# ADVANCED SPEEDS
# IN
# OPERATIVE DENTISTRY

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# PREFACE

This course was originally developed to familiarize dental officers of the U.S. Navy and Naval Reserve with the thinking of the Naval Dental Corps on the use of advanced speed instruments in operative dentistry, and to encourage those not using the equipment to do so. The favorable reception accorded the previous edition of the course justifies our belief that this second edition will serve an equally useful purpose.

Advanced speed equipment is now the ''backbone'' of most dentists' armamentarium; but since the course was first issued, considerable research has been carried on and important advances have been made in such areas as the effects of high-speed cutting instruments on pulp, dentin, and enamel; the design characteristics of cutting instruments; the effects of sound on the auditory apparatus; and even cavity preparation design. This second edition of the course brings the reader up to date on the following subjects:

1. The development of advanced speeds and the equipment currently available.

2. The physical factors associated with the use of advanced speeds, and the control of these factors.

3. The biological reactions to advanced speeds.

4. The application of advanced speeds to current practice.

As always, the knowledge gained from this course should be applied with scientific caution. Enthusiasm for change should be tempered with a realization that we do not wish to mar the prestige that dentistry has earned by its past solid accomplishments. Laboratory developments and findings should always be equated with clinical procedures that take into account the physical, psychological, and physiological interplay between the patient and the dentist.

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# THE UNITED STATES NAVY

## GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

## WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

## THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

# CONTENTS

# ACKNOWLEDGMENTS

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Quotations of considerable length are reprinted with the consent of the authors and the following publishers:

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| Source | Slide No. |
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# CHAPTER 1

# ADVANCED SPEED EQUIPMENT

## A. Development of Advanced Speeds

### HISTORY

Since ancient times, simple hand instruments have been used to treat dental caries, but it was not until fairly recently that handpieces supplying or transmitting rotational power to the dental drill were developed. In fact, G. V. Black opened his office in 1864 with no dental engine and with his armamentarium consisting mostly of chisels, excavators, and hand drills.[1] He was to see a number of innovations during his years of practice, however; and over the past 20 years dentists have accommodated themselves to equally revolutionary improvements. A brief survey of the changes that have occurred will be enlightening.

In 1846, A. Westcott designed a finger ring and drill socket (SLIDE 1).[1,2] Finger propulsion produced the power for rotation. Cutting speed was later increased by adding a jeweler's bow to a similar device (SLIDE 2). (Fauchard, in the 18th century, also had a drill propelled by a bow, which he used to enlarge narrow canals.[3])

In the third quarter of the 19th century, a number of drilling devices appeared. Many of these were made by individual dentists to suit their particular needs.[1] Hickley's spring Archimedean drill (SLIDE 3B) was designed for use in one hand. Two fingers held the rings on the sides of the instrument while the palm of the hand pushed and released the ivory knob on top. This drill was introduced about 1860 and was advertised in an 1871 edition of Ash's catalog for 30 shillings. In 1862 reference was made to an Archimedean drill made by Luer (SLIDE 3A), who gave his name to the hypodermic needle mount. The bur on this drill had a variable working angle.[4]

Around 1864, Harrington introduced a key-winding motor-powered drill that derived its power from a clock-like spring arrangement.[5,6] This is believed to have been the earliest motor-driven dental engine. G. F. Green, in 1868, introduced a pneumatic engine for rotating drills that was operated by the action of foot bellows, the air passing through a rubber tube to a handpiece (SLIDE 4) that propelled the drill[7,8]—so air-driven equipment is not new. Green also introduced the electric burring engine (SLIDE 5),[1,9] the forerunner of the modern electric engine handpiece. A small battery-powered motor was held between the arms of a magnet, to which a handpiece was connected. The bur was activated by the motor. Morrison's foot engine, which appeared in 1871, introduced a new concept in tooth cutting.[1] It reached the then advanced speed of 700 r.p.m. As late as the 1930's, some dental schools were still using improved foot engines; and during World War II, field units of the armed services were equipped with them. According to McKay,[1] "With Morrison's invention of the dental engine, the field of crown and bridgework opened up. Better abutment preparations were possible, although the end results were still nothing to brag about. Wholesale removal of pulps came into vogue, and the gold shell crown blossomed forth. . . ."

In the early 1880's, the electric dental engine with flexible cable arm came into use. The folding bracket-type electric engine appeared in 1902. In 1914, the S. S. White Company brought out its Forsyth unit, which was the first unit-type dental engine.[1] The speed of the drill was generally under 4,000 r.p.m.

The increase in rotary power provided by the electric dental engine was not accompanied by any significant improvement in rotary cutting instruments, and their shortcomings were apparent. To reduce pain and trauma from heat, and to lengthen the life of the steel burs, low speeds and intermittent cutting were recommended. Shortly before World War II, the Germans developed diamond cutting instruments for dental use. These were immediately accepted, for they seemed to offer greater efficiency than steel burs and Carborundum points. It was noted that these diamond instruments cut better when they were run at increased speeds, but owing to the outbreak of the war little was done to increase the speed of engines at that time.[1]

However, research in the United States was intensified when European sources of dental equipment were cut off. During the period from 1947 to 1949, the fusion of tungsten alloys was successfully adapted to the fabrication of dental burs. The harder tungsten-carbide tipped burs were much more efficient at the ordinary speeds than steel burs, but it was apparent that they needed increased rotational speeds to work at their peak.

In 1949, Walsh and Symmons,[10] reporting on a laboratory study of the cutting efficiency of diamond instruments, stones, and burs, stated that "stones and diamond instruments remove enamel approximately three times as fast at 60,000 r.p.m. as at 3,000 r.p.m. and at 1/30th of the pressure." In the same year Larson[11] wrote: "The cutting ability of diamond instruments increases as the number of revolutions is increased. Peak grinding efficiency is reached with a light pressure."

To obtain the increased effectiveness of the diamond and carbide cutting instruments that comes with increased rotational speeds, practitioners began to modify their conventional units by such means as shunting out the motor resistors, altering the arm pulleys, slackening the tension on the belts, and increasing the diameter of the engine pulley. Thus, the modern so-called high-speed era was initiated.

Practitioners working singly and in groups, dental manufacturers, engineers, and practice management specialists all made many and varied contributions to speed up operative dentistry procedures and accommodate more patients during the period from 1946 to 1957. As with many other technological developments of the postwar period in unexplored areas, there were no established guidelines. The dental market was repeatedly introduced to new equipment before sound evaluation of previous equipment could be completed. As motor speeds increased, the conventional handpieces failed to hold up in performance because of increased heat generation. Vigilant maintenance became imperative. Straight handpieces were developed with either polished-glass sleeve bearings or ball bearings that permitted speeds of 25,000 r.p.m., but contra-angle handpieces were still geared to the old speeds and, in clinical practice, failed to complement the manufacturers' other developments. In 1954 and 1955, more accurately machined contra-angle handpieces with ball bearings that allowed them to perform in the 25,000 r.p.m. range appeared. Dentists enjoyed the ease of cutting and the reduced pressure required, and patients enjoyed the greatly diminished perception of vibration, but the care and lubrication problems were discouraging enough to cause Peyton[12] to write in 1955: "It seems doubtful if operating speeds of more than 12,000 to 15,000 r.p.m. offer much practical advantage, in comparison to disadvantages that may be encountered. . . . The most practical range for speed still seems to be 12,000 to 15,000 r.p.m., an increase from the conventional 4,000 to 6,000 r.p.m. previously employed. Further refinements in equipment may shift the optimum speed upward in the future."

The reports of Walsh and Symmons[10,13] in 1949, dealing with heat production, efficiency of cutting tools, and vibration frequencies incident to the higher speeds, stimulated genuine concern for the control of the resultant physical forces as they affect the biological tissues and the people (patients, dentists, assistants) involved. Research resulting from this concern did much to dispel the confusion incident to the introduction of so many new variables to the profession, established the dental researcher as an invaluable member of the clinical team, and brought about mass professional interest.

The elimination of vibration conducted to the patient and the dentist was the objective that led to development of the air-abrasive and ultrasonic units. R. B. Black began investigating the air-abrasive technique in 1942 and reported it in 1945;[14] and in 1951 his air-abrasive unit (SLIDE 6) was offered to the profession. Small particles of aluminum oxide, forced by carbon dioxide at great speed through a small opening in the handpiece, were focused onto the tooth surface to be cut. The hard, jagged particles quickly removed hard tooth structure. Patients accepted the air-abrasive unit enthusiastically since it created scarcely any vibration perceptible to them. Disadvantages that brought about its failure to be accepted by the profession included lack of control of the particles once they left the handpiece, difficulty of maintaining a visible field of operation, failure to cut soft carious tooth structure and metal restorations, and incomplete cavity preparation.

The ultrasonic dental cutting instrument was announced by Nielsen et al. [15,16] in 1955. It adapted to dentistry the industrial method of cutting hard materials by means of high-frequency vibrating tools working in an abrasive slurry. A magnetostrictive force caused a preformed point to vibrate at about 29,000 cycles per second. A slurry (suspension) of aluminum oxide particles was placed intermittently on the tooth under the vibrating point. These particles were forced ahead of the point and removed hard tooth structure in a shape closely resembling the acting point. Advocates of the ultrasonic instrument claimed elimination of heat, pain, noise, and vibration; light operating pressure; and continued tactile sense. Its disadvantages included more rapid loss of cutting efficiency than with burs;[17] lack of control of cavity development;[18] and poor visibility, frequent mouth rinsing, and slow cutting.[19] Also, controversy developed over the ultrasonic instrument's effect on pulpal and periodontal tissues.[20-23]

To the inventors of these two types of equipment much credit must be given for focusing attention on elimination of stress-producing procedures. Air-abrasive equipment was made available only to those dentists who had completed appropriate training courses. Unfortunately, the ultrasonic devices appeared on the market before adequate research had been completed. The safety of any innovation that involves the care and health of people must be validated by means of thorough animal experimentation before clinical application is attempted.

## TYPES OF EQUIPMENT AVAILABLE

The principal types of handpieces in use today are described in the following paragraphs. These handpieces offer a wide range of speeds and other features that may appeal to the individual dentist.

### GEAR-DRIVEN HANDPIECES

Gear-driven straight and contra-angle handpieces are still considered a necessary part of the modern armamentarium. Certain procedures are best performed at low speeds, yet the dentist desires the utility of advanced speeds with the same piece of equipment (SLIDE 7). Coupled with the ball bearings in both the straight handpiece and the contra-angle, various double-pulley and double-belt arrangements now allow speeds from 6,000 to 100,000 r.p.m. This range of speed affords effective use of steel, Carborundum, diamond, and tungsten-carbide cutting instruments. All operative procedures can be performed with those instruments. The contra-angles have long sheaths that increase stability and thus reduce the vibration factor considerably as compared with the short type of contra-angle sheath. An automatic lubrication-injection system prolongs the life of these contra-angles, reduces the generation of heat, and simplifies maintenance problems.

### BELT-DRIVEN CONTRA-ANGLE HANDPIECES

Belt-driven contra-angles were introduced in 1955[1] (SLIDE 8). Page developed a handpiece with an inner belt that replaced the drive shaft and gears and with lubrication built into the bearings.[24] With this handpiece, the cutting action of instruments on hard tooth structure has been described as "melting away like butter." For the first time, in using this handpiece, many dentists experienced the feel of cutting instruments really doing their work without pressure exerted by the operator. As the load is increased, there is insignificant loss of rotational speed. The belt-driven equipment has high torque. Of great significance is the fact that the vibrations produced are at frequencies above the threshold of patient perception. These instruments are considered by many practitioners as being the most versatile contra-angles available.

### HYDRAULICALLY-DRIVEN HANDPIECES

In 1953, Nelsen et al.[25] reported their hydraulically-driven contra-angle handpiece. The unit (SLIDE 9) contains a water-pumping mechanism, a reservoir, a pressure release valve, a speed control valve, and distribution lines for single or dual arms. The contra-angle handpiece is connected to a flexible plastic double tubing. One tube carries the propellant fluid (water) under pressure to the handpiece; the other carries the spent fluid back to the reservoir. The unit is self-contained and portable and needs only to be connected to an electrical outlet for operation.

The handpiece is driven by a small turbine in the head of the contra-angle. The turbine has six blades fixed to the shaft. Bearings are made of plastic, and the water driving the turbine acts as a coolant. Rotational speed of the instrument depends on the amount of fluid that is forced past the turbine in a given amount of time. Also, the amount of torque developed by the turbine is proportional to the pressure of the fluid passing through it. This use of a turbine in the head of the handpiece to propel a dental drill at high speed, without gears or belts, is considered to have been a very significant advance in restorative dentistry. The original handpiece has been presented by the National Bureau of Standards to the Smithsonian Institution for the latter's permanent exhibit on dentistry.[26]

Instruments such as silicon carbide and diamond points cut with exceptional efficiency when operated in this water turbine handpiece. For maximum efficiency of the recommended diamond cutting instruments, the unit is adjusted to run at 50,000 to 60,000 r.p.m. For removal of carious tooth structure and for cavity refinement, the unit can be adjusted to slow speeds. The torque is low enough so that the cutting instruments will stall on soft tissue without causing injury. A special threaded and tapered fitting locks the diamond instruments directly to the turbine in perfect axial alingment.[18]

## AIR-TURBINE HANDPIECES

The prototype of an air-turbine straight handpiece, operated by compressed air and driving the handpiece shaft at speeds ranging from 30,000 to 50,000 r.p.m., was developed by Tanner and Mitchell[27] in 1953. These investigators reported the construction of both straight and contra-angle air-driven handpieces in 1954.[28] During 1955 Tanner and Nagel refined the contra-angle handpiece (SLIDE 10). It utilized standard burs and diamond points secured within the turbine rotor located inside the head of the handpiece, which formed the stator of the turbine (fig. 1). The conventional cutting instruments were held in the turbine rotor by small circular rings inserted therein. The turbine rotor was propelled by compressed air or carbon dioxide striking its notched blades. Using 80 pounds of air pressure, the National Bureau of Standards checked the contra-angle at over 100,000 r.p.m.[29] The pioneer models of the pneumatic contra-angle handpiece mobile unit and the ultrasonic dental cutting instrument, both developed at the U.S. Naval Dental School, are on indefinite loan to the Smithsonian Institution, Washington, D.C.

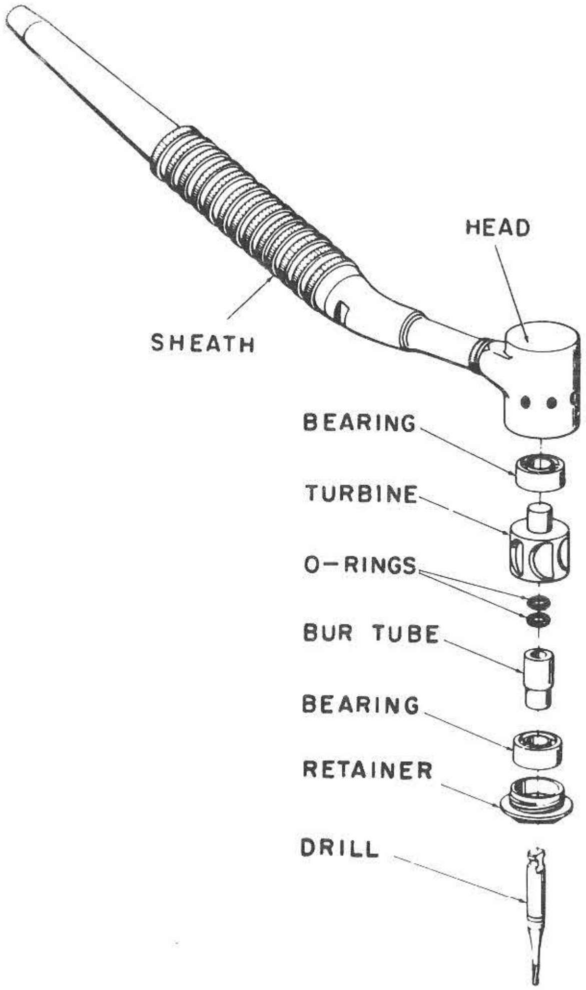

Figure 1.—Exploded view of air-turbine handpiece.

In 1955 Peyton[12] reported development of a straight handpiece with an air turbine in the same position as the pulley on a conventional handpiece. This handpiece was capable of 75,000 r.p.m. when cutting.

Dental manufacturers placed the air turbine contra-angles on the market in 1957. Measured by the rapidity of their acquisition by the country's practitioners, these instruments have proved to be most acceptable. In 1962 it was estimated that 72.5 per cent of the practitioners utilizing "high-speed" rotary instruments used air turbines to achieve their speed.[30] In 1965, the returns from a questionnaire sent to dentists who had graduated from a midwestern dental school from 1935 to 1961 were reported.[31] The returns indicated that the 88 per cent of the dentists who owned "ultra-high-speed" (100,000 r.p.m. and over) equipment performed over 90 per cent of their instrumentation for cavity preparation with the air turbine.

Air-turbine instruments have very low torque and cut tooth substance most effectively. They complement the standard belt-driven handpiece well. Their rapidity of action may be hazardous in areas of difficult access, since control is dependent upon adequate vision. With air-line pressure of 30 pounds per square inch (p.s.i.), the air turbines rotate, free running, at 200,000 to 350,000 r.p.m. During normal cavity preparation the speed may be reduced as much as 40 per cent.[32]

Air turbines have appeared for purchase with a multitude of variables; e.g., different bur attachments or chucks, varying numbers of water-air jets, latch-type or frictional-grip burs, varying amounts of water spray emission, foot rheostat or finger control for activating the units, and differing lubrication systems. Together with conflicting reports as to how the instruments are to be employed, their effects on the vitality of the operated teeth, and their advantages and limitations, these variables have created the aura of uncertainty and bewilderment that this course attempts to clarify.

In 1956, Norlen[33] reported that he had worked clinically for a year with a transitional type of pneumatic turbine-driven instrument, which had been developed in Sweden. According to Norlen's report, "The instrument consists of a suspension unit . . . and two separate turbines, one connected to a straight handpiece, the other to a contra-angle, each with its own air lead. The handpieces are removable and have standardized sockets, so that essentially only one turbine is necessary. For ease of operation, however, one for each handpiece is to be preferred, as a changeover will require only one hand.

". . . .The air is passed through a filter, and through a valve system to the turbines, which rotate at a maximum speed of 140,000 r.p.m. A gear system reduces the operating speed of the bur to a maximum of 50,000 r.p.m.

"The bur speed is controlled manually by means of a spring on the outer casing of the handpiece. . . .

"The expanding air cools the turbine and escapes at the back end. A fine stream of air is led toward the handpiece in order to cool it and help keep it free of debris during cutting."

## AIR-BEARING HANDPIECES

Air-turbine handpieces create noise as the air is exhausted. The very small ball bearings require oil lubrication to extend their life, and oil droplets are dispersed within the air-water spray. Dental engineers developed the air-bearing handpieces in an attempt to overcome these mechanical problems. They were introduced on the market in January 1963. As the term "air-bearing" indicates, the bearings in this type of handpiece consist simply of air, which lies as thin cushions between the rotor and the bearing bobbins. According to Morrant et al.[34] the air-bearing handpieces are of two basic designs. In one design (SLIDE 11) there are two thrust air bearings and two cylindrical journal air bearings surrounding the rotor, which is shaped like a cross. The bearing bobbins are rigidly mounted in the casing. The rotor and the bearings have separate air conduits, and the one supplying the bearings carries a small amount of oil fog as a lubricant. In the second design (SLIDE 12) the air bearings lie between the bobbins (which are mounted in rubber) and the upper and lower conical portions of the rotor. The bearing surfaces (surfaces of the bobbin and the rotor on either side of the air bearings) are made of graphite, which is self-lubricating. While the motor is not in operation, these surfaces are in contact; but when air is applied, the surfaces are forced apart, releasing the rotor. The rotor drive is unusual in that it consists of four flat, perforated disks. Pressure loss due to passage of air between the disks and through the perforations provides the thrust that causes the rotor to revolve.

A more delicate tactile sense must be developed to operate the air-bearing handpieces properly than is needed for ball-race air-turbine handpieces. Free-running speeds are in the 525,000 r.p.m. range. Optimum cutting occurs around 500,000 r.p.m. A steady high speed must be maintained to avoid stalling and to minimize overloading the bearings. The balancing achieved in manufacturing has produced a finer running rotor and a reduction of the noise level as compared with the ball-bearing air-turbine handpiece.

## HIGH-TORQUE AIR-DRIVEN HANDPIECES

Some dentists have found it difficult to develop a new touch to operate efficiently with the air-turbine and air-bearing handpieces. They miss "the feeling of cutting" that they have had with the conventional belt-driven handpieces, and yet they realize the mechanical advantages of the air instruments. Many have wanted to eliminate the need for two different systems in their operatories, i.e., the electric engine arm and belts. As a consequence, high-torque air-driven handpieces have been developed with a variable range from 0 to 30,000 r.p.m. The objective is to deliver multi-pound turning power even at just a few hundred revolutions per minute and provide stall-free power for operation of large disks, diamonds, and burs, and for laboratory use or prophylaxis.

Generally, the high-torque air-driven handpieces operate at all air pressures from 10 to 60 p.s.i. The highest speeds and power are obtained at the higher air pressures, e.g., at 15 to 20 p.s.i., 3-1/2 to 4 pounds of torque; at 40 to 50 p.s.i., 5 to 6 pounds of torque. They appear to operate best at 8,000 to 10,000 r.p.m.[35] At the present time they are slow to respond when activated; it is difficult to get them to perform reliably at low speeds; and they have an undesirable run-out characteristic when the propelling air is released. Engineers are working to eliminate these unfavorable features.

## ELECTRIC ENGINE HANDPIECES

In another attempt to give the dentist higher torque and to eliminate belt-driven instruments, handpieces attached to a small electric motor (fig. 2) have been developed. Recall that the first dental engine turned by electricity appeared about a century ago. Current models produce speeds from 0 to 20,000 r.p.m., start and stop instantly without coasting, and maintain torque at all speeds. The bearings are self-lubricating and sealed. The voltage is low and the motor is grounded.

A report[35] comparing the efficiency of rotary cutting instruments stated: Speed drops were not significant with the electrically powered equipment, indicating greater torque potential. . . .

. . . . . .

"The electric engine straight handpiece had a greater cutting range than the high torque air straight handpieces but did not appear to offer any more efficient cutting than the conventional electric belt-driven equipment."

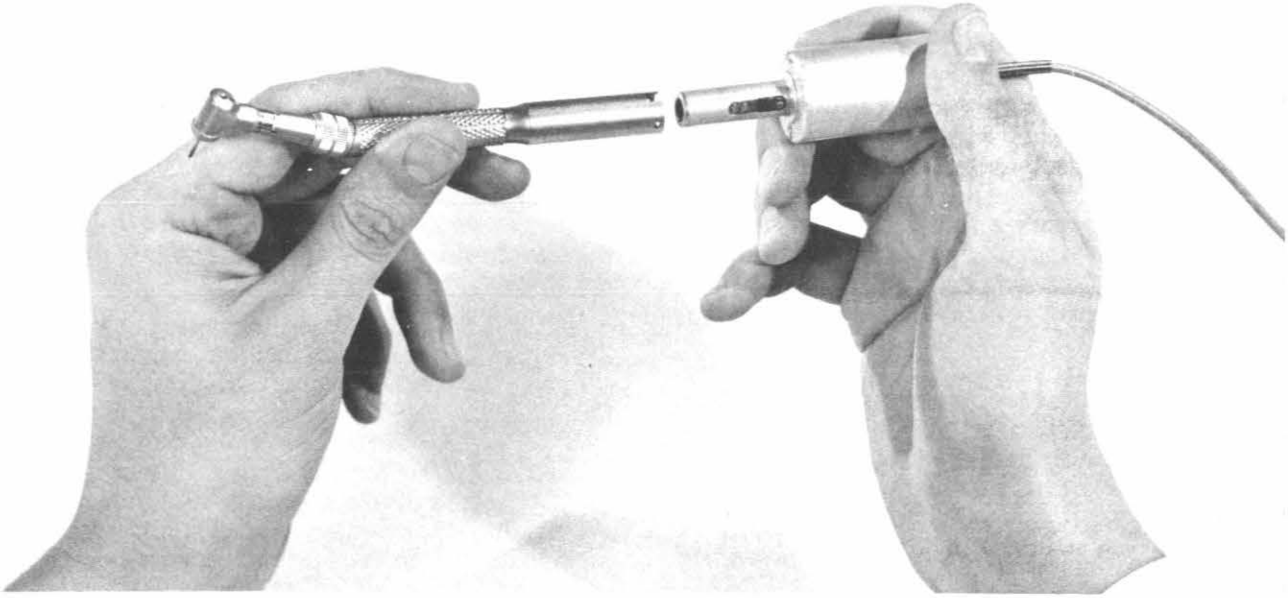

Figure 2.—Electric engine handpiece. From Kerr Manufacturing Company, Detroit.

## B. Physical Factors Associated With Use of Advanced-Speed Equipment

The development of advanced-speed equipment has raised certain questions concerning the physical factors associated with its use and the biological and psychological effects of these factors on the patient, the dentist, and the assistant. We are principally concerned with speed, pressure, heat, vibration, torque, cutting instrument efficiency, and noise. Most of these factors are interrelated, and no one of them can be discussed independently of all the others.

### SPEED

Modern use of the term "high speed" began toward the end of World War II, when the maximum rotational speed of dental cutting instruments was increased to about 10,000 r.p.m. As indicated earlier in this chapter, rotational speeds have increased in the intervening years, and today free-running speeds in excess of 500,000 r.p.m. are obtained. At no time has there been a standard classification of handpiece or cutting instrument speeds, and it seems that each writer on the subject has used his own terminology, which has reflected the speeds available at the time he was writing. In this text, an attempt has been made to use the number of revolutions per minute rather than an adjective to specify a particular speed or range of speeds; but since it has not always been convenient or possible to give the speed in revolutions per minute, the following adjectival terms appear from time to time: "Low speed" or "slow speed" to indicate speeds under 10,000 r.p.m., "medium speed" to indicate speeds between 10,000 and 100,000 r.p.m., and "advanced speed" to indicate speeds above 100,000 r.p.m.

Speed relates not only to the number of revolutions per minute made by an instrument but also to its diameter. Just as a large automobile wheel will cover a greater distance than a small wheel in a given number of revolutions, so an instrument of large diameter will travel a greater number of linear surface feet (LSF) than one of small diameter in the same number of revolutions. Provided the instruments are of the same width and provided equal force is applied, the large diameter instrument will have more cutting surface in contact with a given tooth per minute than will the small diameter instrument.

According to Morrison and Grinnell,[1] industrial investigation has shown that rotary instruments exert maximum cutting efficiency at speeds of 5,000 to 6,000 linear surface feet per minute. The linear surface feet traveled per minute can readily be determined by multiplying the circumference of the instrument (diameter $x\pi$) by the revolutions per minute and dividing the result by 12 to change it from inches to feet. For example, the linear surface feet covered by an instrument 1 inch in diameter, traveling at 3,000 r.p.m., would be determined as follows:

$$1 \times 3.1416 \times 3{,}000 = \frac{9{,}424.80}{12} = 785.4 \text{ LSF/min.}$$

At 20,000 r.p.m., the same stone would travel 5,236 linear surface feet per minute, which is within the zone of maximum cutting efficiency. An instrument 0.5 inch in diameter would have to revolve at 40,000 r.p.m. to travel the same number of linear surface feet per minute, and an instrument only 0.1 inch in diameter would have to revolve at 200,000 r.p.m. to travel 5,236 linear surface feet per minute. There is some question as to whether industrial findings should be applied to the cutting of tooth structure; but assuming the validity of doing so, it can be concluded that large diameter instruments such as disks operate efficiently at low or medium speeds, whereas the small diameter instruments operate best at advanced speeds. Rotational speed and linear surface feet covered per unit of time are only two aspects of cutting instrument efficiency, a subject that is discussed in subsequent paragraphs.

### PRESSURE

Pressure, as it applies to the cutting of tooth structure with rotary instruments, involves two factors controllable by the operator. These are force and area. Force is the effort produced by gripping and positioning the handpiece and placing the cutting instrument against the tooth. Area relates to the amount of the surface of the cutting instrument contacting the tooth at a given instant during the cutting operation. The diameter and width of the instrument and the configuration of the tooth all help to determine the area.

It has previously been stated that the efficiency of a rotary cutting instrument depends to a great extent on the linear surface feet of instrument-to-tooth contact per unit time. A large wheel removes more tooth structure per unit time than a small one of the same width running at the same speed under equal force. Reducing the force, or load, applied by the dentist in controlling the cutting instrument, while at the same time reducing its size, increases its rotational speed and therefore increases its cutting efficiency. The reduction in controlling force is one of the most desirable features in the use of advanced speeds. It has been shown[1] that speeds of 3,000 to 6,000 r.p.m. require the use of 2 to 5 pounds of force; and speeds of 100,000 r.p.m. and over only a few ounces of force. Air turbines lose speed rapidly if the load exceeds 4 ounces.[2] The cutting load for the air-bearing handpieces has been assessed at between 1 and 1.5 ounces.[3]

Ingraham and his associates[4] attempted to determine the optimum workloads and optimum speeds for the most ideal cutting conditions with air turbine handpieces. "Of five makes of turbines studied with the recommended p.s.i. and c.f.m. [cubic feet per minute], the optimum lateral work load ranged from one and one half to two and a half ounces, a variation of only one ounce. While the free running speeds of these instruments ranged from 230,000 r.p.m. to 325, 000 r.p.m. the range of speed at which they cut most efficiently under load ranged from 150,000 r.p.m. to 175,000 r.p.m. . . . most American made turbines operate at the highest degree of efficiency with a lateral work load of approximately one and three-fourths ounces and the speed in the region of 160,000 r.p.m. All turbines tested stalled with lateral work loads in the region of four to five and one half ounces."

## HEAT

Heat is generated during the removal of tooth structure by rotary instruments. Heat production is proportional to applied force, revolutions per minute, and area of the instrument in contact with the surface being cut. If any of the three is increased, heat production will be increased, unless an effective coolant is used.

The effects of heat upon the tooth must be of vital concern to the dentist, and all operative procedures should be evaluated in terms of their effects on the dentin and the pulp. Numerous studies have been undertaken to determine these effects, and the results of some of these studies are discussed in the following paragraphs.

As early as 1899, Jack[5] reported on studies he had conducted on the extremes of temperature that caused discomfort to teeth. He found that the temperature range varied among individuals. In the 1940's, Henschel[6] reported that the zone of temperature tolerance for average vital dentin is between 85° and 130° F. He also stated that steel burs could raise the surface temperature of dentin to 368° F. Hudson and Sweeney[7] pointed out that a bur applied to a noncarious pit in tooth enamel did very little actual cutting with ordinary clinical operating techniques. It was noted, however, that the temperature of the bur rose rapidly, reaching more than 600° F. Peyton and Henry[8] showed differences in the temperature rise produced by intermittent cutting of enamel and dentin with No. 37 steel burs, without a coolant, at 3,400 r.p.m. In enamel, with 2.0 to 2.5 pounds of force applied, the temperature rise was 100° F.; in dentin, with 1.0 to 1.5 pounds applied, the rise was only 38° F. These studies were done in the days of low and medium speeds when pounds of force were employed.

In 1960, Wheatcroft and his coworkers,[9] using a No. 558 carbide bur in an air-turbine handpiece, registered temperatures of 200° to 500° F. at the cutting site when air was the only coolant used. The mean temperature rise was higher when the time required for a given operation was longer. Careful cutting with light pressures produced surface temperatures that approximated 200° F.

