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NATIONAL BUREAU OF STANDARDS REPORT

3127

REPORT ON DENTAL RESEARCH
AT THE NATIONAL BUREAU OF STANDARDS

Progress Report

July 1 to December 31, 1953

Dental Research Laboratory

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, Secretary

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section is engaged in specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside of the back cover of this report.

Electricity. Resistance Measurements. Inductance and Capacitance. Electrical Instruments. Magnetic Measurements. Applied Electricity. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Gage.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenics. Engines and Lubrication. Engine Fuels. Cryogenic Engineering.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Measurements. Infrared Spectroscopy. Nuclear Physics. Radioactivity. X-Rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. Atomic Energy Commission Instruments Branch.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Aerodynamics. Engineering Mechanics. Hydraulics. Mass. Capacity, Density, and Fluid Meters.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure. Chemistry of Mineral Products.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Machine Development.

Electronics. Engineering Electronics. Electron Tubes. Electronic Computers. Electronic Instrumentation.

Radio Propagation. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Frequency Utilization Research. Tropospheric Propagation Research. High Frequency Standards. Microwave Standards.

Ordnance Development.
Electromechanical Ordnance.
Ordnance Electronics.
These three divisions are engaged in a broad program of research and development in advanced ordnance. Activities include basic and applied research, engineering, pilot production, field testing, and evaluation of a wide variety of ordnance matériel. Special skills and facilities of other NBS divisions also contribute to this program. The activity is sponsored by the Department of Defense.

Missile Development. Missile research and development: engineering, dynamics, intelligence, instrumentation, evaluation. Combustion in jet engines. These activities are sponsored by the Department of Defense.

- Office of Basic Instrumentation
- Office of Weights and Measures.

NATIONAL BUREAU OF STANDARDS REPORT

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NBS REPORT

3127

REPORT ON DENTAL RESEARCH
AT THE NATIONAL BUREAU OF STANDARDS

Progress Report

July 1 to December 31, 1953

Dental Research Laboratory

The dental research program at the National Bureau of Standards is carried on in cooperation with the Council on Dental Research of the American Dental Association, the Army Dental Corps, the Air Force Dental Service, the Navy Dental Corps, and the Veterans Administration.

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

REPORT ON DENTAL RESEARCH
AT THE NATIONAL BUREAU OF STANDARDS

1. INTRODUCTION

Investigations of a wide variety of dental materials and studies of natural tooth structures have been conducted in the Dental Research Laboratory at the National Bureau of Standards during the half year ending December 31, 1953. Summaries of results obtained on work now in progress are given below. In addition, copies of reports issued on completed phases of the investigations are included.

2. REPORTS ISSUED

NBS No. 2738	Crazing of Acrylic Resins
J.A.D.A. 47, 324	Hydraulic Turbine Contra-angle Handpiece
NBS No. 3085	Cutting Characteristics of Dental Burs as Shown by High-Speed Microphotography.

3. WORK IN PROGRESS

3.1 Structure of Human Tooth Enamel and Dentin

Investigation of the fluorescence of enamel and dentin when irradiated with ultra-violet light has been continued. During this period emphasis has been placed on the development of equipment for determining the characteristics of the fluorescence of materials. A depolarization fluorometer, which will be used in an attempt to obtain some idea of the molecular weight of the fluorescent material in tooth structures, has been constructed and is now being calibrated. Development of a decay fluorometer is still in the planning stage and the relative advantages of several methods of determining decay time of the order of 10^{-9} seconds are being studied.

3.2 Low Temperature Alloys

Studies of low temperature alloys of the dental amalgam type have included both investigation of experimental alloys containing various combinations of gallium, nickel, silver and indium and X-ray diffraction examinations of the phase changes which occur in the amalgam alloys now in use.

Alloys of gallium and nickel were made and the effects of particle size of the nickel powder of the alloy were determined. Best results have been obtained with nickel powder having a fineness of minus 325 mesh. Powders having a fineness of minus 200 plus 325 mesh result in alloys of low physical properties. When a flake nickel powder is used the alloy hardens too rapidly to be used. The data indicate that particle size will be useful in controlling the hardening time of the alloy.

The properties of the alloy improve with an increasing gallium content in the range of 20 to 40 atomic per cent gallium. Lower gallium contents result in an alloy that is too dry to handle and higher gallium-content alloys tend to harden as a result of the solidification of the excess gallium rather than through reaction between the alloy components.

Alloys of silver and indium were made and powdered. This in turn was mixed with gallium in several proportions. These alloys did not harden in storage at 37°C for 30 days.

Use of X-ray diffraction methods at low temperatures (-125°C) in the investigation of dental amalgam has provided data on the diffusion of mercury through amalgam, the effect of surface polishing and the effect of heating the amalgam. Surface polishing removed a tin-mercury phase revealing a surface rich in the Ag_2Hg_3 phase. Further polishing reduced this phase and revealed the presence of unattacked alloy remnants. Aging of dental amalgam at 65°C resulted in reduction in the Sn_7Hg phase and an increase in free mercury which disappeared on continued heating apparently as a result of volatilization. Heating at 100 to 105°C produced a decrease in both the Sn_7Hg and Ag_2Hg_3 phases and formation of the AgHg phase.

This X-ray diffraction technic has been shown to provide a method for following the fundamental phase changes in dental amalgams on which the physical properties depend.

3.3 Resins

The effects of various accelerators on the polymerization of methyl methacrylate, the relationships between transition temperature and water sorption, methods of determining monomer content, and the properties of dental resin repair materials, resin cements and resin posterior filling materials were investigated.

The study of the effect of amine accelerators in varying concentrations on the polymerization kinetics of methyl methacrylate polymers has been continued. Wide variations in the setting time were observed in studies of over 40 accelerators. In the presence of a large number of the amines, no noticeable change in the viscosity was observed even after a few days. Only a very few accelerators showed short setting times. The reactivity varied somewhat depending on the catalyst-accelerator ratio. Small differences were observed at accelerator concentrations of between one and two percent. The polymerization rate followed no simple overall kinetics. Most polymers formed were highly colored. Further studies will be made using amine mixtures and other catalysts in an effort to produce polymers with short setting times and improved color stability.

The second order transition temperatures (T_g) of methyl methacrylate polymer samples previously used in sorption measurements were determined refractometrically. Values of T_g varied from 55 to 93°C and were well within the temperature range in which an abrupt increase in water sorption takes place. In general, T_g values increased and water sorption decreased with increasing molecular weight. Reversal from this behavior, i.e. lower T_g values at higher molecular weights was always accompanied by increase in water sorption. These discrepancies are probably caused by large variations in molecular weight distribution.

Several methods of determining the monomer content of cured dental resins have been investigated. Infra-red examination of the sublimate collected from frozen polymer-benzene solutions indicates that methyl methacrylate monomer contents as low as 0.02% can be detected by means of an absorption band at 5.75μ. Mass spectrograph and ultra-violet absorption methods of detecting small amounts of monomer in benzene or other solvents were not sufficiently sensitive.

Data obtained on materials used for repairing dentures show that repairs made from self-curing materials had approximately 60% of the strength of the original resin, while repairs made from heat-curing resins had approximately 85% of the original strength. Dimensional changes were smaller when the self-curing materials were used.

Preliminary results in the investigation of the adhesive properties of dental resin cements and resin posterior-filling materials indicate that while the materials do adhere to dry extracted teeth, there is little or no adhesion to wet tooth structure.

3.4 Zinc Oxide-Eugenol Materials

The study of the mechanism of the zinc oxide-eugenol reaction was continued. Use of a zinc oxide of very small particle size (125-250A) greatly intensified the reaction. X-ray diffraction indicated the formation of a hitherto unreported crystalline material on setting which has a different lattice structure than that of zinc oxide or previously reported "zinc hydroxides."

Elementary analysis of purified samples of the zinc containing organic material obtained by chemical separation and checked for purity by X-ray diffraction and electron micrographs gave an empirical formula of C 59.6%, H 5.7%, Zn 17.1%. The molecular weight is presently being determined by boiling point elevation.

Infra-red absorption spectra suggest the formation of a chelate compound of the eugenolate type and substantiate chemical evidence that the propenyl group is unchanged in this setting reaction.

3.5 Chrome-Cobalt Alloys

A standard specimen 2 $\frac{1}{4}$ inches long and 0.09 inch in diameter with 12-24 threaded ends has been selected for tensile and hardness tests on dental chrome alloys. Wax patterns of these dimensions have been prepared and sent to Federal and manufacturers' laboratories for use in casting test specimens. Data obtained on these specimens will be utilized in the preparation of a specification for dental casting alloys.

