A STUDY OF THE CUTTING EFFICIENCY OF DENTAL BURS FOR THE STRAIGHT HANDPIECE

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IN THE preparation of cavities through the use of rotating instruments utilizing burs and stones, the ideal condition of design and operation has been described as the one which will remove the most material with the least patient discomfort due to heat, vibration, and pressure, and which also produces the longest life of the operating instrument. Some have recommended new and ingenious methods of material removal. The Air-Dent method is one example,[1] while Walsh and Symmons[2] in New Zealand have advocated the use of a dental bur at a speed of 60,000 r.p.m. Others advocate the use of diamond pointed instruments at high speed. The use of diamond instruments, however, is not recommended for soft materials. According to one investigator, they should not be used against amalgams and metals. This material should be removed by burs.[4]

Studies on some causes of heat and vibration have been conducted and reported.[5, 6] A third study, namely, the amount of material removed or efficiency of the instrument, is in order and a portion of that study is reported at this time.

The amount of material removed is a function of several variables, such as the instrument design, material to be cut, speed, and pressure. The composition of the bur is also a variable, particularly when the active life of the bur is considered. It is therefore necessary at the outset to establish the limits that will be considered in this portion of the study.

The first is the material to be cut. This report will be limited to results obtained through the use of Ivoryene, a synthetic ivory, having a hardness somewhat comparable to dentin. It has the advantage over actual tooth material of being more uniform and homogeneous. A second condition is the active life of the bur. To overcome this variable, each test (except for carbide burs, stones, and diamond points) was conducted with a new bur. Therefore, no consideration of dulling or bur life is taken into account. These conditions approach the ideal in the case of burs, but perhaps are too ideal for everyday use. This practice was necessary, however, in order to form some measure of standardization from which to obtain information on bur design.

EQUIPMENT AND PROCEDURE

A Meisinger dental motor, capable of rotating at a speed of approximately 12,000 r.p.m. when a voltage of 135 volts is applied, was calibrated by the accepted Prony brake method. Using a constant voltage, the speed, obtained by the use of a stroboscope, and the amperage were recorded for each load applied. A calibration graph was plotted, representing the speed against amperage and torque against amperage, for the different increments of 5 volts between 60 volts to 110 volts. A typical graph is shown in Fig. 1.

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The cutting equipment consisted of a four-wheel carriage mounted on tracks, and counterbalanced to overcome frictional forces. A clamp for holding the specimen (Ivoryene block) was fixed in the center of the carriage. To maintain the desired constant feed or pressure, a pan was attached with a fine wire, on which the different weights could be placed.

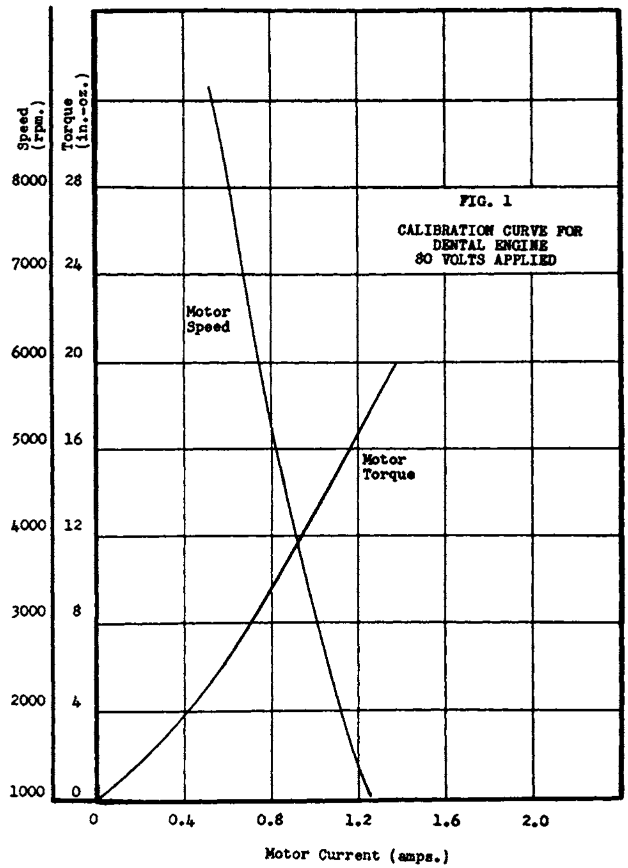

Fig. 1.

The handpiece was firmly held beneath the tracks and could be raised or lowered to insure that the same length of bur was being used for each test. The bur was always placed in the handpiece collet to the same depth and securely held in position to standardize conditions further. As previously noted, a new bur was used for each cutting operation, except in the cases mentioned.

The energy necessary to operate the handpiece alone was determined at various speeds by varying the input voltage of the motor through the full range of calibration. This was followed by the test program (Table I) in which each bur was tested throughout the full speed range for each pressure.

The results of these tests are shown in graphical form in Figures 2 through 14.

TABLE I

BUR TYPE	BUR NO.	PRESSURE (GRAMS)			MFGR.*	REMARKS
Fissure	557	100, 750,	200, 1000	500,	1	Steel, straight flutes.
	557	100,	500		3	Tungsten carbide.
	557	200,	500,	750,	2	Steel, straight flutes.
	557	200,	500,	750,	2	Steel, spiral flutes.
	558	100, ·750	200,	500,	1	Steel, straight flutes.
Inverted Cones	37	100, 750	200,	500,	1	Steel.
	37	100, 750	200,	500,	3	Tungsten carbide.
	39	100, 750	200,	500,	1	Steel.

*Products of only 3 bur manufacturers, designated Nos. 1, 2, and 3, were used.

DISCUSSION OF RESULTS

In Fig. 2 is shown a relationship between the material removed in grams per minute and the energy expended for the No. 557 fissure bur. This energy is given as power (energy per unit time) by the ordinate NT where N represents speed in revolutions per minute and T represents the torque in inch-ounces.

The curves are plotted on log-log paper so that they approach and are drawn as straight lines. These curves were drawn visually. For a high degree of accuracy, they should be calculated by the method of least squares. However, because of the expenditure of time involved in comparison with the information obtained, this was not done.

There are two points of importance to be considered on this type of graphical ploto. The first is the relative position of one particular curve with respect to the other curves, and the second is the slope of each curve. A curve for one bur which is to the right of the curve for another bur would mean that more material is removed for the same expenditure of energy by the bur on the right hand side. The slope of the curve denotes the rate of increase of material removal with respect to an increase of energy expended.

For a light load (100 Gm.-0.22 pounds), the tungsten carbide bur is shown to be superior to the ordinary steel bur (No. 557 fissure type bur). This is shown by the curve for the carbide bur in Fig. 2 which is considerably to the right of that of the steel bur.