In 1963, Kramer[10] reported that in opening occlusal fissures of molars with uncooled tungsten carbide burs in air turbines he had developed temperatures exceeding 212° F. (boiling point of water) on the buccal enamel. He also stated that the dentin had been found to be affected by the use of an air turbine without a coolant. For example, sectioning and processing of prepared teeth had shown that the underlying dentin was stained abnormally and contained rounded spaces resembling gas bubbles. Kramer concluded that the collagenous fibers were denatured. Dentinal changes seemed to occur in the floor of the cavity where the cutting instrument was most likely to be inadequately cooled, and also in small wedge-shaped areas where the cavity crossed the dentino-enamel junction, probably because of heat generated by cutting the overlying enamel. Weiss et al.[11] noted burned dentin in tooth sections prepared from human teeth in which cavities had been cut with steel burs, at both low and high speeds, without a water spray.

Schuchard and Watkins[12] found, "Grinding procedures using ultrahigh-speed low-torque instruments with air coolant, employing a nonabusive technic, produce an average surface temperature drop of 2 to 3° F., whereas abusive cutting intracoronally will result in an average rise of 7 to 8° F."

There appears to be little doubt that excessive heat produces discomfort, pain, and damage to hard and soft tooth structures. Studies attempting to determine surface temperatures at the cutting site and its concomitant temperature effect on the pulpal tissues have many variables, e.g., different cutting instruments, intermittent vs. continuous cutting, differing coolants, depth and extent of cuts, varying thermocouple setups, change of thermocouple positions within the pulp chamber, ad infinitum.

The resultant conclusions cover a wide range. Dentin has excellent insulating qualities, or said another way, it has low conductivity. Peyton[13] felt that, because of this characteristic, heat developed in localized portions of tooth structure tends to be retained there; Henschel[6] also thought that the heat was confined principally to the surface area of the dentin actually in contact with the bur, and that most of the heat escaped into the surrounding air and moisture or into the instrument itself. In 1965, Schuchard and Watkins[12] stated that in light of "the low conductivity of dentin and the ability of pulp circulation to dissipate conducted heat, the hypothetical increase of intrapulpal temperature may not occur."

Hartnett and Smith,[14] operating air-turbine handpieces with air as a coolant on extracted third molars and on cuspids of living and exsanguinated dogs equipped with thermocouples, recorded temperature increases within the pulp chambers of 4° C. (8.48° F.) during normal operating procedures and 9.5° C. (20.14° F.) during abusive procedures such as total reduction of the tooth to the gingiva. Schuchard and Watkins[12] found that at conventional speed the " . . . average temperature rise within the pulp chamber on all cuts was 17° F. with no coolant. Adding air as a coolant, the increase was reduced to an average rise of 1° F. Using the high-torque belt-driven instrument under the same experimental conditions with an air coolant, an average rise of 5.6° F. was recorded. In contrast to the first two series, that run with the low-torque air turbine and air coolant showed an average temperature drop of 6° F. For comparison, a low-torque series was run with the air-water spray, and an average temperature drop of approximately 8.6° F. was registered."

Zach and Cohen,[15] working with rhesus monkeys, measured temperature changes during operative procedures by means of thermistors sealed inside hypodermic needles and inserted in the pulp chambers of teeth in which experimental cavities were to be drilled. For each cavity, the temperature was recorded 5 seconds before drilling started. This reading was called the starting level temperature (see fig. 3). During the 5 seconds before drilling commenced, the coolant (air or air-water spray) was directed onto the tooth. Among other things, this initial cooling period permitted the thermal changes caused by drilling to show more clearly than they would have otherwise. While the cavity was being drilled, the temperature was recorded at 5-second intervals (from 0 to 35 seconds in fig. 3). Drilling, which was done with a fresh No. 557 carbide bur for each tooth, was intermittent. Four groups of cavities, with at least eight in each group, were drilled. Group I cavities were prepared with an air-turbine handpiece run at 238,000 r.p.m. and a water-air spray as the coolant; group II, with an air turbine at 238,000 r.p.m. and dry air as the coolant; group III, with a belt-driven contra-angle at 11,000 r.p.m. and a water-air spray as the coolant; and group IV, with a belt-driven contra-angle and no coolant of any kind.

The results shown in figure 3 represent averages for each group of teeth. In general, small teeth experienced more rapid temperature changes than large ones. In groups I and III, in which the washed-field technique was used at 11,000 r.p.m. and 238,000 r.p.m., temperatures remained below the starting level throughout cavity preparation. When air cooling was used at advanced speed and when no cooling was used at low speed, what the investigators considered to be critical temperatures were reached. Thus they determined that according to thermogenetic evidence "the washed-field technique seems safest at all rotary operative speeds."

In a follow-up study,[16] Zach and Cohen applied heat externally with a soldering iron to sound monkey teeth, induced measured rises in intrapulpal temperatures, and studied the pulpal responses histologically. The purpose was to determine the effect of heat alone without the added effects of drilling or other traumatic procedures. Specimens were taken at 2, 7, 14, 56, and 91 days after the application of heat. Histological examination showed that the pulps

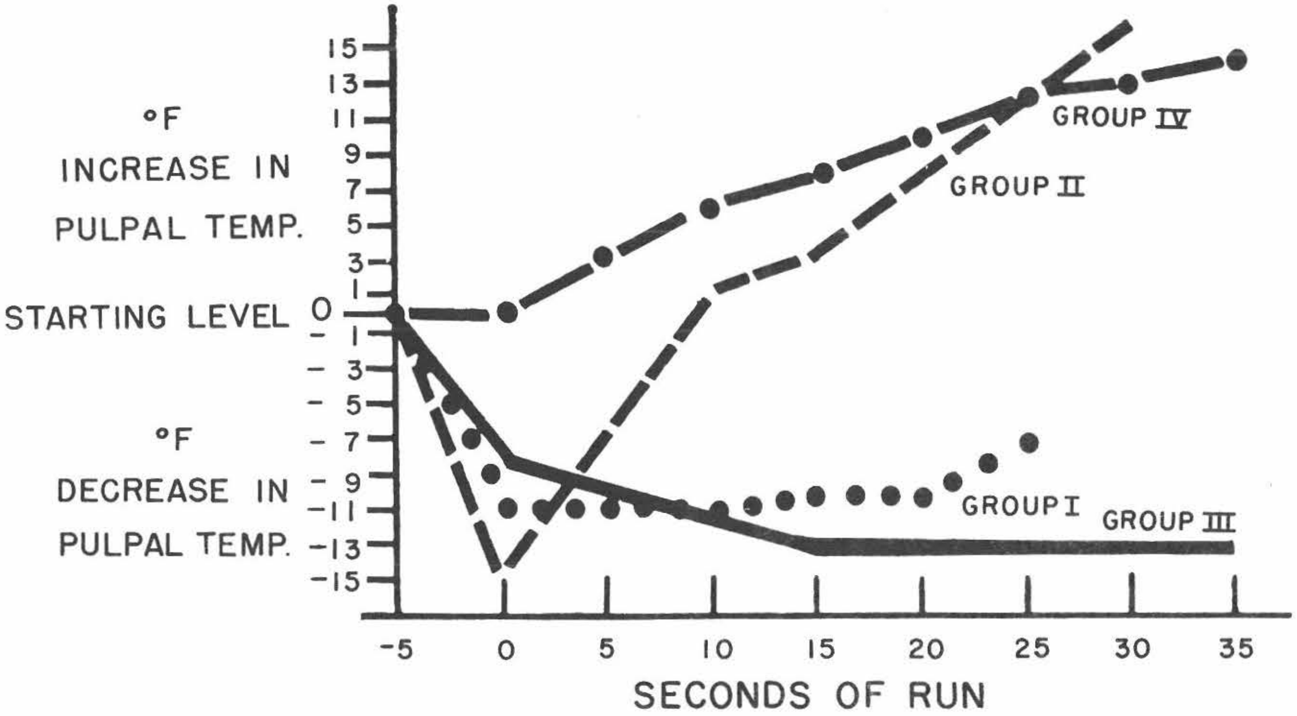

Figure 3.—"A comparison of the four techniques. The washed-field techniques depress the pulpal temperature; the dry techniques produce critical temperature rises. Bur contacts began at the 0 second mark. (. . .) Group I, air turbine with water-air spray; (__ __) group II, air turbine with air only; (____) group III, low speed with water-air spray; (·____·) group IV, low speed, dry, with no coolant." From Zach and Cohen: The Journal of Prosthetic Dentistry 12:977, 1962, The C. V. Mosby Company, St. Louis.

failed to recover from an intrapulpal temperature increase of 20° F. in about 60 per cent of the cases. Fifteen per cent of the teeth heated to 10° F. failed to recover. Heat rises below this critical level produced reactions, relative in severity to the degree of heat, which almost invariably led to pulp recovery but which left histologic stigmata. Heat rises above 20° F. almost invariably destroyed the pulp." To correlate these findings with those of the previous study,[15] in which heat changes during drilling were measured, Zach and Cohen superimposed findings similar to those illustrated in figure 3 on a graph showing safe and critical ranges of pulpal temperature change as determined by the histological findings of the later study[16] (fig. 4).

Histological studies of the response of pulpal tissue to heat and other causes of trauma will be detailed in chapter 2 of this text.

Several other factors are involved with the production of heat trauma in teeth cut by rotary instruments.[6,7,13, 17-19] These include (1) the design, type, and size of cutting instrument used, (2) the duration of the cutting operation, (3) the sharpness of the instruments and (4) the character of the surface being cut, as well as the use of coolants and the insulating qualities of tooth structure. These factors can be analyzed individually, but it must be emphasized that, during a single cutting procedure, there is simultaneous interplay of them all, or any combination thereof. The end result is the production of heat.

In 1958, Peyton[13] presented a series of tables showing temperature increases developed in the cutting area under various conditions. In general, it was shown that an increase in temperature developed when the applied force, speed of rotation, or diameter of the instrument increased. However, the greatest increases in temperature shown in the tables occurred when the No. 557 steel bur was used without a coolant at speeds up to 10,000 r.p.m. and applied force up to 2.0 pounds. When various instruments were

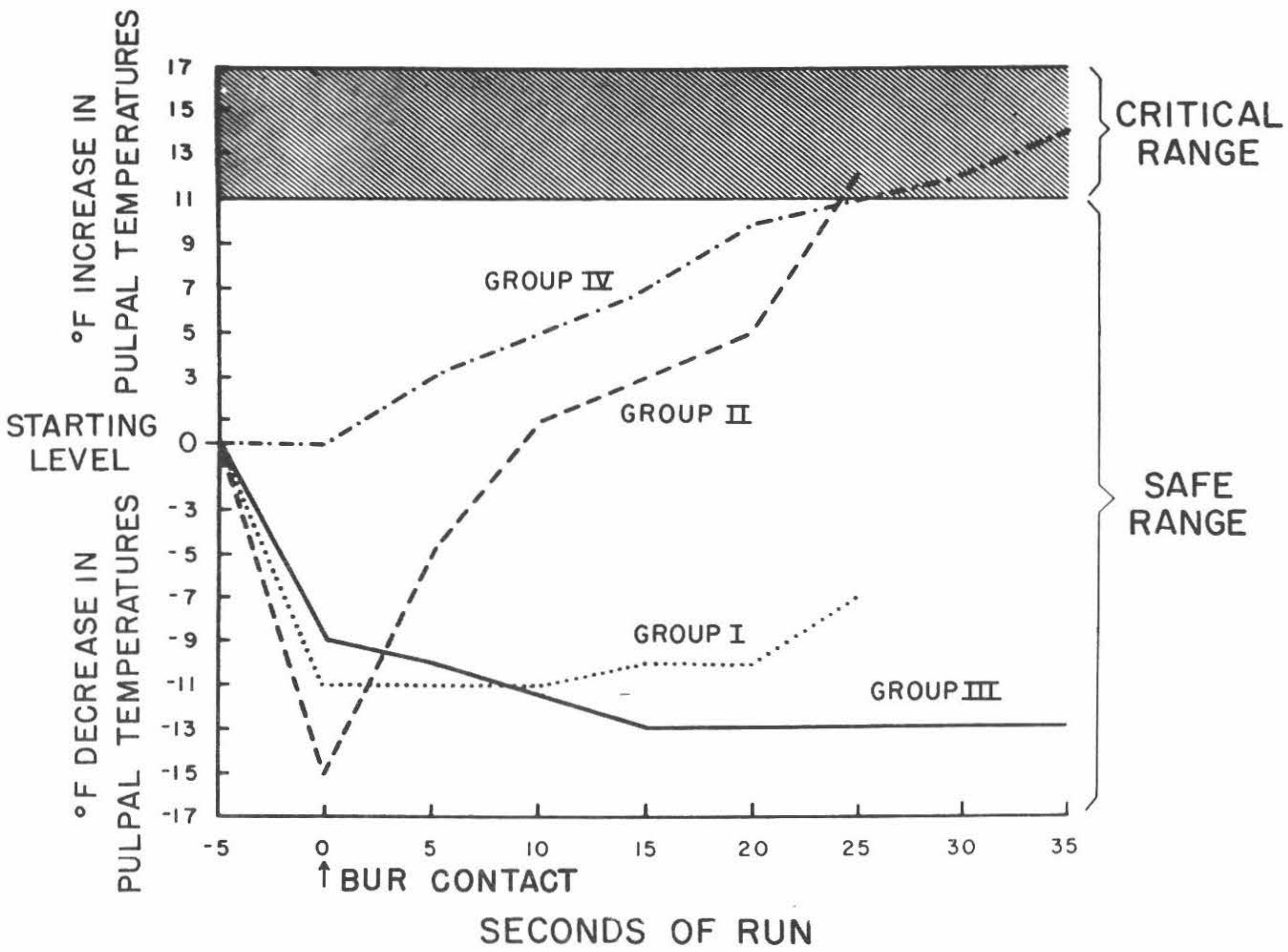

Figure 4.—"Intrapulpal temperature rises produced by four types of operative technique. Group I, air turbine, water-cooled; Group II, air turbine, dry; Group III, low-speed, water-cooled; Group IV, low-speed, dry." From Zach and Cohen: Oral Surgery, Oral Medicine and Oral Pathology 19:515, 1965. The C. V. Mosby Company, St. Louis.

used with an air-water spray or a stream of water at speeds up to 170,000 r.p.m. and at various pressures, the greatest temperature increase noted was under 30° F., and most increases were under 10° F. Of course, this brief summary does not take into account other possible reasons for the differences in temperature increases.

Various investigators have studied the amount of heat produced during use of different types of instruments. Peyton and Henry[8] determined that tungsten carbide burs produce less temperature rise than comparable steel burs operated under similar conditions. Henschel[6] found that steel burs may raise the temperature of dentin to 233° F. or even 368° F. with the application of 4 pounds of pressure at 2,000 r.p.m. Peyton and Henry[17] noted that a No. 701 diamond point produced 50 percent, and a carbide bur 25 percent, less temperature rise than occurred with a steel bur operated under the same conditions. In a study by Vaughn and Peyton,[18] spiral-fluted burs produced a greater temperature rise in extracted teeth than did straight-fluted burs; and at 10,000 r.p.m. the straight carbide No. 557 bur developed somewhat less than two-thirds the temperature rise developed by the spiral design steel bur. Large diameter instruments produce a greater rise in temperature than smaller ones under similar operating conditions.

Any reduction in the time the instrument contacts the tooth during a cutting operation will result in less heat trauma. In 1954, Hudson and Sweeney stated that since the cutting time above 12,000 r.p.m. is less than with low speeds, less heat is transferred from the bur to the tooth.[7]

The "stall-out" feature of the air-turbine handpieces when the force becomes excessive is a built-in safety factor.

A dull rotary cutting instrument, because of its frictional effect, will produce excessive heat during a cutting operation. In addition, cutting time with a dull bur is increased.[13]

The use of coolants to minimize the incidence of heat trauma during cutting procedures at advanced speeds will be explored at length in chapters 2 and 3.

## VIBRATION

Vibration of rotary instruments has been of concern to both dentist and patient. It is generated in the equipment used and transferred to the fingers and hands of the dentist and the teeth and head of the patient. It is also conducted by bone to the patient's hearing apparatus and experienced by him as sound. Vibration, more than any other single factor, has caused patients to fear tooth cutting. It also contributes to the dentist's fatigue and to wear of instruments. The desire to reduce or eliminate vibration was a factor leading to the development of air-abrasive, ultrasonic, and turbine-driven instruments.

Vibration is a wavelike motion that can be produced by the intermittent application of a force to an object or surface. The wavelength of a vibration is the distance from one point in a wave to the corresponding point in the next wave. The amplitude is the maximum displacement from the mean position, i.e., the distance from the mean position to an extreme (or sometimes it is considered to be the distance from one extreme to the opposite extreme).

Frequency is the number of waves, or cycles, per unit of time. It is usually measured in cycles per second. At low instrument speeds, amplitude is great but frequency is low. As speed increases, the frequency of vibration increases but the amplitude decreases. High amplitude vibrations destroy instruments, frighten patients, and tire the dentist.

Several studies have been undertaken to determine the relationship between vibration and patients' discomfort.[17, 20-22] Vibrations of 100 to 200 c.p.s. were reported to be the most distressing to patients. Frequencies above 1,000 c.p.s. are generally beyond the threshold of perception of the average patient. At an instrument speed of 100,000 r.p.m. vibration is at 1,600 c.p.s., which is beyond patient perception. Therefore, at advanced speeds, vibration ceases to be a factor contributing to patients' discomfort and dentists' fatigue.

The use of advanced speeds in dentistry has virtually eliminated the annoyance of excessive vibrations. In clinical situations, patients' appreciation of this improvement has been almost universal.

## TORQUE

Torque is defined as "That which produces or tends to produce rotation or torsion; a moment of forces; the turning moment of a tangential effort."[23] It is the torsional power applied to the handle of a screwdriver that overcomes resistance and cuases a screw to embed itself in a wooden surface. The effectiveness of a force in producing rotation is called the moment of a force, or the torque produced by the force, and is calculated by multiplying the force by the length of the arm on which it acts. In a dental handpiece it is torque that causes the bur or stone to want to continue laterally during extension of a cavity preparation. Considerable torque is produced in the conventional pulley-driven systems; with the ordinary air-turbine handpieces there is an absence of appreciable torque. The ball-bearing belt-driven handpieces achieve 250 to 300 gram-centimeters of maximum torque; the maximum torque attained by the air-turbine handpieces is about 10 gram-centimeters.[24] With increased air pressure, speed and potential torque are increased.[25]

In air-turbine handpieces operated with the typical clinical air pressure of 30 p.s.i., Taylor et al.[24] produced maximum torques ranging from 5 to 10 gram-centimeters at maximum speeds ranging from 170,000 to 340,000 r.p.m. They found that by increasing air pressure both the torque and the speed are increased; but as the air pressure increases, the increase in torque is relatively greater than the increase in speed.

Until a load is applied, as when the cutting instrument is placed against the tooth surface, no torque is experienced by the dentist. Torque from air pressure is not experienced appreciably by the dentist except as stalling loads are approached and as cutting approaches zero.

Generally speaking, within limits, cutting increases as air pressure, speed, and applied load increase. Efficient cutting occurs within a very narrow range and is related to the transverse load applied to the rotating instrument. The application of a transverse load has two effects: (1) it causes indentations or bite of the bur flutes and (2) it controls the rotational speed. At near-stalling loads cutting efficiency is reduced because the bur flutes take larger bites at less frequent intervals. Reduced cutting efficiency is likewise seen at high rotational speeds with near-zero loads because the cutting capability of the individual bur flutes is very slight. It appears therefore that there must be a relation between rotational speed and applied transverse load at which maximum cutting efficiency would occur. The optimum speed and load requirements are also affected by instrument factors such as flute design, sharpness, diamond grit size, and overall diameter.[25]

It has been shown that 10 gm. is optimum loading of the air turbine under test conditions. In clinical use this value must be approached by the dentist through continuous, automatic adjustment of the load by manual control and application of the rotating instrument to the tooth surface. In like manner, rotational speed is controlled since increased loading reduces the revolutions per minute and vice versa. The optimum rotational speed for cutting tooth structure with the air turbine has been experimentally determined to be between 200,000 and 250,000 r.p.m., at 25 p.s.i. operating air pressure,[25] under which conditions a torque of approximately 2 gram-centimeters will be developed.[26] Cutting tooth structure efficiently in a clinical situation therefore requires the delicate control of applied pressures to the instrument by the dentist so that nearly optimum loading and revolutions per minute are obtained. The modern advanced speed air turbine is a very efficient cutting instrument when it is properly employed and when the cutting instrument is perfectly centered in a vibration-free machine.

## CUTTING INSTRUMENT EFFICIENCY

The efficiency of a dental cutting instrument (bur or stone) is defined as its ability to remove a maximum amount of hard tooth structure with a minimum of effort and within a minimum amount of time. Major factors related to cutting instrument efficiency include (1) design, (2) material, (3) rotational speed, (4) applied load, (5) vibration, and (6) skill of the dentist.

As previously stated, Walsh and Symmons' work[27] on cutting instrument performance and efficiency at 3,000 and 60,000 r.p.m., reported in 1949, initiated extensive clinical and laboratory investigation in this area.

Instrument design plays a very important role in cutting efficiency and has been studied extensively. It has been shown that a spiral-fluted fissure bur cuts more effectively than the straight-fluted type under similar experimental conditions.[18,28] Henry and Peyton[29] reported on the efficiency of 13 different brands of No. 557 steel and carbide burs and 9 different No. 37 steel and carbide burs all procured from a retail trade outlet. They stated: "From the standpoint of design, . . . the number of teeth or flutes on the bur, the angle at which these flutes are formed, and the amount of chip clearance space ahead of the tooth are all significant to the operation of the bur. . . ." Figure 5 illustrates how the rake angle and the clearance angle are formed. Depending upon design and manufacturing techniques, one may have either a positive or negative rake angle. As these investigators pointed out: ". . . The more positive the rake angle, the more effective is the cutting action . . .; while the more negative the rake angle, the less effective is the cutting action . . . ." According to Ray,[30] "Negative rake angles are relatively inefficient because the blade follows rather than leads into the work face." Most of the work is done by the tip of the bur and the upper two-thirds of the blades near the shanks do very little work.[30] The clearance angle, as shown in figure 5, may be shallow or deep. The larger the chip space, the less the tendency toward bur clogging. The relationship between the rake angle and clearance angle, as established by bur design, undoubtedly relates directly to cutting efficiency of burs.

In a study of the features of No. 57 spiral carbide burs produced by seven manufacturers, Lasater et al.[31] found the following variations: The rake angle varied from positive to negative through a range of 45 degrees; the flute depth varied from shallow to quite deep; the helix spiral varied through a range of 10 degrees; the diameter of the cutting head varied as much as 0.013 inch; the length of the cutting head varied as much as 0.024 inch; the length of the tapered portion of the shank varied as much as 0.043 inch; and the location of weld joints between shanks and the cutting heads varied from manufacturer to manufacturer. The varying length of the tapering shanks and the location of the weld joints were thought to account for breakage in some instances.

Schuchard and Watkins[2] found that a sharp No. 558 carbide bur, under applied loads up to about 4 ounces, cut equally well either wet or dry in any of several optimally operated low- and high-torque handpieces. Increasing the air pressure produced greater torque in some contra-angle air turbines, and most of the equipment operated efficiently when loads up to 4 to 8 ounces were applied. However, cutting efficiency was diminished when air pressure was reduced to 20 to 30 pounds, regardless of the load applied. From these findings they concluded that low-torque equipment required maximum air pressure for maximum efficiency, and that it is probably more practical to use an instrument of high torque where refined cutting is necessary.

In a comparative study of different types of chucks, Schuchard and Watkins[2] found that cutting instruments held by plastic chucks produced fairly straight cuts of even width without excessive fracture of nearby tooth structure, whereas those held by metal chucks produced cuts that were not true and fractured adjacent tooth structure. It was thought that the resilience of the nonmetal chucks helped absorb the shock produced when a rotating bur contacts tooth structure.

Because of the growing concern of the dental profession regarding the possibly deleterious effect of advanced speed cutting on hard tooth structure, Kasloff et al.[32] studied the degree of cracking produced in the enamel of extracted teeth by cutting with steel burs, carbide burs, and diamond points in various handpieces and at several speeds. Part of their results have been tabulated and appear as table 1. In a subsequent study Kasloff[33] found that none of the "induced cracks" appeared to extend beyond the dentino-enamel junction.

Table 1.—Degree of Cracking Produced in Enamel of Extracted Teeth by Cutting With Steel Burs, Carbide Burs, and Diamond Points in Various Handpieces and at Several Speeds.

(20 Teeth In Each Test Group)

| SPEED AND TYPE OF HANDPIECE | INSTRUMENT | DEGREE OF CRACKING | | | |
|---|---|---|---|---|---|
| | | SEVERE | MODERATE | SLIGHT | NONE |
| Up to 12,000 r.p.m.<br>Belt-driven handpiece | STEEL BURS | 2 | 3 | 7 | 8 |
| | CARBIDE BURS | 0 | 4 | 8 | 8 |
| | DIAMOND POINTS | 0 | 2 | 7 | 11 |
| 60,000 r.p.m.<br>Turbojet handpiece<br>(Water-cooled) | CARBIDE BURS | 8 | 7 | 3 | 2 |
| | DIAMOND POINTS | 0 | 3 | 10 | 7 |
| 100,000 r.p.m. & over<br>Page-Chayes belt-driven handpiece<br>(Water-cooled) | CARBIDE BURS | 3 | 1 | 8 | 8 |
| | DIAMOND POINTS | 0 | 2 | 9 | 9 |
| 100,000 r.p.m. & over<br>Air-turbine handpiece (Water-cooled) | CARBIDE BURS | 0 | 2 | 8 | 10 |
| | DIAMOND POINTS | 0 | 0 | 5 | 15 |

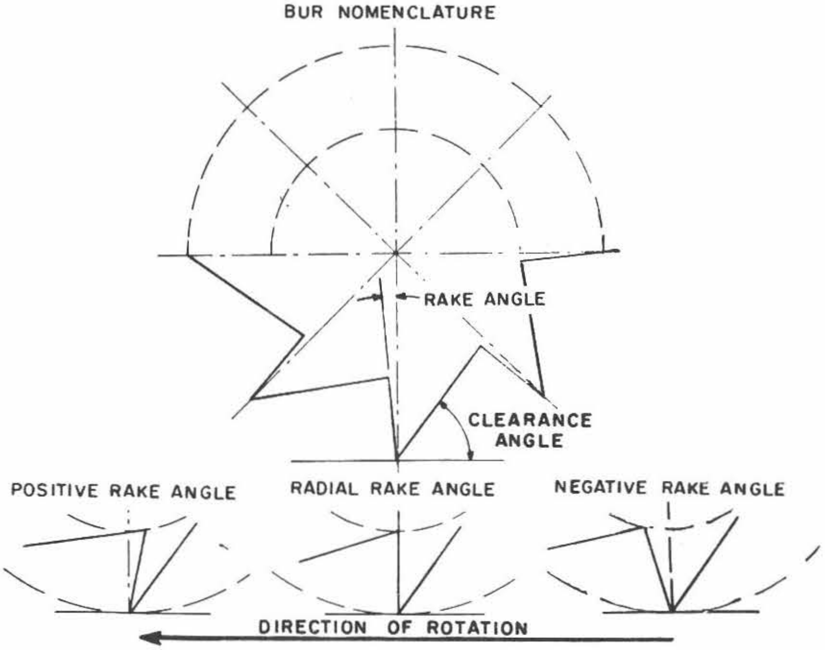

Figure 5.—Rake angle and clearance angle of bur blades. From Henry and Peyton: Journal of Dental Research 33:281, 1954. Chicago.

Tungsten-Carbide Cutting Instruments

The introduction of tungsten-carbide burs around 1947 was the first significant change in dental burs in about 100 years. Recognition of their increased cutting effectiveness over steel burs was immediate. Their superiority was due mainly to greater cutting edge strength and ability to retain the edge longer. Originally, the carbide burs were quite subject to fracture, particularly at the neck where the carbide cutting tip joins the steel shank. Owing to the brittle nature of the material, cutting edges were likely to fracture rather than dull when subjected to excessive pressures. Steel bur blades, being made of a ductile material, tended to turn rather than to fracture.

Efficiency and life of a cutting instrument are closely related. The life of an instrument indicates the period of time over which it will effectively remove tooth structure. Said another way, life represents the instrument's ability to resist dulling. Carbide burs and diamond instruments have a longer life than steel burs and Carborundum stones. The life is also controlled by the design of the instrument.

Kutscher[34] cut an average of 0.87 of a tooth surface with a steel bur before dulling, whereas he cut an average of 19.71 surfaces with a carbide bur before dulling. Ray,[30] studying three different makes of tapered, plain-fissure tungsten-carbide burs, averaged from 20 to 46 cavity preparations for each bur depending upon the manufacturer. Peyton and Henry[8] reported: "... While the most effective life of the steel bur is thought to be somewhat less than five minutes when cutting hard material, the carbide bur may still be effective at the end of 10 to 15 minutes when operated under the same conditions to cut the same material."

Henry[35] studied the finish, heat treatment, end flutes, changes in bur diameter, changes in duration of bur-to-tooth contact (engagement), and changes in the number of flutes of the inverted cone bur. He chose the inverted cone bur because of its short length of engagement. Henry stated that ". . . only the last one-thousandth of an inch of flute edge is effective for cutting a soft material. This distance decreases as the material hardness increases. . . . The largest manufacturing difficulty lies in producing equally sharp edges consistently; i.e., bur flutes that are identical within the outer one-thousandth of an inch.

"The flutes of commercial burs usually have some fins or excess material. It may be removed by subsequent cuttings of the bur flutes; however, it has been found that the small increase in the effectiveness of the bur does not warrant the extra cost. Heat treatment must retain the sharp edge placed on the flute by the cutter as well as harden the bur and increase its cutting life.

. . . . .

"Changing the length of engagement as well as the number of flutes changes the manner in which the external load is distributed among the flutes of the burs. If the force on the flute is increased, the average displacement per flute revolution is increased. This occurs when either the length of engagement or the number of flutes is decreased."

Traditionally, we have thought that burs and stones differed fundamentally in action as they removed tooth structure. Supposedly, burs milled tooth substance, or cut it away in chips, and stones ground or powdered the hard tooth tissue. However, Hartley and his coworkers,[36] using high-speed motion-picture photography, were able to observe the detailed action of each bur blade throughout the cycle of rotation. In 1957, they reported: "In enamel, neither steel nor carbide instruments produced true chips, as would be expected from a milling-type cutter. In dentin, both steel and carbide produced true chip formation. . . .

"Increasing the speed to 10,000 r.p.m., a definite improvement in clearance of debris is noted. The effect of improper design is readily seen in some carbide burs, which are observed to cut poorly even though they did not dull.

"Tungsten-carbide burs present a clean, well-machined appearance. Neither steel nor carbide burs, however, although designed as milling-type cutters, appear to operate efficiently in material as hard as human enamel. No true chips are seen to form as these instruments cut tooth enamel."

Kilpatrick[37] stated, in 1959: ". . . All carbides seemed to perform well at ultra speeds, but some were better than others. All lasted many times longer at ultra speeds than at the slower speeds.

. . . . .

"Carbides give excellent performance with present dental equipment at speeds of from 75,000 to 300,000 r.p.m. The operator is urged to forget revolutions per minute and use the speed which seems to give him the most efficiency with the least amount of discomfort to the patient. . . .

". . . When a bur starts performing poorly, it is desirable to determine first whether the trouble is in the bur or the handpiece. . . . If the handpiece and speed are correct and the bur still does not cut well, it should be examined with a 50 power pocket microscope for clogging and wear. Burs showing extreme wear should be discarded. Although burs cut much longer at the ultra speeds, they do wear out. The duller the bur, the faster the speed to make it cut."

According to Doerr,[38] writing in 1965: "At two ounces of hand pressure, carbide burs and diamond instruments exhibit about the same cutting efficiency. However, at operating pressures of three to four ounces (those most frequently employed with air-turbine or air-bearing handpieces) the carbide bur removes more tissue per unit of time than the diamond instrument. The bur can tolerate a slightly greater load without clogging and smearing because its design facilitates the elimination of cut tooth tissue or debris. There is less temperature rise because energy is not wasted as heat."

