6	40	6	40
6	50	6	50	6	50
6	60	6	60	6	60
6	70	6	70	6	70
6	80	6	80	6	80

Table 3. Summary of the Data

Load (gm.)	Specimen Hardness	Rotational Speed (rpm x 10^3)	Removal Rate (mg./min.)	Heat Transfer (cal./min.)
30	Soft	240.0	0.3	4.0
	Medium	235.0	0.2	4.0
	Hard	235.0	0.4	4.0
	Average	236.5	0.3	4.0
40	Soft	213.6	8.3	12.5
	Medium	232.5	7.7	9.7
	Hard	223.9	7.7	10.7
	Average	223.3	7.9	11.0
50	Soft	213.9	9.0	12.0
	Medium	213.0	13.6	11.3
	Hard	219.3	10.6	11.3
	Average	215.4	11.0	11.5
60	Soft	128.6	12.4	8.1
	Medium	142.9	14.3	7.8
	Hard	155.4	16.5	10.5
	Average	142.3	14.4	8.8
70	Soft	28.9	9.0	3.4
	Medium	50.8	9.8	6.5
	Hard	44.7	13.1	5.2
	Average	41.4	10.6	5.0
80	Soft	stall	0 plus	0 plus
	Medium	stall	0 plus	0 plus
	Hard	stall	0 plus	0 plus

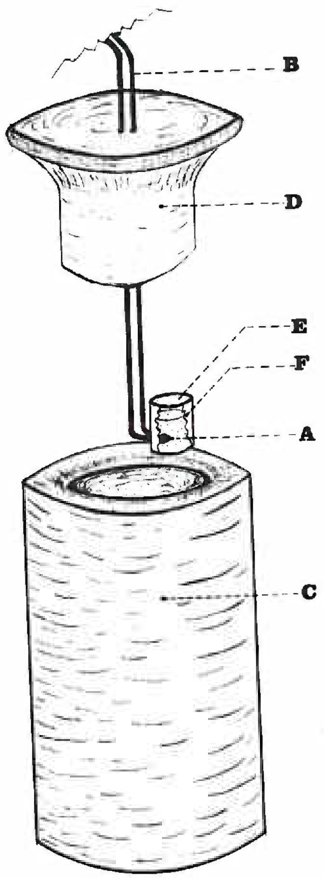
Figure 1



Diagrammatic Sketch of the Force Loading Device

This illustration demonstrates the following: (A) Head of the air-turbine handpiece; (B) Photocell mounted on head of the handpiece; (C) No. 557 bur; (D) Tooth specimen; (E) Light source; (F) Heavy brass plate; (G) Moving table; (H) Jaws of wooden vice specimen holder; (I) Pulley; (J) Track mounted on brass plate; and, (K) Weight used to apply the lateral load during cutting procedures.