3.6 Rotating Dental Cutting Instruments

High-speed motion pictures have been made of dental burs cutting enamel, dentin, glass, brass and various other substances. For the first time, it has been possible to show the actual cutting of individual bur blades and to demonstrate, for example, how an eccentric bur behaves in various media.

A conference was held on December 21, 1953, with research workers' and manufacturers' representatives at which time a discussion of bur test methods was carried on. As a result of this conference standardization of bur testing will be attempted, so that speeds of rotation, test materials, loads applied, etc. will be the same in all laboratories. It is believed that data obtained by the many workers in this field can be made more understandable and more valuable to all concerned, if more uniform test methods are employed.

A survey of the various sizes and types of dental rotating diamond abrasive instruments now in use has been made and a uniform nomenclature and decimal numbering system has been devised for these instruments. The system, based on six basic classifications which are further subdivided to designate variations in shape and position of abrasive, will do much to eliminate the confusion which now exists because of the wide variations of nomenclature and numbering used by different manufacturers.

3.7 X-ray Film Survey

To obtain information from the dental profession on the properties required in X-ray film, eighty-five questionnaires and penetrometers have been sent out to cooperating dentists. Approximately 80% of these have been completed and returned. All films are developed immediately upon their return and the work of measuring their density is now 65% completed. The returns to date indicate that there is a wide variation in the methods of exposure and processing of X-ray film by the profession.

3.8 Panographic X-ray Investigation

The development of methods and equipment for making X-rays of the entire dental arch on a single film was started. Literature describing previous panographic X-ray methods has been reviewed and the relative advantages of various approaches are being studied. A mechanical model is being constructed for use in investigating the various motions and relationships inherent in a device of the type under development. The data obtained will be used in the development of electronic equipment for automatically producing the motion required.

3.9 Electric Wax Spatula

A wax spatula was designed and developed to improve upon the traditional spatula used in the construction of waxed prosthetic appliances. The new electric spatula, heated automatically rather than manually by a gas flame is a practical time and labor saving device. Its components are: a 6 volt CT transformer, a rheostat, a switch, a heating element and interchangeable spatula blades.

3.10 Evaluation of Material

Materials evaluated for the cooperating Federal dental service and the American Dental Association by specification or special test methods included amalgam alloys, silicate cements, denture base materials, wrought gold wire alloys, zinc phosphate cements and inlay casting golds.

For the Director,

W. T. Sweeney

W. T. Sweeney, Chief
Dental Research Laboratory

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

0708-20-3824 August 14, 1953 2738

Progress Report

on

CRAZING OF ACRYLIC RESINS

by

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This work is a part of the Dental Research Program conducted at the National Bureau of Standards in cooperation with the American Dental Association, the Army Dental Corps, the Air Force Dental Service, the Navy Dental Corps and the Veterans Administration.

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

CRAZING OF ACRYLIC RESINS

Abstract

Crazing is a common phenomenon in acrylic dentures cured against tin-foil substitutes. In this investigation causes of crazing in denture resins and plastic teeth were studied. The results obtained show that the increased water sorption by straight chain methyl methacrylate resins at elevated temperatures is an important factor in crazing. Polymer specimens exposed to water during the processing become susceptible to crazing. Materials protected from water during the heating period do not craze readily. On the basis of the data obtained it is believed that during storage of the polymer specimens at room temperature, evaporation of excess water from the resin surfaces sets up strains which ultimately are released by crazing of the resin.

1. INTRODUCTION

Appearance of small surface cracks is often observed in dentures and plastic teeth. These cracks lower the esthetic qualities of the restorations and greatly reduce their strength. Crazing is the result of local stresses set up in the resin. When the stress exceeds that necessary to fracture the resin, crazing occurs. The object of this investigation was to determine the factors which produce crazing in dental acrylic resin and to explain the crazing mechanism.

Typical photographs of crazing in a denture and in plastic teeth are shown in Figures 1 and 2. It has been shown (references 1, 2 and others) that crazing in polymethyl methacrylate is caused either by application of external mechanical stresses or by the action of chemical agents (solvent crazing). The latter type of crazing may occur in the presence of residual monomer, solvents and oxygen or depolymerization products. These substances will produce local strains greater than the material can withstand. Often the simultaneous action of solvents and external stresses produces crazing. It is probable that the crazing of dentures results mainly from solvent action in combination with strains due to internal stresses in the resin.

2. METHODS AND RESULTS

Examination of dentures in service and of laboratory specimens showed that there was a wide variation in the amount of crazing occurring in denture bases and in plastic teeth made of the same brands of material. It was also observed that plastic teeth which did not craze on the application of a solvent before being placed on a denture were often craze susceptible after being subjected to the denture processing procedure. Since these observations indicated that the craze susceptibility of the resins was dependent upon variations in

the processing procedure the effects of several of these variations were investigated. Included were the effect of the type of investment or mold material used in processing the denture, the effect of water sorption during processing and the effect of the molecular weight of the resin.

The "standard" craze test selected for determining the craze susceptibility of the resins consisted of three cycles of alternately immersing the specimen in methyl methacrylate monomer for 5 seconds and then drying it in air. Specimens which were crazed by this standard procedure also crazed on the application of ethyl alcohol and many other solvents.

To determine the effect on crazing of stresses produced due to the differential thermal expansion between resin teeth and investing media, teeth were invested in a number of materials varying widely in thermal expansion and in strength. Teeth invested in dental stone, dental investment containing silica gel, Boilsoft investment and alginate impression material were held in a water bath at 100°C for one-half hour. After cooling, the teeth were subjected to the standard craze test and crazing was observed in all cases regardless of the type of investing material used. The uniformity of crazing observed after investment of the resins in materials varying so widely in physical properties strongly suggested that differences between the thermal expansion of the investing media and the resin were not major factors in crazing.

The results of experiments in which teeth were maintained at 100°C by techniques which prevented their coming in contact with water, indicated that water sorption was a major factor in the crazing of teeth. Teeth heated in air gave no craze pattern. Teeth invested in Acrawax C (melting point 137°C) and then suspended in a water bath at 100°C for 3 hours showed no craze marks on application of the craze test. Teeth heated in stone investment from which free water had been removed by drying in vacuum and heating to 110°C did not craze. Acrylic dentures polymerized at 71.1°C and 100°C against tin-foil-lined plaster molds did not craze, whereas those prepared against alginate tin-foil substitutes invariably blushed and showed extensive craze patterns. It has been reported [3,4] that water from the plaster or stone penetrates the resin when it is polymerized against alginate separating media, which are water permeable. Sweeney [3] showed that a loss in weight on drying of resin disks cured against alginate base material was 2.7% whereas tin-foil-lined specimens lost only 0.6%. This loss of water was accompanied by volume shrinkage. The effect of water sorption during processing was illustrated with sheets of resin 1.5 mm thick polymerized against alginate on one side and against tin foil on the other side. When these specimens were dried, the side polymerized against the alginate shrank more than the side cured against tin foil due to the greater loss of water, and the specimens warped.

Crazing was found to be more pronounced when specimens were allowed to dry for a few hours before being subjected to the crazing test. Furthermore, if an increased amount of water was introduced into the specimen during processing (for example by processing the resin in an autoclave), more severe crazing resulted.

In order to determine the effect of water temperature on crazing, Plexiglas sheets 0.04 cm thick were immersed in water for a few days and weighed. Positive craze test results were observed for samples stored at 100°C, 70°C, 50°C and 37°C. The results show that crazing occurs on exposure to water

above as well as below the second-order transition point, i.e. the temperature in the 55° to 75°C range at which a relatively abrupt change takes place in the mechanical, thermal, electrical and optical properties of the polymer. Specimens stored at 4°C did not craze. As can be observed from Figure 3 which shows the water sorption-temperature relationship, lack of crazing at 4°C cannot be attributed to difference in water sorption. Increase in craze resistance with decrease in temperature has also been observed by Maxwell and Rahm for polystyrene [5].

Measurements of the water sorption of polymethyl methacrylate disks (0.4 mm thick) which were molded in a Carver press at 140°± 5°C and 10,000 lb/in.^{2} from duPont HG4 (fine) molding powder were made at various temperatures. Samples were stored in water and weighed at various time intervals. Specimens kept below the second-order transition temperature, T_g, reached sorption equilibrium (attained constant weight) within less than 10 days. Water sorption below T_g was slightly temperature dependent and increased about 10% over the 4° to 70°C temperature range. (See Figure 3; in this figure water sorption at 100°C does not represent the equilibrium value. The disks still increased in weight after 200 days of water exposure.) On storage of purified straight chain polymethyl methacrylate* at 100°C, which is well above T_g, a continuous weight increase was observed even after 100 days (Figure 4). Depending on the viscosity molecular weight, water sorption values of the order of 2 to 10 times those found at room temperature were obtained.