The studies on burs led to improvements in their construction. The number of flutes on carbide burs was reduced from the original eight to six, to allow the cut tooth structure to escape more readily and increase cutting efficiency. The shanks were thickened to reduce whip, vibration, and breakage. Manufacturers established closer tolerances in fabrication, and cutting heads become more symmetrical.

### Diamond Cutting Instruments

Nelsen and Nelsen[39] wrote, in 1959: "The most efficient cutting tool available to dentistry is the diamond-coated instrument. A well made, diamond-coated tool mounted in a vibration-free handpiece gives the dentist a controlled orbit of very small, highly abrasive particles. If these hard, sharp, whirling particles are applied to the tooth surface so that only their tips contact the tooth, a very desirable nontraumatic abrasive action is effected and, in addition, complete control of the particle of abrasive and the development of the cavity are maintained." They pointed out that the dentist's manual dexterity must be highly developed so that he applies the instrument to the tooth with just enough pressure to ensure efficient cutting. Nelsen and Nelsen also stated that one-piece steel instruments plated with 180-mesh diamonds and operated at 50,000 r.p.m. have optimum cutting qualities. They said that to obtain these optimum qualities the cutting speed must be sufficient to complete the operation quickly; the torque/speed ratio must provide tactile stimulation that will enable the dentist to feel the instrument cutting the tooth; the diamond coating must be even over the entire working surface; and the instrument must run concentrically, i.e., run true. The latter is accomplished by having a concentric instrument securely chucked and locked into the machine rotating it, which also must be perfectly centered. Failure to ensure concentricity and positive, true chucking and locking will result in excessive vibration during operation. This vibration can be experienced by holding the handpiece lightly while the instrument is free running.

Lammie[40] reported diamond stones and disks to be the most efficient in the removal of enamel. Ingraham and Tanner[19] felt that the efficiency of the diamonds increased in proportion to the increase in speed. In 1955, Doerr[41] quoted a dental engineer to the effect that between 12,000 and 17,000 r.p.m. about 90 percent of the efficiency of a diamond instrument is used, and that at 23,000 r.p.m. about 95 to 98 percent of the efficiency is used.

Chayes,[42] also in 1955, estimated that with diamond instruments the optimum speed range is between 5,000 and 9,000 surface feet per minute. He determined that to obtain a speed of 5,000 surface feet per minute a 0.25-inch diameter instrument should travel at 75,360 r.p.m.; a 0.125-inch diameter instrument, at 150,000 r.p.m.; and a 0.105-inch diameter instrument, at 200,960 r.p.m. In 1959, Nelsen and Nelsen[39] felt a free-running speed of 50,000 r.p.m. "to be most appropriate to all factors involved in the cutting procedure."

Hartley and Hudson[43] wrote in 1958: "Removal of tooth structure by grinding with abrasive instruments is accomplished by means of a combination of crushing and friction at each of many contacts of the points of abrasive. Grinding is the method of choice for reduction of very hard materials in industrial application; the same principles apply to the removal of tooth enamel.

"Large diameter diamond abrasive instruments (1/4 to 3/4 inch) will operate satisfactorily in the conventional speed range if water lubrication and light pressures are employed. The use of moderate diameter diamonds (3/16 to 1/2 inch) will effectively remove enamel at rotating speeds of 16,000 to 30,000 r.p.m. Smaller diamond points do not have adequate peripheral speeds when operated at speeds below 40,000 r.p.m. The use of small points and wheels at slower speeds results in a rapid loss of the abrasive because of the heavy pressures employed in order to cut effectively. Diamond instruments which have been discarded as no longer clinically effective show loss of the abrasive at relatively small areas or points. The other surfaces show little or no loss of diamonds. These areas of breakdown occur where the instrument is repeatedly subjected to the highest pressures per unit area during the performance of exacting cuts in shaping a preparation. Commercial grinding practice calls for wheel surface speeds of from 5,000 to 7,000 feet per minute. Dental diamond points 3/32 inch in diameter have a peripheral speed of only 720 feet per minute at 30,000 r.p.m. In order to obtain the recommended peripheral speed for effective removal of tooth structure, these small instruments require rotational speeds of approximately 245,000 r.p.m. Satisfactory results and long life for small diamond instruments are dependent upon the use of light pressures and the highest possible rotational speeds.

". . . The greatest heat production during removal of hard tooth structure occurs in the ultra speed range; burs and diamonds can produce incineration with incandescence of enamel and dentin. . . .

. . . . .

". . . Burs produce the lowest frequency and highest amplitude of vibrations at any one load and speed. Abrasive instruments, on the other hand, having multiple grinding points, produce vibrations higher in frequency than those produced by a bur revolving at the same speed. Since grinding enamel is more effective than milling, and less pressure is required to cut effectively, the amplitude of vibrations is decreased proportionately. As rotational speeds increase, vibrations are higher in frequency and lower in intensity. . . . abrasive instruments rotating in the ultra speed range, with their multiple points of contact during a single rotation, will produce vibrations very nearly approaching the ultrasonic range, thus decreasing patient discomfort. Since cutting efficiency improves as speed is increased, the benefits are two-fold: (1) there is less audible bone-conducted noise while cutting, and (2) the time of contact during which vibrations are transmitted through the skull is reduced.

" . . . Milling cutters (burs) of small diameters, although inefficient, cut enamel very effectively at these ultra speeds. The burs become, in effect, grinders, and remove hard tooth structure by sheer impact of the blades, even at very light handpiece pressures. The momentary but extremely high forces involved apparently crush the enamel, frequently breaking it away from the tooth a slight distance ahead of the actual blade contact. This action produces an irregular surface which requires finishing with suitable hand instruments. . . ."

Considerable care is recommended in the selection of diamond cutting instruments. The variables of design and construction are many. The features that determine instrument efficiency include suitability of size and shape, concentricity of the wheel or stone to a balanced shaft, uniform size and even distribution of the diamond particles, and symmetry and uniform thickness of the instruments. The use of a pocket magnifying lens is recommended for inspection of diamond instruments. Accuracy and smoothness in operation can be obtained only from a true instrument. Instruments with coarse grit and uneven distribution of the particles are not true.

Instruments of 80 to 120 mesh (rough grit) are acceptable for speeds up to 12,000 r.p.m.; 180 to 300 mesh (fine grit) up to 60,000 r.p.m. By careful selection of strong diamond particles and strong bonding materials, instruments of around 240 mesh are now available for use at speeds above 100,000 r.p.m. Instruments of 420 mesh (very fine) can be used for finishing (smoothing) cavity preparations. The fine mesh diamonds are effective at the advanced speeds because more abrasive particles strike the tooth surface in a given unit of time than would strike when an instrument of rougher grit is used under the same conditions.

## Cutting Instrument Standards

In December 1963, a report[44] on cutting instrument standards was published in the Journal of the American Dental Association. A portion of that report is quoted herewith:

"For several years the Specifications Committee of the Dental Materials Group, International Association for Dental Research, has been formulating, for the American Dental Association, specifications for excavating burs and diamond rotary instruments.

" . . . . It was decided . . . . to formulate standards for shapes and dimensions of excavating burs and diamond instruments . . . . to insure uniformity.

"These standards established classes of instruments based on shank designs and provided a uniform system of numbering the shapes and sizes of the heads of the instruments. Therefore, for any one size of excavating bur, a number, or series of numbers, indicates the shape, the minimum number of blades, the head diameter and minimum length, the taper angle, where applicable, and the neck diameter of the bur. Thus the manufacturer has a guide to uniform production control and the dentist has a guide for purchasing uniform sizes and shapes. Whereas it was possible to assign definite numbers for bur shapes and sizes, it is not possible, at the present time, to do so for the diamond rotary instruments; here the diversity of shapes and sizes is much greater than that of the burs. Therefore, in the present standard, there is a range of numbers for a range of sizes within a definite shape designation. This is the first attempt at standardizing shapes and sizes of the diamond rotary instruments. It is probable that future revisions of the standard will include nominal head sizes with tolerances, as have been designated for the burs. There is, however, a general correlation between the number designations of shapes and sizes of the burs and those for the diamond instruments. For example, the round bur is designated by the 1-11 series and the 100-199 series designated the round or ball-shaped diamond instruments. Further, the inverted cone bur is designated by the 30 to 40 series, and the 300 to 399 series is used for diamond instruments. The 500 series are the straight fissure burs and the 500 series of diamond instruments are the straight cylinders, and so on. Therefore, there was an attempt to correlate numerical designations for the shapes of burs and diamond instruments. . . ."

The quoted report would be helpful to anyone in the selection of cutting instruments. A reprint of it can be obtained from the American Dental Association, 211 East Chicago Avenue, Chicago, Ill. 60611. The same information appears in the 1964 and 1966 editions of the Guide to Dental Materials,[45] also published by the A.D.A.

## NOISE

The "whine" from air-turbine dental equipment has proved to be annoying to some dentists and patients. In addition, the possible effects upon hearing ability of daily exposure to air-turbine and other high-speed handpiece noise has been of considerable concern to many dentists using the equipment.

Noise-induced hearing loss is related to at least four major factors:[46-48] (1) the overall level of intensity of the noise, (2) the frequencies of the noise, (3) the daily distribution of the noise and the total time (or dose) of exposure, and (4) individual susceptibility to noise damage.

Noise level measured objectively (without reference to human hearing ability) is referred to as "sound pressure level," commonly scaled in decibel units. Sound pressure levels, measured at working distances from dental air turbines, have fallen within the range of 70 decibels (db) to slightly over 100 db.[49-52] The levels vary, depending on whether the equipment is running free or is cutting, on the type of drive, and on the physical condition of the equipment, especially that of its bearings.

Although these sound pressure levels are within the range of concern of hearing conservationists dealing with industrial noises, the findings and recommendations with respect to industrial noises cannot be applied directly to the problem of turbine noise in the working environment of the dental operatory. One reason is that for the most part different frequency ranges are involved. The important military and industrial environmental noises lie in the range below 5,000 cycles per second (c.p.s.).[49] On the other hand, most investigators[49,50,52] have found the peak noises from dental air turbines to be high pitched (4,000 to 16,000 c.p.s.), though lower frequencies (2,400 to 4,800 c.p.s.) were measured by the Navy[51] and were also measured by Penn and Kortsch[53] from Page-Chayes drills (1,430 to 4,000 c.p.s.).

Furthermore, industrial safe limits for noise levels have been generally based on continuous exposure throughout an 8-hour day. This type and amount of exposure, of course, does not occur in the operatory or in the dental laboratory. In practice, exposure to turbine noise is intermittent, with total daily exposure for a typical dentist having been estimated as 12 minutes to 1 hour.[49,50,52] For the chairside assistant, the amount of exposure may be greater, especially in the Navy where he may be assisting more than one dentist, but he will often be farther from the sound source than is the dentist.

Together, these factors of high pitch, intermittent exposure, and relatively short length of exposure have led most investigators to conclude that turbine noise levels should not cause hearing loss in normal practice. Limits of exposure have been suggested;[49,51] the ones currently adopted by BUMED are given in chapter 3.

Two studies, however, have reported permanent hearing loss by dentists exposed to turbine noise.[50,52] The more recent one (1965)[50] found that 40 British dentists, after an average 3.7-year exposure to handpiece noise, had sustained definite, permanent threshold losses at higher frequencies. Although the losses were above the speech frequency range and hence undetectable by the individuals, it was predicted that with continued exposure the losses would increase and would gradually encroach on the upper frequencies of the speech range. This prediction was based on the history of continued exposure noted in other recent surveys by the same investigators.

Finally, there is the factor of individual susceptibility to such damage. The fact that there is wide variability in tolerance has not been sufficiently emphasized in many of the studies to date. Thus it is hazardous for an individual to accept unknowingly a given maximum safe level of noise that applies to the average population. If he is prone to hearing loss, that level will not be safe for him. The solution lies in periodic examinations of auditory sensitivity that can reveal susceptibility to damage.[54] It is generally accepted that early, and perhaps even temporary, threshold shifts will predict eventual permanent hearing loss that will be socially significant.[49,50,54] If shifts are detected, the individual can take personal protective measures, mentioned in chapter 3 and described in greater detail in the references given.

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The attention given to the physical factors incident to the use of advanced speeds has reduced the contact time of the cutting instruments, the amount of force applied by the dentist, the heat transmitted to vital structures, and the traumatic vibrations. It has also increased cutting efficiency of the instruments. The improvements in devices and techniques have made it possible for patients to receive more dental care per treatment hour. Studies aimed at improving the quality of care are continuing. Further consideration of the control of physical factors will be discussed in chapter 3.

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# CHAPTER 2

# BIOLOGICAL REACTIONS TO ADVANCED SPEEDS

G. V. Black, although remembered by most for his contributions in the fields of cavity preparation, restorative materials, and instruments, was responsible for much of the early work in histopathology and microbiology of the oral structures. Arnim[1] has quoted from an article published by Black in 1910: "In later years conditions have arisen which tend to mar the progress of the more scientific phases of thought in dentistry by diverting thought to the mechanical . . . . The result is that the more fundamental subjects are unable to command proper consideration and the mechanical parts are too often not well done. For this reason development in the scientific field is lagging behind."

In this section an attempt will be made to evaluate biological reactions to advanced physical speeds and to reach conclusions with respect to the acceptability of the modern instrumentation and its effect upon living tissues.

Several years ago the Council on Dental Research of the American Dental Association, being concerned about the safety of the newer techniques for cavity preparation, invited Dr. Harold R. Stanley of the National Institute of Dental Research to prepare a critical review and evaluation of the published histopathological studies of the response of the pulp to advanced-speed and ultrasonic instrumentation. In a paragraph introducing the article,[2] which was published in 1961, the following statement appears: "The Council believes that this authoritative commentary merits the careful attention of all who are interested in the rational application of high-speed and ultrasonic devices in clinical practice." Dr. Stanley's report is reprinted in the following pages as a part of this course.

## Traumatic Capacity of High-Speed and Ultrasonic Dental Instrumentation*

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In order to obtain a meaningful evaluation of the histopathological changes which occur in human pulp tissue under the traumatic influences of modern instrumentation, it is necessary to make a preliminary survey of the literature on the subject accumulated prior to the high-speed and ultrasonic era. This approach is especially indicated in view of the inherent difficulties in preservation, preparation, and interpretation of the particular type of histopathological specimens involved.

Although the art of pulp study and interpretation was greatly handicapped by the lack of effective histologic technics, technical improvements in recent years have eliminated many of the more common artifacts. Also, the need for a three dimensional perspective in order to interpret intelligently the vagaries of pulpal histology has been realised.

Concepts regarding the function of the pulp in fully erupted teeth have changed considerably since the end of the nineteenth century. This change is illustrated by comparing the operative technics of that era, which advocated destruction of the pulp even in minor procedures, to the

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*Complete bibliographic references are given in the published article.

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often complex methods used by modern dentists to preserve this tissue.

The nineteenth century belief that the pulp of a fully formed tooth served no further function found ready advocates for pulpectomy of normal teeth used as bridge abutments in order to prevent future episodes of pulpitis. However, as early as 1891 Miller pointed out that the mouth was an incubator of pathogenic organisms and suggested that they might play a role in various disorders of the body. W. Hunter in 1900 propounded a similar genesis of many systemic diseases. Billings in 1909 reported a case of chronic infectious endocarditis in which the source of infection was considered an alveolar abscess. It was not until 1910, however, after Hunter's famous lecture on oral sepsis at McGill University, that a wave of reaction spread throughout the dental profession. Although pulpless teeth were not mentioned by either Hunter or Billings, millions of pulpless teeth were nominated as focal points of infection for most of the systemic ills of man without positive clinical or roentgenographic evidence of focal lesions.

To stop this needless destruction of the oral cavity as a functional physiological unit, the dental profession next proposed that every effort be made to maintain the health and vitality of the pulp. Many procedures in operative dentistry underwent careful scrutiny in order to eliminate or modify those steps which were possibly harmful to the pulp. Thus began the era of pulp conservation.

Although considerable clinical evidence had been accumulated by 1932, very few histopathological studies of the dental pulp had been conducted. Black taught that pain-producing procedures caused pulpal hyperemia. Teeth heated or chilled to induce severe pain and then extracted at the peak of discomfort revealed engorged blood vessels. He listed several causes of hyperemia: heat generated while polishing fillings, heat-conducting metallic fillings placed over nearly exposed pulps, large fillings in broad contact with many dentinal tubules even in the absence of extreme temperature changes in the mouth, and the grinding away of enamel of a vital tooth even while using a jet of water.

In 1899, Jack determined the highest and lowest temperatures that would not cause discomfort to healthy teeth of patients. Consequently, the clinicians of that period became very aware of the phrase "hyperemia of the pulp" and associated all subjective dental pain with hyperemia. Any procedure causing pain was assumed to induce hyperemia and possibly permanent pulpal damage. The traumatic effect of drilling was considered to be minimal if the cavity could be cut painlessly without the use of anesthesia.

From this time on, pulp studies tended to fall into three categories, singly or in combination: (1) clinical studies on teeth in vivo; (2) thermocouple studies; (3) histopathological studies. The histopathological studies will be emphasized in this review.

## PULP STUDIES OF LOW-SPEED ERA

In the 1920's, the great number of pulps becoming necrotic beneath silicate cements stimulated a group of animal experiments. Wannemacher in 1928 appears to have carried out the first human study. Thoma in 1925 initially showed that pulp tissue could respond to irritation with all the characteristics of the inflammatory process. Until then it has been assumed that pulpal tissue differed from other mesenchymal tissues and lacked this capacity. Fish's work on monkeys in 1931 stands out as a landmark. He found that injury to the dentinal fibrils caused a reaction at their pulpal ends and the reaction was always confined to the pulpal surface of the injured tubules, where reparative dentin eventually formed. Manley recommended that clinically and biologically the dentin and pulp should be regarded as one tissue. Confinement of the pulpal reaction to cut tubules appeared to be the rule until Shroff's work with synthetic porcelain and Lisanti and Zander's work with heat revealed more extensive lesions.

Fish, and Van Huysen and Gurley found responses beneath unfilled cavity preparations more severe than those under fillings. Manley, Fasoli, Van Huysen and Gurley, and James and Diefenbach agreed that there was a direct relation between cavity depth and degree of pulpal reaction. Gurley and Van Huysen emphasized that the most important factor affecting the severity of pulpal response was the distance between the cavity floor and the pulp. James and Diefenbach were the first in the English literature to measure this distance precisely in tenths of millimeters and emphasized the pulpal reactions found in that section of a series which showed the deepest part of the cavity. In 1946 Shroff, having adopted the term "effective depth" for this measurement, generally found that cavities having an effective depth greater than 0.5 mm. would eventually induce the formation of reparative dentin. If the distance between the cavity floor and the pulp was less, the picture was one of progressive destruction of more and more pulpal tissue. Differences of 0.2 mm. in the thickness of the remaining dentin produced notably different pulpal reactions. His control specimens revealed considerable injury induced solely by the act of cavity preparation. Shroff pointed out that although the pulp might already have been sealed with reparative dentin as a result of the caries process, in all cavity preparations large numbers of sound and healthy tubules, unlined by such dentin, would be opened and placed in contact with filling materials.

Fish demonstrated that focal hemorrhages, not interspersed with inflammatory cells, could be found in experimental teeth extracted after several weeks without evidence of absorption, phagocytosis, or pigment formation. Also, normal control teeth occasionally showed minute foci of escaped red cells. He did find, however, that hemorrhages were more certain to occur under the more extensive preparations. He described capillary invasion of the odontoblastic layer associated with a round cell invasion in older, four week, specimens. Little did he realize that future pulp studies would reveal capillary invasion of the odontoblastic layer as early as 24 hours after cavity preparations. His work demonstrated the need for distinguishing between newly formed capillaries and those already present but nonfunctioning.

Seelig in 1950 showed that blood plasma diffusing through capillary walls produced an eosinophilic coloring of the ground substance. He considered this change the first stage of inflammation.

In 1952 Shroff emphasized that claims based on clinical evidence were extremely unsatisfactory and unreliable with regard to pulpal pathology. Although detailed descriptions of pathological states resulting from experimental procedures are not necessary, it is important to learn whether the procedure is or is not irritating to the pulp.

He further pointed out that in human studies careful selection of both subjects and teeth is necessary because of the many variable factors. Pulpal reaction to the same irritant varies not only between different individuals, but also between different teeth in the same mouth. Individual peculiarities make it mandatory, in order to obtain conclusive results, that large numbers of both experimental teeth and subjects be employed.

He indicated a need for a control filling material which permits differentiation between pulpal effects due solely to cavity preparation and those due to the filling material itself. Fortunately an acceptable standard of comparison can be obtained with ZNOE (zinc oxide & eugenol). Amalgam should not be used as a control because of its proved irritating nature. Shroff recommended that each worker report in detail his method of operation, use of an anesthetic, rubber dam, cutting speed, pressure, and so forth. Lack of this information lessens the value of the work and makes it impossible to repeat experiments satisfactorily for confirmation. Differences in histological appearances may be brought about by variations in extraction and fixation technics. The pulp of a tooth extracted under the influence of a vasoconstricting anesthetic and immediately fixed may present an ischemic appearance quite different from that of one removed under a general anesthetic.

In the same year, Kramer and McLean, reporting work on a large number of teeth, also showed an appreciation for the necessity of establishing a systematic method of assessing pulpal responses. They recorded not only the presence and location but also the severity of pulpal reactions. The intensity of the cellular infiltration, the degree of displacement of odontoblasts and the thickness of the reparative dentin were recorded as: +, ++, +++ and so on. Being aware of numerous nonspecific characteristics which could not be established as part of a reaction pattern in their results, they deemphasized hydropic changes in the odontoblasts, eosinophilic zones unrelated to the area beneath the cavity preparation, and focal hemorrhages, since these characteristics could all be found in nonprepared teeth.

Thermal shock, long discussed and assumed as deleterious to the pulp since the late 1800's, was experimentally produced and demonstrated by Lisanti and Zander in 1952. Elevations in temperature were produced by a device designed to apply heat to the floor of a previously prepared cavity in dogs. They determined in vivo the temperature rise in the pulp tissue resulting from heat transmission through various thicknesses of dentin beneath the floor of the cavity preparation and also observed the histopathologic changes resulting from the application of the same temperature. The application of temperatures as high as 600° F. for ten seconds resulted in massive destruction and blister formations in the pulp with lesions extending far beyond the cut tubules.

In 1953 Van Huysen and Boyd stressed the absolute necessity for serial sections in order to rule out unequivocally the minute exposures that can go undetected in semiserial sections. They felt that hyperemic and congested capillaries, as described by Black, could not be accepted as reliable criteria for pulp damage since they could be found in normal control teeth.

James and Schour in 1955 established a comparative index of response based on the degree of inflammatory reaction multiplied by the percentage of incidence. This study revealed that the degree of irritation produced could be evaluated more accurately when the cavity preparations were deep. In 1959 James, Schour and Spence improved further on this coding method.

## PULP STUDIES OF HIGH-SPEED ERA

Although the high-speed rotary era was introduced in 1920 when Huet demonstrated the advantages of a handpiece running at 10,000 r.p.m., it was not until 1949 when Walsh and Symmons built a turbine operating at 60,000 r.p.m. that there was any real impetus in this direction. At this time, concern was expressed over possible pulpal reactions to these increasing speeds, but the first mention of a histopathological study relative to the problem did not appear until 1956.

In 1957, Langeland published the first complete report of a comparative histopathological study of pulpal responses produced by a conventional low-speed (6,000 r.p.m.) and an air-turbine high-speed (50,000 r.p.m.) handpiece. Forty-seven human teeth were prepared, 15 at 50,000 r.p.m., 32 at 6,000 r.p.m., which were extracted within 20 minutes.

Langeland considered odontoblastic displacement the only histologic feature that could be recorded with certainty. The method of cavity preparation was considered noninjurious if displaced odontoblasts were not found. This feature occurred in all instances in which the preparations were carried out under an air stream but only in exceptional cases when the cavity was kept wet. He found no difference with either instrument, but the water jet, or spray, greatly minimized the incidence of displaced odontoblasts at both speeds.

Two studies with very similar results appeared in March 1957. Marsland and Shovelton reported on 34 human teeth prepared at speeds from 500 to 15,000 r.p.m. The teeth were extracted immediately and at intervals up to 38 days. Except for the immediate specimens, the cavities were restored with ZNOE. The cutting, using carbide or steel burs, was a continuous operation, lasting 15 to 90 seconds.

These investigators found that the degree of immediate damage from cavity preparation was greater with increased speed, that is, up to 15,000 r.p.m. From 5,000 to 15,000 r.p.m. the lesions beneath cavities prepared without a coolant extended beyond the cut tubules. The appearance of heat fixation gave the pulp a "burned" look. In this situation odontoblastic displacement was reduced as compared to displacement in those lesions resulting when the lower speeds were used. It was assumed that the severity of these lesions was due to thermal factors since these histological disturbances were not found when coolants were used. These findings also indicated that the thermal damage with steel burs was greater than with carbide burs.

Swerdlow and Stanley prepared Class V cavities in 60 human teeth with an inverted cone diamond stone (no. 37) at 20,000 r.p.m. with and without an air-water spray. Except for the teeth extracted during the first hour, all others were restored with ZNOE and extracted at intervals up to 36 days. In contrast to the method used by Marsland and Shovelton, intermittent rather than continuous grinding was used when the teeth were cut without a spray. The remaining dentin thicknesses (Shroff's effective depth) were measured. Lesions in the less-than-one-hour specimens, when present, were very slight and similar in both the "with spray" and "nonspray" categories.

By comparison, in the later time intervals the "nonspray" specimens revealed a more acute and prolonged pulpal response. Three specimens in this category revealed abscesses and several others had actively expanding lesions which could have developed into abscesses if a longer time interval had been provided. When a coolant was used, the floor of the cavity preparation could be extended much closer to the pulp tissue without inducing abscess formation, even with a remaining dentin thickness of 0.3 mm. The boundaries of the "with spray" lesions coincided approximately with the cut tubules but 15 of the "nonspray" lesions, possessing the burn characteristics described by Marsland and Shovelton, extended beyond the cut tubules.

In February, 1958 Bernier and Knapp reported using diamond stones and a water spray in preparing ten cavities in two dogs and six in human teeth. Their instruments consisted of conventional straight and contra-angle handpieces which ran up to 26,000 r.p.m. and several high-speed handpieces, the Turbojet (45,000 r.p.m.), the Midwest (40,000 r.p.m.), the Imperator (26,000 r.p.m.), and the Page-Chayes (100,000 r.p.m.). Although the exact running speed was not given, the conventional handpiece apparently was not operated at the ordinary standard speed of about 6,000 r.p.m. All teeth were restored with amalgam. One dog was sacrificed at 2 days, the other at 12 days. The human teeth were extracted at 2, 7, and 14 days.

With the high-speed instruments, including the conventional handpiece running up to 26,000 r.p.m., they observed a new type of lesion which they termed the "rebound response." This response occurred in a region directly across the pulp from the cavity site or at a site distant from and unrelated to the cut dentinal tubules. It was manifested by any combination of the following features: a change in the ground substance, edema, fibrosis, odontoblastic disruption, and reduced predentin formation. It was found in 100 percent (5) of the dog teeth examined after two days and 80 percent (4) of those examined after 12 days.

This response appeared to be primarily an alteration in the ground substance, such as the beginning of a necrotic change, with a concomitant stage of fibrosis and without an intervening exudative phase. The ground substance contained small fragmented and rounded, smooth, granular, eosinophilic bodies in a coarse reticular network. Many of the eosinophilic bodies appeared to lie in lacunae. Hyaline-like, eosinophilic regions were often found as a background for some of these changes. It seemed possible, but unlikely, that the smooth granular bodies were a terminal phase of degenerated erythrocytes.

The unique location of the "rebound response" to rotary cutting led to speculation that the waves of energy transmitted to the pulp were focused into a certain region by the structure and contour of the pulpal walls. The response was similar regardless of the instrument used and varied little in intensity and distribution in the sections made either at 2 or 12 days after operation. The possibility that high speed, alone, may be the precipitating factor of the "rebound response" gave cause for reflection on the use of high speed, even though its ultimate effect on the pulp vitality remained to be determined. They pointed out that although these responses did not necessarily indicate serious harm to the pulp, the possibility existed that if misused, the high-speed dental instrument, like any other instrument, could cause irreversible damage.

Three of the six human teeth also revealed a peculiar lesion morphologically resembling a circumscribed focus of degeneration. The distinct outline of the lesions suggested localization of the physical agent which produced this peculiar change. Bernier and Knapp considered it probable that the circumscribed focus of degeneration was another manifestation of the "rebound response" seen in the dogs.

In March, 1958 seven reports appeared in the literature concerning the effects of high speed. Zach and Cohen prepared 36 cavities in the teeth of monkeys with the Page-Chayes instrument (140,000 r.p.m.) using a No. 36 carbide bur. The animals were sacrificed after 30 days and a distinct almost linear correlation was found between the bulk of dentin removed and the pulpal reaction. They also observed an unusual degenerative response of odontoblasts on the opposing pulpal wall (opposite the region of directly cut tubules). They postulated that a possible cause of this response was harmonic vibration induced by extremely high rotary speeds.

Swerdlow and Stanley prepared 53 human teeth with the Page-Chayes equipment (150,000 r.p.m.) using a No. 35 carbide bur. They compared these results with the results of their previous study at 20,000 r.p.m. and found that the responses induced by the Page-Chayes instrument were less severe even though the average remaining dentin thickness of the high-speed specimens was smaller. They also noted the presence of an increased eosinophilic staining beneath the cut tubules in 13 instances.

Lefkowitz, Robinson and Postle published the results of a study of 249 cavities prepared in the sound teeth of dogs and humans in which low speed, high speed, air abrasive and ultrasonics were compared. Of this number, they prepared 17 human teeth and 16 dog teeth at low speed (5,000 r.p.m.) and 12 human and 58 dog teeth at high speed (24,000 r.p.m.). The cavities were prepared to an optimum depth of 0.5 and 1.0 mm. pulpal to the dentinoenamel junction. All cavities included the entire width of the buccal or labial surfaces and were restored with ZNOE. The teeth were removed at 1, 7, and 28 days.

When cavities were prepared at both low and high speeds, no histological evidence of injury was found. They advocated that experimental cavities be prepared to an optimum depth to help standardize the evaluation of pulpal response to cavity preparation. The adverse pulp reactions after cavity preparation beyond optimum depth must be construed as evidence of injury caused by depth of preparation rather than the effect of instrumentation alone. In the absence of caries, temperature rise in preparation, and chemical injury by filling materials, the only factor remaining to be investigated is traumatic injury. Their study showed that traumatic injury to the pulp is minimal and reversible when optimum cavity depth and thermogenetic factors are respected.

Nygaard Østby demonstrated that the Borden Airotor, running at top speed (250,000 r.p.m.) and the maximum water spray, produced no deleterious effect on the pulp. The pulpal reactions were less noticeable as compared to those observed when the conventional engine (6,000 r.p.m.) was used without a water spray.

In July, 1958 Shovelton and Marsland published some follow-up results after utilization of speeds up to 37,000 r.p.m. Human teeth were cut either with No. 558 carbide burs or cylindrical diamond instruments. They found that the No. 558 carbide bur could produce burns and other extensive lesions when used uncooled up to speeds of 22,000 r.p.m., but that very little pulpal disturbance was observed when a coolant was used. Cutting periods were continuous, varying from 17 to 75 seconds. The results indicated that pulp damage became progressively more severe as the cutting speed was increased up to 37,000 r.p.m. without coolants. With speeds up to 30,000 r.p.m., carbide burs with properly used coolants produced negligible pulpal damage. The effects of uncooled diamond instruments and carbide burs on the dental pulp were very similar. Although a cooling agent with diamond instruments did not eliminate damage to the pulp completely, it did reduce the damage to such an extent that full recovery of the pulp could be expected. Uncooled diamond instruments produced a considerable degree of fibrous change with some regularity in teeth retained for extended experimental periods. When carbide burs were used this change was infrequent.

Although the immediate response was similar with both types of instruments, the teeth retained after cavity preparation with the diamond instruments showed considerable changes in the odontoblastic layer.