With a two-hundred gram load applied, the same bur (No. 557) was compared[1] with a similar bur made by another producer, and with[2] another type No. 557 bur on which the axial cuts are spiral instead of straight.

At a load of 500 grams (1.1 pounds), the bur with spiral axial grooves is shown to be slightly superior to the bur with straight grooves, as indicated by the horizontal spacing between curves. The same tendency is shown by the curves obtained at a load of 750 grams. It is interesting to observe that, on an energy basis, a rather large increase in material removal (grams per minute) is achieved when the pressure is raised from 200 grams to 500 grams; whereas, when the pressure is increased from 500 grams to 750 grams, the amount of material removed is increased, but the relative increase is considerably less than that between the 200 and 500 gram load change. This, however, is on an energy basis, which is purely physical and should not be construed to mean that from a standpoint of dental operating efficiency the same conclusion would hold. The amount of material removed per unit time with changes in speed and pressure will be presented later in this report.

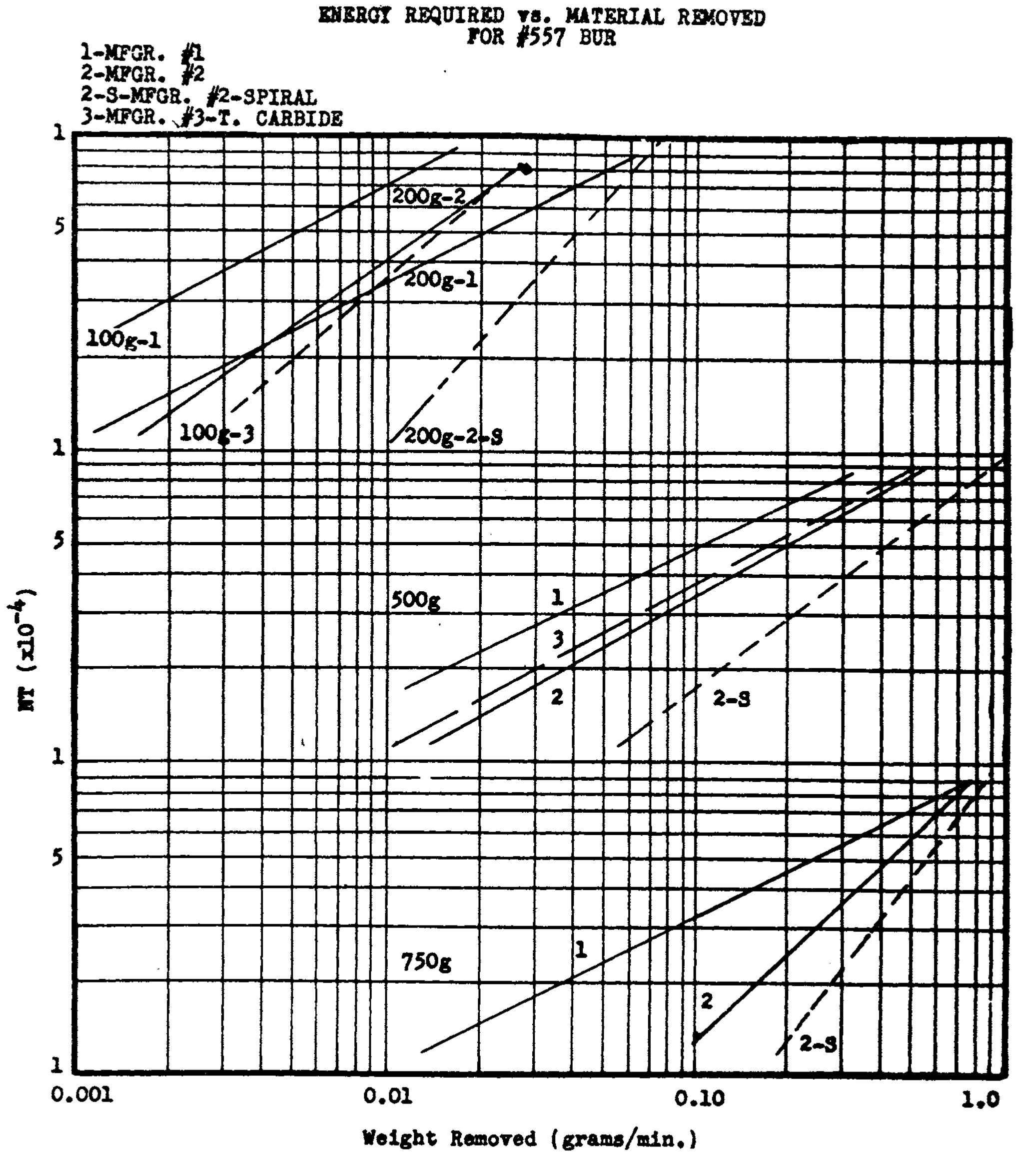

Fig. 2.

In Figs. 3-6 are shown the amounts of material removed as a function of the speed of the motor, for pressures of 100 grams (0.22 pounds), 200 grams (0.44 pounds), 500 grams (1.1 pounds), and 750 grams (1.65 pounds), respectively. On each curve is shown a vertical line at 4000 r.p.m. This is considered to be

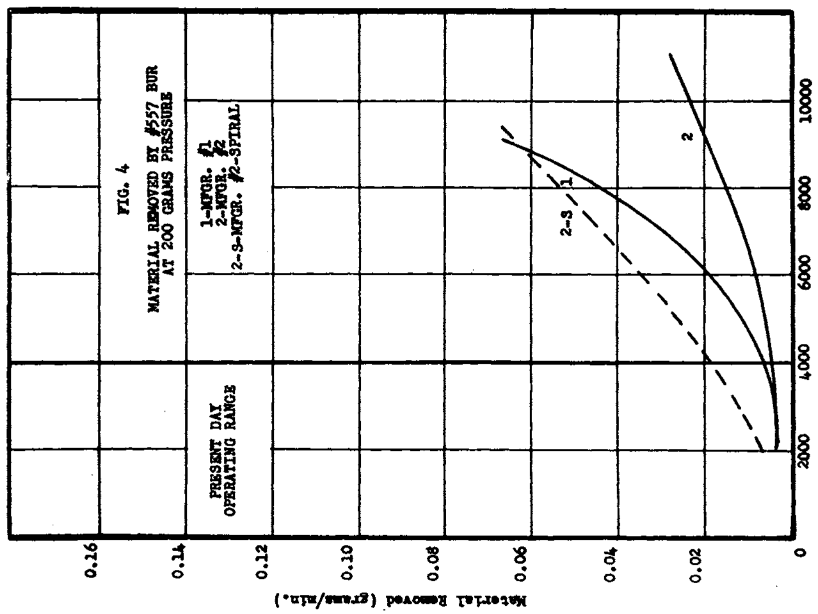
FIG. 4
MATERIAL REMOVED BY #557 BUR AT 200 GRAMS PRESSURE
1-MFGR. #1
2-MFGR. #2
2-S-MFGR. #2-SPIRAL
PRESENT DAY OPERATING RANGE
2-S
1
2
Speed (rpm.)
Material Removed (grams/min.)
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
2000
4000
6000
8000
10000

Fig. 4.