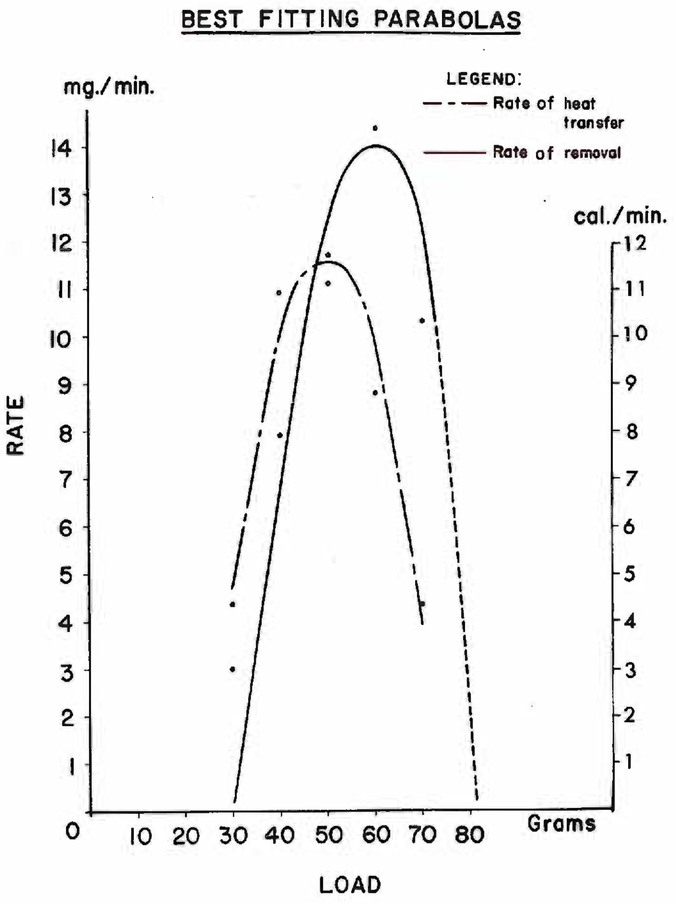
Figure 2



Calorimeter and Specimen Holder

This sketch shows the following: (A) Thermister for temperature measurement; (B) Electrical leads to thermistor bridge; (D) Insulated lid of vacuum bottle; (E) Specimen container with water; and, (F) Silvered outer surface of specimen container.

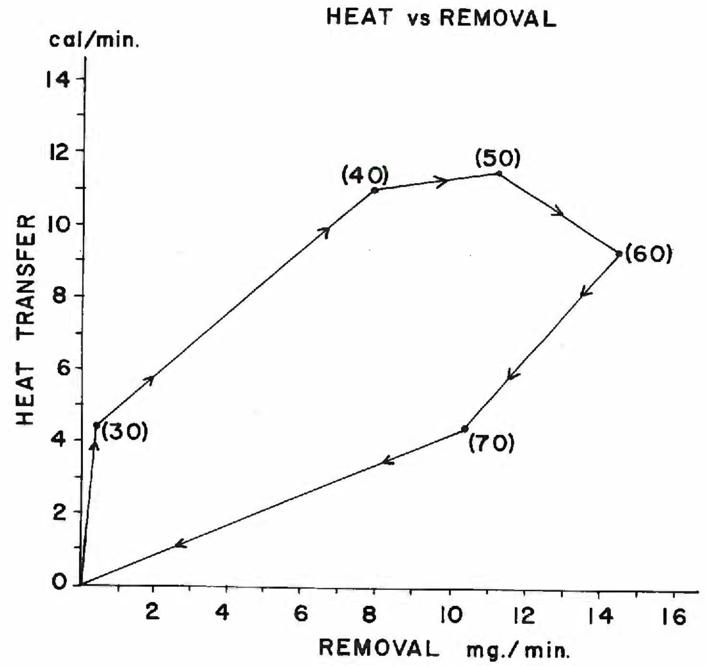
Figure 3



Best Fitting Parabolas: Rate of Removal versus Load, and Rate of Heat Transfer versus Load

The individual points which are plotted on this graph represent the observed mean values of each load group. The curves shown are the best fitting parabolas as calculated from the observed data.