In the lower speed range, odontoblastic displacement occurred to a lesser extent with diamond instruments than with carbide burs. With both instruments it was noted that the cellular displacement, when it did occur in the higher speed ranges, most frequently occurred in tubules on the opposite side of the pulp horn, not directly involved in the cavity preparation.

Tylman, Spence, Weiss, and Massler, in September, 1958 prepared seven anterior teeth for jacket crowns using diamond disks and diamond stones revolving at 6,000 and 20,000 r.p.m. with and without a water spray. One side of each tooth was cut at low speed, and the other at high speed. Shallow, medium, and deep inlay preparations were also made in 72 teeth using diamond stones and burs at speeds ranging from 3,000 to 70,000 r.p.m. with and without a water spray. All preparations were covered with ZNOE. The teeth were extracted after 48 hours or 7 days.

Shallow, jacket-type preparations resulted in little or no pulpal damage. The changes were not significantly different from those observed under much less extensive, shallow inlay preparations. Pulpal damage was progressively more severe as the inlay preparations became deeper. Absence of a coolant had no significant effect under the jacket preparations or shallow cavities but resulted in more severe pulpal damage under deep cavities. Pulpal damage was more severe under cavities prepared at speeds above 16,000 r.p.m. than those prepared at speeds under 6,000 r.p.m. It was concluded that pulpal damage in human teeth was more directly correlated with cavity depth than with extent or width of the preparation.

In October, 1958 Bruner prepared cavities in 17 human teeth at speeds in excess of 150,000 r.p.m. and at conventional speed and found very little difference in the pulpal response to either type of operative procedure.

In February, 1959 Bernier and Knapp, continuing their studies of high-speed preparations on young dogs, again emphasized the "rebound response" but stated that the selection of this term in no way implied a factor of causation. They reasoned that with high-speed instruments there could be an extensive transmission of energy into the pulp chamber which transcends those forces that would normally localize such effects at the base of the cavity. One could also assume that the physical characteristics of the chamber might influence the point of localization. An assessment of the cyclic quality of the sound vibrations peculiar to high-speed instruments seemed a likely place to begin, in that the "rebound response" seemed similar, at least histologically, to changes seen in teeth subjected to ultrasonic vibrations.

Another new response which they considered an immediate one, was "varicosity," the formation in the pulpal tissue of "large air-filled spaces" devoid of any lining cells. It appeared that high-speed instrumentation produced a greater range of pulpal changes, some of which may be more severe than those produced with low-speed devices. Knapp had found earlier, in teeth prepared with the Cavitron instrument, cystic spaces lined by mesenchymal cells and assumed that they were caused by edema.

In May, 1959 Stanley and Swerdlow presented the results of a comparative study on over 450 teeth of eight operative technics ranging in speed from 6,000 to 200,000 r.p.m. Class V cavity preparations were made and restored with ZNOE. The specimens were extracted at intervals of less than one hour to 132 days. Comparisons were made by recording the incidence and intensity of several specific histopathologic characteristics.

Speeds of 50,000 r.p.m. and over, with instruments utilizing the belt-driven or turbine principle with coolants, were found to be less traumatic to the human pulp than speeds of 6,000 to 20,000 r.p.m. with the conventional ball-bearing handpiece. The value of coolants became more significant at the higher speeds. In the absence of adequate coolant, intermittent grinding was of no appreciable benefit when cutting with diamond stones. Preparation time at the higher speeds was of little consequence provided frictional heat was controlled by adequate cooling. The combination of high speed, controlled temperature, and light load was conducive to the production of minimal pathologic pulpal alteration.

In the less-than-one-hour specimens, disruption of the odontoblastic layer with shallow displacement of odontoblasts represented the only pathologic alterations found. In the absence of adequate coolants these characteristics were more conspicuous, but no inflammatory cells were found regardless of the thickness of the remaining dentin.

Lesions extending beyond the cut tubules were found when those technics were employed with inadequate coolants. Also, the greatest incidence of reparative dentin occurred in these same groups. The incidence of reparative dentin in the lower speed categories did not approach the low incidence seen in the high-speed categories when adequate coolants were used, even when the specimens in the low-speed categories posssessed greater average remaining dentin thicknesses.

Stanley and Swerdlow later demonstrated that coolants, although adequate to prevent burn lesions, did not minimize inflammatory responses when the operative technic required an applied force above 8 ounces. Their results had corroborated Peyton's findings that frictional heat was readily controllable even at the higher speeds. Only 7 specimens of 400 prepared with an air-water spray revealed evidence of excessive temperature rise. With frictional heat being controlled, the presence of pulpal pathology was explained on the basis of differences in applied pressures determined by the design of the instrument and the requirements of the operative technic. Previously they had shown that the prevalence of cellular infiltration and cellular displacement was greater when lower speed technics rather than the higher speed technics were used, regardless of whether an adequate coolant was employed. Burn lesions produced at high speed were not generally characterized by the phase of massive leukocytic infiltration, as seen with the lower speeds. Without this influx of leukocytes, repair began earlier and with greater ultimate success.

In November, 1959 Seltzer and Bender used several speeds in preparing 15 human teeth for full crowns, then extracted them immediately. Two teeth were prepared at 5,000 to 8,000 r.p.m., 5 teeth at 25,000 r.p.m., 3 teeth at 40,000 to 50,000 r.p.m., and 5 teeth at 100,000 to 150,000 r.p.m. Their impression was that the pulpal reactions were much less severe when the teeth were prepared at higher speeds (50,000 to 150,000 r.p.m.) than at the lower levels (5,000 to 25,000 r.p.m.), provided copious quantities of water were used.

Swerdlow and Stanley also compared the response of the human pulp to amalgam insertion and ZNOE at low and high speeds. In the high-speed categories they found that the average response to the amalgam filling was greater than the average response for the ZNOE restored teeth, but no differences in response were observed with the two restorative materials with the low-speed technics. The primary response to cavity preparation at the low speeds was sufficiently great that no additional effect due to amalgam insertion was discernible. It became clearly evident that the biologic advantage, expressed in terms of minimal responses, associated with the high-speed technics was decreased or absent when amalgam was inserted on dentinal tubules which were not underlaid pulpally by secondary dentin.

### DISCUSSION OF PULP STUDIES OF HIGH-SPEED ERA

Langeland found no difference between conventional rotary speed and the Dentalair (50,000 r.p.m.); however, all his specimens were extracted within 20 minutes. Swerdlow and Stanley and Stanley and Swerdlow found no significant differences when comparing their specimens extracted early, regardless of speed or type of coolant. Some investigators feel that the full potential of a pulpal response cannot be predicted by looking at immediate specimens. Even 24 hours is not a sufficient length of time to predict the maximum response which will develop after a burn. Langeland more recently has indicated that a pulpal reaction which started at the time of cavity preparation may persist in the pulp tissue despite the insertion of an inert filling material. No doubt some distinction can be made with immediate specimens but older specimens provide more criteria for obvious groupings.

Stanley and Swerdlow demonstrated that 20,000 r.p.m. with a diamond stone and without a coolant was the most traumatic operative technic, even with intermittent cutting—more so than 6,000 r.p.m. without a coolant. Marsland and Shovelton showed that the damage increased as the speed increased up to 15,000 r.p.m. Using operating speeds from 5,000 to 15,000 r.p.m. and up to 37,300 r.p.m. without a coolant produced lesions extending beyond the cut tubules. Stanley and Swerdlow found this to be true at all speeds when no coolant or just an air jet was used with diamond stones and at high speed with carbide burs. Marsland and Shovelton were able to produce burn lesions with an uncooled No. 558 carbide bur, but Stanley and Swerdlow were not able to with an uncooled No. 35 carbide. However, Marsland and Shovelton employed continuous cutting whereas Stanley and Swerdlow employed intermittent cutting.

Shovelton and Marsland, as did Swerdlow and Stanley and Stanley and Swerdlow, demonstrated that odontoblastic displacement was less pronounced within the cut dentinal tubules in the presence of burn or extensive lesions. Displacement also occurred to a lesser degree with diamond instruments than with carbide burs. Shovelton and Marsland also noticed that when displacement did occur at the higher speed, it occurred in the tubules on the opposite side of the pulp and not directly involved in the cavity preparation. Similarly, Swerdlow and Stanley noted in their 20,000 r.p.m., nonspray specimens, that all the missing odontoblasts in the region of the cut tubules could not be explained on the basis of displacement. When displaced odontoblasts were not found in the cut tubules, they were found beyond the cut tubules, even on the opposite surface. The reason for this condition is that the odontoblasts beneath the cut tubules were destroyed by the burning process and so could not be displaced. However, as the postoperative intervals increased, the lesions, resulting from burning, expanded beyond the cut tubules to involve a greater portion of the pulp and with more odontoblasts being involved by the expanding inflammatory response, additional odontoblasts were displaced.

Shovelton and Marsland also noticed that older specimens, prepared with uncooled diamond instruments, showed a considerable degree of fibrous change. This was explained by Stanley as representing regeneration on the part of the pulp to replace the damaged tissue created by the burning episode. The increased number of fibroblasts was often accompanied by many mitoses.

Shovelton and Marsland appreciated the fact that even with a coolant damage to the pulp was not completely eliminated when diamond instruments were used. Stanley and Swerdlow also found this to be true but related the pulpal responses to the excessive pressure of grinding rather than to a property of diamond instruments.

In a study in which there were no pulp deaths, Lisanti and Zander pointed out that the normal pulp of healthy dogs was capable of recovery from severe heat injury. A similar favorable response of the human pulp after thermal injury does not necessarily follow, since recovery depends on additional factors including the state of health of the organ at the time of the cavity preparation, the depth and extent of the preparation, the extent of the tissue damage and the presence of enough remaining cells capable of differentiation to effect healing. Lisanti and Zander emphasized that in cutting their preparations under an air stream, extreme care was taken to eliminate undue pressure and friction. The studies of Shovelton and Marsland and Stanley and Swerdlow possibly shed some light on the successful results obtained by Lisanti and Zander. Stanley and Swerdlow found that healthy pulps were more apt to recover from burns induced by a high-speed, low-pressure technic and indicated that this recovery was influenced favorably by the frequent absence of a massive influx of leukocytes into the damaged region which they believed adversely affected healing in the injuries produced by low-speed instrumentation.

The investigators who cite Lisanti and Zander's work as a indication that frictional heat is of no consequence in pulp damage and repair are on untenable grounds. Sullivan in July 1955, in referring to their work, expressed doubt as to the importance of frictional heat in terms of injury to the pulp and stated that the subject of damage to the pulp caused primarily by mechanical and temperature abuses should be re-evaluated.

Murphy in 1957 also referred to this same treatise and interpreted it to mean that irreversible pulp damage never resulted from the heat produced by rotary burs alone. He assumed that previous concepts might well be in error since the protective ability of the pulp has been underestimated. Fortunately, he emphasized that even though the healthy pulp tissue appeared capable of recovery from even the most abusive drilling procedures, nevertheless a sensible attitude toward reversible pulp damage from heat production was encouraged. In addition he pointed out that when the cumulative effects of the preoperative caries process, the operative procedures, and the postoperative irritants are considered, the pulp might well be irreversibly damaged and that this total picture should be kept in mind in considering the effects of rotary instruments.

Some investigators preferred to use amalgam as a filling material in experimental teeth although several references in the literature describe its irritating properties. Hori found that his control teeth filled with amalgam often showed no improvement after 30 days and many pulps had further deteriorated. Nygaard Østby, however, was able to obtain favorable results with this material in his study of high speed. The insertion of a filling material whose irritating properties can camouflage initially favorable responses created by mildly traumatic grinding technics may also explain the lack of differences in response to different operating technics in many previous studies when filling materials other than ZNOE were inserted. It would be helpful in the future if pulp studies evaluating cutting technics would employ ZNOE as the standard filling material, since the majority of previous studies have utilized this substance and several have found that it at least did not apparently compound the irritation to the pulp.

As recently as 1957 Langeland pointed out that eosinophilic staining became particularly distinct after delayed or insufficient fixation, and low temperature fixation. He emphasized that eosinophilic staining should be considered a criterion only if sharply limited to the region subjacent to the experimental cavity and considerably stronger in intensity in that region as compared to the pulp as a whole. Zander, in 1958, felt that too much emphasis was being placed on ground substance tissue alteration (eosinophilic staining). According to Zander, from the information then at hand, it was impossible to decide whether this characteristic resulted from cavity preparations, extraction, preparation of the tooth for fixation, fixation itself, or even represented a post-mortem change.

Few investigators have given support to the "rebound response." Shovelton and Marsland at first interpreted some of their high-speed specimens as exhibiting this response. But in no instance did they find normal pulp tissue between the area beneath the cavity and the opposite side of the chamber, whereas Bernier and Knapp did. The extensive lesions, reaching the opposite side of the chamber, also involved all the intervening soft tissue. This condition was also found in the extensive lesions studied by Lisanti and Zander, Swerdlow and Stanley, and Stanley and Swerdlow.

Zach and Cohen mentioned the presence of an unusual degenerative response of odontoblasts on the opposite pulpal wall only once in a series of reports.

Swerdlow and Stanley observed that the tissues involved within the eosinophilic zone appeared morphologically normal. The eosinophilic staining was present at the ends of the shortest cut tubules if there was no exudate. If an exudate was present at that site, then the eosinophilic staining was seen to one side of the shortest tubules, either above or below or in both places. The intensity of the eosinophilic staining was somewhat greater than in the amorphous material seen in the lumina of the adjacent lymphatic capillaries. Occasionally the cut dentinal tubules showed the same intense eosinophilic staining, thus indicating a flooding of the region rather than a necrobiotic change as had been indicated. This reaction appeared as early as 5 days and was still found after 132 days, with no obvious change in character other than possibly an increased intensity of staining. It seemed peculiar that the characteristic was missing in those specimens in which the response was severe enough to produce an exudate. Since it occasionally occurred peripheral to an exudate the eosinophilic change may signify a milder response. A possible reason that this characteristic was found more often in the high-speed categories was because of the general mildness of the pulpal responses. One would therefore expect to find eosinophilic staining in those specimens in which more superficial cavities were prepared using the more traumatic low speeds. Such an interpretation would suggest that eosinophilic staining represents a favorable rather than a detrimental criterion.

Pohto and Scheinin demonstrated in the living pulp tissue of rats that thermal irritation created by a temperature elevation of 5 to 7° C. caused an increased permeability of the blood vessels. Plasma penetrated into the surrounding tissues especially from the venules but also from the capillaries.

The peculiar lesion described in human teeth as a circumscribed focus of degeneration represents one of the pitfalls in interpreting the condition of the pulp and is often found in sections of nontreated teeth. Such a configuration represents a small island of cross-sectioned odontoblasts surrounded by a portion of the zone of Weil. This feature results from sectioning through the irregular projections of the pulpal tissue which are often found.

Although the findings of Lefkowitz, Robinson and Postle in their comparative study of the effects of the various technics are in general agreement, it is felt that their work would have been more significant if the experimental cavities had been prepared to a greater depth.

Nygaard Østby's illustration No. 4 shows beautifully what can be accomplished with high-speed instruments when properly operated. With a remaining dentin thickness of only 30 microns, the width of about 4 to 5 erythrocytes, reparative dentin was being formed at 32 days with minimal inflammation of the adjacent pulpal tissues.

The work of Tylman and others was in agreement with the results of other investigators. Like Seltzer and Bender, they found less reaction when the high speeds were used in crown preparations which are relatively shallow. Pulpal damage became progressively more severe as the preparations deepened. The absence of coolant had no significant effect on the jacket preparations or shallow cavities. This agreed with the findings of Stanley and Swerdlow who eliminated specimens with a remaining dentin thickness of 2.00 mm. or greater because experience had shown a lack of response except in the most traumatic instrumentations. Tylman and co-workers also showed that the pulp response was more directly correlated with cavity depth than with extent or width of the preparation, which also agreed with the work of Lefkowitz and co-workers and other investigators.

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## SUMMARY AND CONCLUSIONS

A sufficient number of histopathological studies have been completed throughout the world to provide some confirmed information about the response of the dental pulp to the newer cutting technics.

Generally it has been found that high-speed operative technics are biologically acceptable to the dental pulp when the frictional heat of grinding is neutralized with the adequate use of an air-water coolant. No doubt, at any speed the elimination of frictional heat is desirable. Air alone as a coolant was not found to be consistently protective. Without coolants the diamond instruments were found to be the most destructive cutting tools. Intermittent grinding in the absence of coolants did not diminish the destructive capacity of diamond stones sufficiently to make it worthy of practice. However, certain carbide burs with intermittent grinding procedures in the absence of coolants were found to be not as destructive to the pulp.

It has been shown that even when frictional heat was neutralized, a greater pulpal response occurred with the lower speed technics because of the amount of applied pressure (force). As the amount of applied pressure was decreased with the increasing rotary speeds, the pulpal response was minimized.

Cavity depth, quite obviously, has become the all important dimension in determining the pulpal response with any operative technic. Extensive shallow cavity preparations involving an entire surface of teeth or full crown preparations produced pulpal responses of a mild nature, if any, with the high-speed technics, as compared to more remarkable responses resulting from deeper but more confined cavity preparations. Two millimeters of dentin thickness between the cavity floor and the pulp chamber provided an adequate insulating barrier against the more traumatic technics in spite of intentional abuse. But as the dentin thickness decreased from this value the pulpal response inversely increased.

In the future it is recommended that the standard filling material in all studies evaluating the pulpal responses to cutting technics be ZNOE. Experience has shown that subtle pulpal changes due to cutting procedures can be greatly magnified or camouflaged by the irritating properties of other filling materials.

Despite the advent of less traumatic, high-speed technics, all problems concerning pulpal irritation and death are not at an end. This circumstance has become more apparent as an increasing number of fully crowned teeth, prepared with high-speed instruments, require endodontic treatment.

It must be remembered that with low-speed technics, sufficient irritation resulted from full crown preparation to cause the pulp to seal off freshly cut tubules with reparative dentin before the fabricated crown was cemented into place. With the high-speed technics a longer postoperative period is required before the pulp forms reparative dentin. Even then, the quantity of reparative dentin is generally less as compared to the amount formed following low-speed procedures. Consequently, finished crowns are often cemented into place before the freshly cut dentinal tubules are sealed naturally. More than ever, investigations are needed to develop improved and more certain methods of lining and coating unsealed dentinal tubules to offset the irritating properties of cements.

The lack of confirmatory evidence at this time minimizes the need for specifically delineating eosinophilic staining of the pulp with the term "rebound response." However, more studies are recommended so that eosinophilic staining may become better understood.

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## SUBSEQUENT BIOLOGICAL STUDIES

Dr. Stanley's article is considered by many to be a classic of dental literature of recent years, but it is now several years old and does not include the latest investigative studies. The results of some of the studies not covered in the Stanley article are discussed in the following paragraphs.

Kramer,[3] in 1960, reported having prepared cavities in the cervical thirds of about 200 noncarious bicuspids. Air rotors were operated with 30 p.s.i., giving 320,000 r.p.m. free-running speed. An operating load of 2 to 2-1/2 ounces was employed with diamond cylinders and tungsten carbide fissure crosscut burs with and without water spray. The teeth were sectioned and studied from a period of a few minutes to 231 days. In addition to pulpal changes, in some experiments changes in the dentin bordering the cavity had occurred. It was reported that these changes "appeared to include varying degrees of damage in the collagenous matrix and were divided into two categories provisionally termed 'burning' and 'darkening.' 'Burning' was never seen in control teeth with cavities cut at conventional speeds." When the turbine was used with water spray, the incidence was low; but when the bur was used dry, it reached 60 per cent. "'Darkening' was occasionally found after cutting by means of conventional handpieces, but after cutting using turbine handpieces without water spray the incidence was 80 per cent." Changes in the collagenous matrix were shown by special stains. All the changes were reproduced in teeth in which areas of dentin were exposed to heat after extraction.

Studying the effect of operative procedures on the pulps of 225 older adult teeth, Weiss et al.[4] found that a dry diamond stone at 3,000 r.p.m. burned the dentin on the floor of the cavity and produced a mild to moderate reaction in the pulp. At 70,000 r.p.m. a dry diamond stone quickly became clogged with debris and there was an odor of burning dentin. With water cooling, preparation of a tooth at 3,000 r.p.m. was slightly more injurious than at 70,000 r.p.m. (probably because of a greater applied load and more vibration of the cutting instrument), and cutting dry at 3,000 r.p.m. was more injurious than cutting wet at 70,000 r.p.m. or even at 250,000 r.p.m. Burning of dentin occurred in the corners of the cavities and was thought to result from faulty procedure that prevented the coolant from reaching the cutting site. The investigators suggested that holding the handpiece at an angle would remedy the situation.

In the studies of Weiss et al.,[4] steel burs with water spray produced greater injury than carbide burs and diamond stones at comparable speeds. Steel burs lost sharpness quickly at 30,000 r.p.m. and up; and at 70,000 r.p.m., dry, they glowed red and the metal lost its temper. The investigators concluded that steel burs should not be used to cut dentin at high speeds. Although carbide burs lost their sharpness more rapidly than was generally thought, they did not dull so rapidly as steel burs. Carbide burs caused the least pulpal damage and were the most effective cutting tools. Wet diamond stones caused intermediate injury, but when used dry they were the most injurious, caused more pain then the burs, and were the least effective.

Weiss et al.[4] concluded that the differences in pulpal reactions to steel burs, carbide burs, and diamond stones "per se were slight compared to the differences between cutting dry or with water spray using the same tool." Preparation of shallow cavities at 30,000 r.p.m. without coolant (fig. 6) burned the dentin and severely affected the odontoblastic layer. Operating dry at 70,000 r.p.m. caused deeper burning of the dentin (fig. 7), destroyed the odontoblastic layer, and caused essential narrowing of the blood vessels by mural coagulum. Severe reactions were unchanged after 30 days, but moderate pulpal ractions usually resolved in 30 days and mild reactions usually resolved in less than 14 days.

Figure 6.—"Shallow cavity with dentine burned by steel bur revolving at 30,000 r.p.m. without coolant. Odontoblastic layer is severely affected (follow arrows)." From Weiss et al.: Dental Progress 4:6, 1963, University of Chicago Press.

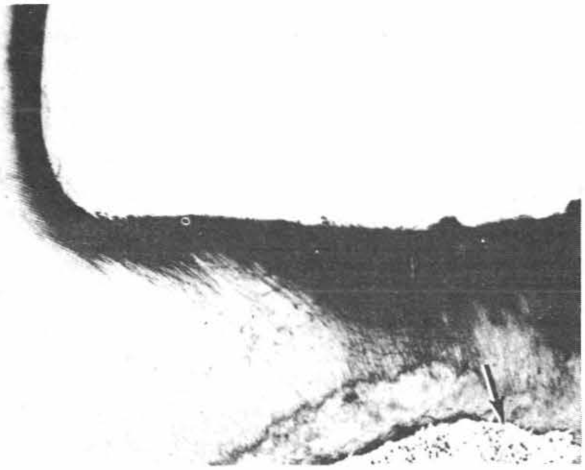

Figure 7.—"Deep cavity with dentine burned by steel bur used with heavy pressure at 70,000 r.p.m. dry for only 9 seconds. Note destruction of the odontoblastic layer." From Weiss et al.: Dental Progress 4:6, 1963, University of Chicago Press.

Weiss et al.[4] noted that there was no evidence of reparative dentin formation in their experimental teeth within 30 days following the operation and concluded that perhaps "adults require a longer period for reparative dentin formation." (See Stanley's findings, discussed subsequently.) They also found that in older teeth silver nitrate (fig. 8) and silicate cement (fig. 9) may cause greater injury to the pulp than excessive heat generated during cavity preparation. They stated: "Histologic appearance of the main body of older pulp had little relationship to the chronological age of the patient [fig. 10]; the pulp of some patients aged 50-60 resembled that of patients aged 20-30. . . ." Weiss et al. concluded that the clinician should protect the pulps of older teeth as well as younger teeth from the harmful effects of cavity preparation and certain chemical agents.

These findings reinforced the conclusions of Stanley,[5] who sought to establish the effect of age and pulp chamber size on the pulpal response of teeth subjected to cavity preparation. He reported: "In the age factor group, eleven

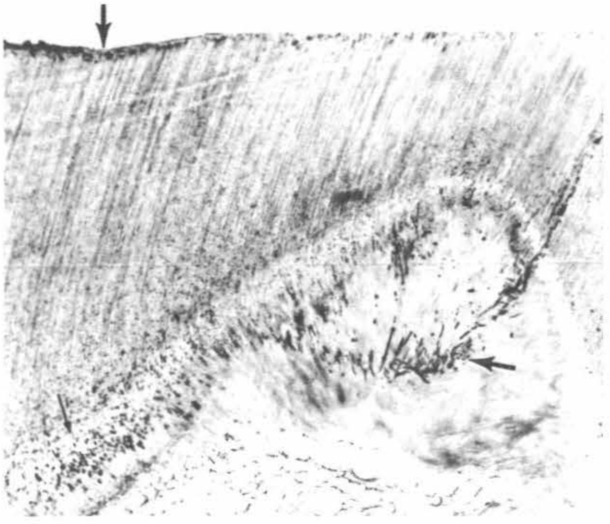

Figure 8.—"Marked fibrotic atrophy of pulp tissue underlying a cavity preparation to which ammoniacal silver nitrate solution had been applied 14 days earlier and reduced with eugenol. Reduced silver particles fill the dentinal tubules (arrows)." From Weiss et al.: Dental progress 4:6, 1963, University of Chicago Press.

older teeth (45.8 per cent) showed a more severe lesion and thirteen (54.1 per cent) demonstrated less severe lesions than their younger counterparts. In the older teeth where the pulpal horns or occlusal portions of the coronal pulp chamber were filled in with irregular dentine, the lesions were confined to the cut tubules not lined by the irregular dentine. The presence of the irregular dentine modified only the size and not the intensity of the lesion.

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"... When the R.D. [remaining dentin] difference [between two teeth being compared for intensity of response] is 0.2 mm. or less, it is impossible to predict which teeth will reveal the . . . [most] severe pulpal reactions.

. . . . .

"Age, as manifested in the form of tooth hardness, sclerosis, or decreased permeability, provided no obvious protection to the pulpal tissues subjected to cavity preparation, except in the older teeth where the pulpal horns or occlusal portions of the pulpal chambers were filled in with irregular dentine. . . . Apparently, one need not be concerned with variations in age of the patients from whom the specimens came so long as irregular dentine does not underline the tubules being cut in the operative procedure. . . .

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"Experience has taught us that lesions involving the uppermost portion of the pulpal horns, where the depth or breadth of the pulpal tissues is very thin, require a more prolonged resolution period. The distal position of the horns in relation to the main blood supply evidently contributes to this circumstance. . . .

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"Tooth size did not appear to play an important part in determining the pulpal response. . . ."

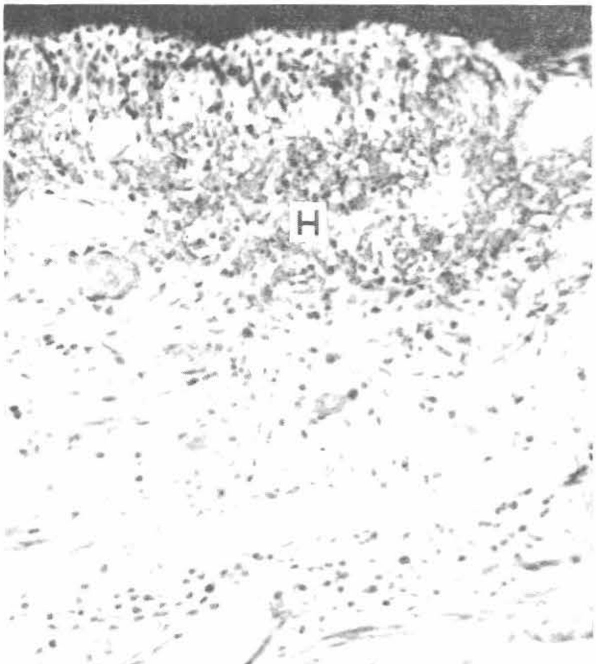

Figure 9.—"Pulp reaction 7 days after silicate filling. Odontoblastic layer and zone of Weil show severe hemorrhage (H)." From Weiss et al.: Dential Progress 4:6, 1963, University of Chicago Press.

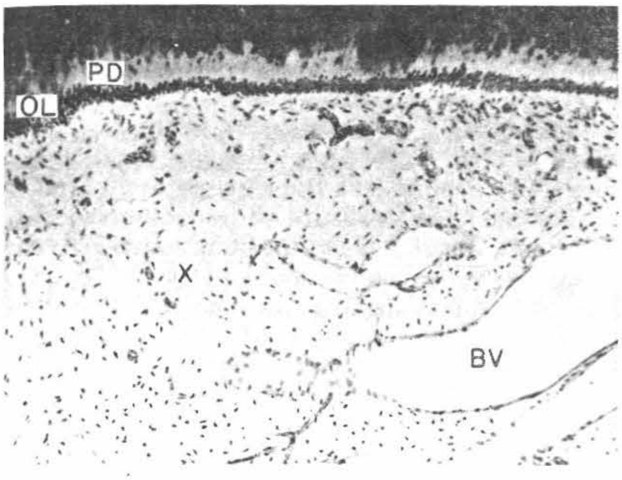

Figure 10.—"Pulp tissue of an older patient. This pulp has the characteristic embryonic appearance of a much younger tooth; a great amount of gelatinous ground substance (X), many primitive mesenchymal cells (small black dots) and large vessels, a wide predentine (PD), and a continuous wide layer of odontoblasts (OL). An "old" pulp would be fibrotic with calcifications, fewer cells and vessels, and narrow predentine and irregular odontoblast layer. (See also fig. 8)" From Weiss et al.: Dental Progress 4:6, 1963, University of Chicago Press.

Thomas[6] studied the pulpal effects of direct gold condensation into Class V cavity preparations of adults 36 to 55 years of age. In those teeth with carious lesions or eroded areas, preoperative secondary dentin, covering either all or some of the cut dentinal tubules, was found in only 72 percent of the specimens. Where secondary dentin was subjacent to the tubules of the preparations, there was no pulpal response to the cutting, basing, or condensation.

Langeland and Langeland[7] observed migration of odontoblastic nuclei and erythrocytes in the teeth of persons up to 73 years old. ". . . Similar results occurred in teeth with irritation dentin. . . .

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"Irritants might more readily penetrate the more open dentinal tubules of young individuals than the narrower one of older individuals. On the other hand, the stronger recuperative power of young teeth, having wider apical foramina, would presumably outweigh this advantage. Accordingly, the same care should be shown in clinical procedures, regardless of age."

Langeland[8] had shown in 1959 that migration of odontoblasts occurred when the dentin of the floor of the cavity was blown dry, even if the preparation had been carried out under a water spray. Odontoblastic nuclei in the pulpal ends of cut dentinal tubules are considered by most histopathologists as an immediate or early reaction of the pulp to an abusive procedure. Brännström[9] stated: "Although the dentine's insulating qualities will keep the frictional heat from reaching the pulp, this heat will hasten evaporation of fluids from the dentine—particularly from the tubules." In addition, he stated that directing an airstream against exposed dentin will have the same effect. Ostrom,[10] in 1963, reported observing a much faster inflammatory response in the pulps of rat molars prepared with room temperature air coolant when compared with teeth prepared to the same depth with room temperature air-water coolant. The response was also greater in the air-cooled teeth. Air cooling altered the nature of the dentin during the cavity preparations. Ostrom's findings suggested that the "greater trauma of air-cooled cutting caused reduced permeability of the cut dentinal tubules. It is not known whether this was the result of alteration of tubular proteins due to heat, whether it was the result of increased pressure and stasis associated with pulp inflammation and edema localized at the ends of the cut tubules, or whether it resulted from partial occlusion of the tubules by displaced odontoblasts. . . ."

Cotton et al.[11] evaluated the immediate response of the pulp following drying of a cavity by a stream of temperate air for 5 minutes. "All twenty air-dried cavities showed odontoblast nuclei displacement into the dentinal tubules. Thirteen of fifteen non-air-dried cavities did not show nuclei displacement into the tubules."