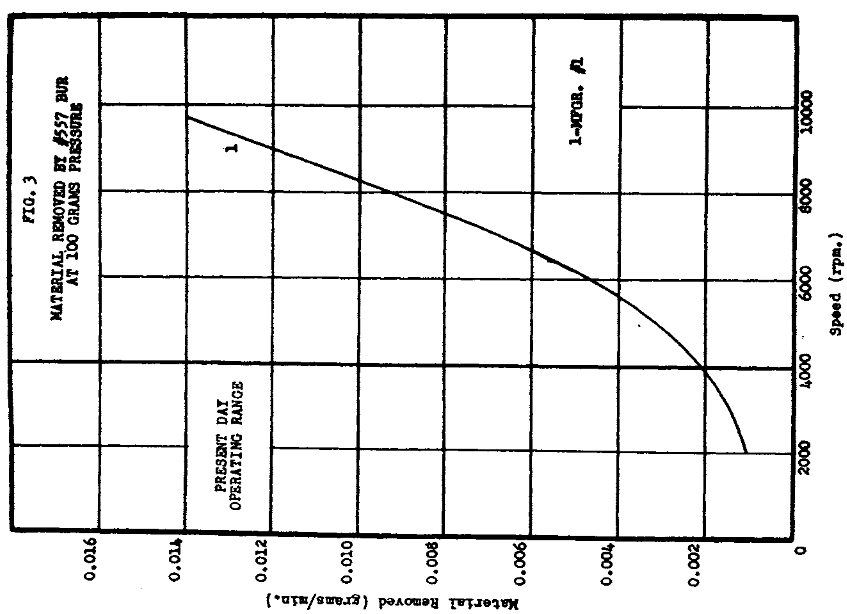
FIG. 3
MATERIAL REMOVED BY #557 BUR AT 100 GRAMS PRESSURE
1-MFGR. #1
PRESENT DAY OPERATING RANGE
1
Speed (rpm.)
Material Removed (grams/min.)
0
0.002
0.004
0.006
0.008
0.010
0.012
0.014
0.016
2000
4000
6000
8000
10000

Fig. 3.

close to the average maximum limit of the present day operating range, since most dental engines have a maximum speed of 3600 r.p.m., while others approach 4500 r.p.m. These curves are all of the same general shape and show a large increase in the material removed as the speed is increased beyond 4000 r.p.m.

The curves in Fig. 5 show that the fissure bur (No. 557), made of tungsten carbide, and the two different No. 557 steel burs by different manufacturers, all with straight cut axial grooves, produce essentially the same performance. The steel bur with spiral cut axial grooves was superior to those with straight grooves, except possibly at high speeds (in the order of 10,000 r.p.m.). Observations when the tests were carried out would indicate that the No. 557 spiral burs reach a maximum cutting ability at about 9000 r.p.m., and beyond that speed the amount of material removed per unit time decreases. This condition could be due to a filling of the flutes of the bur with Ivoryene, which is relatively soft, and also being a plastic may further soften with elevated temperature. This tendency of the amount of material removed to decrease at high speeds is less pronounced as the load is increased, as shown in Fig. 6.

The data on steel burs from these curves (Figs. 3-6) are condensed in Table II.

TABLE II

BUR	MFGR.	PRESSURE (GRAMS)	WEIGHT (GRAMS PER MINUTE) REMOVED AT SPEEDS OF			
			2000 RPM.	4000 RPM.	6000 RPM.	8000 RPM.
No. 557	1	100	.0011	.0022	.0047	.0097
		200	.003	.007	.019	.044
		500	.015	.067	.17	.32
		750	.08	.19	.32	.495
No. 557 Straight Flutes.	2	200	.003	.005	.0085	.015
		500	.03	.085	.18	.31
		750				
No. 557 Spiral Flutes.	2	200	.007	.028	.034	.053
		500	.07	.225	.40	.487
		750				

One general rule that may be concluded from the data is that for the straight grooved No. 557 bur, the amount of material removed in grams per minute is approximately doubled for each speed increase of 2000 r.p.m. up to 8000 r.p.m. while the applied pressure remains constant.

An indication of the amount of material removed as a function of the speed and pressure applied is shown in the three dimensional Fig. 7. This is shown as a surface whose vertical ordinate is the material removed. The line of intersection of a horizontal plane (an imaginary plane parallel to the base plane) with the surface would show the different combinations of speed and pressure that would remove a given amount of material per minute. The amount of material removed is represented by the vertical height at which the plane is drawn.

CHARACTERISTICS OF NO. 558 FISSURE BUR

In Fig. 8 is shown the relationship between the amount of material removed per minute and the energy input for a No. 558 bur at different pressures. This

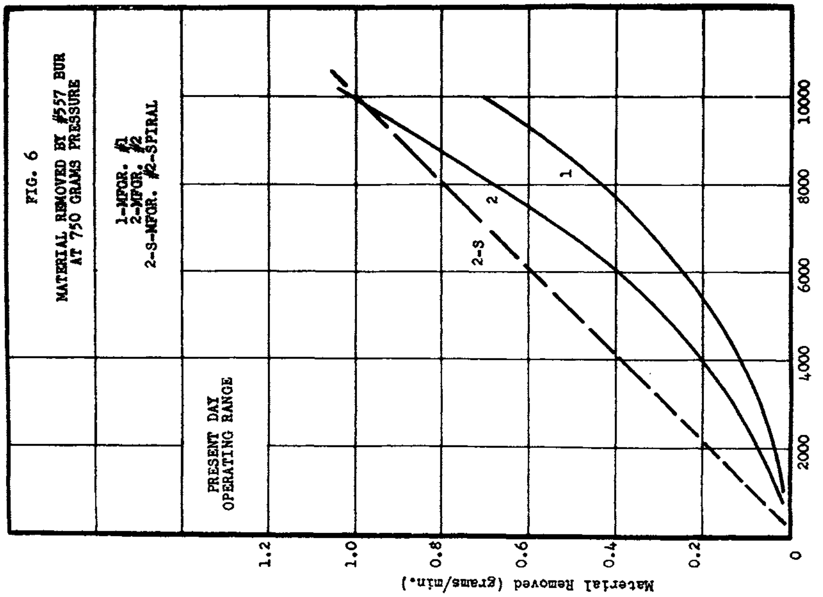
FIG. 6
MATERIAL REMOVED BY #557 BUR AT 750 GRAMS PRESSURE
1-MFGR. #1
2-MFGR. #2
2-S-MFGR. #2-SPIRAL
PRESENT DAY OPERATING RANGE
1
2
2-S
1.2
1.0
0.8
0.6
0.4
0.2
0
Material Removed (grams/min.)
2000
4000
6000
8000
10000
Speed (rpm.)