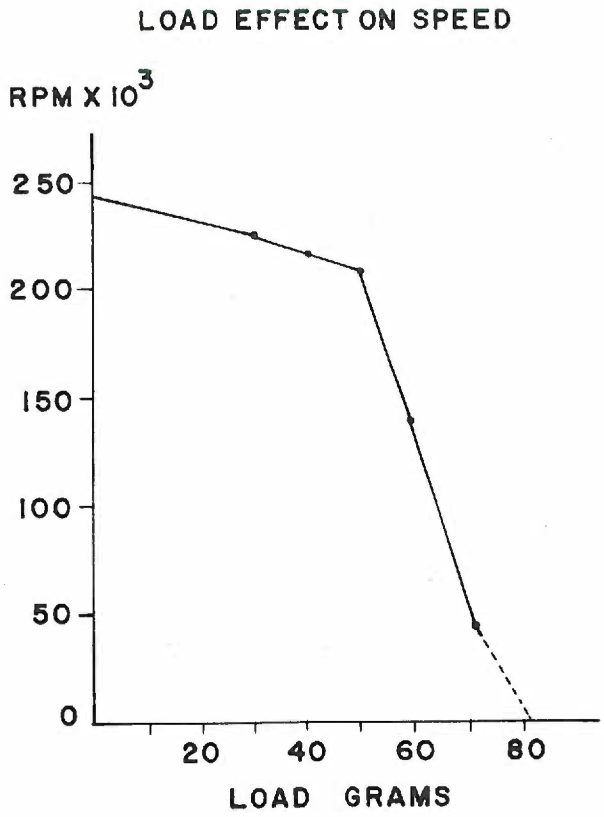
Figure 4



Rate of Heat Transfer versus Rate of Removal with Increasing Loads

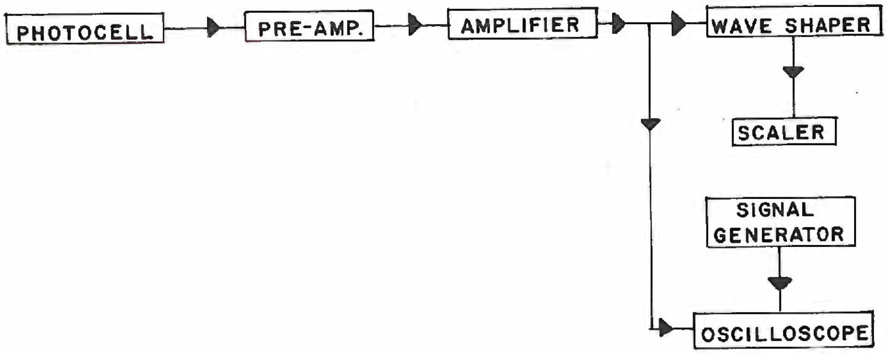
The numbers in parentheses indicate the cutting load in grams at the points indicated. The arrows indicate the progression of loading from zero through 80 grams.

Figure 5



Effect of Loading on Rotational Speed

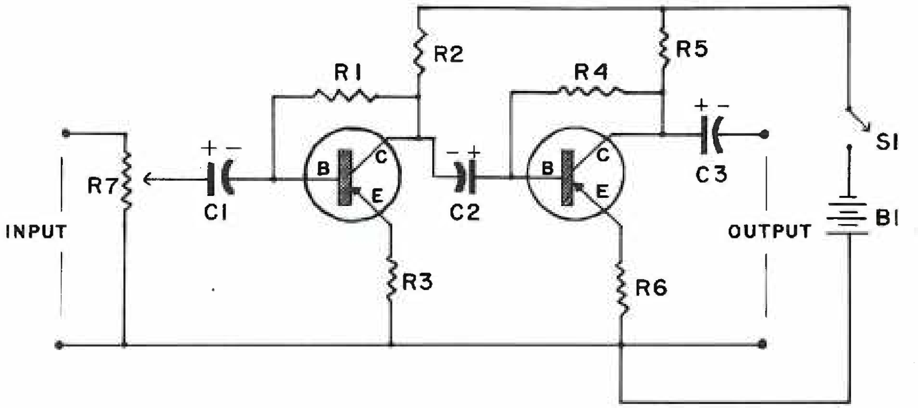
Figure 6



Speed Measuring System-Block Diagram

With each rotation of the dental bur a small electrical signal is generated by the photocell. This signal is amplified by the preamplifier, then the amplifier. The signal is then fed to a waveformer which converts the sine wave signal to a square waveform. This modified signal is then fed to an electronic scaler which registers each electric pulse. The signal generator and oscilloscope are used to check calibration of the scaling system.