Schuchard and Watkins[12] believe that air is an adequate coolant when used with low-torque "ultrahigh-speed" (225,000 to 250,000 r.p.m.) air turbines, provided sharp burs are used with light pressure and with short-time contacts with the tooth. According to their findings to date of publication (1965) they believe that the cellular response is "within physiologic limits and is reversible." They also believe that if low-torque "ultrahigh-speed" equipment is used properly, there is not only less temperature change than with "conventional speed" cutting and with high-torque "ultrahigh-speed" (160,000 r.p.m.) cutting, but that there is probably less temperature change than is experienced daily. (It is assumed they refer to the change caused by hot and cold items in the normal diet.)

In the same 1965 report,[12] Schuchard and Watkins stated that in more than 37,000 restorations placed by undergraduate students at the University of California no increase in pulpal pathosis has been evidenced either clinically or by roentgenograms or vitalometer tests. They have also conducted histological studies on a relatively small number of these teeth. In cavities of normal depth they found that initially there was some inflammatory response and some loss of odontoblastic nuclei beneath the cut dentinal tubules. This loss was less with low-torque "ultrahigh-speed" instruments than with "conventional speed" or high-torque "ultrahigh-speed" instruments. In less than 2 weeks following use of the low-torque "ultrahigh-speed" instruments, new odontoblasts were observable in the affected region; and within 30 days they appeared normal except that they were smaller than those in unaffected areas and the nuclei were more nearly like the short nuclei in pulp tissue near the apex. With cavities that were very close to the pulp, they observed that secondary dentin had formed beneath dentinal tubules approximating the gingival floor of the preparation and that the remainder of the pulp appeared normal.

Over a 4-year period, Bouschor and Matthews[13] conducted clinical studies on teeth cut with a carbide fissure bur at 2 to 3 ounces of pressure in an air-turbine handpiece having a free-running speed of 250,000 r.p.m. Air was the only coolant used. Each of 2,500 teeth was examined 1 week postoperatively, and 1,914 of these were reexamined 4 years later. In the 1-week postoperative clinical examinations, there was no evidence of pulpitis or sensitivity, and the patients reported that "they had less discomfort and that a dry field was more pleasant than having the water spray." After 4 years, 1,865 of the 1,914 teeth were "vital and non-sensitive," and 49 of the teeth (in 22 patients) were somewhat painful or sensitive, but this could not be directly related to the original preparations.

As others have done, Bouschor and Matthews commented on the unpleasant odor detected when tooth structure is cut dry. They pointed out that odor per se is not an indication of burned tooth structure since fine tooth particles cut under water have the same odor; and stated that manipulating the handpiece with a painting or wiping motion causes less odor than applying pressure constantly.

Shovelton and Marsland[14] prepared cavities in 20 caries-free young permanent teeth using tungsten carbide burs in an air rotor handpiece at maximum air pressure with air coolant only. "In teeth extracted immediately after cavity preparation, vacuolization and destruction of the odontoblast layers with hemorrage were seen. Within the next 14 days, displacement of nuclei into the dentinal tubules was seen, and an accumulation of inflammatory cells occurred at the edge of the dentin. The larger single vacuoles between the dentin and the pulp found in some teeth were not seen after experimental periods longer than 4 days. After 18 days, the odontoblast layers re-formed, and tubular secondary dentin was deposited beneath the tubules opened up by the cavity preparation. Calcification of the secondary dentin was irregular, and occasionally there were vascular inclusions."

Morrant and Kramer[15] studied the pulpal reaction of 220 sound young human teeth to "ultrahigh-speed" air-turbine handpieces, using carbide burs and diamond instruments with water spray as a coolant and also with air alone as a coolant. They compared these results with those obtained with a "conventional speed" handpiece under water spray. Some of the teeth were extracted immediately, and some were filled with zinc oxide and eugenol and extracted at intervals up to 242 days. Remaining dentin thickness was recorded and pulpal reaction was determined by infiltration of inflammatory cells, formation of secondary dentin, displacement of odontoblast nuclei, edema, and coagulation. Morrant and Kramer's results showed that neither the type of cutting instrument, the depth of the cavity, nor the use of local anesthetics had any effect on pulpal response but that all five histological criteria could be demonstrated more frequently in the teeth prepared completely dry than in teeth prepared under a water spray. They concluded that in order to cause minimal pulpal damage with air-turbine instrumentation, teeth should be prepared under an adequate water spray.

In the past 10 years, Stanley and Swerdlow have performed a variety of pulp studies on more than 4,000 intact human teeth. In a report published in 1964[16] they said: "The most important single factor in determining pulpal response to a given stimulus is the remaining dentin thickness between the floor of the cavity preparation and the pulp chamber. This measurement differs from the depth of cavity preparation since the pulpal floor in deeper cavities on larger teeth may be further from the pulp than in shallow cavities in smaller teeth. . . .

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"'. . . The pulpal response becomes increasingly severe as the remaining dentin thickness decreases. . . .

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"'. . . Although a Grade IV (XXXX) response [most severe of four grades] may occur at low speed and air-water spray, [fig. 11], the possibility of development of a nonreversible intrapulpal abscess is very slight when an air-water is used during preparation. . . . The lesions created with the use of an air-water spray, regardless of speed, are always confined to the regions related to the ends of the cut dentinal tubules.

"At the low speeds it is irrelevant whether air-water spray or air alone is used in superficial cavities. . . . [fig. 12] The potential for creating burn lesions becomes real only if the remaining dentin approaches a thickness of less than 1.5 mm. . . . a resulting burn lesion can extend not only beyond the cut tubules but completely across the pulp chamber to the opposite surface of the tooth. About 23 per cent of all burn lesions develop into intrapulpal abscesses, the others being reversible with the formation of reparative dentin. . . . The percentage of reversibility would be less for cavity preparations in carious teeth which possess decreased pulpal resistance due to existing preoperative pathosis.

"For those who continue to cut with no coolant or with air alone, no burn lesion will develop with a No. 35 carbide bur at operating speeds of 6,000 or 20,000 r.p.m. . . . However, at the higher speeds, a No. 35 carbide bur will produce a burn lesion as readily as a dry diamond point. . . .

"'. . . At the same remaining dentin thickness, higher speed techniques will induce half the pulpal response of the more traumatic lower speeds. At 1.0 mm. of remaining dentin, the average intensity of the inflammatory response is only Grade I (X) [least severe of four grades] as compared to Grade III (XXX) with the low speed technique. . . .

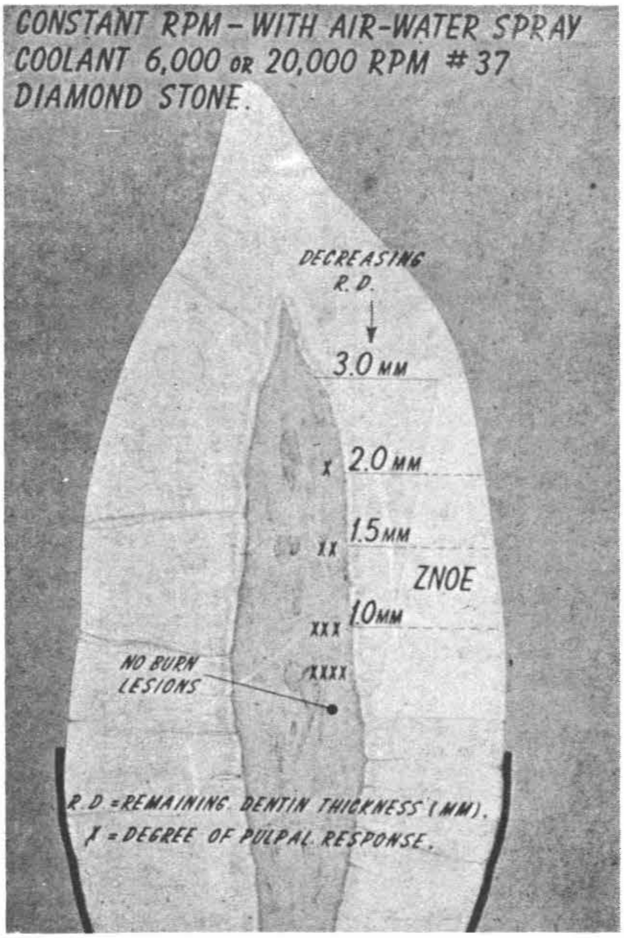

Figure 11.—"Utilization of the smaller carbide burs . . . permits deep cavity preparations at lower speeds without inducing burn lesions. At higher speeds, carbide or diamond instruments are capable of inducing burn lesions in deep penetration." From Stanley and Swerdlow: The Journal of Prosthetic Dentistry 14:365, 1964, The C. V. Mosby Company, St. Louis.

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"'. . . Given adequate water coolants, the same cutting tools, and comparable remaining

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[16] From Stanley and Swerdlow: The Journal of Prosthetic Dentistry 14:365-371 Mar.-Apr. 1964, The C. V. Mosby Company, St. Louis.

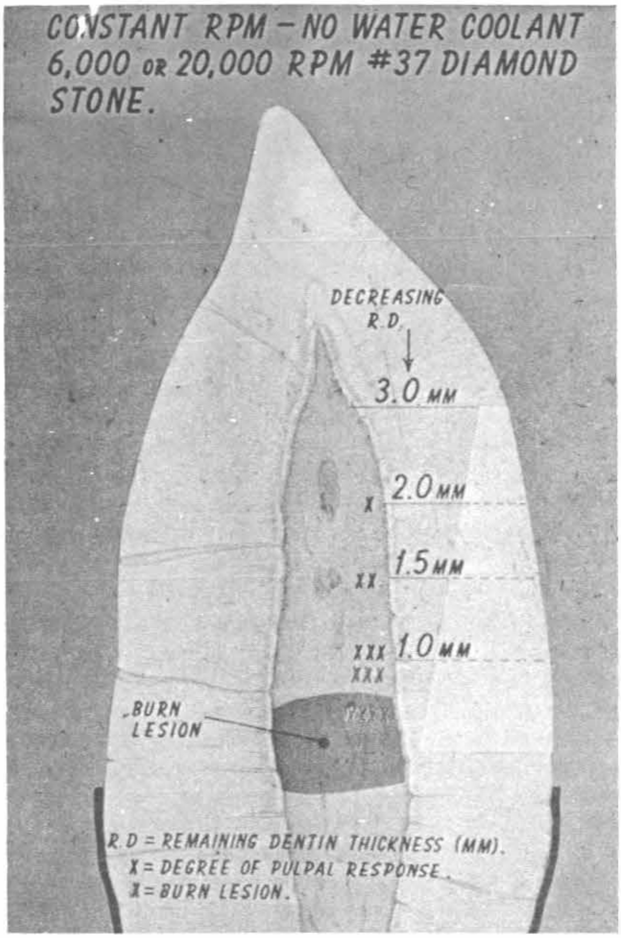

Figure 12.—"Without the use of an adequate water coolant, larger cutting tools, such as a No. 37 diamond point, will create typical burn lesions within the pulp when the remaining dentin thickness becomes less than 1.5 mm." From Stanley and Swerdlow: The Journal of Prosthetic Dentistry 14:365, 1964, The C. V. Mosby Company, St. Louis.

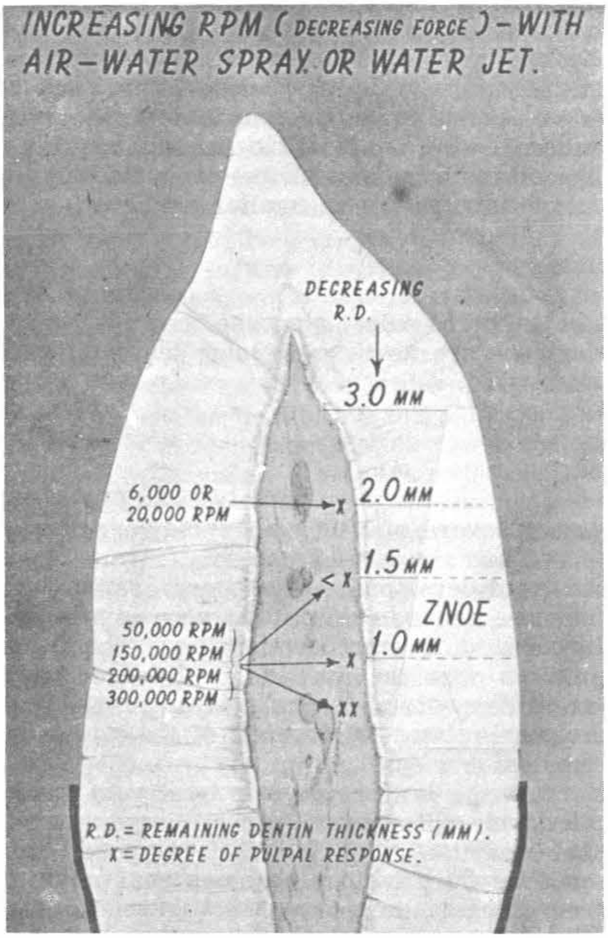

Figure 13.—"Given adequate water coolants, the same cutting tools, and comparable remaining dentin thickness, the intensity of the pulpal response with the high speed techniques (decreasing force) is considerably less traumatic than the lower speed techniques (increasing force)." From Stanley and Swerdlow: The Journal of Prosthetic Dentistry 14:365, 1964, The C. V. Mosby Company, St. Louis.

dentin thickness, the intensity of the pulpal response with the high speed technique (decreasing force) is considerably less traumatic than the lower speed techniques (increasing force) [fig. 13]."

Seltzer and his coworkers[17] observed the histological changes in the pulp that might develop after application of pressure alone or pressure in conjunction with microorganisms, silver nitrate, or phenol. Their cavity preparations were made in the teeth of dogs and monkeys. They, also, noted, "The deeper the cavity cut, the greater the change observed in the pulp. If the layer of dentine beneath the base of the cavity was thick, it shielded the effect of irritants applied to the cavity. Next to the trauma of cavity cutting itself, the greatest damage to the pulp was caused by the application of pressure. Silver nitrate or phenol caused severe damage if applied to deep cavities or if used in combination with other irritants. Bacteria (Streptococcus faecalis) placed on the base of the cavity could penetrate the dentine and reach the deep pulp, particularly if pressure was exerted or if the dentinal tubules were opened wider by application of phenol.

"In the dog, only the reactions to the irritation of cavity cutting were apparent in pulps examined immediately after treatment, but the effects of the other irritants could be seen in specimens taken fourteen hours after treatment. By the end of one month, the pulps had recovered, to a limited degree, from the effects of all the irritants tested with the exception of phenol. . . ."

In a later report Seltzer et al.[18] observed, "Injury of the odontoblasts initiates a series of changes within the dental pulp, observable as inflammation of the pulp and as formation of reparative dentine.

"The inflammatory responses within the pulp tend to disappear within one or two months if the only trauma is that of shallow cavity preparation, but cells characteristic of acute and chronic inflammation may persist even six months after operation if additional trauma is imposed by the application of irritants to the cavity, particularly to a deep cavity. The experiments seem to indicate that chronic inflammation can persist for long periods after initial injury, in some instances perhaps not eliciting any symptoms. Such a chronically inflamed pulp might not recover readily from an additional injury.

"The formation of new dentine appears to be proportional to the amount of injury. The greatest deposition occurs in response to deep cutting of the dentine. In deep cavity preparation, the odontoblastic processes are out close to the cell body. The base of a deep cavity is close to the pulp, and the latter is therefore more accessible to the action of irritating agents. Application of pressure and drugs to the cavity is a further stimulus to extensive formation of reparative dentine. In particularly severe damage there may be areas in which no reparative dentine is formed. In most instances, severe injury results in rapid but irregular deposition of dentine. In some instances, deposition is so rapid that cells are trapped within the reparative dentine.

"The formation of reparative dentine is analogous to scar formation in other wounds. In dentine, however, unlike soft tissue, the scar becomes calcified. A scar is not capable of further defensive activity, for there are few cells left within the tissue. Our impression is that the formation of large quantities of reparative dentine has the same effect as the aging process in tissues elsewhere in the body. The quantity of reparative dentine is not so much a manifestation of physiologic reponse to injury as an indication of the extent and severity of that injury. It would seem that efforts directed toward stimulating the excessive formation of reparative dentine are not in keeping with the basic concept of reducing tissue damage.

"Severe tissue damage is caused by pressure. The pressure may be delivered by the bur during cavity preparation or by operative procedures which follow cavity preparation, such as placement of gold-foil restoration, taking of impressions for inlays and crowns, and cementation of crowns and inlays. High-speed turbines operate with low torque and hence exert less pressure than do instruments operated at normal speed. . . ."

## DISCUSSION

In developing the textual material for this section, an attempt has been made to present the results of sound investigations that have clinical application for the operative dentist. Controversy still exists in several areas. The variables in biological research are many, e.g., speed, pressure, amount and temperature of coolants, cutting instruments employed, time of application of cutting instruments to tooth structure, depth and extent of cavity preparation, and so forth. There are biological variables within individual animals and humans and within their teeth. The criteria for evaluating the pulpal responses to the various procedures are not firmly agreed upon by the numerous investigators. The techniques of preparing histological specimens are often different. Early investigators reported some findings as pathological responses that later refinements in technique proved to be artifacts. Histopathology of the dental pulp is still a developing science.

However, the efforts of the clinical researcher have added greatly to our knowledge. The stature of operative dentistry and the dental profession has been elevated. We have advanced from the mechanical plateau in our profession's growth to the biomechanical. This we owe to the researcher. As we read the dental literature, we must call upon our scientific training and analyze the methodology and the conclusions of research reports with a critical but open mind. As each new bit of knowledge is introduced, we must reevaluate its effect upon the total knowledge.

The pulp of a tooth has definite functions: To supply viability to the dentin, sensitivity responses to stimuli, and defense mechanisms to battle against bacterial, mechanical, and chemical irritation. Every effort should be made to preserve the pulp. All operative procedures—not just the cutting of tooth structure but cavity sanitization, application of the protective lining, impression making, and choosing of restorative materials—must be assessed in terms of the biological response that can be expected. Pulpal response is the rational guide for determining which techniques are acceptable.

At the present time we have no clinical methods of determining in advance how severely a pulp has been insulted by disease processes, attrition, abrasion, previous operations, or traumatic incidents; nor can we establish how successful the pulp has been in defending itself against these insults.

Our objective is not to determine how abusive we can be and still have the pulp survive. Hippocrates wrote that a cardinal use of therapy is to "cause no injury." Our objective is to treat the tooth kindly with conservative techniques, giving it time to recover from the irritants and reestablish its health before final restorative treament is instituted. The traumatic potential of all our treatments must be kept to a minimum.

Massler,[19] in 1965, pointed out that the relationship of marrow to bone and of pulp to dentin are closely analogous (fig. 14); that both bone and dentin are composed of proportionate amounts of collagen and hydroxyapatite and both contain living cells and are avascular; that neither bone nor dentin contains nerve processes; that both bone marrow and pulp contain blood vessels and possess reserve cells for new matrix formation and are capable of repair; and that dentin and pulp must be considered as one organ just as are bone and marrow.

Today's microscopes are discovering features of dental tissues undreamed of a quarter of a century ago, e.g., direct communication between the pulp and the periodontal membrane via heretofore unseen lateral canals. We are learning that what affects one dental tissue, be it hard or soft, influences the others. We are learning to think of dentin, pulp, and periodontium as an entity. Today's practitioner must realize that when he excises an active carious lesion or reduces a clinical crown he is cutting living tissue, for viable dentin contains thousands of living cells. He must realize that his medicaments and the materials he uses to replace lost tooth structure will be placed directly on living protoplasm. He must ask himself whether his techniques will be harmful or acceptable to the tissues, and, more importantly, whether they will promote healing and regeneration.

Swerdlow et al.[20] have made the following recommendations "to minimize pulpal trauma in clinical dentistry.

"1. Treat all teeth as potentially 'sick.'

"2. Keep the cavity preparation as shallow as possible in dentin.

"3. Handpiece speeds above 50,000 r.p.m. are more biologically compatible.

"4. Use an adequate water coolant when cutting tooth structure.

"5. Exert light force when in contact with exposed dentin.

"6. Use smaller cutting tools at higher speeds.

"7. Keep irritating drugs away from exposed dentin.

"8. Use zinc oxide and eugenol on dentin when possible.

"9. Delay final setting of restoration, when possible, for reparative dentin deposition.

"10. Sedate, seal and insulate all deep cavity preparations."

## HISTOLOGICAL RESPONSE OF PULP TO CUTTING PROCEDURES AND RESTORATIVE MATERIALS

The slides and the comments regarding them presented in this section illustrate and explain the pulp's response to various cutting procedures and to the use of certain restorative materials. Both the slides and the comments are presented through the courtesy of Dr. Harold R. Stanley of the National Institute of Dental Research.

SLIDE 13. Normal pulp tissue (X100).

This specimen demonstrates the principal components of the dentin and the pulp: Tubular dentin, tubular predentin, odontoblastic layer, cell-free zone, cell-rich zone, and the deeper tissues of the pulp. These elements are of vital concern in pulpal studies. The dentinal tubules can reveal displaced odontoblasts and blood cells, the number and depth of which indicate the severity of the response. The predentin can become narrowed or thickened depending upon whether the postoperative interval is short or long, and whether the response is severe or mild.

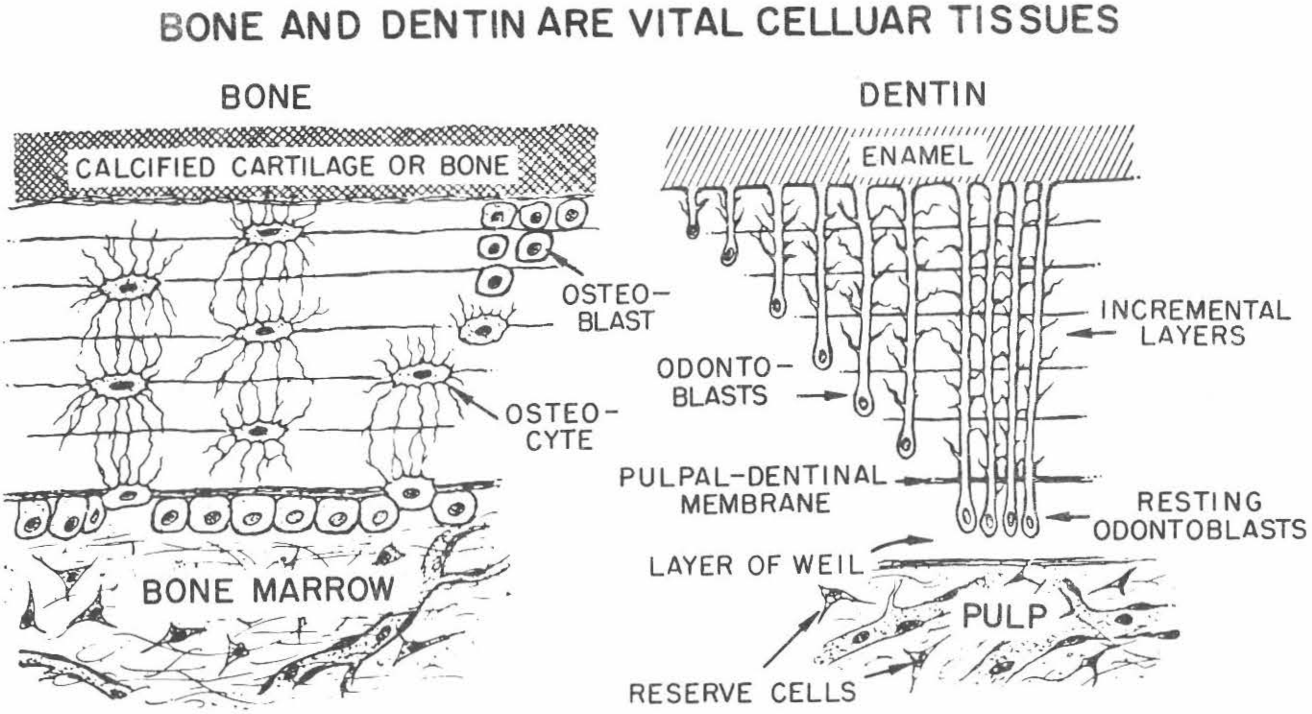

Figure 14.—"Diagram showing similarities in development and structure of bone and dentin." From Massler: Dental Clinics of North America, March 1965, p. 131, W. B. Saunders Company, Philadelphia.

The odontoblastic layer, the cell-free zone of Weil, and the cell-rich zone make up the superficial layers of the pulp and are most concerned with pulpal regeneration. As odontoblasts are injured or destroyed, the undifferentiated mesenchymal cells of the cell-rich zone multiply to replenish or restore the odontoblastic layer. The cell-free zone harbors a nerve plexus, which is seen only with special stains. The undifferentiated mesenchymal cells in the deeper tissues also serve as a source for cellular proliferation if the cell-rich zone is destroyed.

SLIDE 14. Acute inflammatory response (20,000 r.p.m. with air-water spray, 1-day postoperative period, X100).

This specimen presents a typical acute inflammatory response with infiltrating leukocytes, edamatous changes, focal hemorrhages, and cellular displacement. An acute response such as this can occur with almost any cutting procedure but is less frequent with the "high-speed" techniques (compare with SLIDE 16) unless very deep preparations are made. As severe as this response may appear at this time, experience has shown that most of the inflammatory cells will disappear by 15 days, the focal hemorrhages will resolve; and evidence of regeneration will be apparent, provided no further traumatic episodes compound the injury and sustain or enlarge the lesion.

SLIDE 15. Cellular displacement and infiltration (X450).

During the acute stages, inflammatory cells crowd the odontoblastic layer. Many odontoblasts move into the predentin and dentinal tubules and appear as long, slender rods. The segmented bodies represent leukocytes also displaced into the tubules. Erythrocytes and eosinophils have been shown to do the same.

SLIDE 16. "High-speed" response (150,000 r.p.m. with air-water spray, X100).

This specimen demonstrates a typical "high-speed" response to a cavity preparation, leaving beneath it a remaining dentin thickness comparable to the specimen illustrated in SLIDE 14. Note the very slight disturbance of the odontoblastic layer, the general lack of inflammatory cells, and the scattered number of displaced cells. This picture is generally typical of the response to all the "high-speed," low-pressure techniques utilizing adequate air-water spray coolants.

SLIDE 17. Burn lesion (6,000 r.p.m. without spray, 3-day postoperative, X21).

A burn lesion can be produced at any speed with diamond instruments when no coolant or only air is used and when the preparation comes within 2.0 mm. of the pulp. Such lesions can also be produced at the higher speeds with small carbide burs in the absence of an adequate coolant.

Pulpal responses are usually confined to the tubules involved in the preparation. Notice here that this lesion extends beyond the cut tubules to the tip of the coronal pulp chamber and even down the opposite pulpal wall. The fact that such a lesion has occurred long after resolution is completed can be detected when reparative dentin has been deposited beyond the cut tubules. Note the loss of the odontoblastic layer and the coagulation necrosis extending into the deeper tissues.

SLIDE 18. Burn lesion (X450).

A high-power illustration is used to demonstrate the total destruction with necrosis of the superficial pulpal tissues. The odontoblastic layer, the cell-free zone, and the cell-rich zone have all been destroyed. A few leukocytes are making their appearance. If regeneration is to occur, it must come from the surviving deeper tissues.

SLIDE 19. Abscess formation (20,000 r.p.m. without spray, 10-day postoperative period, X21).

About 20 percent of such burn lesions produced in teeth initially containing normal pulp tissue will not resolve. Instead, an abscess will form, beginning as early as 6 days postoperatively. Here is an example of massive necrosis involving most of the pulp tissue with early abscess formation beginning opposite the lower portion of the cavity preparation.

SLIDE 20. Reparative dentin formation (20,000 r.p.m. without spray, 36-day postoperative period, X18).

Reparative dentin formation in the pulp is comparable to scar formation in the rest of the body. The greater the initial injury, the more reparative dentin will form and the sooner it will form unless the trauma has been so extreme that necrosis and abscess formation intervene. Here you see the production of large quantities of reparative dentin in a "low-speed," nonspray specimen (compare with SLIDE 21).

SLIDE 21. Reparative dentin formation (200,000 r.p.m., 42-day postoperative period, X100).

Note the fine, thin strip of reparative dentin as compared with the bulbous production of reparative dentin shown in SLIDE 20. Appreciate the fact that this illustration has a magnification more than five times greater than SLIDE 20. Also note the lack of a persisting inflammatory response and the fairly well-reconstructed odontoblastic layer.

SLIDE 22. Lesion of delayed healing (20,000 r.p.m. with spray, 35-day postoperative period, X100).

Because individual responses vary in intensity, some specimens will show lesions that have not completely resolved by the end of the experimental period but nevertheless will present healing characteristics representative of a favorable prognosis. SLIDE 22 presents such a lesion where the superficial pulpal tissues were destroyed and replaced by granulation tissue. Although this lesion appears quite severe at this time, with the absence of necrosis and pooled leukocytes, and without further irritation, the prognosis would be most favorable. However, many more weeks would be required for complete resolution as compared to a lesion in which only a few odontoblasts were destroyed and the cell-rich layer was left intact.

SLIDE 23. Lesion of delayed healing (150,000 r.p.m., 132-day postoperative period, X100).

This represents the most severe lesion produced by the Page-Chayes technique used with the proper coolant. The remaining dentin thickness was only 0.23 mm. and yet a well-formed layer of reparative dentin is present despite the presence of chronic inflammation. Again, there is no pooling of leukocytes to indicate abscess formation. This is another example of a lesion that will require a long postoperative interval before resolution is complete.

SLIDE 24. Immediate specimen (20,000 r.p.m. without spray, X35).

Some investigators work predominantly with specimens extracted within the first 20 minutes following cavity preparation. Some characteristics can be seen in such specimens, but the full potential of a lesion may not become apparent for 24 hours or longer. Here is a specimen extracted in the first hour with a very traumatic technique that reveals only minimal disturbance to the odontoblastic layer, no inflammatory cells, and focal hemorrhages probably due to surgical manipulation. We know from experience that this same specimen would look far different in another 24 hours.

SLIDE 25. Immediate specimen (150,000 r.p.m. with spray, X100).

This is another example of an immediate "high-speed" specimen with no apparent disturbance to the pulp tissues despite the obviously deep cavity preparation.

SLIDE 26. Immediate specimen (200,000 r.p.m., X100).

In this portion of the cavity only a thin layer of predentin covers the pulp tissue, but there is very little, if any, disturbance to the superficial tissues. This is a very misleading picture.

SLIDE 27. Immediate specimen (6,000 r.p.m. without spray, X100).

This is the earliest evidence of a burn lesion. Note the minimal disturbance to the superficial tissues, displacement being the only prominent feature. Keep in mind the burn lesions previously illustrated in SLIDES 17, 18, and 19. This picture is very misleading because of the short postoperative time interval.

Stanley summarized his findings on the effects of instrumentation in cavity preparation as follows:

1. Techniques employing speeds of 50,000 r.p.m. and over, both belt-driven or turbine principle, cutting with No. 36 diamond stones and No. 35 carbide burs were less traumatic than 6,000 and 20,000 r.p.m. techniques using conventional ball-bearing handpiece and No. 37 diamond stones and No. 35 carbide burs.
2. The value of coolants becomes more significant at the higher speeds.
3. Intermittent grinding is of no appreciable benefit in the absence of adequate coolants.
4. Preparation time at the higher speeds is of little consequence provided frictional heat is controlled by adequate coolants.
5. The combination of high speed, controlled temperature, and light load is conducive to minimal pulpal pathology.

SLIDE 28. Minimal reparative dentin formation (150,000 r.p.m., 123-day postoperative period, X100).

A possible disadvantage to the "high-speed" techniques is the fact that the initial trauma is sufficiently mild that the incidence of reparative dentin is low and the lag period for its formation is prolonged in many cases. Whereas at "low speed" the initial trauma is adequate to produce an adequate amount of reparative dentin by 4 to 5 weeks, here is an example of only the slightest amount of reparative dentin having been produced after 4 months. This suggests that any toxic substances in restorative materials might pass without obstruction through the open tubules and irritate the pulp tissue for a much longer period of time. Consequently, cavity liners are of even greater importance in the "high-speed" era than they formerly were.