Fig. 6.

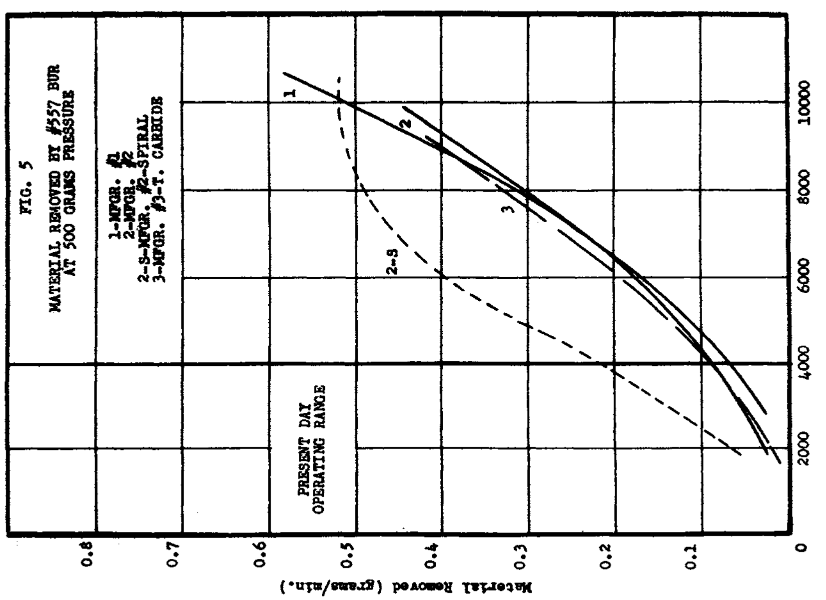
FIG. 5
MATERIAL REMOVED BY #557 BUR AT 500 GRAMS PRESSURE
1-MFGR. #1
2-MFGR. #2
2-S-MFGR. #2-SPIRAL
3-MFGR. #3-T. CARBIDE
PRESENT DAY OPERATING RANGE
1
2
3
2-S
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Material Removed (grams/min.)
2000
4000
6000
8000
10000
Speed (rpm.)

Fig. 5.

TABLE III

PRESSURE (GRAMS)	MFGR.	AMOUNT (GRAMS/MINUTE) REMOVED AT SPEEDS OF			
		2000 RPM.	4000 RPM.	6000 RPM.	8000 RPM.
100	1	.0014	.0033	.0059	.0117
200		.003	.01	.02	.034
500		.03	.062	.105	.17
750		.06	.155	.292	.61

is similar to Fig. 2 for the No. 557 fissure bur. As was true for the No. 557 bur, considerably more material is removed by the No. 558 bur when the pressure is raised from 200 grams to 500 grams, than from 500 grams to 750 grams. For a No. 558 bur the amount of material removed as a function of speed and pressure is shown in Table III.

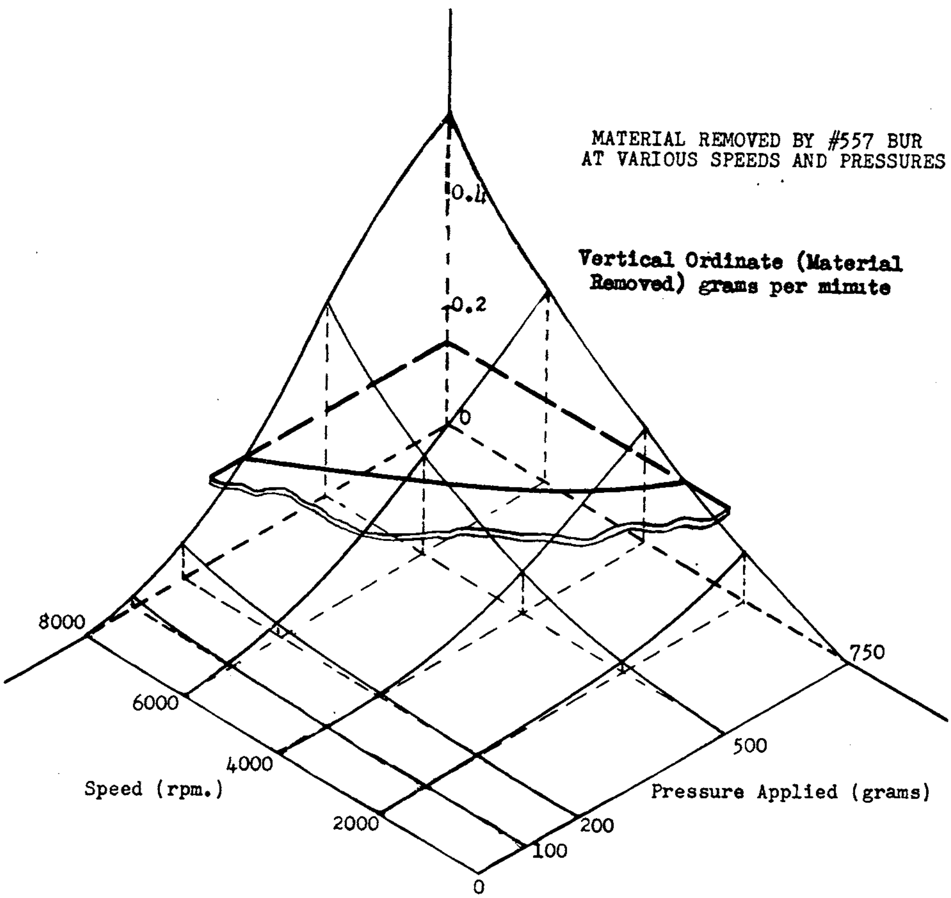

Fig. 7.

These data show that the amount of material removed per minute by a No. 558 fissure bur is not greatly different from that removed by the No. 557 bur. In some cases, the No. 558 bur removes more material, as one would feel it should, since it is a larger bur. This is particularly true at a lighter load of 100 grams. It is also true at a load of 750 grams and 8000 r.p.m. However, the differences in any situation are not large.