Figure 7

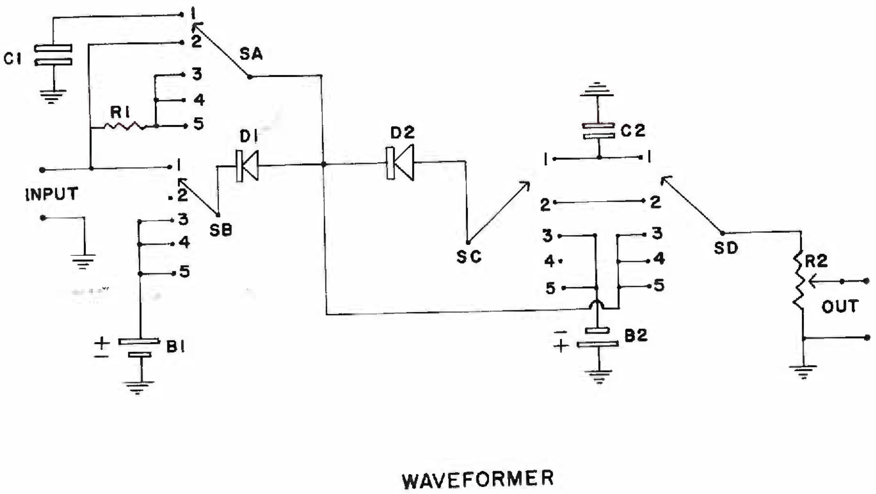


PREAMPLIFIER

Preamplifier Schematic Diagram

This unit provides the first two stages of signal amplification. Maximum gain is approximately 500.

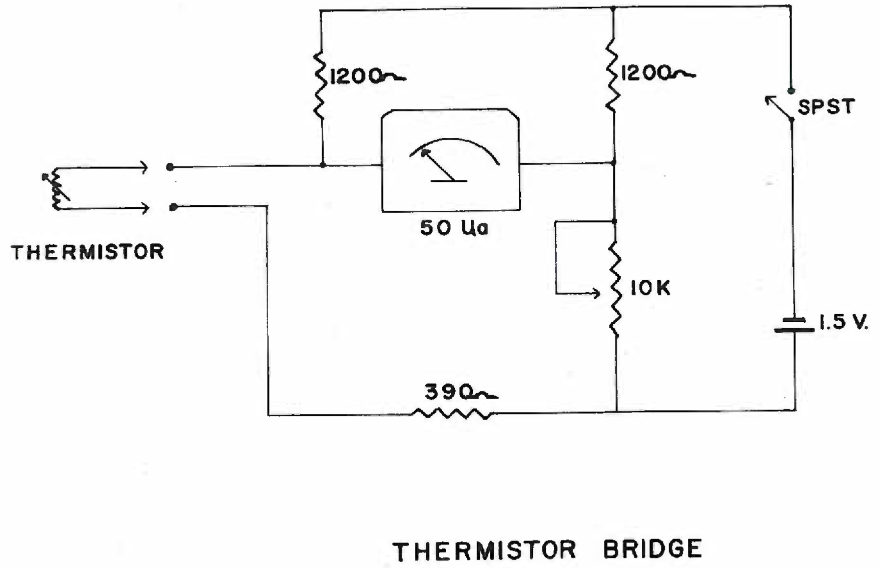
Figure 8



Waveformer Schematic Diagram

Several different waveforms may be obtained depending upon the position of the multiple switch. For use in this investigation, the square wave achieved with the switch in position 4 proved ideal.

Figure 9



Thermistor Bridge Circuit Diagram

This is a simple Wheatstone Bridge in which the thermistor resistance is the unknown to be determined. The sensitive microammeter measures degree of imbalance as the thermistor resistance changes. Previous calibration of the microammeter with the thermistor held at known temperatures allows direct temperature readings to be taken from the meter.

APPENDIX 2

INSTRUMENTATION

I. Measurement of rotational speed during cutting. After trial of several methods for measuring rotational speed, including stroboscopic and electromagnetic methods, it was decided that the photoelectric method described by Taylor, Perkins, and Kumpula[21] with some modification, would best meet the special needs of this study. Figure 6 is a block diagram of the modified speed measuring system which was devised. The photocell was constructed by soldering appropriate electrical leads to a small, rectangular block of photosensitive selenium which had been cut to the desired dimensions (0.5 mm. X 5.0 mm. X 10.0 mm.). This unit was mounted securely to the head of the handpiece. Relative size and orientation of this unit can be seen in Figure 1.

The very small electric current pulses (0.5 ua. to 1.5 ua.) generated by the mounted photocell had to be greatly amplified before they were of sufficient magnitude to operate the scaler circuits. A two stage transistor preamplifier having an overall gain of approximately 500 was designed and constructed to amplify the photocell output sufficiently to operate a standard audio amplifier. A schematic diagram of this preamplifier is shown in Figure 7.