SLIDE 29. Pulpal response to amalgam condensation.

Compare SLIDE 29 with SLIDE 16 (150,000 r.p.m. with water spray, X100). SLIDE 16 illustrates a typical pulpal response to a "high-speed" preparation. SLIDE 29 (150,000 r.p.m., 1-day postoperative period, X100) demonstrates how the condensation of amalgam has intensified the pulpal response to such a degree that it resembles the more traumatic "low-speed" responses (compare with SLIDE 14). The mere pressure of amalgam condensation on open dentinal tubules not joined or lined by reparative dentin can intensify the pulpal response. This would not occur except where virgin tubules were involved.

SLIDES 30 and 31. Comparison of response to ZnOE and gutta-percha following "high-speed" procedures.

Compare SLIDES 30 and 31. SLIDE 30 (remaining dentin thickness 0.65 mm., X100) represents the pulpal response to cavity preparation at 300,000 r.p.m. followed by filling with ZnOE. SLIDE 31 (remaining dentin thickness 1.13 mm., X100) reveals the much greater response following the insertion of gutta-percha, despite the fact that the remaining dentin thickness is almost twice as great as in the ZnOE specimen.

SLIDE 32. Eosinophilic staining (150,000 r.p.m., X100).

Eosinophilic staining represents a very mild response, so mild that the stage of leukocytic infiltration is not reached. Considerable confusion has arisen in the literature because certain publications have indicated that with the use of "high-speed" instruments this response represents an extensive transmission of energy into the pulp, which could be potentially harmful to these tissues. However, this characteristic was described long before the advent of "high speed" and represents merely the transudation of plasma, one of the early phases of the inflammatory process.

SLIDE 33. Eosinophilic staining - Masson stain (150,000 r.p.m., X35).

Some investigators have considered this characteristic to be due to collagen deposition, a form of repair. However, this special stain demonstrates no collagen (which would stain blue with the Masson stain if it were present in this lesion). At some later date collagen might be deposited here before reparative dentin formed.

SLIDE 34. Cellular displacement (X450).

A high-power example of cellular displacement to demonstrate the peculiar characteristics of this phenomenon. Note the absence of odontoblasts where the odontoblastic layer should be and the presence of long, thread-like basophilic structures within the dentinal tubules. This phenomenon can be produced artificially by increasing the intrapulpal pressure, by decreasing the surrounding atmospheric pressure, by desiccation, by burning, and by impingement of forceps. However, the present example is believed to have resulted merely from the development of an inflammatory response adjacent to the odontoblastic layer. A buildup in intrapulpal pressure at this point causes the odontoblasts to travel the path of least resistance, which is into the adjacent tubules.

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## CHAPTER 3

# ADVANCED SPEEDS IN CURRENT PRACTICE

In chapters 1 and 2 emphasis is on the physical factors associated with advanced speed instrumentation and the possibilities for abuse of vital dentin and pulp. This chapter will deal with the control of certain of the physical factors and with the adaptation of clinical procedures to make the best possible use of the modern instruments.

## A. Control of Physical Factors

### CONTROL OF THE HANDPIECE

Upon first using advanced speeds, some recently graduated dental officers complain of inadequate cutting of the burs and diamonds. Others complain of difficulty in controlling the rapid cutting. These may be valid objections, but they usually result from lack of experience with the instruments. Other features that may be annoying at first include (1) the constant need for a water coolant that may obscure direct or reflected vision, (2) the greatly diminished feel of tactile sense while the bur is working, (3) the need for direction vision, (4) the slightly larger head of the handpiece, and (5) the inaccessibility of some areas, especially the distal surface of upper molars.

No one disputes that advanced speed handpieces driving the cutting instruments are different. What is touched by the instrument is cut. The tooth does not resist, and only "feather touch" pressure is required to reduce tooth structure rapidly. The dentist must therefore always be alert to the increased possibility of inadvertent mechanical exposure of the pulp, overextension, undermining of cusps, and excessive reduction of tooth structure. Untrained or careless dentists increase the cases of pulpitis requiring endodontic therapy and increase their own vulnerability to malpractice actions. Safety depends upon the skill and knowledge of the dentist! The newly graduated dental officer or the occasional practitioner making the transition to advanced speeds must acquire new skills, reeducate mind and hands, and undergo a period of practice. A new exactness of technique and trained vision are essential.

Accidents are sometimes spoken of as unfortunate events descended from a long line of unheeded advice. A regimen of preliminary laboratory practice is recommended prior to intraoral operation to lessen the possibility of embarrassing accidents. A quadrant of freshly extracted teeth mounted in a block of gypsum stone provides an acceptable working model. For easy disposal of the water irrigant, the model can be placed on a screen over the cuspidor, or a mechanical evacuator can be employed.

The learner should attempt to develop the "feather touch" that comes from using just an ounce or two of force. Speed and cutting effectiveness are not prerequisites at this time. A change in the cutting technique—a new "feel"—must be developed. The bur or stone must move constantly over the tooth surface to accomplish bulk removal. The best results are obtained by a to-and-fro, drag-or-pull movement of the handpiece rather than a pushing movement. Some describe the action as "brush-like"—a series of intermittent applications. A pressing force of 9 to 11 ounces will stall the air turbines. Attempts should be made to have water always ahead of the cutting instrument and to open the cavity preparation as early as possible to permit the coolant spray to contact the dentin. Tilting the head of the handpiece at an angle of 45 degrees to the occlusal plane of the tooth allows not only greater cutting action but increased coolant action. Cavity depth is developed gradually by reducing minute layers of tooth structure as opposed to the old "plunge or sink to optimum depth" approach.

The use of a No. 35 or No. 557 carbide bur in an attempt to make an entry equal in diameter to the given bur size provides an interesting practice exercise. The learner soon discovers that it is impossible to cut as small a hole at advanced speed (over 100,000 r.p.m.) as at low speed. The cut with the No. 35 bur at advanced speed will approach in size the cut of the No. 37 at low speed; and the cut of the No. 557 will approach in size the cut of the No. 559. This emphasizes the need for new thinking in cavity outline preparation, and it demonstrates that at advanced speeds instruments of small diameter should be used for all parts of cavity preparation. Smaller instruments such as the No. 1/4 round, the No. 699 tapered fissure crosscut, and the No. 170 tapered fissure noncrosscut carbide burs have been developed to produce more conservative preparations.

Ingraham[1] stated that "it is imperative that the approach change from the old concept of cutting and then thinking to one of thinking first and then cutting." One must have a definite concept of outline form before activating the cutting instrument. Tissue removal is so rapid that one must stop short of his planned extension. Decision as to final outline cannot be made while the cutting operation proceeds.

In order to develop a new tactile sense of ounces of force, Kilpatrick[2] recommended operating on extracted teeth mounted on the platform of a postal letter scale. The scale pressure should never exceed 8 ounces (227 gms). Uncooked eggs held in the hand are also suggested. Cuts can be made on the shell without penetrating the underlying membrane (SLIDE 35).

The following exercise will demonstrate the positive control one can develop with the air turbines. After the occlusal outline is "roughed out" with a No. 699 or No. 170 carbide bur, the bur is directed apically (just inside the dentinoenamel junction) to begin a tentative proximal box on the mesial or distal surface of the tooth (SLIDE 36). When the bur is at the correct vertical depth, a mesiodistal movement will remove the contact area of the tooth without fragmentation. Control of the instrument can be so precise that this can be accomplished without touching the adjacent tooth. Burs at these speeds do not skip, jump, or crawl to another part of the tooth—nor to another tooth! From this exercise one learns the importance of a firm finger rest position allowing freedom of handpiece movement and previsualization of the cut before placement of the bur against tooth structure.

A quadrant of teeth mounted in apposition allows the learner to practice reducing the mesial and distal surfaces of teeth for a full crown preparation with pointed diamond stones without damage to adjacent surfaces. The proximal surfaces of the teeth can be painted or dyed prior to mounting. This allows the learner to note whether he has damaged the adjacent tooth with any inadvertent "phantom cuts." As the contact area is approached with the pencil-shaped diamond instrument, the contour of the adjacent tooth is followed. This results in a concave cut of the tooth being operated on that conforms to the external contour of the adjacent tooth. As the proper taper of the crown preparation is developed, the initial concave cut disappears.

The learner should train his hearing to detect variations in sound levels that indicate too heavy or too light pressure loads differing from the steady whine characteristic of optimum cutting efficiency. The removal of amalgam and of gold restorations should both be practiced because different pressures are needed.

Occlusal cavities in the lower right quadrant are recommended for the first trials within the mouth because visibility is generally best in that area. Several occlusal preparations should be done before proximal preparations are attempted. The proximal surfaces of adjacent teeth should be protected with matrix band material until the learner feels competent to control the handpiece. Many dentists use a binocular loupe when operating in critical areas.

Ingraham,[1] writing in 1957, concluded: "Dental operations cannot be performed with the same calculated precision as engineering procedures. The personal entities of the dentist and the patient are factors to be considered. We will not, at least in the immediate future, be operating by a table of 'feeds and speeds' as is suggested by some enthusiasts in the field. We still must rely primarily upon an acute 'tactile sense' to determine the required pressures and to maintain instrument control. The key to the successful employment of increased speeds and modern instruments is a constant and continual re-evaluation of their effectiveness in the hands of the dentist using them. Many will find that their needs will be best served by employing one of the intermediate ranges of speed, and others, with more experience, will find definite advantages in the higher speed ranges. . . ."

## CONTROL OF HEAT PRODUCTION

Progressive increases in speed have led to greater frictional heat, but speed per se is not the only factor in heat production. The size and sharpness of the cutting instruments, the amount of pressure on the instrument, the direction of the applied pressure, the continuity of the pressure, and the dryness or dampness of the operative site are all of concern.

The clinical experience of pain resulting from heat generation and the consideration of heat control were not introduced with the development of advanced speeds. With the advent of the burring engine in the late 19th century, came recognition of the need for controlling heat generated by the cutting instrument and causing pain. Many devices were used to reduce the amount of heat transmitted to the teeth. One of these consisted of a bottle filled with water and suspended above the level of the handpiece and a rubber tube that, by siphoning action, provided a constant flow of water on the instrument. Some dentists had their assistants supply water from a syringe or even a sponge, and as early as 1874 Barker[3] designed an appliance consisting of a small metal tube attached to the handpiece and connected to a reservoir of water by a rubber tube. When the tooth became heated or when the dentist directed him to do so, the patient activated the device with an elastic hand bulb. Interestingly, Barker dedicated the device to public use without restriction.

Jeserich,[4] in 1935, demonstrated that the use of air and water on rotating instruments reduced temperature rise appreciably. Henschel,[5] in 1941, advocated the use of a stream of water as a coolant to control pain and trauma during cavity preparation. He said that the use of water at 100° F. in a continuous fine stream delivered to the rotating instrument at the rate of 8 to 16 cc. per minute resulted in no pain in over half his patients during cavity preparation; and that those patients who required anesthetics received other benefits from the water stream. In 1944, Hyams[6] wrote of the analgesic properties of a stream of water at body temperature; and in 1946, Lieber[7] stated that a flow of water prevented pain in half the patients. Sherman,[8] in 1947, reported a "vapor spray" controlled by the patient; in the same year Lawton[9] reported a "water spray." Panzer,[10] in 1950, demonstrated that intermittent drilling, during operation with increased speeds, cannot be relied upon as an effective method of temperature control. Henschel[11] determined the lower tolerance limit of average vital dentin to be 85°F. and the upper limit to be 130° F. When this upper limit of 130° F. is compared with temperatures that burs and stones are capable of producing, the necessity for effective temperature control is obvious. For example, let us recall from the first chapter of this text that temperatures of 200° F. and over have been developed when the air turbines have been used with light pressures in conjunction with carbide burs. The generation of frictional heat sufficient to cause pain, burn dentin, and initiate histopathological changes in the pulp must be prevented.

Peyton,[12] in 1952, felt that the most effective coolant was the combination of air and water spray. Ingraham and Tanner,[13] Beebe,[14] Herzberg,[15] Tascher,[16] Doerr,[17] Stanley and Swerdlow,[18] and many others have reported favorably on the use of the air-water spray. There seems to be general agreement that the air-water spray when directed to the cutting head will keep the temperature rise within acceptable limits.

Recommendations as to the quantity of water to be used in the spray range from 6 to 30cc. per minute. A rate of 20 cc. per minute seems to be clinically acceptable. Although most authorities agree that water at the operative site should be isothermic (body temperature), Croft and Stanley[19] have shown that no detrimental response of pulpal tissue per se results from exceptionally chilled water coolant. If water is to be isothermic at the cutting site, its temperature at the reservoir should approximate 130° F. Otherwise, the air of the spray and the evacuator will chill the water to a degree that can cause pain and discomfort if no anesthetic has been used. Most direct water supplies, without the use of thermostats or heaters, will deliver water much colder than the lower limit of 85° F. mentioned by Henschel.[11] The use of nonisothermic water no doubt has accounted for much postoperative pain and some of the negative reports on the acceptance of the advanced speeds by patients operated on without local anesthetics.

Some extra precautions must be taken when coolants are used with the advanced rotational speeds. These speeds create a zone of centrifugal force about the cutting bur or stone that is difficult to penetrate with a slow, gentle stream of water. The air pressure of the air-water spray must drive the water through this zone. Although some deny that odor denotes damage to the tooth, cutting without moisture for just a few seconds will elicit an odor suggesting burned tooth structure. Water must precede the cutting head and always be in direct contact with it and with the tooth structure being cut. Having the shank of the cutting instrument tilted at a 45-degree angle to the surface being prepared on the initial cuts and using intermittent, short touches of the cutting head to the tooth structure will ensure cooling and irrigation of the operative area and the cutting or grinding tip. Deep initial cuts must be avoided to prevent rapid heat rise. Preparations are opened laterally rather than pulpally. Some operating regions do not permit adequate vision and preclude the use of advanced speeds and their attendant water irrigants. A mouth mirror dipped periodically in a detergent that reduces surface tension will afford reflected vision in many situations. The use of an airstream across the mirror also helps to keep the mirror clear. Care must be exercised that the irrigant is not deflected by the tongue, lip, cheek, finger, mirror, adjacent tooth, or evacuating tip. A spray arrangement that emits from several directions onto the operative area will help eliminate this concern.

### Washed Field Technique

Thompson[20] deserves great credit for having developed the "washed field" technique in dentistry. This technique utilizes the negative pressure airstream of a high-powered mechanical evacuator in all clinical areas of dentistry. It maintains gentle but powerful suction close to the operating field.

In describing the technique, Thompson[20] wrote, soon after its introduction: "Accompanying the air stream is a flow of isothermal water which is projected copiously onto the operative field. This water is entrained into the vacuum air stream, which draws it rapidly across the operative area. The irrigant pulls away with it tooth cuttings and other debris. These are taken into the vacuum air stream and disposed of in a filter system. A clean, clearly visible operative field is provided.

"The washed field technique offers new and extensive advantages to dentistry. It facilitates the use of high-speed instruments, maintains visibility during copious irrigation of the operative field, reduces operating time, improves the patient's well-being and introduces a new concept of cleanliness.

. . . . .

". . .Aspirators most commonly used in dentistry pull about 0.33 cubic feet of air a minute. . . .The new pump [mechanical evacuator] pulls 8 to 10 cubic feet of air a minute. . .. The significance of air movement is great in the new technic. The washed field air stream is able to pick up solid as well as liquid materials. Furthermore, this air movement obviates the need of occluding the suction tip with the liquid being removed. The liquid appears to be raised as in a vortex to be entrained into the air stream. A 10 mm. orifice will pull the liquid over an air space of 12mm. This means that liquids and solids are lifted from the mouth without need for the suction tip to touch the tissues being operated upon. Liquids in the mouth become part of the air stream, and disappear with it as a mist.

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"The entire vacuum force is constant and is immediately available. No build-up occurs after the tip is occluded. . . . Because of the gentleness of this new suction force, its 10 mm. orifice can be occluded on the oral mucosa or even the eyelid without significant trauma, and this in spite of the voluminous and fast air movement.

. . . . .

"Human tissues should be respected and maintained in their natural wet state. Use of the washed field technic results in increased patient comfort, not only during the operation but postoperatively. Soft tissues that are constantly irrigated with isothermal water during scaling, prophylaxis and surgery heal much faster with much less postoperative trauma and pain. The avoidance of dehydrating soft tissues during surgery has been stressed by Sumner L. Koch and Michael L. Mason. This important principle has been neglected somewhat in dentistry for want of some practical means of accomplishing such irrigation without obscuring the operating field and without flooding the patient's mouth with the irrigant. The washed field technic adheres to the Koch-Mason idea of avoiding dehydration during surgery by providing copious irrigation as the operation proceeds. Clinical results have been gratifying.

"It is reasonable to assume that avoiding desiccation of the harder tissues of the body is advantageous. Dentin and cementum are particularly sensitive to the air jet which not only suddenly cools the tooth but drives water from these hard tissues. Clinical evidence of the irritating results of desiccation is seen when alcohol is applied to dentin. Seldom is dental pain so sudden and severe as when air and dehydrating drugs rob the tooth dentin of its natural moisture. Despite this, cavity preparation has long been carried out with the rubber dam in place and repeated blasts of desiccating and dehydrating air applied to sensitive dentin. . . .

. . . . .

"The Journal of the American Dental Association has commented editorially on the infractions of proper consideration for tissues under local anesthetic. Too often heat, cold, desiccation and other abuses have been inflicted on tooth structure because the patient could not feel these abuses when the involved sensory nerve was blocked. When a stream of isothermal water is directed on the cutting surface of the bur or diamond, the advantages of a well administered anesthetic can be enjoyed with no fear of damage from heat and desiccation. . . .

. . . . .

"The negative pressure air stream functions most efficiently when the rubber dam is in place so that the irrigant and the debris are carried away effectively without flooding the patient's mouth. . . .

"One problem with the rubber dam has been the cleansing of the field after the dam has been placed, prior to seating restorations. The washed field technic solves this problem by flushing blood and other contaminants from the field. A forced flow of water washes away chips which compressed air will not blow away. When the dam is removed, the mouth is again flushed with warm water so that no blood or debris remains to disturb the patient.

. . . . .

"Pastes that surround the cutting diamond and bur and obscure the field can be washed away instantly with the copious irrigation possible with the washed field technic. Heretofore, water in cavity preparation was blown from the mouth or inadequately aspirated by the saliva ejector. The disposal problem dictated the use of small volumes of lubricant—10 to 20 cc. a minute. The new technic permits copious irrigation of 150 to 200 cc. a minute. These larger volumes of water wash the operative field clean of all debris, and have the added advantage of maintaining body temperature.

"Clinical evidence shows that caries can be differentiated much more accurately if a damp field can be seen alternately with a dry field during excavation of carious dentin.

. . . . .

"The amount of work that can be completed by a dentist is determined by his skill, his use of up-to-date equipment and methods, and by the organization of his technic to save time and motion. The washed field technic greatly reduces the cost of dental operations. It eliminates the washing, rinsing, expectorating and drying. It eliminates the pauses during cutting to allow the tooth structure to cool. Its copious lubrication permits the full use of high-speed handpieces. It facilitates the practice of time-saving 'quadrant dentistry' wherein multiple restorations are performed in one quadrant of the mouth at one time.

. . . . .

"Often precious metals used in dentistry fall into the cuspidor, over the clothing and uniform of patient and operator, or onto the floor. The instrument used in the washed field technic is equipped with a filter bag which collects these scraps for salvage.

. . . . .

"The average patient seated in the dental chair is usually concerned with four questions: (1) How little will this dentistry hurt? (2) How little will this dentistry cost? (3) How long will these restorations last? and (4) How soon can I get out of this dental chair? The washed field technic facilitates favorable responses to each of these questions.

. . . . .

"A patient is more relaxed when placed in a near prone position and not required to rise constantly to expectorate. In using the washed field technic, it is recommended that the patient's head be offered the additional comfort of a small pillow over the headrest. Often a cool towel over the eyes is further relaxing. . . . Exudates which accumulate in the back of the throat can be picked up quickly and frequently and carried away without having to touch the tissues of the troat.

. . . . .

"One of the great services of the washed field technic is elimination of offensive blowing of bacterial contaminants into the atmosphere breathed by patient and operator. It also prevents soiling of the patient's clothing during dental operations, and aids in keeping clean the gowns of the operator and assistant."

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Some clinicians still contend that air alone can be employed as a coolant; however, the majority of investigators feel that air desiccates tissues unduly and does not control temperature so effectively as an air-water spray or a water stream. Stanley and Swerdlow[18] wrote, in 1960; "Although some operators report no clinical evidence of pulpal damage when employing an air jet alone for a coolant, the fact that the teeth do not immediately manifest symptoms of disease is not necessarily a sign of good pulpal health. These teeth may develop difficulties several years later. Many teeth fortunately do recover owing to the fantastic recuperative powers of the pulp, but there is a limit to the abuse that any living tissue can withstand."

Water irrigants are of advantage for reasons other than to control heat. Among the most important are:

1. Preventing the cutting instruments from becoming clogged with tooth debris or old restorative materials, thus prolonging the efficiency and life of the instruments.
2. Acting as a lubricating medium for the cutting action and helping to cushion vibrations.
3. Keeping the operative site free of debris and thus more visible.
4. Maintaining tissues in their natural warm and moist state.
5. Reducing the need for anesthesia for a sizable percentage of patients.
6. Providing a psychological benefit for patients through the realization that heat and pain are being controlled. The patient does not detect the odor of cut tooth structure, which was so prevalent during the days of the low speeds.

## CONTROL OF AEROSOLS

Every user of the advanced speed handpieces that are equipped with water attachments has experienced having his face, glasses, and operating light splattered by water and debris. This is a potential health problem to the patient, the dentist, and the assistant. The microbial population of the oral cavity is one of the most dense and most varied in the human body and, with the splattering from the air and the water, an aerosol is created. Heavy bacterial counts have been reported in this aerosol.[21,22] Tracer organisms planted in the water supply have been recovered up to 6 feet from the air turbine handpiece, with the highest concentration being at 18 inches.[23] In one study, positive cultures of Mycobacterium tuberculosis were obtained from samples taken up to 4 feet in front of the patient with the air rotor in operation, the highest concentration of the organism being found 2 feet in front of the patient's mouth.[24] In addition to droplets of water, the aerosol contains tooth particles, chips of previous restorations, and droplets of oil lubricants. Any of these may be contaminated.

In one study in which the air-turbine handpiece was used with a water spray,[25] 60 to 65 percent of the particles contained in the aerosol were determined to be in the size range (5 microns or less) that is capable of penetrating the alveolar spaces of the lungs. Other studies[26,27] have yielded different percentages. That portion of the aerosol having the capacity to penetrate the alveolar spaces increases as the volume of water spray increases, according to Hausler and Madden,[25] and increases at least to a distance of 30 inches from the cut surface.[28] These investigators have stated:[28] "The quantities of bacteria-containing droplet nuclei rapidly decrease as the distance from the cutting surface of the tooth increases. The ratio of particles capable of penetrating the alveolar space, however, increases with distance."

There have been complaints from dentists of a greater tendency to upper respiratory infection since the advent of the air handpieces. Cases of rhinitis, bronchitis, asthma-like attacks, and allergic cold have been reported.[29, 30]

In a study by Pelleu,[27] the instruments of principal concern in the problem of cross-contamination were the air-turbine handpiece, the water syringe, and the air syringe. Practical means must be sought for the sterilization—not merely disinfection—of these and other instruments. (The use of hand instruments from sterilized packs or canisters fits into this concept.)

Potential pathogens that might be found in the mouth include those causing active pulmonary tuberculosis, pneumonitis, influenza, and infectious hepatitis. Since neither the dentist nor the patient may know the true state of the patient's health, protective measures should be taken with all patients. The patient should be asked to use an oral rinse before starting operative procedures. According to one study,[31] the use of a mouthwash can clear the mouth of approximately twice as much debris as does water alone and can reduce the number of bacteria in the mist by 76 percent. A professional oral prophylaxis should be routine for each new patient before restorative treatment. The rubber dam should be placed prior to any cutting procedures whenever possible and the isolated teeth and the rubber dam disinfected with hydrogen peroxide, alcohol, or germicidal detergent. The air pressure and the quantity of water to the handpiece should be kept to a minimum in keeping with good operating efficiency, generally 30 p.s.i. of air pressure and 20 cc. of water per minute for the average air-turbine handpiece.

To reduce the possibility of inhalation of oils, the minimum oil drip feed compatible with efficient running and maintenance should be used. Vegetable oils free of impurities should be used for lubrication. According to Kazantzis,[32] droplets of vegetable oil "are usually broken up and removed via the lymphatic system by phagocytes so that eventually no trace of oil is left." Kelln et al.[33] stated: "Animal and fish oils are known to cause marked fibrosis with a giant cell inflammatory response. Mineral oil has been known to be quite bland, causing an inert foreign body reaction in the lung."

Eyeglasses and a face mask are necessities when air turbines are being used. If the patient has, or has recently had, a communicable disease, the dentist and his assistant should wear, in addition to the eyeglasses and the face mask, a surgical headcap, gown, shoecovers, and rubber gloves in accordance with generally accepted aseptic procedure. The patient's face and body should be draped as completely as possible. After the dental operation is completed, all equipment up to 6 feet in front of the patient should be decontaminated.

The washed-field technique used with an efficient mechanical evacuating system is recommended to reduce the danger of cross-contamination and the inhalation of foreign bodies.

## CONTROL OF NOISE

Controversy still exists as to whether the noise levels of highspeed handpieces can affect the hearing acuity of the dentist and his assistant. Most investigators have concluded that the average practitioner runs no real risk in that his average exposure does not reach pathologic limits. However, until manufacturers can reduce the noise output to less questionable figures, a certain reservation seems to be in order, particularly for those dentists using such instruments consistently in a practice limited to operative dentistry and/or fixed partial denture prosthesis.

In 1961 the Dental Division, BUMED, promulgated the permissible exposure limits to air turbine handpieces as shown in the following table:[34]

| Daily time exposure (Minutes) | Decibel Level Permissible for Frequencies 1,200-2,400 and 4,800-9,600 c.p.s. |
|---|---|
| 480 | 85 |
| 240 | 88 |
| 150 | 90 |
| 50 | 95 |
| 15 | 100 |

It was also concluded that "repeated daily exposure of less than 150 minutes to the highspeed drill would be within the limits and should not constitute a hazard to hearing."

In 1965 a Working Group of the National Academy of Sciences—National Research Council Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) specified damage risk criteria for exposure to both steady-state and intermittent noise.[35] This was the same group whose earlier recommendations led to the Air Force damage risk criteria published in 1956,[36] which served for 10 years as the authoritative standard in most discussions of noise hazards. Their revised recommendations, in part, can be interpolated from their charts as follows:

| Decibel Level<br>(Full Octave Band 2,400-4,800 c.p.s.) | Maximum Duration<br>Continuous Exposure (Minutes) | Maximum Duration*<br>Interrupted Exposure (Minutes) |
|---|---|---|
| 85 | 220 | 480 |
| 90 | 46 | 480 |
| 95 | 11 | 480 |
| 100 | 9 | 480 |

---

*The duration of daily exposure consists of the sum of the durations of the noise bursts and the effective quiet, each burst not exceeding 2 minutes in duration. The lowest "on-fraction" given by CHABA is 0.2, which would presume a total of 96 minutes of noise during an 8-hour day. In fact, for noise of the 2,400 to 4,800 c.p.s. frequency, the CHABA chart shows that about 2 hours and 45 minutes of 100-db interrupted noise during an 8-hour day would be the maximum tolerable duration.

These recommendations for interrupted exposure pertain to short-burst-duration intermittent noise, with bursts of 2 minutes or less in duration. This exposure is much more typical of the dental operatory than is the continuous exposure assumed by other, earlier damage risk criteria and also given by additional CHABA charts.

However, whether even these newer criteria can be applied to the problem of turbine noise is conjectural. One question that must be resolved is that of the main frequencies of such noise. If the spectrum measured by the Navy at Brooklyn[34] is characteristic of turbine noise, then the 1965 CHABA recommendations[35] suggest that there is little hazard for average ears. With respect to nonaverage ears, however, that study points out that "the tolerable exposures given will be unsafe for a certain portion of a given population."[2]

If, on the other hand, the spectrum is characteristically like that found in some of the other studies, from 5,000 or 6,000 c.p.s. to 16,000 c.p.s., then there is currently not enough information to warrant any damage risk criteria for even average ears. The CHABA study[35] said, "As yet, there are very few data on the effects of sounds below 100 c.p.s. and above about 7,000 c.p.s. In the opinion of the Working Group there is at the present time insufficient evidence to warrant extrapolating the damage risk contours as a function of frequency beyond the frequencies mentioned."

A 1963 article on noise exposure from dental drills[37] recommended the dentist's "having a competent acoustician measure the sound pressure level produced by his drill during regular use, getting an objective estimate of his drill use time pattern, and checking his individual maximum safe level. . ."from damage risk criteria. Having obtained this data, however, the dentist still would not know whether his hearing might be permanently impaired, because the admittedly imprecise criteria are for the average person. It would seem more reasonable for the individual dentist to have his hearing checked and, if so advised by a hearing specialist, to take appropriate control measures.

Overall noise may be somewhat attenuated by modifying the operatory. Acoustic tile ceilings, and walls partially covered with the same material, together with heavy drapes, will help absorb some of the sound.

Earplugs should give from 30 to 35 decibels of protection.[39] In dentistry, earplugs that allow continuous hearing are needed. Contraindicated is a "sound valve" type of plug with the valve closing upon a sudden noise and opening again after the sound has passed. With the proper plugs, one can hear ordinary conversation quite well in spite of high noise levels.

For maximum protection and comfort, ear plugs should be carefully fitted after a thorough examination of the ears. A plug that is too small loses much of its value because even a slight leak greatly decreases the protection; one that is too large will be uncomfortable. Examination by a qualified physician is recommended, because disease or deformities of the external canal may prevent the proper fitting and use of plugs.[38] Also important is proper maintenance and replacement of the plugs. It is not well known that ear wax can be destructive. "The more destructive ear waxes may make some plugs, such as those made with natural rubber, useless within only a few hours. However, plugs made with new improved materials should last several months, even when used with the most destructive ear waxes."[39]

Turbine design can be an important factor in the amount of noise produced. Taylor et al.[40]

found ball-bearing turbines producing overall levels of 80 to 90 db at the practitioner's ear level compared with 70 db for an air-bearing turbine. Maintenance of the equipment is also important. From one ball-bearing turbine, they measured an atypical 100 db, which they attributed to worn bearings. Obviously then, maintaining the handpieces properly and promptly replacing worn bearings will help to minimize the noise hazard.

What is needed is further research on the entire problem of handpiece noise; for example, to follow up the British findings[40] to see whether the hearing losses impinged on speech levels as predicted, to extend that type of study to American dentists whose modes of practice may be different, and to establish better guidelines that can be used until noise levels are reduced by improved design of equipment.

## B. Clinical Application

### PROFESSIONAL ACCEPTANCE

Many reported studies have documented the acceptance of advanced speeds by the dental profession since their introduction. Early reports in particular emphasized reduced preparation time. The following examples are illustrative.

In a study at Fort Belvoir, Va.,[1] reported in 1954, a total of 2,000 cavities involving 3,000 surfaces were prepared by two teams of dentists of comparable skill. One team worked at "standard speed" (maximum of 4,500 r.p.m.) without water spray; the other, at "high speed" (up to 13,000 r.p.m.) with water spray. The "high speed" team saved 1 minute of preparation time per surface compared with the "standard speed" team.