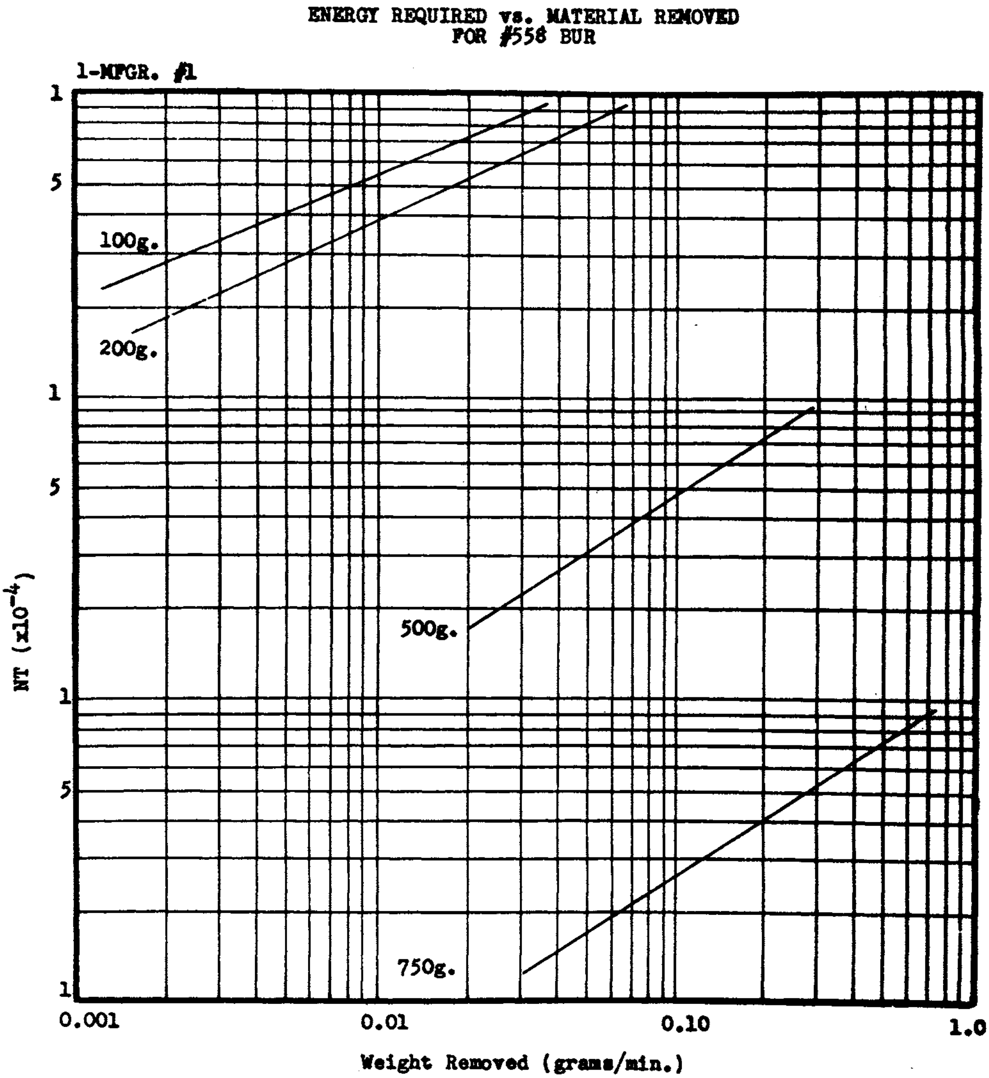

Fig. 8.

In Fig. 9, which is comparable to Fig. 7, is shown the material removed as a function of both speed and pressure. It was observed in using the No. 557 and No. 558 burs that the material which had been cut away was packed rather hard in the cut. If this is characteristic of this material or type of cut only, it would be of no practical consequence, but if this should happen in actual cavity preparation, it might have an influence on the problem of heat generation. This effect did not occur with the inverted cone type bur, which is described presently.

CHARACTERISTICS OF THE NO. 37 INVERTED CONE BUR

The No. 37 inverted cone bur has an average diameter of approximately 0.045 inch and a length of 0.050 inch, while the No. 557 fissure bur has an average diameter of 0.038 inch and a length of 0.185 inch. A notable difference between the No. 37 and No. 39, and the No. 557 and No. 558 is that although the inverted cone type bur possesses about one-third the active cutting area of the fissure type bur, it is capable of removing approximately five times as much material per unit time. This is demonstrated by comparing the abscissa coordinated (material removed-grams per minute) which for the No. 37 inverted cone burs (Fig. 10) is ten times as great as those for the No. 557 fissure bur previously shown in Fig. 2. This observation should be somewhat tempered

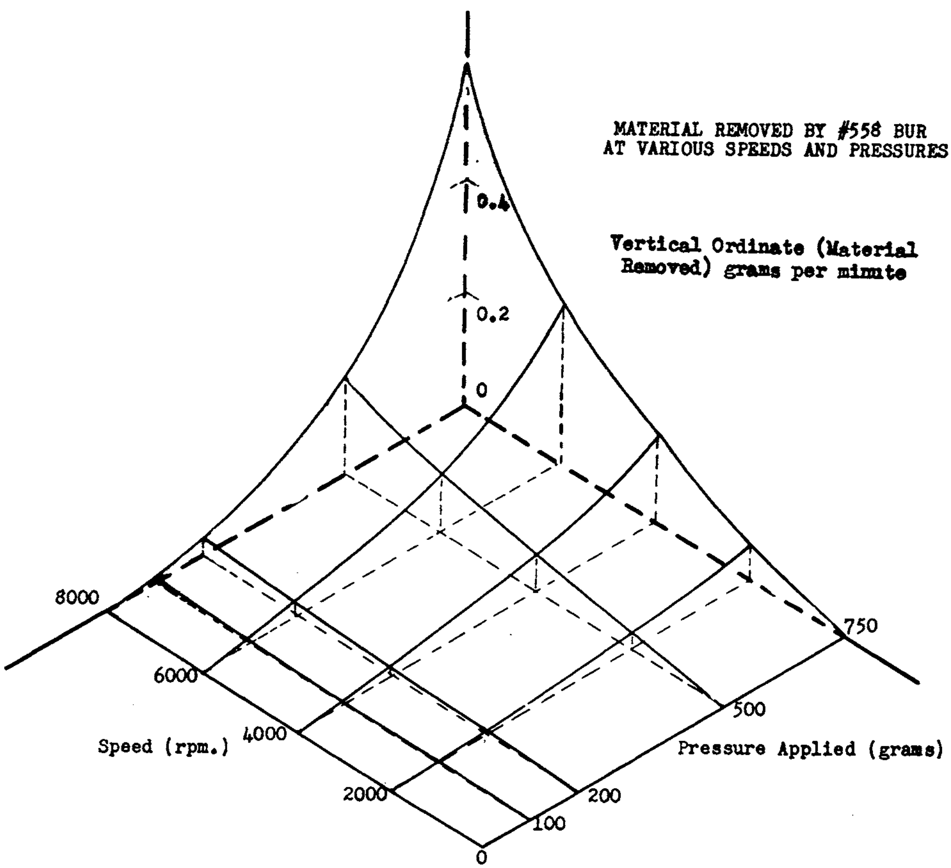

Fig. 9.

though by noticing that the curves are not similarly placed. As an example, with an input energy (NT) of 30,000 (.03HP) and a pressure of 750 grams, an inverted cone No. 37 bur removed 0.62 grams per minute while a No. 557 fissure bur removed 0.08 grams per minute, and a No. 558 fissure bur, 0.12 grams per minute.