Blushing (evidenced by the hazy appearance due to light scattering) occurred when a Plexiglas sheet which had been dipped into monomer was exposed to water-saturated air. The bleached or milky white portion extended to a very shallow depth as evidenced by the disappearance of blushing on removal of a thin surface layer. Examination under the microscope showed no distinct cracks at a magnification of 500.

When a blushed and crazed sample was heated slowly to 150°C, blushing and craze marks disappeared and did not return on cooling. Specimens annealed in this manner showed no crazing. Efforts to reduce craze patterns by drying samples at room temperature in a high vacuum were unsuccessful.

It was observed that crazing is affected by the molecular weight of the specimen. Five samples of different molecular weights (45,000 to 1,615,000) were given the test for crazing after being heated for one hour in water. The higher molecular weight material was more craze resistant than specimens of lower molecular weight.

A very slight increase in number average and viscosity average molecular weight was observed for samples polymerized with tin-foil substitutes as compared with those processed against tin foil. This difference was too small, however, to change crazing characteristics. These results show that crazing of dentures packed with tin-foil substitutes is not due to a lower molecular weight of the denture resin.

* The authors wish to thank W. F. Bartoe of the Rohm and Haas Co. for supplying the samples.

3. DISCUSSION

It is evident that a complete description of the mechanism of crazing is not possible from data available at this time. The observed effects, in the opinion of the authors, may be explained as follows.

During processing the denture base material is heated above the transition temperature. After the polymerization is complete and while the polymer is still above T_g the less rigid chains of the polymer remain uncoiled. The chain network is expanded as compared to its normal arrangement below the transition temperature. This allows the water molecules to permeate more easily between the polymer chains, and an increased quantity of water is absorbed. Greater water sorption above T_g may also be caused by a possible increase in hydrogen bonding due to the presence of small amounts of depolymerization and hydrolysis products, especially if the material is a copolymer of polyacrylic acid ester. On cooling below T_g, the resin becomes supersaturated with water. On placing the specimen in air, water and residual monomer evaporate from the surface. The shrinkage resulting from the evaporation of water and monomer from the outer layer or skin causes the surface layer to be in tension. When the strain is sufficiently large, fracture of the weak secondary forces between the chains occurs and crazing cracks appear at right angles to the direction of stress. Often delayed fracture occurs because of the increase in magnitude of stresses. Craze marks appear after storing the resin for a few days. On subjecting the sample to the rapid craze test, crazing probably occurs by a mechanism similar to that described above.

Whether the blushing of the material which takes place during the cooling period is due to the precipitation of water as a distinct phase or is caused by numerous submicroscopic openings which cause a large portion of the light striking them to be reflected, cannot be decided from the present investigation. Possibly clues regarding this mechanism can be obtained from X-ray diffraction measurements and observations under the electron microscope. Samples of polymethyl methacrylate can be annealed in air at elevated temperatures. On heating above T_g, more and more segments of the molecule have sufficient energy to execute vibrations and rotations. Strains are released and blushing and craze marks disappear. Furthermore, any water present in the polymer can diffuse more readily to the surface where it evaporates.

Craze resistant teeth are now commercially available. These teeth contain cross-linked polymethyl methacrylate of high molecular weight. The material is insoluble in most solvents, does not swell readily, and has a softening point above 130°C. In the preparation of the denture the teeth are probably not heated above the transition temperature. Also, reinforcement of the chains through cross linking probably increases the amount of stress necessary to break chains. Hence, the craze resistance is increased through cross linking.

4. SUMMARY

Investigations of the crazing of acrylic dentures and plastic teeth demonstrated that when linear methyl methacrylate polymer comes in contact with water during processing at elevated temperatures, the material is susceptible to crazing. Material protected from water during the processing does not craze.

An explanation for the crazing process, based on the experimental evidence, is advanced. Sorption of excess water at elevated temperature causes the surface of the material to be supersaturated with water when the specimen is cooled. Evaporation of excess water sets up strains which eventually are released by the formation of craze marks.

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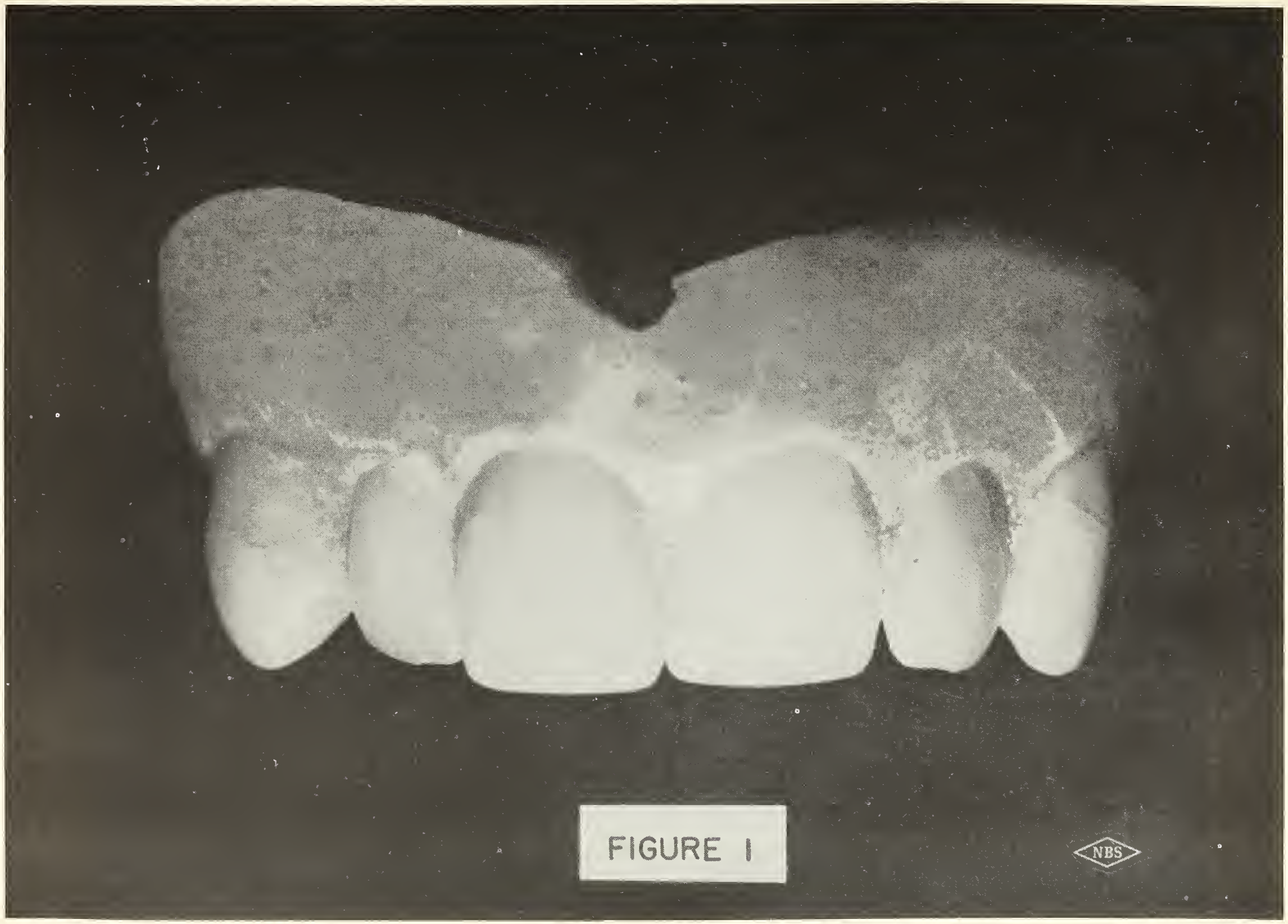