The wave form of the signal generated by the photocell was that of a sine wave. Because the electronic scaler input signal must have a very short rise time to accurately trigger the scaler circuits, the amplified sine wave had to be changed, or shaped, to a wave form having the desired fast rise characteristics. For this purpose, the wave former diagrammed in Figure 8 was constructed. With the function switch ($S_{A,B,C,D}$) set to position 4, the sine wave input signal was transformed to a square wave output signal of the same frequency and approximate amplitude. The square wave thus formed was used to activate the scaler circuits.

The scaler used in this study was a Berkeley Scaler, model 2000, having a maximum counting rate capacity of 600,000 cpm. By feeding the modified photocell signal into this unit, one count for each revolution of the dental bur was obtained. Thus, total revolutions of the bur during cutting could be directly read from the scaler. Since an accurate record of the time of cutting was also kept, average rotational speed could be easily calculated.

The signal generator and oscilloscope designated in Figure 6 were utilized to calibrate and check the scaling system prior to each day's run. By feeding the amplified photocell signal to the vertical deflection plates, and a known frequency from the signal generator to the horizontal deflection plates of the oscilloscope, an accurate determination of rotational speed could be made for comparison with the scaler readings. Use of these units allowed quick, easy adjustment of signal strength inputs to the scaler, thus insuring uniform operation from day to day.

II. Measurement of heat transferred during cutting. Figure 9 is a schematic diagram of the thermistor temperature measuring circuit which was constructed as a part of the calorimeter apparatus. The simple Wheatstone Bridge circuit shown provided an accurate, rapid means of determining the temperature of the water in the specimen container of the calorimeter at any time during a test procedure.

Placement of the thermistor in the specimen container can be seen in the diagram of Figure 2. Test procedure with the calorimeter unit was as follows: Immediately after a test cut was completed, the specimen was transferred (using insulated tweezers) to the specimen container which held 0.5 cc. of water at room temperature. Time required for completion of the specimen transfer was between 5 and 8 seconds. The temperature of the water was constantly monitored until an equilibrium temperature was reached, at which time the temperature value was recorded.

III. Calculation of heat transferred. If a heated object is placed in a known volume of water of lesser temperature, heat from the sample will be transferred to the water until a point of equilibrium is reached. If this temperature is measured, and if the initial water temperature was known, the number of calories given up by the object to the water can be calculated. (One calorie will raise the temperature of 1 gram of water 1 degree centigrade.) If the specific heat, the weight, and the initial temperature of the sample are also known, the total calories transferred by the heating procedure can be calculated.

Definition of Symbols

Ws = weight of water in calorimeter (grams)

Ss = specific heat of the specimen

Ws = weight of the specimen

Te = temperature at equilibrium

Ct = calories transferred to water (as determined by the increase in water temperature after introduction of the sample)

CT = total calories contained by the specimen at the time of transfer to the calorimeter

Ti = temperature of specimen and of water prior to the cutting procedure

Ca = calories added by the heating process

Ci = calories contained by specimen prior to cutting

Ce = calories contained by specimen at equilibrium

$$(1) \quad Ce = (Ss)(Ws)(Te)$$

$$(2) \quad Ci = (Ss)(Ws)(Ti)$$

$$(3) \quad Ct = \frac{Te-Ti}{Ww}$$

$$(4) \quad CT = Ci+Ct$$

$$(5) \quad Ca = CT-Ci+(\text{correction factor})$$

IV. Correction for heat loss within the calorimeter. The correction factor for calorimeter heat loss was determined in the following manner:

1. Samples, similar in all respects to those used in the experiment, were placed in an incubator oven set at 27°C.. After the samples had reached oven temperature, determinations of total calories were made as described above. The starting temperature of the sample

was known (27°C.), therefore, the total heat contained by the sample could be calculated. This calculated value was then compared to the observed, or measured, value. The difference between calculated and observed values was taken as the correction factor for heat loss within the calorimeter and was, therefore, added to all heat determinations involved in the experiment. Value of the correction factor was 0.06 calories.