TABLE IV

PRESSURE (GRAMS)	MFGR.	MATERIAL (GRAM/MINUTE) REMOVED AT SPEEDS OF 2000 RPM.	4000 RPM.	6000 RPM.	8000 RPM.
100	1	.001	.007	.026	.075
200		.02	.074	.15	.24
500		.21	.44	.72	1.02

The amount of material removed as a function of both speed and pressure is given in Fig. 11. The data in Table IV were used to construct Fig. 12.

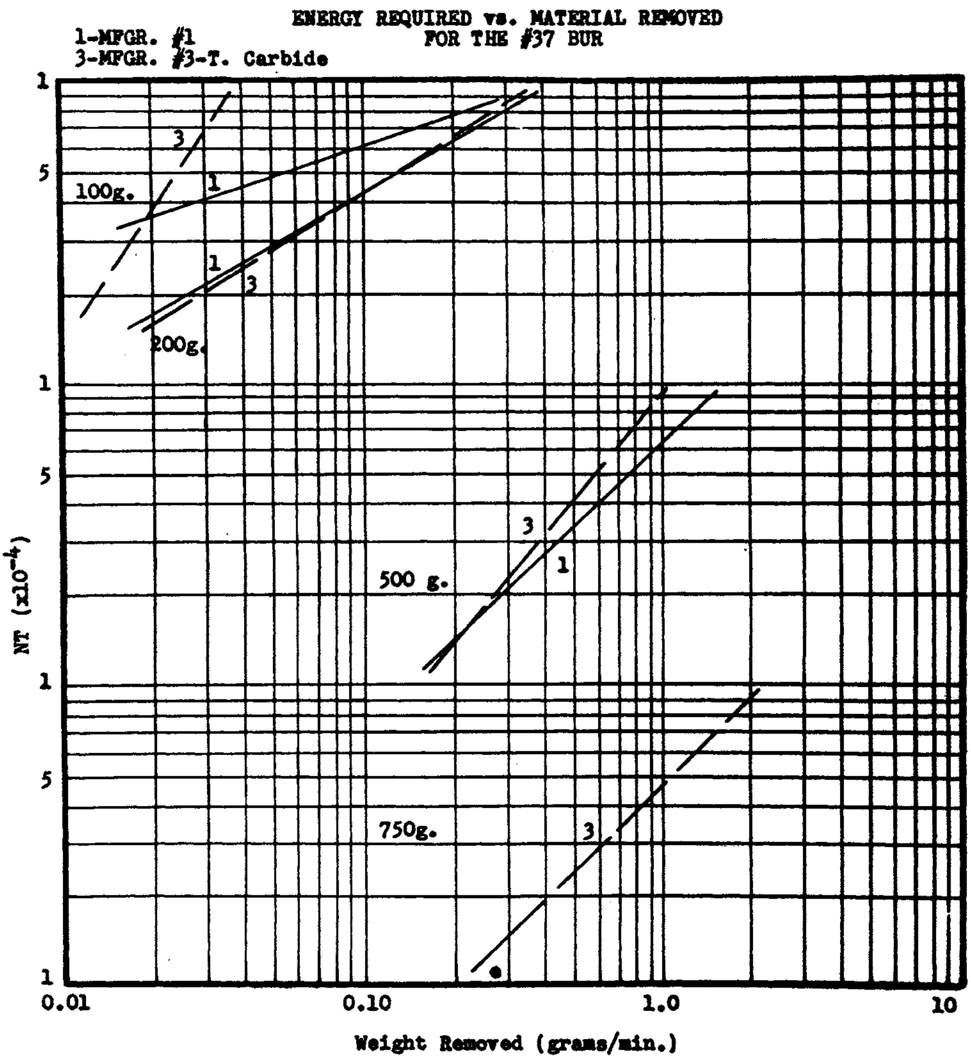

Fig. 10.

CHARACTERISTICS OF THE NO. 39 INVERTED CONE BUR

The relationship between the material removed per minute and the energy input for pressures of 100 grams, 200 grams, 500 grams, and 750 grams is given in Fig. 13. There is a considerable difference in the amount of material removed when the applied pressure is varied. For example, with an energy input (NT) of 30,000 the following Table V is taken from this graph.

TABLE V

PRESSURE (GRAMS)	MATERIAL REMOVED (GRAMS PER MINUTE)
100	.005
200	.092
500	.400
750	.720

With an increase from 100 to 200 grams, the amount of material increased 0.087 grams per minute. With an increase from 200 to 500 grams pressure, or an increase of 300 grams, there was an increase of 0.31 grams per minute, which is an average of 0.10 grams per minute increase per 100 grams increase of load. From 500 to 750 grams pressure, the increase in material removal was 0.31 grams per minute, which would be an increase of 0.13 grams per minute per 100 grams increase in pressure. This indicates that as the pressure was raised more material was removed on a constant input energy basis, but takes into account only the kinetic energy of the motor, and leaves out any consideration of the potential energy due to the pressure exerted by the operator.

The amount of material removed as a function of speed and pressure is shown by Table VI.

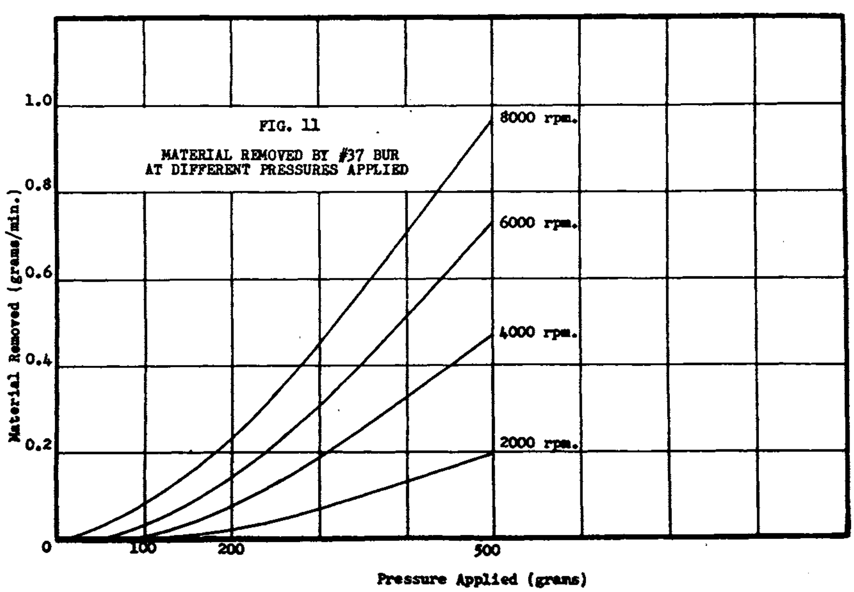

Fig. 11.