FIGURE I

FIGURE 2

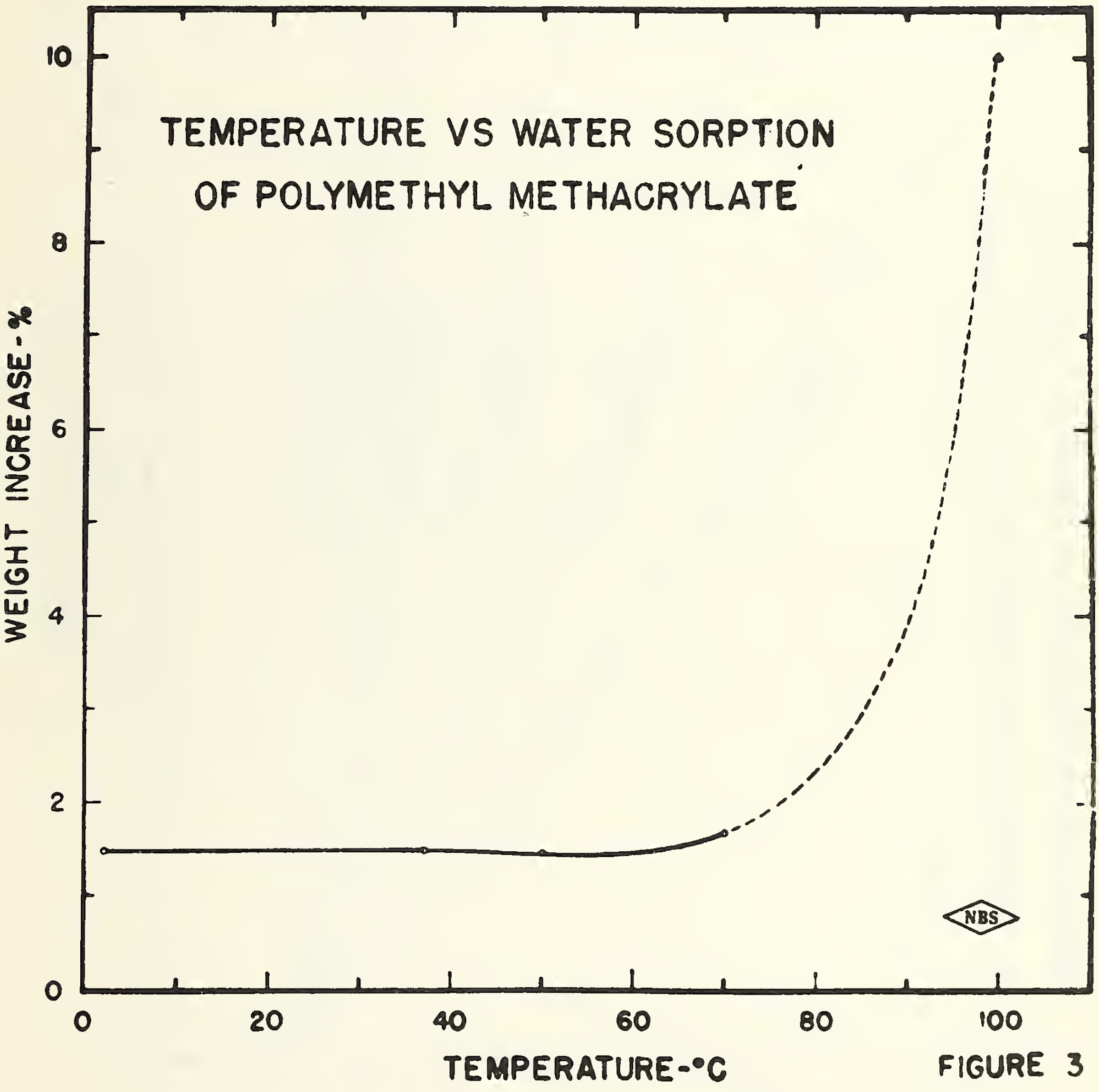
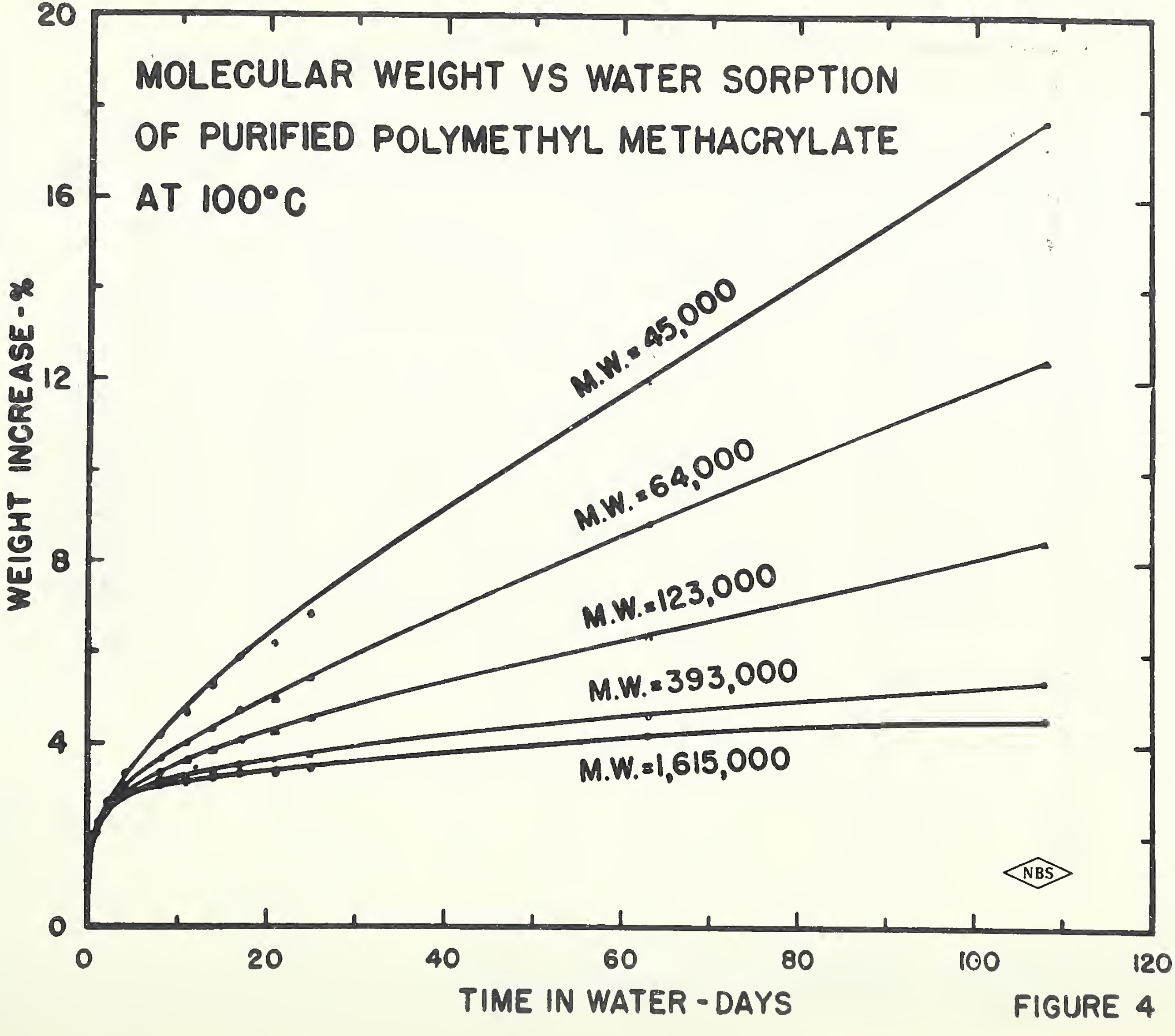

TEMPERATURE VS WATER SORPTION
OF POLYMETHYL METHACRYLATE
WEIGHT INCREASE - %
0
2
4
6
8
10
0
20
40
60
80
100
TEMPERATURE - °C
NBS

FIGURE 3



MOLECULAR WEIGHT VS WATER SORPTION
OF PURIFIED POLYMETHYL METHACRYLATE
AT 100°C
M.W.=45,000
M.W.=64,000
M.W.=123,000
M.W.=393,000
M.W.=1,615,000
WEIGHT INCREASE - %
TIME IN WATER - DAYS
0
4
8
12
16
20
0
20
40
60
80
100
120
NBS

FIGURE 4

Hydraulic turbine contra-angle handpiece

Robert J. Nelson, D.D.S.; Carl E. Pelander,
and John W. Kumpula, Washington, D. C.

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Hydraulic turbine contra-angle handpiece

Robert J. Nelsen, D.D.S., Carl E. Pelander† and John W. Kumpula,‡ Washington, D. C.*

A high rotary speed enhances the efficiency of instruments used for cutting teeth in operative procedures. The small diameters of the dental cutting tools make it necessary to turn the instruments at high rates of speed in order to obtain effective linear speeds for the removal of enamel. For example, a 7/8 inch (22.2 mm.) disk rotating at 1,000 rpm has the same linear or surface speed as a 5/32 inch (3.9 mm.) disk dental tool rotating at 5,600 rpm. Some dentists have been reluctant to use high speeds in many operations in the mouth because of the hazard to the patient. This danger is due chiefly to the high inertia of the revolving instrument.