APPENDIX 3

Table 4. Individual Sample Values for Speed, Removal and Heat (Group I Soft)

Load (gm.)	Speed (rpm x 10^3)	Removal Rate (mg./min.)	Heat Transfer (cal./min.)
30	235.5	0.3	2.7
	237.5	0.3	5.4
	240.0	0.1	3.1
	242.0	0.4	1.6
	239.0	0.4	7.0
	246.0	0.2	4.2
40	199.0	9.9	12.4
	222.5	7.5	9.9
	218.5	9.4	12.2
	213.0	9.9	15.6
	211.0	8.1	11.5
	218.0	5.1	13.5
50	217.5	8.3	12.7
	210.5	8.2	11.1
	193.5	9.7	12.3
	216.0	15.2	17.6
	226.0	5.1	5.6
	220.0	8.0	12.4
60	51.0	10.6	1.3
	55.0	14.9	1.3
	50.0	10.2	4.1
	205.0	15.5	15.4
	200.0	15.0	14.0
	210.0	8.2	12.3
70	25.0	5.5	4.2
	40.0	7.9	4.1
	20.0	10.2	4.8
	30.0	11.8	2.1
	18.5	8.3	1.3
	40.0	10.2	4.2

Table 5. Individual Sample Values for Speed, Removal and Heat
(Group II-Medium)

Load (gm.)	Speed (rpm x 10^3)	Removal Rate (mr./min.)	Heat Transfer (cal./min.)
30	234.5	0.1	5.7
	238.5	0.1	5.0
	229.0	0.4	3.2
	241.0	0.2	1.8
	230.5	0.5	4.0
	236.5	0.6	5.5
40	243.0	3.2	4.4
	242.0	9.9	5.6
	236.0	2.8	7.1
	226.0	9.9	15.3
	222.0	5.6	8.5
	224.0	15.0	17.2
50	170.5	32.3	13.6
	210.5	11.0	12.6
	230.0	9.0	16.5
	202.0	9.5	14.0
	230.0	13.8	6.7
	235.5	5.9	4.3
60	70.0	12.8	1.2
	78.0	12.6	2.8
	209.5	17.2	9.9
	220.5	11.1	12.4
	80.0	19.4	5.7
	199.5	12.9	14.8
70	15.0	3.5	6.9
	15.0	10.6	2.8
	18.0	10.0	5.6
	20.0	13.0	7.0
	18.0	3.5	1.2
	52.0	11.8	4.3

Table 6. Individual Sample Values for Speed, Removal and Heat (Group III–Hard)

Load (gm.)	Speed (rpm x 10^3)	Removal Rate (mg./min.)	Heat Transfer (cal./min.)
30	217.5	0.2	5.0
	228.0	0.2	11.4
	239.5	0.3	1.2
	238.0	0.5	3.9
	247.5	0.6	5.5
	240.0	0.1	2.0
40	205.5	10.6	10.8
	218.0	10.6	13.5
	226.0	3.2	14.2
	230.0	7.1	6.7
	230.0	7.9	12.4
	234.0	6.7	6.7
50	238.0	5.1	13.9
	227.0	12.6	11.5
	222.5	12.3	8.5
	210.0	12.2	12.4
	210.0	14.6	10.9
	208.0	7.1	10.7
60	208.5	13.3	13.9
	50.0	14.6	5.0
	42.0	11.6	4.4
	224.0	13.0	12.3
	213.0	19.2	16.6
	196.0	27.4	11.0
70	40.0	11.3	2.7
	48.0	16.6	1.5
	80.0	22.4	5.5
	25.0	8.3	6.9
	45.0	11.8	7.2
	30.0	8.2	7.2

Table 7. Analysis of Variance for Rate of Removal

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Square
Total	104	3488.01	
Between Loads	4	2018.04	504.51*
Between Hardness	2	50.87	25.44
Load X Hardness	8	132.29	16.54
Error	90	1286.81	14.30
Residual	98	1419.10	14.48

*Significant at 5% level

Table 8. Analysis of Variance for Rate of Heat Transfer

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Square
Total	104	1805.24	
Between Loads	4	866.31	216.58*
Between Hardness	2	39.28	19.64
Load X Hardness	8	137.14	17.14
Error	90	762.51	8.47
Residual	98	899.65	9.17

*Significant at 5% level