This table is plotted as a surface in Fig. 14 and it should be realized that the surface extends beyond the limits of this study.

TABLE VI

PRESSURE (GRAMS)	MATERIAL (GRAMS PER MINUTE) REMOVED AT SPEEDS OF			
	2000 RPM.	4000 RPM.	6000 RPM.	8000 RPM.
100	.007	.016	.0295	.054
200	.027	.098	.17	.242
500	.28	.56	.84	1.12
750	.34	.84	1.51	3.4

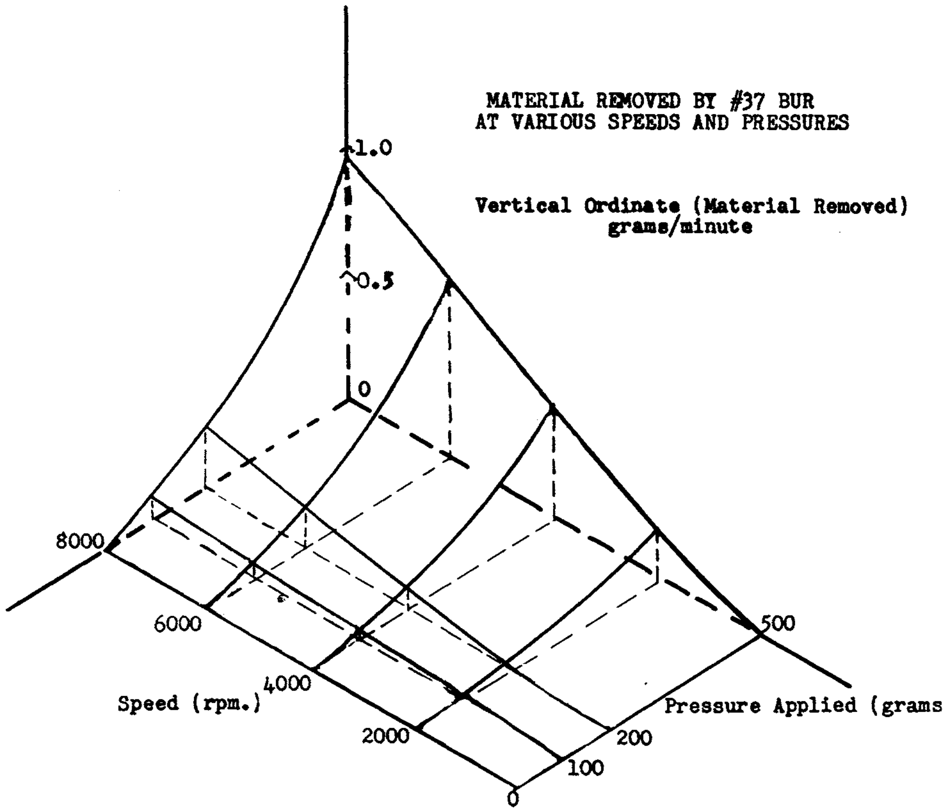

Fig. 12.

SUMMARY

This study has been limited to a comparison of the efficiency of the fissure and inverted cone type of dental burs when cutting a material with a hardness similar to dentin. This permitted a comparison of bur types on a basis of design only and did not consider the endurance of the bur, or the tendency to become dull which would result if hard materials like glass or enamel were cut. The effect of bur size and composition as related to cutting efficiency were also studied to a limited extent. The physical factors of speed of rotation between the limits of 1000 and 8000 r.p.m., and force applied to the cutting instrument from 200 grams (0.44 pounds) to 750 grams (1.65 pounds) were studied. An effort was made to integrate these variables as far as practicable.

It was observed that the tungsten carbide burs examined cut at essentially the same rate as the steel burs when operated under comparable conditions, but the carbide burs retain their cutting edge longer. The carbide burs were more brittle and susceptible to breakage than steel burs when subjected to side pressure and torque due to being embedded in the material cut.