This report describes a contra-angle dental handpiece containing a small turbine which is propelled by a high speed stream of fluid in a closed system. This handpiece was developed at the National Bureau of Standards in cooperation with the American Dental Association. Because of certain characteristics inherent in hydraulic systems, many of the objections to the use of high rotary speeds in cavity preparation can be eliminated with the use of this new instrument.

THE UNIT

The unit is shown in Figure 1. It consists of a mobile cabinet which contains a fluid pumping mechanism, a reservoir, a pressure switch, a solenoid valve and distribution lines. The contra-angle handpiece (Fig. 1, A) is connected to a flexible coaxial double tubing (Fig. 1, B). The 3/8 inch inside tube carries the propellent fluid (water) under pressure to the contra-angle handpiece while the 5/8 inch outer tube carries the spent fluid back to the reservoir. The tubes join (Fig. 1, C) with the line directly from the pump (Fig. 1, D) and the line to the reservoir tank (Fig. 1, E). The flexible rubber hose (Fig. 1, F), which rests on the floor, is connected to a relay system by which the operator controls the fluid flow to the handpiece.

The unit is self-contained and needs only to be connected to an electrical outlet for operation. The fluid is stored in a reservoir tank and is used over and over; hence the unit requires no adjustment during its normal operating use. The pumping equipment is enclosed in a sound-insulated cabinet which minimizes undesirable noise during operation.

THE PUMPING MECHANISM

The pumping mechanism consists of a constant-volume pump (Fig. 2, A), close-coupled to a one-half horsepower electric motor (Fig. 2, B). The output of the

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†Senior instrument maker, National Bureau of Standards.

‡Laboratory mechanic, National Bureau of Standards.

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pump in this unit under no-load conditions is 1.6 gallons per minute. The fluid is taken into the pump from the reservoir tank above through the connection (Fig. 2, C). The fluid is discharged from the pump into a line (Fig. 2, D) which leads to the contra-angle handpiece. The fluid from the handpiece is returned to the reservoir through a line (Fig. 2, E). To stop the turbine, the operator steps on a tube (Fig. 2, F). This force closes the pressure switch (Fig. 2, G), completing a circuit and opening the solenoid valve (Fig. 2, H), which allows the fluid to bypass the turbine through a line (Fig. 2, I) and return to the reservoir.

While the instrument is being used, the motor and pump operate continuously; the handpiece is energized as needed by the operator controlling the flow of fluid through the instrument as just explained. The motor is controlled by a switch located on the side of the unit.

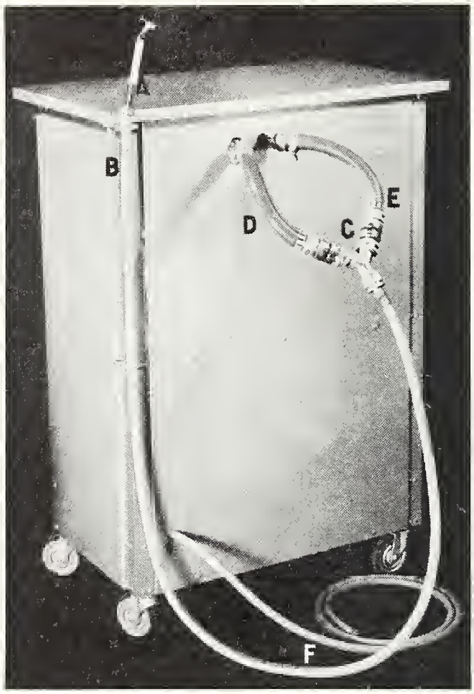

Fig. 1 • External view of assembly showing handpiece, A; coaxial double tubing, B; and junction, C, of line, D, from pump, and line, E, to reservoir tank

THE HANDPIECE

The use of air or water as motive power for dental rotary cutting instruments is not new. Iseman in a United States patent secured in 1940[1] and Norlen in a United States patent secured in 1952[2] both describe dental engines propelled by compressed air. In United States patents secured in 1878, 1877 and 1879 respectively, Straub,[3] Wilkerson[4] and Laurence[5] describe different means of driving a dental engine by the use of water as a propellent. Each of the engines was designed for the straight dental handpiece, and each required that a gear-type contra-angle handpiece be attached.

The handpiece is driven by a small turbine in the head of the contra-angle. The over-all size and shape of the new instrument are within the general proportions of the conventional gear-driven contra-angle handpiece. Figure 3 shows the comparative sizes of the hydraulic handpieces, A and B, and a conventional contra-angle handpiece, C, attached to a straight handpiece and wrist joint. The instrument shown in Figure 3, A is of an experimental design which permits various turbines and bearings to be inserted for testing. Figure 3, B shows the design of the instrument which would be more suitable for clinical use than that in Figure 3, A. The cutting tool in these instruments is attached directly to the shaft of the turbine.

1. Iseman, John. Dental tool. U. S. Patent No. 2,251,057, July 29, 1941.

2. Norlen, Per Ivar. Dental engine for compressed air. U. S. Patent No. 2,618,064, Nov. 18, 1952.

3. Straub, Ambrose W. Improvement in instruments for giving motion to tools. U. S. Patent No. 154,569, Sept. 1, 1874.

4. Wilkerson, Basil M. Improvement in dental engines. U. S. Patent No. 189,409, April 10 1877.

5. Laurence, Henry. Improvement in dental engines. U. S. Patent No. 213,909, April 1, 1879.

The comparative size of the turbine and of the head of a gear-type contra-angle handpiece (S. S. White) is shown in Figure 4.

The turbine has six notched blades fixed to the shaft and measures 7.5 mm. in diameter and 4.8 mm. in height. In the design shown in Figure 5, stainless steel ball bearings are used. A thin metal disk to direct the flow of water away from the bearings is mounted on the shaft at each end of the turbine (Fig. 5, A). The radial load on the shaft is taken by the two stainless steel ball bearings (Fig. 5, B) placed at each end of the turbine. The upper bearing fits into a collar (Fig. 5, C) while the lower bearing is a press fit into the end plate (Fig. 5, D). The axial thrust is taken on a sapphire bearing (Fig. 5, E) mounted in the cap screw (Fig. 5, F).

Various combinations of plastic bearing materials have been used in place of the stainless steel ball bearings, which proved rather noisy and harsh in this application. Figure 6 shows an expanded view of a turbine assembly using plastic bearings, A, and journals, B. Nylon, Teflon, Rulon and stainless steel have been used in combinations. The three plastic materials have a low coefficient of friction and were not lubricated while in use. Bearings of these materials are much quieter in operation and give more satisfactory results than bearings of any other material used in this application to date.

The turbine shaft (Fig. 6, C) fits into the hollow shaft of the cutting instrument. A spring key attachment (Fig. 6, D) fits into a keyway in the instrument shaft and secures it to the turbine shaft. The centrifugal force developed by the rotating shaft causes this spring to lock the cutting instrument in place. When the shaft is still, however, it is relatively easy to attach and remove the cutting instruments.

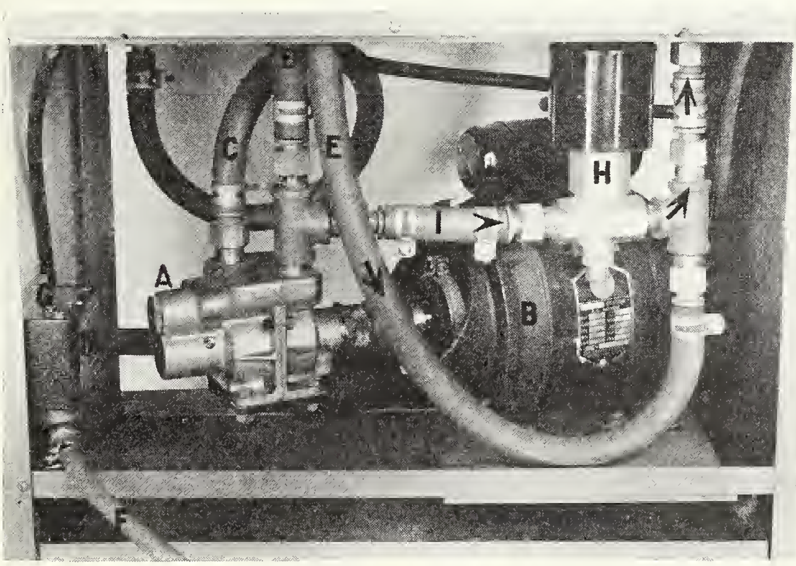

Fig. 2 • Pumping mechanism consisting of constant-volume pump, A, operated by one-half horsepower motor, B. Fluid enters pump from reservoir through line, C, and leaves pump through line, D, to handpiece. Line, E, returns the spent fluid to reservoir. Foot pressure on tube, F, closes switch, G, which opens solenoid valve, H, so that fluid is permitted to by-pass handpiece through line, I