Hartley,[2] in 1958, reported a study comparing the clinical effectiveness of "high-speed" (12,000 to 16,000 r.p.m.), "superspeed" (80,000 to 120,000 r.p.m.), and ultrasonic instruments with the "conventional low-speed" (4,500 to 6,000 r.p.m.) instruments. He evaluated cutting time, overall time of operation, vibrations transmitted to the skull during cutting, and patient response. His findings concerning cutting time and overall time of operation were as follows:

"Cutting time averaged 3.4 minutes for all intracoronal preparations by the low-speed handpiece. The average time for profound anesthesia, including administration, was 5 minutes; over-all time of operation, which included all procedures necessary for cavity preparation by rotational cutting at 4,500-6,000 r.p.m., was 11.7 minutes. The over-all time of operation for all extracoronal preparations was 34 minutes.

. . . . .

". . .Removal of tooth structure by high-speed cutting at 12,000 to 16,000 r.p.m. was more rapid than by the low-speed technique; average cutting time was 2.3 minutes. Over-all time of operation was reduced considerably, since an anesthetic was required in only 50 per cent of the preparations. Over-all intracoronal preparation time was 4.8 minutes. Over-all time of preparation of extracoronal restorations was 16.5 minutes. . . .

". . .Removal of tooth structure by the hydraulically driven handpiece at 45,000 r.p.m. reduced the average cutting time to 2.0 minutes. The over-all time of operation was reduced to 3.2 minutes (average), and the average-over-all time for extracoronal preparations was 12.3 minutes. Local anesthetic was not required.

. . . . .

"Cutting with the superspeed handpiece, rotating at 80,000 to 120,000 r.p.m., was slightly more effective than with the 45,000 r.p.m. handpiece. Cutting time average was 1.7 minutes for intracoronal preparations. Over-all time of operation was 2.9 minutes. A local anesthetic was not requested by any of the patients. Average over-all time of extracoronal preparations was 12.3 minutes. . ."

In 1959, Steen[3] reported on the time required to complete jacket and veneer crown preparations with "conventional" and water-turbine handpieces. With the "conventional" handpiece the average molar preparation required 30 minutes and the average anterior preparation, 25 minutes. With the water turbine the average molar preparation required 14 to 15 minutes and the average anterior preparation, 10 to 12 minutes.

The results of polls taken over a few years' span tell the story of the rapid acceptance of advanced speeds. For example, the Bureau of Economic Research and Statistics of the American Dental Association[4] reported on the speeds being used by nonsalaried dentists participating in the 1959 survey of dental practice in the United States. "Super speed" (100,000 r.p.m. and over) was "normally" used by 46 percent of the dentists of all ages participating and by 59 percent of those aged 30 to 39 years. A Fauchard Academy poll of December 1961[5] reported that most of the dentists who had advanced-speed equipment had purchased it during the preceding 4 years. A poll of 1935 through 1961 graduates of a midwestern dental school, published in 1965,[6] revealed that 88 percent of those reporting owned and "routinely" used "ultra-high-speed" (100,000 r.p.m. and over) equipment. ". . .Over 43 per cent reported extra air turbine handpieces; of these 23 per cent owned one extra handpiece while 14 per cent reported two or more . . . ./and/ as many as 20 per cent of the ultra-high speed owners had purchased a miniature head contra-angle. . . ." The returns also showed that the 88 percent of the dentists who owned "ultra-high-speed" equipment performed over 90 percent of their instrumentation for cavity preparation with the air turbine.

The fact is that, for the majority of dentists, the advanced speed instruments are now the conventional handpieces and the low-speed handpieces are the auxiliaries. For example, most of the graduates reporting in the 1965 poll[6] said that they still used "conventional speed" (10,000 r.p.m. and under) handpieces for laboratory work and prophylaxis but that the use of these handpieces in preparing cavities "is almost entirely reserved for finish of the cavity walls, post holes and retention placement." However, the type of handpiece and cutting instrument used for each procedure should depend on the judgment and skill of the individual dentist and on what is best for the individual patient.

## ACCEPTANCE BY PATIENTS

Acceptance of advanced speeds by patients has also been enthusiastic. For example, a 1962 Pierre Fauchard Academy poll of dentists using the advanced speeds[7] showed that 98 percent had received favorable comments from their patients. The most favorable aspects listed were shortened operating time and reduced vibration pain, pressure, and heat. The unfavorable aspects mentioned were high-pitched sound, odor of overheated tooth structure, and spraying of water.

## ADVANTAGES

The advantages of the advanced speeds are summarized:

1. They contribute greatly toward the achievement of the ideals of modern dentistry.
    a. Nervous apprehension of patients prior to the dental appointment and postoperative fatigue are reduced. Difficult and emotional patients can now tolerate procedures that were previously refused. This increase in patient comfort permits greater acceptance of procedures by small children.
    b. The ease of cutting sound tooth structure, e.g., in extending cavity margins into cleansable areas, greatly facilitates the accomplishment of clinically acceptable cavity preparations. The time saved in gross cavity preparation can be used to advantage for cavity refinement and for placement and finishing of the restoration.
    c. More treatment can be provided for more patients in a given period of time.
    d. Patients can tolerate longer appointments; therefore, acceptance of crown and bridge procedures has increased.
    e. The need for water irrigants has resulted in increased use of the rubber dam, which contributes to better dentistry.
    f. The elimination of the engine arm, belt, and pulley and the shift to a below-the-eye-level approach to the patient's mouth with the handpiece are of great psychological benefit.

2. Advanced speeds reduce the energy required to perform a given procedure.
    a. Less hand force is required. The light finger pressure and ease of manipulation changes cavity preparation from an arduous task to a more satisfying experience.
    b. The efficiency of carbide burs and diamond stones is increased and prolonged.
    c. Vibration is minimal and the dentist, therefore, is permitted to operate with greater ease and efficiency because the patient is more relaxed.
    d. Water, used as an irrigant, reduces heat trauma.

3. The dentist's control of the cutting instruments is improved.

a. Burs, stones, and disks do not grab, bind, and run around the tooth or lacerate the gingival tissues as sometimes occurred at the low speeds.

b. The number of cutting instruments needed to perform a given procedure is decreased.

c. Smaller cutting instruments can be used, permitting conservation of tooth structure and precise cavity preparation.

4. Minor operative procedures are simplified.

a. Occlusal adjustments in the natural dentition, on gold restorations, and on dentures are accomplished in less time.

b. The oral surgeon can section a difficult tooth with ease.

c. The endodontist can quickly gain access into an acutely infected pulp.

d. Old restorations can be removed in a fraction of the time formerly required.

5. The advanced speeds have made care and maintenance of the equipment a necessity.

a. The precision workmanship of the handpieces requires constant vigilance to ensure proper lubrication, fit of the chucking device, opening of the water-air jets, and quantity, temperature, and angle of emission of water.

b. The advantage of this added attention results in smoother and longer performance of the instruments and long-range economy.

### DISADVANTAGES

The disadvantages of the advanced speeds are summarized:

1. The dentist first using advanced speeds must reorient his mental processes and tactile sense.
2. A water irrigant must be used.
3. More work must be done by direct vision.
4. The high pitch of the air turbines is annoying to some dentists and to some patients; and the sound, because of its intensity, may possibly be detrimental to dentists' hearing.
5. If the physical factors are not controlled, there is greater potential for abuse of the hard and soft dental tissues.
6. Protective measures against aerosol contamination must be taken.

All the above disadvantages, however, are within the individual control of the average dental practitioner.

## CAVITY PREPARATION

The graduate dentist is aware of the fundamental concepts of sound cavity preparation. Moreover, it is assumed that he is a practitioner who gives attention to all the intricacies and details of cavity preparation that mean the difference between success and failure in a restoration. The basic requirements of cavity preparation have not changed with the development of advanced speeds. Procedures for satisfying the basic requirements, however, have been altered as well as greatly facilitated, so words of caution are appropriate in several areas. Modifications of technique and instrumentation that take advantage of the advanced speeds are the subject of the following discussion.

### AMALGAM RESTORATIONS

#### Class I

Most occlusal cavity preparations can be accomplished with a single carbide bur such as the No. 170 tapered fissure noncrosscut. With advanced-speed handpieces there is no need to open with an inverted cone bur and then extend the outline form with a fissure crosscut bur. It is not necessary, or desirable, that an inverted cone bur or a thin diamond wheel be used. It is impossible to envelop these instruments with water spray. To conserve sound tooth structure, one should select the smallest effective instrument. It is distressing to see and to read of the wide use of the No. 557 straight fissure crosscut bur for opening and extending cavity preparations. At today's speeds, the No. 557 removes tooth structure that needs to be preserved.

The small, tapering burs can be used at the angle necessary to form the desired undercut, tapering, or parallel walls. The cutting instrument is positioned in a groove of the tooth at an angle that will provide maximum initial contact of the blades or diamond particles with the tooth surface to be opened. This is usually an angle approximating 45 degrees to the occlusal plane, which allows the maximum amount of water irrigant to precede the cutting instrument and thereby permits rapid initial penetration without heat generation.

The cutting operation is one of light, intermittent touches allowing the cutting instrument to do the work without pressure. The preparation is widened as quickly as possible to allow water to enter the cavity and to increase visibility.

When the cutting instrument has penetrated to the desired occlusal depth, the shaft of the cutting instrument is moved into a vertical position, in an arclike motion, so that the shaft is parallel to the long axis of the crown of the tooth.

As extensions are made into the developmental grooves, and into those supplemental grooves that may need extension, only the sides of the instrument are used for cutting. The direction of cutting is lateral from the original penetration rather than toward the pulpal chamber.

The ideal depth of the pulpal floor is 1 to 1.5 mm. below the average depth of the main occlusal fissure or, said another way, 1 mm. pulpal to the dentino-enamel junction. This depth is adequate for all restorative materials and fulfills the requirements for both resistance and retention forms. The faciolingual width should be most conservative ( SLIDE 37). The occlusal margins should not be in direct contact with opposing cusps in occlusal contact. The lateral walls are smoothed with a No. 600 steel finishing bur at low speed.

In small bicuspids and occlusal pits of molars, the No. 1/2 round carbide bur is the instrument of choice for opening to conserve sound tooth structure. Conservation of tooth structure during the development of the class I preparation facilitates a finer class II preparation in the future if the tooth becomes carious on a proximal surface.

Class II

The same instrument, No. 170 or No. 171, used for the occlusal preparation is used to prepare the proximal box of compound preparations. The marginal ridge over the proximal carious lesion is thinned to expose the dentino-enamel junction. The cutting head is positioned at the dentino-enamel junction so that it works approximately one half in the dentin and one half in the enamel as it is moved facially and lingually. These burs cut the facial, lingual, and axial walls so deftly that the proximal (mesial or distal) enamel of the contact area will either remain intact or gradually flick off in pieces as the bur works gingivally. This approach utilizes the enamel to keep the bur cutting within the tooth and prevent scarring the proximal surface of the adjacent tooth.

The proximal box is prepared with an arclike faciolingual movement of the cutting instrument. The shaft of the bur is righted slightly as the cavosurface margin is approached. The proximal box takes the form of an inverted truncated cone; i.e., the facial and lingual walls converge slightly toward the occlusal surface. The width of the occlusal isthmus need not equal more than one fourth the width between the facial and lingual cusp tips (SLIDE 38). The side of the bur head, not the end, is employed to do the proximogingival cutting. The cutting operation is intermittent, with care being taken to ensure that the box preparation is well flooded with water irrigant. The lateral extensions made by the burs into areas that the patient can easily clean are stopped short of the previsualized, proximal cavosurface margins.

If the shaft of the bur is kept in a faciolingual plane parallel to the long axis of the tooth, there is little chance of nicking the adjacent tooth with the cutting blades or of burnishing it with the rapidly rotating shaft. However, the adjacent teeth may be protected with metal band material until greater skill is acquired. The ideal mesiodistal width of the gingival wall is 1 mm. Once sound dentin is reached in the area of the lesion, bur cutting should stop. Stains from caries or previously used medicaments should not be cut away if the tooth surface is solid. The objective is to involve only those dentinal tubules that must be cut to remove the disease and to provide resistance and retention for the restorative material.

The facial and lingual walls that were stopped short of their previsualized mark are extended and finished with sharp hand chisels or hoes. Minimal occlusal preparation and extension of the facial and lingual margins to areas where the toothbrush can keep them clean are essential to maintain the original strength of the tooth following the insertion of amalgam restorations. Excessive reduction of tooth structure, whether by caries or by injudicious use of cutting instruments, renders a tooth liable to cusp fracture and pulp death, and often results in masticatory malfunction. In figure 15a, Brass[8] shows how little tooth structure unites the facial and lingual portions of a tooth following an MOD cavity preparation. In figure 15b, he calls attention to the length of the fulcrum in relation to the remaining portion of dentin and to how additional loss of dentin appreciably increases the possibility of fracture. In order to overcome the

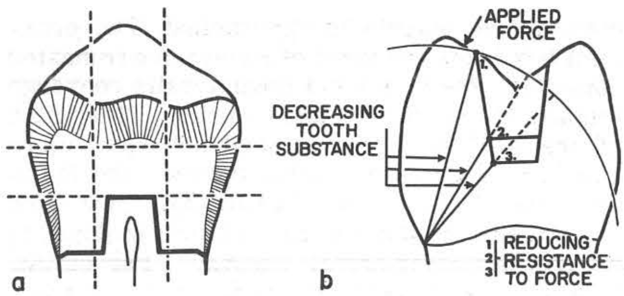

Figure 15.—"Sagittal views of MOD preparations. (a) Note how little tooth structure unites the buccal and lingual cusps. (b) Diminishing tooth substance increases the possibility of fracture." Copyright by the Canadian Dental Association. Reprinted by permission.

possibility of fracture of a tooth following intracoronal preparations, Brass recommends a cavity preparation in which the greatest portion of occlusal force would be directed to the gingival seat. He further believes that the gingival floor must resist rotation of the restoration by being "distinctly flat" and by having "squared angles."

No cut should be attempted with the advanced speeds unless the area is easily accessible and plainly visible. Visibility is sometimes hindered because of gingival hemorrhage, either spontaneous (resulting from a pathological condition) or mechanical (caused by laceration of the papillae by the bur). Visual obscurity may be prevented by the use of the rubber dam wherever possible and by the placement of a well-fitted soft-pine gingival wedge into the interproximal space over the dam. The bur cuts both the tooth structure and the wooden wedge as the gingival wall is developed (SLIDE 39). The wedge retracts and protects the papillae, and also prevents entanglement of the bur in the dam.

Class V

Most of the outline and convenience forms for the average class V cavity may be prepared with a No. 2 round or No. 34 inverted cone carbide bur. The instrument of choice is planed gradually and cautiously to obtain the desired shallow depth. This allows water to be underneath the cutting head at all times. The floor of the cavity is formed to approximate the contour of the original external surface; and the outline is formed short of the final cavosurface margins. The bur shaft is directed perpendicularly to the enamel surface. Final extensions, smoothing of margins, and the placement of retentive features should be done with low-speed instrumentation and hand instruments.

Gingival cavities on the lingual surfaces of lower molars, because of their inaccessibility and because of possible displacement of the handpiece by the tongue, do not lend themselves to advanced-speed preparation unless the dental dam with the clamp appropriate for the tooth being operated on is used to retract the tongue and isolate the area (SLIDE 40).

## CAST GOLD INLAYS

Because thin amalgam restorations exhibit little resistance to fracture, this material cannot always be used for restoring teeth, especially if a defect is in a stress-bearing area. In such instances cutting instruments operating at advanced speeds can quickly and effectively reduce the cusps to allow construction of a cast gold restoration. Since margins must always extend beyond functional areas of the cusps and since chamfers are desirable, preparation of such teeth to receive cast gold inlays often involves removal of considerable amounts of tooth structure.

The same basic cutting instrumentation can be utilized for cast gold inlay preparations as for silver amalgam. The difference in technique is primarily confined to the angle at which the cutting and finishing instruments must be used to permit withdrawal of the impression or wax pattern.

Close attention must be given to the final finishing of the inlay preparation walls to remove irregularities created by the carbide burs and diamond instruments. The use of very fine diamond finishing instruments, stones, and cuttlefish disks for finishing procedures will facilitate obtaining smooth dies, wax patterns, and finished castings.

The gingival margin taper (chamfer), so difficult to perfect with hand instruments, is developed and finished best with a flame-shaped stone. This type of finishing diamond stone is available with a shank 3 mm. longer than regular stones, which allows better access to this all-important area.

The diamond instruments designed for use with the air turbines are excellent for reducing cusps and placing accessory bevels (SLIDE 41).

Brass[8] has pointed out that although the natural position of maxillary teeth buccal and labial to the mandibular teeth somewhat diminishes the show of gold, the placement of inlay margins should be properly planned to provide maximum esthetics. Brass states emphatically that the inclined planes of the lingual cusps of maxillary teeth and the facial cusps of mandibular teeth are functional and must be protected by inlay margins extending beyond these functional areas (fig. 16). He emphasizes that inlays must have sufficient bulk to resist deformation under stress and recommends a chamfer that "helps to ensure the integrity of the finished margins. . . ."

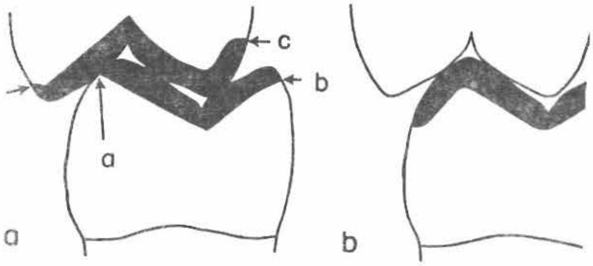

Figure 16.—"Part a. Cusp protection and replacement of cuspal surfaces. Margins must not terminate in an area of active function [a]. This plain straight line finish disregards enamel rod direction [b]. This chamfer margin is beyond the area of active function, produces a distinct terminal line, and is consistent with enamel rod direction [c]. This margin reflects minimal extension for aesthetic purposes and is consistent with the direction of enamel rod endings [d]. Part b. Both the buccal and the lingual inclines of the buccal cusps of lower posterior teeth are involved in masticatory function. Preparations should be extended onto the buccal incline of the buccal cusps and should include all of any wear facets present." Copyright by the Canadian Dental Association. Reprinted by permission.

## COMPLETE COVERAGE

Advanced speeds have facilitated tooth preparation for complete veneer crowns more than than any other restorative procedure. Gross reduction, shoulder development, and chamfer finishing can be accomplished in a fraction of the former time, with minimal fatigue to both patient and dentist. Full-mouth reconstruction has become a special branch of restorative dentistry. Some practitioners of complete rehabilitation rely almost exclusively upon complete crowns as the abutment retainers for their prostheses. This practice is looked upon with considerable question by other leaders of restorative dentistry. An editorial in the Journal of the Canadian Dental Association, May 1964,[9] pointed out that because of the ease with which tooth reduction can be accomplished with advanced-speed instruments, some dentists are indiscriminately restoring teeth with large castings instead of conservative amalgam or inlay preparations. It was emphasized that such arbitrary procedures may mutilate occlusal relationships and lead to periodontal and other problems. The editorial went on to say: "This practice is dangerous for the patient, for the dentist and for the profession as a whole. It is time to reassess high-speed cutting devices for what they really are: valuable when used with care and sound judgement; dangerous when they are indiscriminately abused. Dentists will have to display greater acumen if they are to reap the full benefits of these devices."

A complete crown preparation removes all the natural contours of the tooth. These are difficult for the trained dentist to reestablish. To impose this requirement upon the unsupervised laboratory technician is illogical. The complete crown invades the gingival crevice all the way around the tooth. Superb skill is required to prevent gingival inflammatory responses. Potential pulpal responses are maximal with complete crown preparations simply because so many more dentinal tubules are severed.

Langeland and Langeland[10] studied the histological response to complete crown procedures on 138 human teeth. They divided the teeth into four groups each presenting a major step in crown procedure. Their observations are quoted.*

"Group 1 [Full crown preparation, 36 teeth].—Crown preparations, made with an adequate air/water spray, showed no inital reaction

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*From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129-143, 1965, The C. V. Mosby Company, St. Louis.

[fig. 17a]. If, however, the air/water spray was deficient, the sections showed burned dentin on the surface of the preparation [fig. 17b] and odontoblastic nuclei and/or erythrocytes in the pulpal ends of the cut dentinal tubules [fig. 17 c and d]. The reaction was not exclusively influenced by the rotational speed of the engine, but by the diameter and shape of the rotating instrument, the relationship of the spray jet to the instrument/tooth contact area, and the air pressure at which the spray was operated. A large wheel or disk or, particularly, a grinding surface not facing the spray would deflect the spray, thus preventing it from lubricating the instrument tooth contact area. If for any of these reasons the spray was deflected, the dentin surface was burned and odontoblastic nuclei alone, or together with erytheocyles, were observed in the pulpal ends of those dentinal tubules having burns on their peripheral surfaces.

"Group 2 [Full-crown impression, 54 teeth].—Based on the results of the crown preparations (Group 1), it was possible to select teeth which had or had not been subjected to an injurious tooth reduction procedure. Impressions made with Dietrich's and elastic materials showed no reaction or a slight reaction if the teeth had not been subjected to injurious tissue reduction [fig. 18a and b]. Impressions of similarly prepared teeth, made with heated Kerr's stick compound, showed evidence of heat, or desiccation injury; large numbers of odontoblast nuclei and erythrocytes migrated into the dentin [fig. 18c]. This reaction may occur as a result of desiccation, without evidence of burns. In 7 teeth subjected to an inadequate spray during enamel and dentin reduction, odontoblast nuclei and occasional erythrocytes were observed in the dentin after impression making with Dietrich's and the elastic materials. Since these materials caused no reaction in teeth adequately cooled and lubricated during the crown preparation, it is likely that the reaction observed was caused by the thermogenic preparation and not by the impression materials. Impressions made with stick compound showed an increased number of cells or cell remnants present in the dentinal tubules. Teeth subjected to injurious crown preparation techniques were further injured by the heated stick compound.

"Group 3 [Temporary crown, 38 teeth].—This part of the investigation was concerned

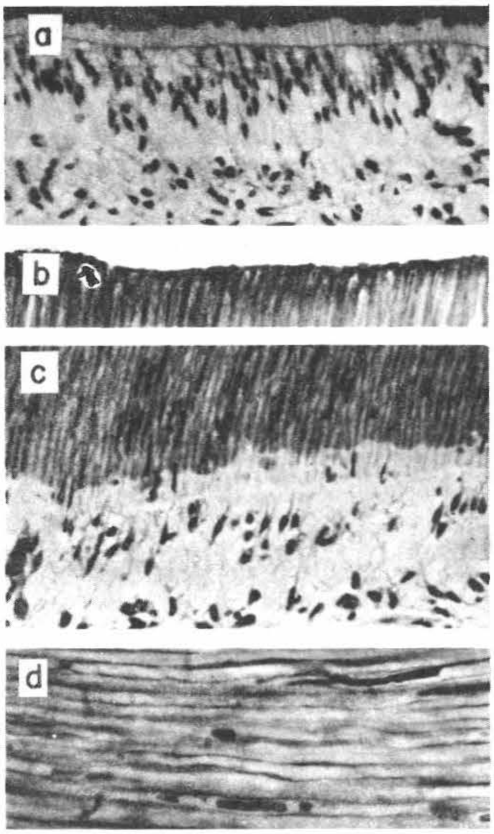

Figure 17.—"[a]. A section of the pulp of a tooth prepared with. . .[an air rotor] at approximately 100,000 r.p.m. with air/water spray. The specimen was taken immediately after the preparation. The shortest distance to the pulp along the dentinal tubules was 1.5 mm. There was no reaction. (b). "A section of dentin reduced with. . .[an] air rotor at approximately 160,000 r.p.m. with air/water spray. The tooth was extracted immediately after preparation. The distance to the pulp was 1.7 mm. The cut surface of the dentin was burned. (c). "Pulpal areas of the same section as in (b). There were odontoblast nuclei in the pulpal end of the cut dentinal tubules. (d). Another section from the same tooth as in (b). There were erythrocytes and odontoblast nuclei in the pulpal ends of the cut dentinal tubules." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

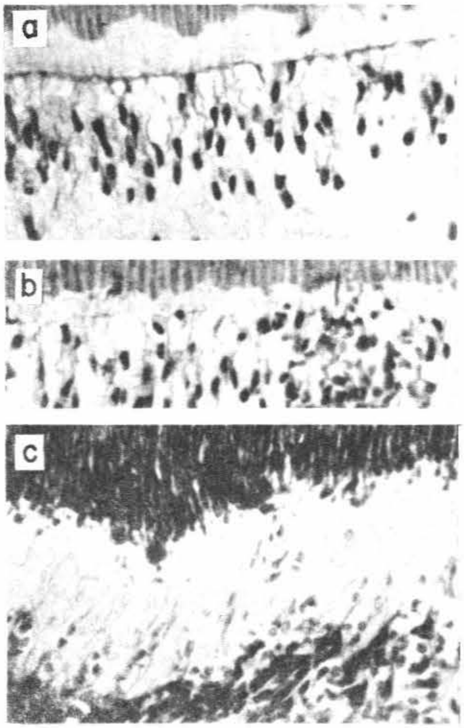

Figure 18.—"(a). A section of the pulp of a tooth prepared with. . .[an air rotor] at approximately 50,000 r.p.m. with air/water spray. The specimen was taken immediately after preparation. The distance to the pulp was 1.3 mm. There was no reaction. (b). A section of the pulp of a tooth prepared as in (a). An impression was made with. . .[an elastic impression] material, after which the tooth was immediately extracted. There were a few odontoblastic nuclei and erythrocytes in the dentinal tubules, interpreted as showing practically no reaction. (c). A section of the pulp of a tooth prepared with a belt driven engine at approximately 10,000 r.p.m. with air/water spray. An impression was made with. . .green stick compound. The tooth was extracted immediately after the impression was made. The distance to the pulp was 1.2 mm. Numerous erythrocytes had migrated into the pulpal end of the cut dentinal tubules in spite of a thick layer of irritation dentin." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

with the effect of temporary coverage of teeth prepared for crowns and subjected to impression making. The results depended on the previous procedures. If the crown preparation was injurious and the impression making innocuous, a pulp reaction was still observed, even if a nonirritating thick mix of zinc oxide and eugenol was used for the temporary crown. Observations made in the first days showed neutrophilic and occasional eosinophilic leukocytes in the odontoblast area of dentin which had been heat-injured or desiccated during tooth reduction. Specimens taken at later periods showed fewer migrated cells in the dentin, chronic pulpitis, and irritation dentin [fig. 19a, b, and c]. However, if the preparation was not injurious, the impression made with Dietrich's or elastic material, and a preformed acrylic resin crown was cemented with a mix of zinc oxide and eugenol, the pulp showed no reaction. The histologic picture was the same as [figure 17a].

"In another group of teeth subjected to noninjurious crown preparation and noninjurious impression materials, the temporary crowns were made of self-curing resin. The resin was in contact with the prepared tooth only until the initial polymerization. The fully polymerized crown was cemented with a mix of zinc oxide and eugenol. The teeth reacted strongly to the resin [fig. 20a, b, and c]. A similar result occurred when gutta-percha was used as a temporary coverage material [fig. 21a, b, and c] or if the tooth was left unprotected. If more than one harmful procedure had been applied to the tooth, the effects were cumulative [fig. 22a, b, and c].

"Group 4 [Cementation, 10 teeth].—The effect of cementation with zinc-phosphate cement depended upon the previous experiences of the abutment. If the earlier procedures caused injury, the end result was a chronic pulpitis [fig. 23a, b, and c]. The pulp reaction increased in severity with each injurious step in the procedure. On the other hand, permanent cementation with zinc-phosphate cement caused no pulp injury if the preceding procedures were not injurious and if the tooth surface was gently dried without the use of desiccating agents [fig. 23d]."