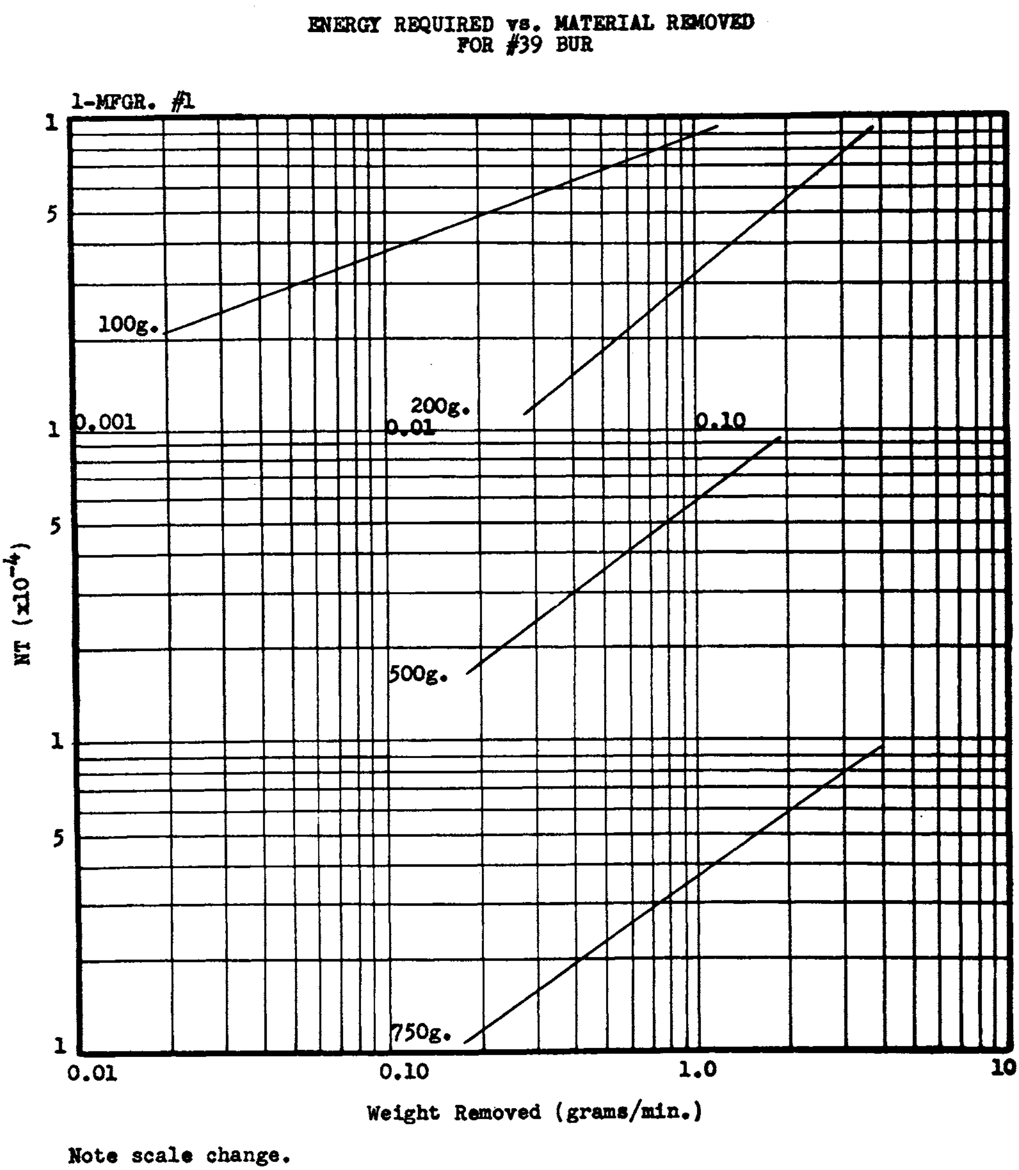

Fig. 13.

The No. 557 fissure type steel bur with spiral axial grooves removed more material per unit time than burs with straight grooves when operated under the same conditions. It was observed that the spiral type bur showed a little greater tendency to become clogged with cut material than did the straight bur.

A pronounced difference in the amount of material removed per unit time by the inverted cone type bur as compared with the fissure type bur was observed. Although the No. 37 bur has only about one-third as much active area as the No. 557 fissure bur, it is capable of removing approximately five times the amount of material per unit time as the fissure bur. On a basis of unit active area this would indicate a ratio of approximately 15 to 1 in favor of the inverted cone type.

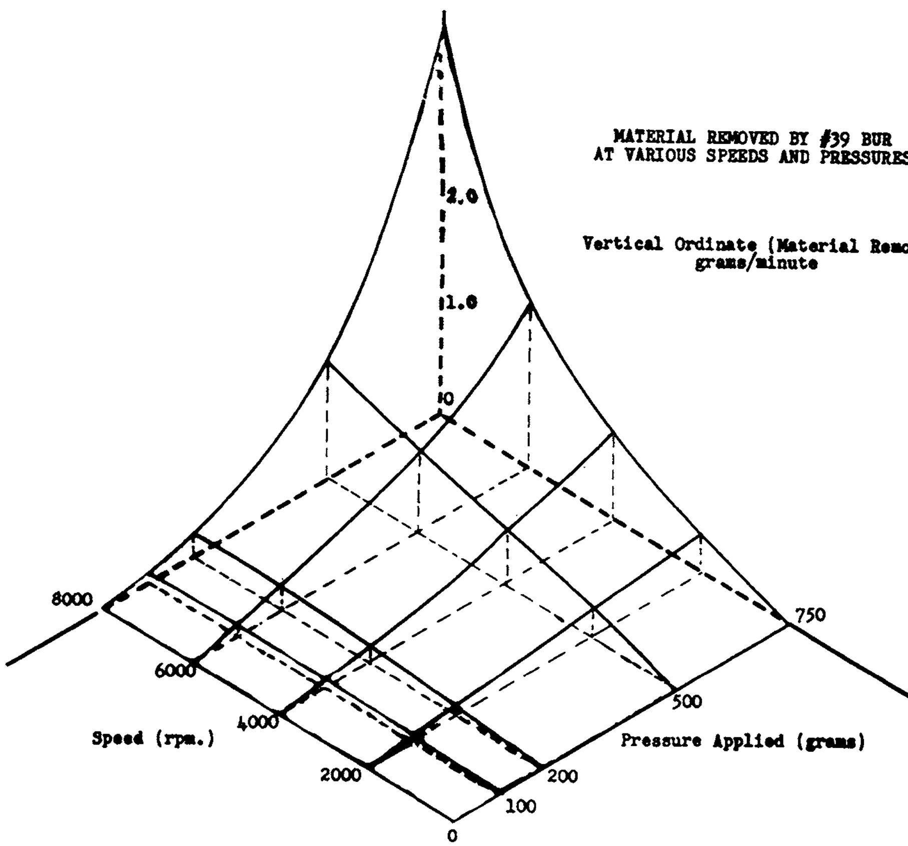

FIG. 14.

When using the No. 557 steel bur it was found that for each speed increase of 2000 r.p.m., between the limits of 2000 and 8000 r.p.m., the amount of material removed per unit time was approximately doubled, while the applied pressure remained constant. Accordingly, the rate of removal increases rapidly at speeds greater than 4000 r.p.m., which is near the upper limit of most present day engines.

When using a No. 557 bur with a constant energy input, a comparatively large increase in material removed is achieved when the pressure is raised from 200 to 500 grams. With an increase in pressure from 500 to 750 grams, the amount of material removed is increased, but the relative increase is less pronounced. With an inverted cone bur, however, this trend is reversed so that with increased pressure there is an increased rate of removal of material.

The results reported indicate that an increase in size of bur for a given type will result in greater amounts of material removed when other factors remain constant.

REFERENCES

1. Black, R. B.: Technic for Nonmechanical Preparation of Cavities and Prophylaxis, *J. A. D. A.* **32**: 955, 1945.
   Black, R. B.: Airbrasive: Some Fundamentals, *J. A. D. A.* **41**: 701, 1950.
2. Walsh, J. P., and Symmons, H. F.: Vibration Perception and Frequencies, *New Zealand D. J.* **45**: 106, 1949.
3. Larson, N. H.: The Efficient Use of Carbide Burs and Diamond Points for Cavity Preparations, *D. Dig.* **55**: 442 and 495, 1949.
4. Hislop, T., and Hislop, R. B.: Notes on Diamond Instruments, *D. Mag. & Oral Topics* **67**: 268, 1950.
5. Peyton, F. A., and Vaughn, R. C.: Thermal Changes Developed During the Cutting of Tooth Tissue, *Chicago D. Soc. Fortn. Rev.* **20**: 9, 1950.
6. Henry, E. E., and Peyton, F. A.: Vibration Characteristics of the Rotating Dental Instrument, *J. D. Res.* **29**: 601, 1950.