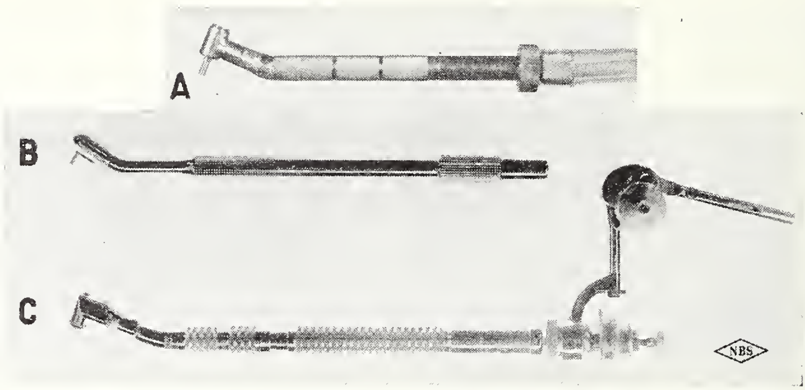

Fig. 3 • Comparative size of hydraulic handpieces, A and B, and conventional contra-angle handpiece attached to straight handpiece and wrist joint, C

OPERATIVE CHARACTERISTICS

Since the only rotating or moving element in this contra-angle handpiece is the turbine to which the cutting tool is directly attached, the vibrations due to the belt-and-gear driving mechanism of the conventional contra-angle are eliminated. The fluid passing over the turbine and shaft acts as a coolant. In spite of the high rotational speed developed, overheating of the instrument is prevented. Therefore, this instrument has a distinct advantage over the gear-type instruments which heat excessively at high speeds.

The rotational speed of the instrument depends on the amount of fluid which 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 fluid passing through it. With the pumping mechanism previously described, 1.6 gallons per minute forced through the turbine produced a speed of 61,000 revolutions per minute. At this speed and with a 2 ounce radial load used against a Densco diamond instrument SC-6 (7 mm. in diameter and tapered from 1 mm. thick at the hub to a knife edge), an average of 4.2 mg. of tooth structure was removed per second from fresh extracted teeth. During this test it was found that a load of 3½ ounces on this diamond tool stopped it from rotating. This, in effect, means that if the operator were to press too heavily on the cutting tool or if the tool were to catch or bind in some manner that would ordinarily be hazardous, this instrument automatically would stop rotating. For instance, a belt-driven diamond-cutting instrument will entangle in a rubber dam or will cut through it if it makes contact with it while it is rotating. The same cutting instrument mounted in the hydraulic handpiece will not engage the rubber dam to any extent because there is insufficient torque developed to enmesh or tear the rubber. When disks of larger diameter are used, the effective torque is lessened. This is not a disadvantage, however, because with the increased diameter of the disk, there is an increase in the peripheral speed of the tool which compensates for the reduced torque. The actual cutting rate remains approximately the same. With the larger disks an extremely light pressure on the tool is used. Also, the disks will stop rotating when the cutting loads are light, and in this way the safety feature of the instrument is maintained. Any of the cutting instruments used, including the ⅞ inch diamond disks, can be stopped while rotating at top speed (61,000 rpm) by placing a finger abruptly against the edge of the disk. The disk will stop immediately and will not injure the finger. As soon as the disk is released, the instrument will start rotating again. If excess pressure is exerted on the cutting tool and then released, no manipulation or adjustment of the instrument is required to start or stop the turbine.

The use of city tap water (about 40 pounds per square inch) to operate the turbine does not produce the same amount of torque and rotational speed that occur when the pumping unit is used. With tap water pressure one gallon of water per minute is forced through the instrument, and a rotational speed of 35,000 rpm and proportionally less torque are produced. The cutting ability of the instrument is considered not adequate when city water pressure is used.

It is extremely important that all the cutting tools used at these high speeds be accurately balanced. Any eccentricity or unbalance is apparent, as it causes vibration of the instrument and immediately produces an uneven wear on the cutting tool. The diamond instruments which have been used with this contra-angle handpiece show little sign of wear even though many old amalgam fillings have been removed with each of them. Silicon carbide mounted points and disks of medium grit used in this instrument were found to be highly efficient. The fine grit points, however, did not cut well. The silicon carbide points are less expensive than the average diamond instruments. Although they wear faster than the diamond tools, they retain their cutting ability as they wear, whereas the diamond instruments lose efficiency as soon as they begin to wear.

With this handpiece the preparation of teeth in the mouth can be performed with considerably less strain on the operator

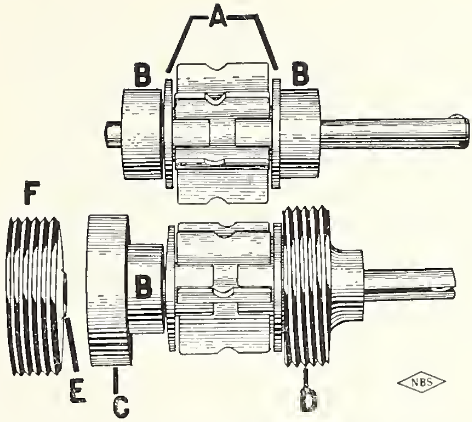

Fig. 5 • Turbine assembly using stainless steel ball bearings. Thin disks, A, direct water away from ball bearings, B, which are fitted into collar, C, and end plate, D. Sapphire axial thrust bearing, E, is mounted in cap screw, F

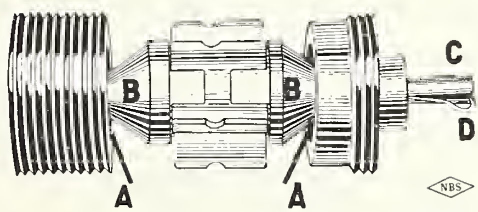

Fig. 6 • Turbine assembly using plastic bearings, A, and plastic journals, B. Turbine shaft, C, contains spring key attachment, D, which engages keyway on shaft of cutting tool

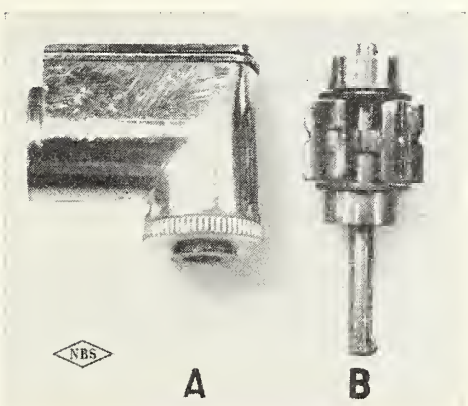

Fig. 4 • Head of conventional contra-angle handpiece, A, compared with turbine assembly, B because of the extremely light pressures used. The cutting tools do not climb or roll out of the cavity as do those used in the slower-rotating instruments. The greatest advantage of the instrument is in the making of extracoronal preparations. For intracoronal preparations, the instrumentation advocated by Ingraham and Tanner is most suitable.[6] The extremely rapid cutting rate of this instrument makes it uniquely suited for occlusal equilibration procedures.

PATIENT REACTION

The patient's reaction to this type of instrumentation has been varied. None have remarked that this method of cutting teeth was more unpleasant than the usual method. The speed at which tooth structure can be removed and the short time that the instrument must be used are factors which enhance its acceptance by the patient. An insufficient number of patients have had cavities prepared with the instrument to draw a definite conclusion regarding the patient reaction to the actual cutting sensations.

LIMITATIONS OF THE INSTRUMENT

Because of the extremely rapid rate of cutting, this contra-angle handpiece does not lend itself to every type of rotary instrumentation. It is doubtful if the instrument can be used effectively with diamond or silicon carbide cutting tools smaller than a no. 560 steel bur (1.8 mm. in diameter). The various types of carbide burs did not cut tooth structure with any practical efficiency when used in this instrument. It is believed that the design of the cutting blades of all burs will have to be modified before they can be used at the rotational speeds of this instrument.

SUMMARY

1. The advantages of using increased rotary speeds in tooth-cutting procedures have long been recognized.

2. The operational hazards attendant on the use of high rotational speeds with conventional belt-and-gear-propelled cutting tools have been considerably reduced by the development of a hydraulic turbine contra-angle handpiece.