Most dentists prefer diamond instruments for the bulk of complete crown preparations. A small wheel stone is used for gross reduction (SLIDE 42), a slender pencil-shaped tapered cylinder for reduction of contact areas

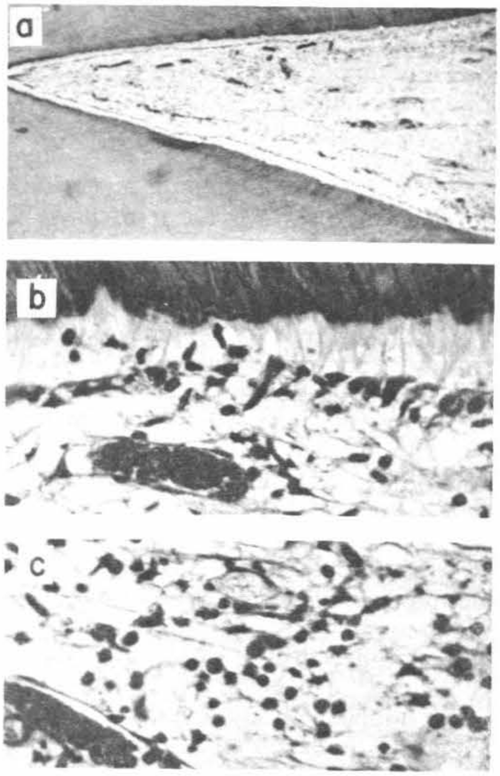

Figure 19.—"(a). A section of a tooth prepared with. . .[an air rotor] at approximately 50,000 r.p.m. with air/water spray. A 12 mm. diameter grind-wheel was used. An impression was made with. . .[thermoplastic] impression material and a temporary crown was cemented with a mix of zinc oxide and eugenol. The observation period was 30 days and the distance to the pulp was 2 mm. A broad layer of irregular irritation dentin had formed and was bordered by a reduced odontoblast layer. There was an accumulation of inflammatory cells in the subjacent pulp horn. (b). High magnification of the irregular irritation dentin and reduced odontoblast from (a). (c). High magnification from the pulp horn in (a). There were lymphocytes and macrophages in the pulp tissue." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

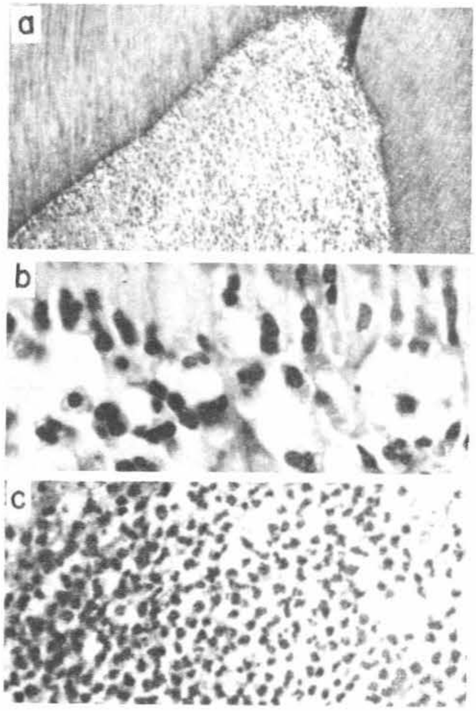

Figure 20.—"(a). A section of the pulp of a tooth prepared with. . . . [an air rotor] at 50,000 r.p.m. with air/water spray. An impression was made with. . .[thermoplastic] impression material. A temporary crown was made of. . .self-curing plastic material. . .directly on the abutment and left on the tooth for a sufficient time for setting, removed and cemented with a mix of zinc oxide and eugenol for 2 days, after which the tooth was extracted. The distance to the pulp was 1.8 mm. Odontoblast nuclei were observed in the cut dentinal tubules and there was an accumulation of inflammatory cells in the pulp horn. (b). High magnification of the same section as in (a). Odontoblast nuclei and erythrocytes appeared in the cut dentinal tubules. There were neutrophilic leukocytes in the predentin and in the adjacent odontoblast layer. (c). High magnification of the same section as in (a). Neutrophilic leukocytes had accumulated in the pulp horn resulting in a severe acute inflammatory reaction." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

(SLIDE 43), a rounded-end tapered cylinder for facial and lingual reduction and establishment

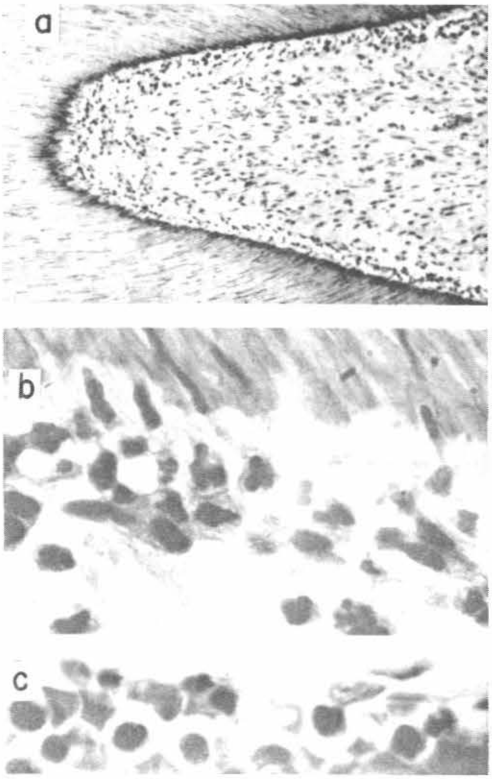

Figure 21.—"(a). A section of the pulp of a tooth prepared with. . .[an air rotor] at 50,000 r.p.m. with air/water spray. An impression was made with. . . [thermoplastic] impression material. The abutment was covered with a gutta-percha temporary crown for 2 days after which the tooth was extracted. The distance to the pulp was 2 mm. There were numerous odontoblastic nuclei in the pulpal end of the cut dentinal tubules and an accumulation of inflammatory cells in the odontoblastic layer. (b). High magnification from the section shown in (a). The accumulation of neutrophilic leukocytes in the odontoblast layer in the region in which odontoblast nuclei appear in the cut tubules indicate deterioration of these odontoblasts. (c). High magnification of the same section as in (a). There is a significant increase in number of leukocytes in the vessels in the pulpal horn, indicating an acute inflammatory reaction." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

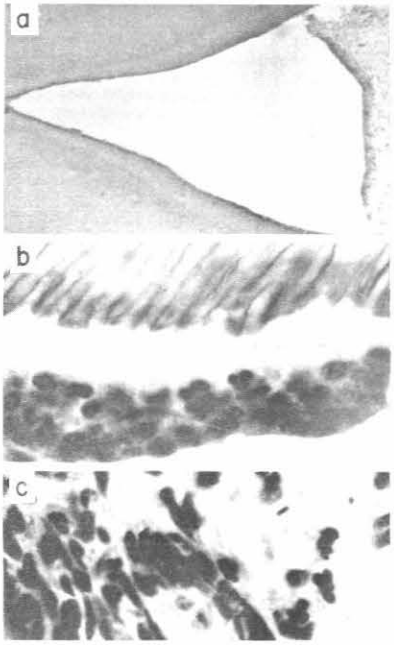

Figure 22.—"(a). A section of the dentin and pulp of a tooth prepared with. . .[an] air rotor with air/water spray; the impression was made with. . .green stick compound; a pre-made temporary plastic crown was cemented with a mix of zinc oxide and eugenol and left for 2 days, after which the tooth was extracted. The distance to the pulp was 1.2 mm. There was a large empty space in the pulpal horn, part of which is due to an artefact as a result of the histologic procedures. (b). High magnification of the same section as in (a). There was an accumulation of neutrophilic leukocytes along the predentin in the area in which the pulpal horn seemed empty in (a). "(c). High magnification of the same section as in (a). Numerous neutrophilic leukocytes had accumulated in the tissue bordering the empty space. This indicated that the empty space is partly accounted for by liquefaction caused by enzymes released from deteriorating neutrophilic leukocytes. This liquefied tissue was washed out during the histologic processing." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

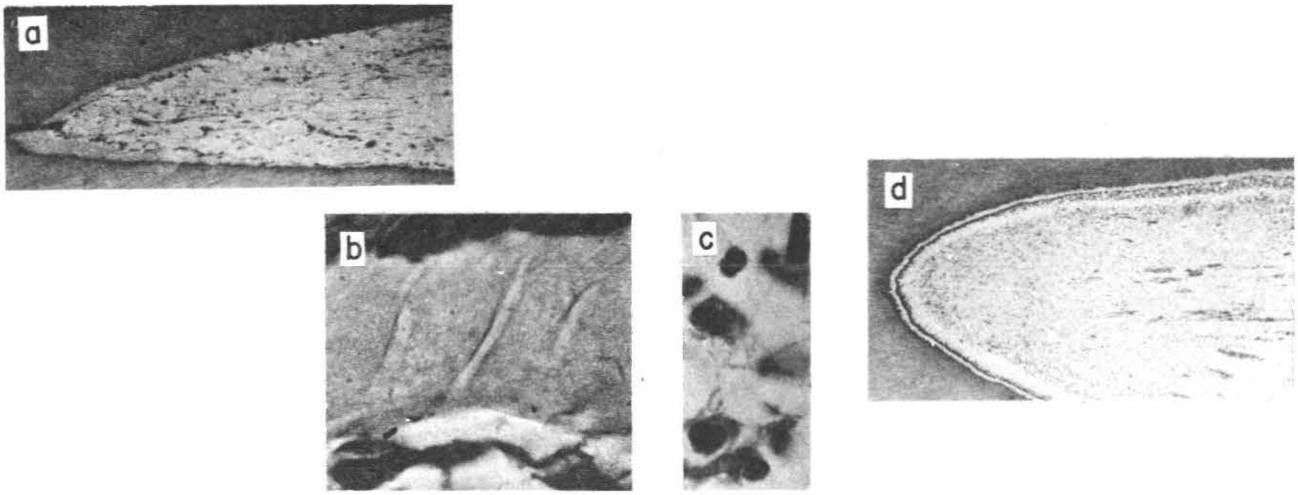

Figure 23.—"A section of dentin and pulp of a tooth prepared with. . .[an] air rotor with air/water spray; an impression was made with. . .[thermoplastic] impression material; a temporary crown was made with. . .self-curing plastic material as in fig. [20] and cemented with a mix of zinc oxide and eugenol for 7 days, the temporary crown was then removed and the permanent crown was cemented with. . .oxyphosphate cement, carefully avoiding desiccation or medicaments. The crown was left in situ 63 days after which the tooth was extracted. The distance to the pulp was 1.6 mm. An irregular irritation dentin was bordered by a chain of remaining odontoblasts. (b). High magnification of the same section as in (a). Irritation dentin had formed; it was penetrated by irregularly running dentinal tubules and bordered by a chain of odontoblasts. (c). High magnification of the same section as in (a). Lymphocytes, plasma cells, and transition forms of inflammatory cells were observed in the subjacent pulp tissue. (d). A section of dentin and pulp of a tooth prepared with. . . [an air rotor] at approximately 50,000 r.p.m. with air/water spray. An impression was made with. . .[thermoplastic] impression material. A pre-made temporary crown was cemented with a mix of zinc oxide and eugenol. After 2 days the temporary crown was replaced by a permanent crown which was cemented with. . .oxyphosphate cement and left in situ for 94 days. The distance to the pulp was 1/8 mm. No alterations were observed in the dentin or subjacent pulp tissue." From Langeland and Langeland: The Journal of Prosthetic Dentistry 15:129, 1965, The C. V. Mosby Company, St. Louis.

of a chamfered gingival margin (SLIDE 44), and a flame-shaped stone for gingival finish or beveling of a shoulder (SLIDE 45).

Those preferring carbide burs use the No. 170 and 171 tapered fissure noncrosscut to reduce the enamel surfaces and to make shoulder outlines (SLIDE 46). An endcutting carbide (No. 900 series) is most effective in extending the shoulder below the gingival crest (SLIDE 47).

## MANAGEMENT OF THE PULP

All the known facts point up the need to protect the pulp following tooth preparation by sealing off the dentinal tubules from the toxic effects of medicaments and restorative materials and from the physical traumas of impression making, condensation, and cementation. The following discussion relates directly to possible postpreparation abuses to the tooth that tend to increase pulpal responses related to instrumentation during cavity preparation.

### Cavity Sterilization

G. V. Black,[11] in his text on operative dentistry, wrote that swabbing out a dry, freshly cut cavity "with alcohol or other substance for better cleaning, is useless and is liable to do harm by introducing something with the liquid that will not be easily removed." Many dentists today accept "toilet of the cavity" as a necessary step in cavity preparation, based on the assumption that it may do some good.

In contemplating the possibility of adding insult to injury, we must remember that there are 35,000 to 75,000 tubules per sq. mm. of dentin and that they average 1 micron in diameter at the dentino-enamel junction and widen to 4 micra at the pulpal end.[12] The size of the dentinal tubules allows the ingress of microorganisms and diffusion of liquids. Although the penetration of a germicide may be limited to the surface because of the coagulation of organic matter in the dentin, it is reasonable to assume that a germicide potent enough to kill bacteria may also kill living cells.

A review of the literature proves helpful in a consideration of the controversy over cavity sterilization and its clinical application. Perreault et al.[13] concluded that eugenol, thymol, eucalyptol, beechwood creosote, chloroform, acrylic monomer, hydrogen peroxide, and benzalkonium chloride produce little or no injury to the odontoblasts and pulp. Alcohol and sodium fluoride caused slight injury. Phenol caused severe injury to odontoblasts but did not penetrate into the pulp. Orthophosphoric acid and silver nitrate produced a destructive reaction of the pulp. The effects of the medicaments increased as the cavity preparation depth and time of application of the medicaments increased.

According to Seltzer's studies,[14-16] 90 percent of all cavity preparations showed the presence of microorganisms, and sterilizing agents apparently were ineffective. He also concluded that the presence of bacteria in dentin should not lead one to assume that decay is progressing but that microorganisms (latent because of lack of moisture) may later become activated by obtaining moisture through percolation of saliva between the restoration and the tooth structure or seepage of fluid from the pulp.

It is highly speculative that the preparation can be sealed and any attempted cavity sanitization maintained. Nelsen et al.[17] demonstrated the ingress and egress of liquids at the cavosurface margins due to the unequal coefficient of expansion between restorative materials and the tooth. Radioisotope and dye studies confirmed the phenomenon of marginal percolation.

Massler[18] reported the germicidal properties of zinc oxide and eugenol as well as its palliative effects.

Generally, the attempt to "sterilize" appears to be ineffectual, and most dentists are content to cleanse the cavity preparation with sterile water, physiological saline, or tap water. With this accomplished, our concern should be to find a liner adequate to seal the interface between the cut tooth and the restorative material.

## Cavity Liners

The ideal cavity liner would perform these functions:

1. Protect the pulp from thermal shock
2. Insulate against galvanic action
3. Inhibit penetration of discoloring mercury
4. Be palliative to the pulp
5. Sterilize dentin and residual decay
6. Neutralize the acid of cements
7. Prevent marginal leakage

Obviously, we do not as yet have a liner that fulfills all these requirements. Johnson and Wick[19] found that cavity varnishes and liners are penetrated quite easily by the phosphoric acid of silicate cements. In their studies, calcium hydroxide liners provided the greatest protection, plastic liners the next, gum-resin liners the next, and collodion liners the least. Berk[20] showed that the calcium hydroxide liners are very effective against the low pH of silicate cements. Barber and Massler[21] found the calcium hydroxide liners to be less effective in blocking isotopes and dyes under silicate restorations that the copal resin varnishes; however, the isotopes and dyes were prevented from penetrating dentin. Zinc oxide and eugenol was not found to be effective in preventing penetration around margins of silicates and into the dentin; zinc phosphate cement increased marginal penetration.

Barber et al.[22] found that "copal resin varnish was effective in preventing marginal penetration of ionic and molecular tracers around and under amalgam restorations." Their principal question was how long it would provide an effective seal. Going [23] confirmed that copal resin varnish is most effective under amalgam; and that a "poly-liner" and calcium hydroxide liner are also effective. He stated that zinc oxide and eugenol is a good thermal and galvanic insulator and an inhibitor of mercury but causes silicate cements to stain; and zinc phosphate is a good insulator but of no value as a liner. Going felt that calcium hydroxide or zinc oxide and eugenol covered with copal resin varnish comes closest to fulfilling the requirements of a liner. The membrane formed by varnish is not impermeable. Two to three applications should be made, with each allowed to dry before the subsequent thickness is placed. The varnish does reduce the increased permeability produced by phenol, zinc chloride, or orthophosphoric acid. Cavity liners protect the dentin from desiccation when air is used to dry the gingival crevice prior to placement of a restoration. Varnish left over the cavosurface margins of amalgam preparations improves the seal.[24]

Doerr[25] is of the opinion that in unlined deep amalgam preparations mercuric ions penetrate the nuclei of the odontoblasts and inhibit secondary dentin formation, accounting for sensitivity of teeth to heat and cold for months following restoration. He reasons that pulpal degeneration is due to heat and cold responses rather than to the amalgam per se, and recommends liners in all deep amalgam preparations. If there is a near or possible pulp exposure, Doerr recommends the regular pulp-capping technique; but if the cavity is "merely deep," he places zinc oxide and eugenol nearest the pulp, followed by cavity liner and then zinc phosphate cement sufficient to reduce the cavity extension into dentin to the limits of the "normal" preparation. Doerr discourages the practice of using only zinc oxide and eugenol because he thinks it does not provide sufficient compressive strength to withstand the pressures of condensation and to prevent pressure damage to the pulp. He explains that when both zinc oxide and eugenol and zinc phosphate cement are used, an intervening layer of cavity liner prevents orthophosphoric acid from injuring the pulp. He also points out that zinc phosphate cement should be placed under all silicate restorations because silicates contain free acid for quite long periods after placement. Doerr's procedure to help prevent inflammatory responses under silicate cement includes placing a base of zinc oxide and eugenol or calcium hydroxide, followed by zinc phosphate cement, and then the silicate cement. He says that liners containing calcium hydroxide alone are not sufficient.

Finn[26] indicated that "the dentin beneath the restoration based with calcium hydroxide has a physical increase in hardness of 20 to 30 percent in less than 4 months." This dense radiopaque zone is not observed to any great extent under other restorative materials and is considered to be protective to the pulp.

### Pulp Capping

An exposed vital pulp may possibly be saved by direct pulp capping provided it is not infected and provided it still retains the odontoblastic layer responsible for the deposition of secondary reparative dentin. According to Berk and Krakow,[27] slight mechanical penetration of the odontoblastic membrane does not contraindicate direct pulp capping provided the penetration is slight and the blood clots quickly. Mohammed et al.[28] have pointed out that since microscopic exposures cannot always be determined clinically it is wise to treat all deep preparations as possible exposures. Zinc phosphate cement as a direct pulp-capping agent is contraindicated; it causes severe pulpal necrosis. Zinc oxide and eugenol in apposition to the pulp produces a chronic inflammation that does not resolve, and no dentinoid bridge formation is observed. Calcium hydroxide is the least irritating material; with its use the odontoblasts undergo regeneration and there is deposition of reparative dentin.[29]

Berk and Krakow[27] have outlined a technique that protects an exposed pulp from chemical irritation from cement base and that stimulates the formation of secondary dentin. They dry the dentin and apply a coating of thin calcium hydroxide suspended in aqueous methyl cellulose, leaving a dry, thin white film. Next they cap the pulp with thicker calcium hydroxide in aqueous methyl cellulose which, when dry, will support the cement base that follows. They recommend placing the final restoration at the same sitting.

In the case of a near but not actual exposure of the pulp, indirect pulp capping may be employed. If a tooth with gross caries has no history of prolonged pain, if it responds to warm gutta-percha and an ice cone, and if it is not painful on pressure, its prognosis for indirect pulp capping is favorable. The soft, mushy diseased dentin is excavated until the dentin becomes leathery or tough. The dry, flaky dentin closest to the pulp is allowed to remain; i.e., an exposure is intentionally avoided.

Calcium hydroxide in a methyl cellulose paste is applied over the residual carious dentin. A base of accelerated zinc oxide and eugenol or zinc phosphate cement is used to cover the calcium hydroxide. The tooth is then restored with amalgam if feasible. Oftentimes it is good, expeditious practice to protect the pulpal agents with a mixture of cement and silver alloy. A copper band or aluminum crown can be used to contain the medicaments and restorative materials on badly broken-down teeth. Teeth so treated should be reexamined every 3 months; and complete excavation of all carious dentin and final restoration should not be started until vitality is confirmed, no periradicular pathology is evidenced roentgenographically, and a radiopaque bridging of secondary dentin is demonstrable. Six months is a clinically acceptable period of time to allow the pulp to recover and to perform its protective functions.

## FINISHING OF WALLS AND MARGINS

One feature of the advanced speeds that is looked upon with displeasure is that tungsten carbide burs and diamond instruments impart a rougher surface to the cut tooth structure than did steel burs at low speeds. As early as 1953, Street,[30] working with burs, disks, chisels, and diamonds at speeds up to 5,000 r.p.m., called attention to the effects of these cutting instruments on the enamel walls. He reported:

"The No. 558 crosscut fissure bur caused irregular notched areas which were not deep nor as wide as those made with the No. 702 tapered crosscut bur. The No. 58 plain fissure bur left only minute nicks, and the No. 600 plain tapered fissure bur produced similar results.

. . . . .

". . .The furrows of the tooth sections cut with the diamond-impregnated three-fourths inch disk were similar to but definitely wider than those made by the carborundum disk. The section cut with the cylindrical diamond instrument had more notched areas than the sections cut with the chisels.

"The microscope revealed many notched areas of various widths on the sections prepared with the Wedelstaedt and binangle chisels. Some of the surfaces appeared similar to those prepared with the rather rough-cutting stones."

Examination of the specimens made in this study failed to substantiate the emphasis placed on the use of chisels to obtain smooth or planed surfaces, as is generally taught to dental students. Street[30] noted that "the speed of rotation [from 300 r.p.m. to 5,000 r.p.m.] did not appreciably vary the appearance [of the enamel specimens].

"Little difference was noted in the fragmenting of enamel margins by the rotational direction of the stone. . . .

. . . . .

"The sandpaper disk produced the smoothest finished surface."

Peyton and Mortell[31] did a similar study in 1956 at speeds of 4,000 to 12,000 r.p.m. With the thin Carborundum disk there was no pronounced evidence of a different surface appearance when it was used at the different speeds or wet or dry. Carborundum stones were recommended for finishing surfaces cut with diamond disks. Diamond cylinders produced deeper scratches than the No. 558 fissure crosscut steel bur. The No. 58 straight fissure steel bur, at low speed, produced the smoothest and most uniform surface. The investigators reported that it resembled a surface accomplished with a planing instrument. Realizing that the skill of the individual dentist is an important factor when surfaces prepared with hand hatchets are compared, Peyton and Mortell reported that "in general the hand instruments do not seem to present a superior surface to that resulting from rotary instruments." Charbeneau and his coworkers[32] reported, in 1957: "The irregularity of the cut tooth surfaces resulting from the shaping of cavities would appear to have a twofold significance. First, these irregularities should have some effect on the adaptation of the specified filling material to the cavity walls, and second, they may tend to undermine or weaken groups of enamel rods at the cavo-surface margins, thus resulting in a failure of the tooth structure surrounding the restoration rather than a failure of the restoration itself.

. . . . .

". . .Theoretically, rough cavity walls will result in a distortion of the wax pattern or nonelastic impression material with the resulting inability to reseat the casting completely. The investment material itself imparts a roughness to the casting superimposed upon the irregularities from the cavity wall; this increases the possible discrepancy of fit, assuming a proper compensation was used in the casting procedure. Preliminary investigations by the use of actual castings made from cavities, whose walls varied in the degree of surface irregularity, support these viewpoints. . . . the roughness produced by the investment is very closely spaced, similar to that of the abrasive stones or plain fissure bur, while the roughness produced by many other rotating instruments is much more widely spaced.

"The average diameter of an enamel rod is generally considered to be 4 microns or 160 MU''. [1 MU'' is 1 microinch, or one-millionth of an inch.] Since the use of the diamond instruments results in roughness of about 2,000 MU'', it is apparent, theoretically, that 12 or 13 rods may lose their own support, or the support of the underlying dentin. At 8-ounce pressure with a 701 carbide, some 10 rods may become unsupported. This loss of normal support of enamel rods results in weakening of the cavo-surface margin with the tendency toward fracture. This type of failure of a restored tooth is frequently observed clinically and may be due either to a gross undermining of the enamel or the more subtle weakening by the instrumentation irregularities described."

Charbeneau and his coworkers[32] compared the profile characteristics of tooth surfaces cut with various rotating instruments. Their conclusions were as follows:

"1. The carborundum disk produced the smoothest disked surface, with a roughness of approximately 60 MU''.

"2. Cylindrical diamond points produced surfaces with the maximum roughness heights ranging from 800 to 2,000 MU''. Diamond point size and force exerted upon it appear to act independently in the roughness produced.

"3. The 701 steel and carbide burs produce similar roughness values of about 400 MU'' with a 2-ounce force. Increasing the force to 8 ounces increases roughness slightly with the steel bur and triples the roughness produced by the carbide.

"4. The 600 steel tapered finishing bur produces a relatively smooth surface of about 75 MU''.

"5. The white finishing stone results in roughness of about 40 MU'' or one half that produced by the green stone.

"6. Light force results in 1.5 times greater penetration of the cutting blades into the enamel than in dentin for both steel and carbide tapered cross-cut fissure burs. The small tapered diamond appears to cause little difference in penetration.

"7. Increased cutting speeds from 18,000 r.p.m. to 170,000 r.p.m. with comparable diamond and carbide instruments resulted in no detectable difference in surface roughness with a 2-ounce force."

Vale,[33] working at 250,000 r.p.m., showed with his photographs that the tungsten-carbide fissure crosscut bur produces irregular and stepped surfaces within the cavity and at the margins; the diamond point produces a considerably better surface; and the plain fissure bur produces a relatively smooth surface (SLIDE 45). He found a radical difference in the cutting patterns between advanced and low speeds. Probably at low speed, with the greater operating pressure of the bur on the surface of the tooth, its cutting edges are all successively contacting the tooth structure. Successive contact of the cutting blades tends to obliterate surface irregularities. At 250,000 r.p.m., the bur does not appear to rotate on a simple axis but tends to follow a conical pattern of movement with the base of the cone being described by the tip of the cutting head. With the very light pressure, succeeding cutting edges are not actually brought to bear on the tooth, and thus irregularities are developed and remain.

Norman,[34] working with an air-bearing handpiece, observed that the bur ran "true" without the conical pattern described by Vale[33] with the ball-bearing air-turbine handpiece.

Cantwell et al.[35] reinforced the belief that ". . . enamel walls of a cavity preparation should be as smooth as possible in order to minimize the presence of unsupported enamel rods, which are likely to fracture and leave a marginal discrepancy between the restoration and the tooth structure. An irregular and rough cavo-surface angle may contain impregnated debris, which would also detract from optimum marginal integrity.

"A plane fissure bur, in most instances, produced a smoother surface than a cross-cut fissure bur.

"A smoother surface resulted when any given instrument was used at a lower speed."

Operating the air-turbine handpiece at 200,000 r.p.m. with water spray, Scott and O'Neill[36] prepared plane surfaces in the crowns of extracted teeth with commonly used carbide burs and cylindrical diamond stones, examined the surfaces by high-power optical microscopy, and then photographed them. O'Neill's findings were as follows: "Under the present conditions the smoothest surface was produced by the smooth fissure burs [fig. 24]. The surfaces produced by the crosscut fissure burs were quite similar except that typical wide troughs were produced by the serrated cutting edges. A much rougher finish was obtained with the diamond point [fig. 25], both from the standpoint of number and depth of the tool marks. It was observed that the basic texture between tool marks in all cases was less smooth in the enamel than in the dentin. Enamel prism outlines were never seen and dentinal tubules were observed only in a few areas. At the optical level, however, it was difficult to establish how much histological structure might have gone unrecognized because of interfering tool-mark patterns."

## QUADRANT DENTISTRY

The advanced speeds are a tremendous boon to the practice of quadrant dentistry. The technique of performing a series of preparations in one sitting is equally advantageous for amalgam restorations, indirect inlays, cast gold splinting, and fixed partial denture prostheses. With one injection of anesthetic, one placement of the rubber dam, a sequential procedure with cutting instruments, and a single basing procedure, a number of preparations can be made in a fraction of the time it would take to do them individually. Nonproductive changing of patients is minimized.

The patient's time is respected. It is poor treatment planning for the patient to have to make nine visits to obtain an equal number of restorations. Four or five appointments are usually sufficient to complete amalgam restorations in the posterior teeth of all four quadrants. Operating on alternate teeth, e. g., the first bicuspids and first molars at one sitting and the second bicuspids and second molars at a subsequent sitting, prevents the loss of anatomical landmarks such as marginal ridge heights and contact area positions. The comfort to the patient from the employment of modern instruments makes multiple services readily tolerable. Seldom is premedication or postmedication needed.

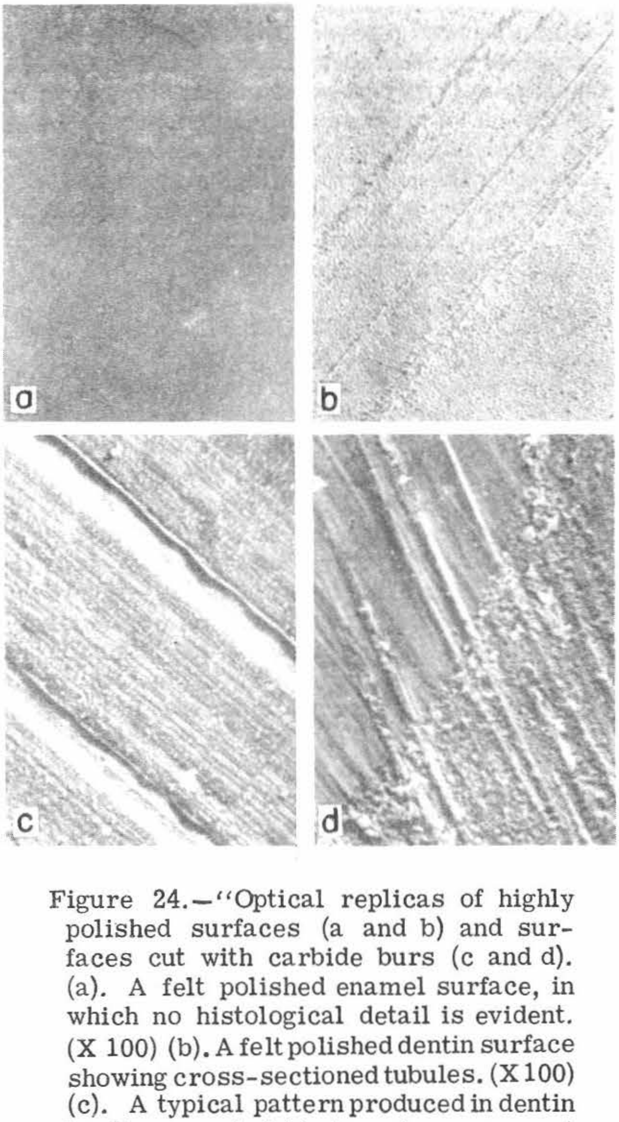

Figure 24.—"Optical replicas of highly polished surfaces (a and b) and surfaces cut with carbide burs (c and d). (a). A felt polished enamel surface, in which no histological detail is evident. (X 100) (b). A felt polished dentin surface showing cross-sectioned tubules. (X 100) (c). A typical pattern produced in dentin by the serrated blades of a cross-cut fissure bur (No. 557). The broad bands actually represent the depressed tracks left by the teeth in the cutting edge. (X 100) (d). A pattern produced by a smooth fissure bur (No. 57). This replica shows both the dentin and enamel at their junction and it is evident that the basic texture of the dentin is smoother. (X 100)" From Scott and O'Neill: Adhesive Restorative Materials (Workshop) pp. 27-37, 1961, USPHS.

Occasionally, patients present a condition of rampant caries when the workload does not permit taking the time that is necessary to complete the restorations in one quadrant. With advanced speeds, the caries can be removed from the teeth in one quadrant, sedative insulating bases placed, and the cavities sealed with a mixture of zinc phosphate cement and amalgam alloy powder. This technique can save countless numbers of teeth that are in danger of being lost from bacterial invasion of the pulp. Permanent restorations can be inserted later as time permits.

## REMOVAL OF PREVIOUS RESTORATIONS

Previous restorations can be removed rapidly with present-day instruments. A No. 2 round carbide bur in the air-turbine handpiece is generally the instrument of choice for the removal of amalgam restorations. In the proximal box areas, it is often advantageous to use a small fissure carbide bur, such as the No. 699. Diamond instruments are contraindicated for removing amalgam because amalgam will clog the spaces between the diamond particles, and the cutting ability of the instrument is then lost. Gold inlays and crowns are easily sectioned with No. 2 round or No. 699 carbide burs. It is impractical to reserve burs purely for cutting different materials in that no marked change appears to occur after cutting any particular material.[37]

Extreme caution is required when old restorations are being removed. The velocity of the dislodged metal particles can be great. It is better to grind the restorations away by degrees, not leaving a central fragment, which at a certain point in the procedure is likely to fly off with great force. The mechanical evacuator tip should always be functioning near the operative area. Placement of the rubber dam, prior to any cutting, eliminates the possibility of the patient's swallowing or inhaling flying debris.

## CONCLUSION

The material presented in this course is designed to broaden the knowledge of dental officers of the U. S. Navy in the use of advanced-speed rotary cutting techniques. An effort has been made to present the subject in the light of historical as well as current clinical and laboratory investigations.

Great emphasis is placed on the biological aspects of advanced-speed cutting procedures. Evidence derived from research in this area points out the potentially detrimental effects of operative procedures upon the vital dentin and pulp. The widespread use of advanced-speed techniques must therefore increase attention to measures designed to protect vital teeth from irreversible pulpal damage. Failure to implement protective measures will negate the many useful and desirable aspects of modern

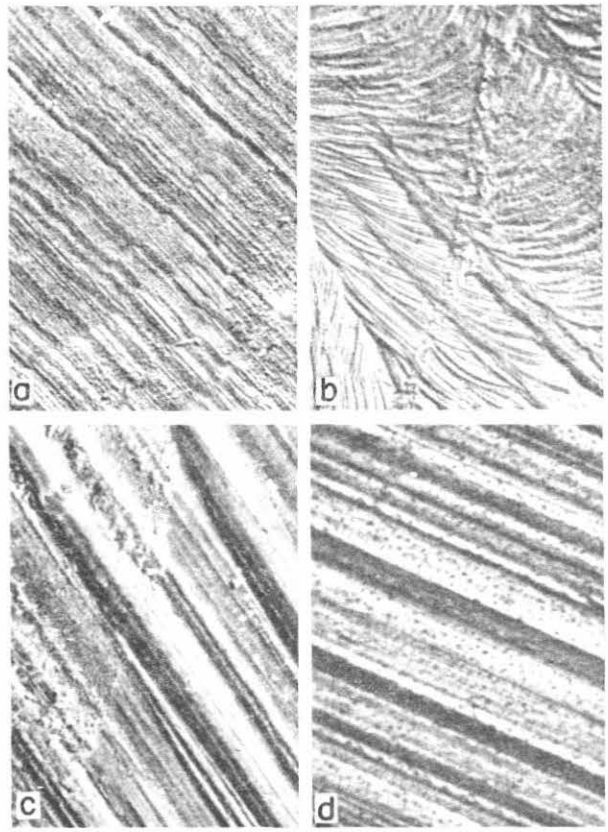

Figure 25.—"Optical micrographs of some configurations produced by a diamond stone. (a). A zone of parallel toolmarks. (X 100) (b). A region of overlapping circular marks. (X 100) (c). A region at the dentino-enamel junction, in which the basic enamel texture is rougher than that of the dentin. (X 200) (d). A rare instance in which dentinal tubules could be recognized. (X 500)" Scott, D. B. and O'Neill, J. R. Microstructures of enamel and dentin as related to cavity preparation. Adhesive Restorative Materials (Workshop) pp. 27-37, 1961. USPHS.

operative techniques. All steps of all procedures must be evaluated biologically.

Several clinical procedures involving advanced rotary speeds have been presented. It is suggested that other techniques that utilize these modern instruments will be developed, and the student is encouraged to attend continuing education courses and to study the many articles relating to these subjects appearing in current dental literature.

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