3. Rotational speed of 61,000 rpm with considerably higher cutting rate and lower cutting pressure than can be attained with conventional instrumentation is now possible.

4. The mechanical difficulties of excessive vibration and heating characteristic of the gear-type contra-angle handpiece have been eliminated by positioning the turbine in the head of the new instrument. Therefore, no gears are required.

5. Milling cutters such as steel and carbide burs of current design do not function well in this hydraulic headpiece. Grinding tools such as silicon carbide and diamond points and disks used with the handpiece cut with exceptional efficiency.

6. Even though some adjustment in the dentist's operative procedures is necessary, the instrumentation is basically the same as his present methods. Therefore, the use of this equipment will require no special training.

6. Ingraham, Rex, and Tanner, H. M. The adaptation of modern instruments and increased operating speeds to restorative procedures. J.A.D.A. 47:311 Sept. 1953.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT **NBS REPORT**

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CUTTING CHARACTERISTICS OF DENTAL BURS AS
SHOWN BY HIGH-SPEED MICROPHOTOGRAPHY

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This work is a part of the Dental Research Program conducted at the National Bureau of Standards in cooperation with the American Dental Association, the Army Dental Corps, the Air Force Dental Service, the Navy Dental Corps and the Veterans Administration.

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

CUTTING CHARACTERISTICS OF DENTAL BURS AS SHOWN BY HIGH-SPEED MICROPHOTOGRAPHY

Abstract

High-speed still and motion picture microphotography has been used in the study of the mechanism of cutting of dental burs. Two-microsecond flash still photographs were made of dental burs cutting glass and Bakelite cast resin at 5,000 rpm with a load of 300 grams. Slow motion studies employing a high-speed motion picture camera at 3,000 frames per second were made of steel and carbide burs at 2,500 rpm with a load of 300 to 500 grams, cutting human enamel, dentin and laboratory test materials. The action occuring in one second was extended to approximately three minutes for study by projection at 16 frames per second. These methods permitted dynamic observations hitherto not recorded, of clogging, intermittent cutting, and eccentric rotation. Selected frames from a cycle of rotation were enlarged and printed from negative 16mm film for detailed studies. A slight superiority of carbide over steel burs was noted when cutting human enamel and dentin. It is believed that this results from the extreme hardness of the tungsten carbide instruments and superior workmanship. Data obtained by conventional laboratory test procedures based on weight loss were in accordance with the motion picture studies.

1. INTRODUCTION

In the study of rotating dental instruments being carried on at the National Bureau of Standards, temperatures and cutting rates of revolving dental burs have been measured (1) and work on the development of suitable tests for diamond abrasive instruments is in progress. Considerable work has been accomplished by other investigators in the study of the mechanism of milling and in the design and production of industrial cutting tools (2). The characteristic forms of chips have been classified. Charts are available for low and high-speed cutting, for clearance and rake angles, and for correct speed and depth of cut which give optimum performance in a specific material. Little is known, however, of the cutting action involved in the use of the dental bur for the cavity preparation of a human tooth. A better understanding of this mechanism could logically lead to improvement in the design and use of rotating dental cutting instruments. To obtain basic information on the manner of performance of dental burs, a program of high-speed photography of the instruments as they rotate under load in contact with human enamel, dentin, and other test materials was undertaken.

2. PROCEDURE AND RESULTS

Still photographs were made first, employing a General Radio "Microflash" unit which emitted an intense light of 2-millionths of a second duration and which effectively stopped the action of a dental bur rotating at 5,000 rpm. This light was focused by means of a condensing lens system which increased the effective illumination by concentrating the light on the bur head. Four by five inch panchromatic film, ASA speed 64 Tungsten, was exposed by the open-flash method in an American Optical Company photomicrographic camera equipped with a Bausch and Lomb Micro-Tessar F 4.5 lens (Figure 1). The film was developed four and one-half minutes in DK-19 at 68 degrees F.

Figures 2 and 3 are typical of the photographs obtained using this technique. Figure 2 shows a Number 559 tungsten-carbide bur cutting a glass microscope slide. The load was 300 grams and speed of rotation was 5,000 rpm. It can be seen that a pulverizing action rather than a chip formation was taking place. The powdered-glass debris accumulated on the entrant side of the excavation. This phenomenon demonstrates one reason for clogging of the bur, in that the debris is not thrown out at the exit side but is carried around to the entrant side, where it is occasionally picked up and carried back through the excavation by the bur.

Figure 3 shows a Number 559 tungsten-carbide bur cutting a test material, Bakelite cast resin BT-44-992, used in previous work (1), as a substitute for dentin. Speed of rotation was 5,000 rpm with a load of 200 grams. The true chip formation seen here, would be expected when a milling-type cutter is employed in its proper medium. The chips accumulated on the exit side of the excavation, apparently because they were too large to be carried around by the vortex of air created by the revolving bur.

The single exposure, high-speed flash method of photographing a rotating dental bur, did not permit sequential studies of the cutting action of any particular blade. It was decided, therefore, to employ a high-speed motion picture camera, which would photograph the cutting action occurring in one second at a rate of 3,000 exposures per second. The film, when projected at normal speed, would allow about three minutes for the study of this action.

These studies were made using the Eastman Kodak 16mm high-speed motion picture camera. Adequate magnification was obtained through the use of extension tubes 8 inches long, in combination with an F 4.0, 6-inch telephoto lens and a 2-plus Proxar auxiliary lens. This combination permitted a working distance between lens and bur of about six inches. The camera speed of 3,000 frames per second resulted in an exposure time of 1/15,000 second per frame. This short exposure time, combined with the reduction in effective aperature of the lens to F 9.3, due to the extension tubes *, established the requirement for a high intensity light source. Eleven 750 watt focusing photoflood bulbs were arranged on a ring above the subject (Figure 4). An internally chrome-plated ring about the bur chuck, aided in concentrating illumination on the

* The formula $EA = \frac{V}{F} f$ applies; EA = effective aperture, V = lens-film distance, f = marked lens aperture, and F = focal length of the lens. (3)

subject. Reversal type 16mm motion picture film, ASA 64 Tungsten, was used when photographs were made for projection study. Negative film of the same characteristics was employed when prints were desired.

Although the action of the burs is best seen by observation of the projected motion picture, information can also be obtained from examination of selected prints, prepared from individual frames of the 16mm motion picture film. Figure 5 is a print from a motion-picture film study of a Number 559 steel bur rotating at 2,500 rpm, with a load of 300 grams against human tooth enamel. Very little cutting is evident. The debris is so finely powdered that it is barely visible.

A complete rotation cycle of a bur turning at 2,500 rpm, photographed at 3,000 frames per second could be observed in approximately 74 frames. Every fourth frame from a rotation cycle was enlarged and printed. Key pictures chosen from these studies are shown in Figure 6. Row A of Figure 6 illustrates the sequence of events from left to right as a Number 559 eight-bladed tungsten-carbide bur cuts human enamel. The force applied in all cases was 300 grams. This bur was 0.003 inch eccentric. It can be seen that only four blades actually cut, and that in one phase of its rotation cycle, the bur was not in contact with the tooth structure. Some of the debris is finely powdered and follows the vortex of air about the bur, and is seen to be carried back into the excavation. The bulk of the cut material, however, is being deposited at the exit side, where it is seen to accumulate. Very little difference between the cutting effectiveness of steel and carbide burs is evident in these pictures (Figures 5 and 6-A), taken during the first five minutes of use of each instrument. The effective life of a carbide bur will, however, extend over a much longer period of time since the extreme hardness of tungsten carbide permits burs of this material to cut hard substances with less dulling of the blade edges. Superior workmanship noted on microscopic examination of the carbide burs (Figures 7 and 8) may be a factor affecting the cutting ability of these instruments.

Row B of Figure 6 shows the key pictures in a rotation cycle of a Number 559, six-bladed steel bur cutting human dentin. This bur was 0.002 inch eccentric. Note that there is definite chip formation, but that the chips are fragmented and tend to follow the instrument as it rotates. Eccentricity is not evidenced by lack of contact of the instrument with the dentin at any point in this cycle, possibly due to flexure of the steel bur, however; a study of the debris reveals that the cutting is intermittent.

Row C in Figure 6 illustrates the cutting cycle of a Number 559 tungsten-carbide bur in human dentin. The chip formation is superior to that seen in the case of a steel bur cutting the same material. These larger chips tend to be thrown out of the operating field. The first photograph in the series shows the bur in a phase of its cycle of cutting in which a great amount of dentin has been removed and is leaving the excavation. The blades in cutting position at this stage are ineffective, since the instrument is 0.002 inch eccentric. The fourth photograph in this series shows the bur after rotation of 180° has occurred; it can be seen that the blades now in the excavation are cutting effectively. This intermittent cutting action was observed in all burs studied, which were over 0.001 inch eccentric, but not observed in those which were less than 0.001 inch eccentric. Increasing the load to 500 grams did not serve to bring all blades into play, and only accentuated the intermittent cutting action.

This study would indicate that calculations of bur efficiency based on the amount of material removed per blade per revolution would be of little value as all blades of a bur do not remove equal amounts of material during a cutting cycle.

The relative cutting rates of steel and carbide burs in human enamel and dentin are shown in Figure 9. Calculations were based on weight of material removed in one-minute periods of cutting at 2500 rpm and with a load of 300 grams. These data showing slightly more effective cutting by the carbide burs are in accordance with the action demonstrated by the motion picture studies.

3. CONCLUSIONS

High-speed motion picture photography of dental burs under actual operating conditions permits detailed, slow-motion study of the action of each bur blade throughout the cutting cycle. In combination with conventional laboratory test methods it provides a new approach to the study of rotating dental instruments.

Under the conditions of this experiment, a slight superiority of carbide burs over steel burs was noted when cutting human enamel and dentin. This difference is possibly due to the greater hardness and to the higher quality of workmanship and finish of the carbide burs.

Laboratory data obtained by conventional methods alone do not give a true picture of the cutting efficiency of individual bur blades. Photographic evidence shows that, with very few exceptions, all burs used in these experiments were intermittent cutters, due to eccentricity and irregularities in blade formation.

High-speed motion picture photography should prove of considerable value in the study of experimental burs, since by this method, new designs can be quickly evaluated dynamically, prior to complete investigation requiring many hours of laboratory procedure.

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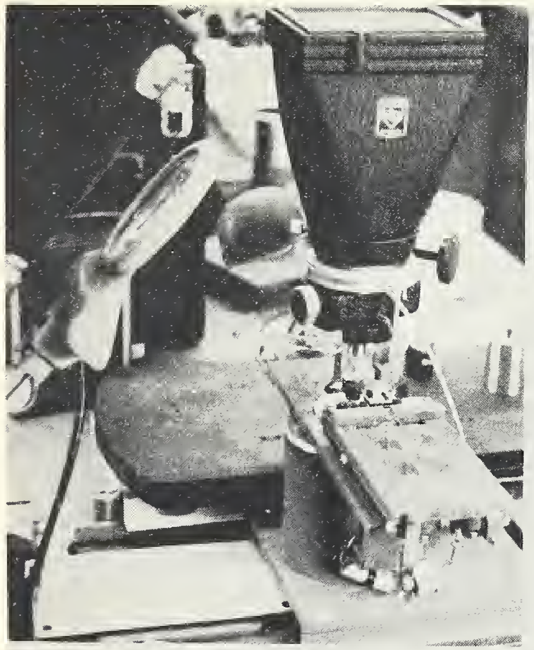
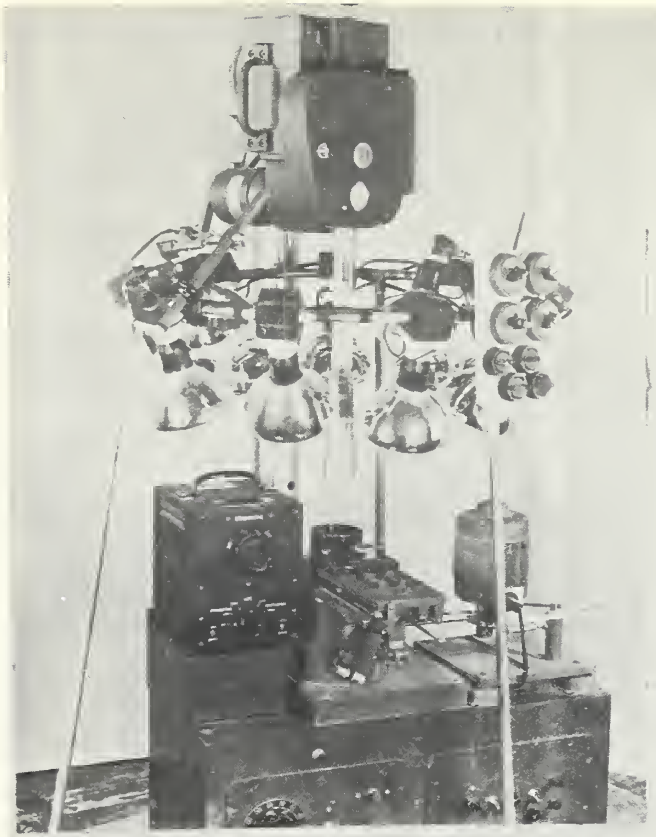


FIG 1. SET-UP FOR SINGLE EXPOSURE, HIGH-SPEED FLASH MICROPHOTOGRAPHY OF A DENTAL BUR WHILE CUTTING.

FIGS 2-3. TWO-MICROSECOND FLASH PHOTOGRAPHS; DIRECTION OF ROTATION IS COUNTER-CLOCKWISE AS VIEWED BY THE READER. AT LEFT: CARBIDE BUR CUTTING GLASS, 5,000 RPM, 300 GRAM LOAD; RIGHT: CARBIDE BUR CUTTING A DENTIN SUBSTITUTE (BAKELITE CAST RESIN), 5,000 RPM, 200 GRAM LOAD.



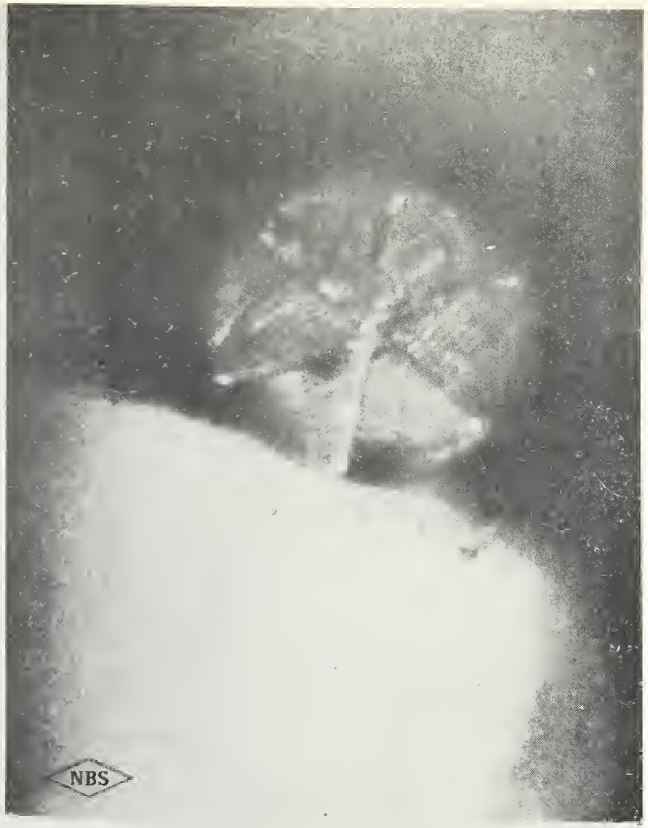
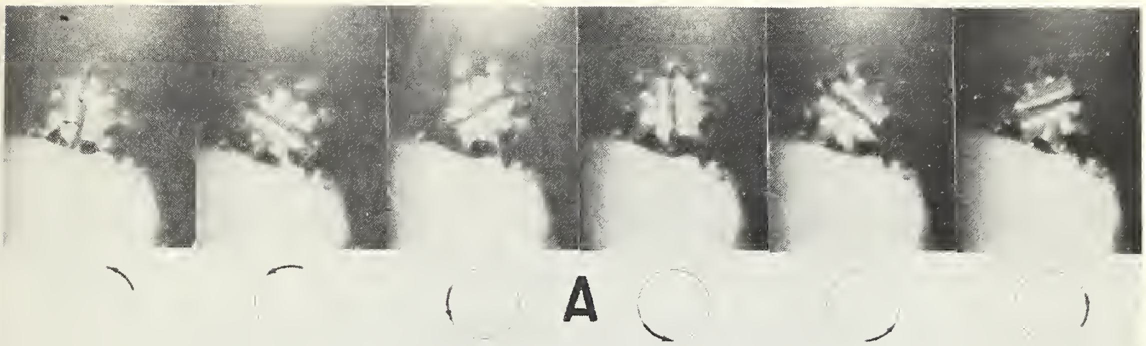


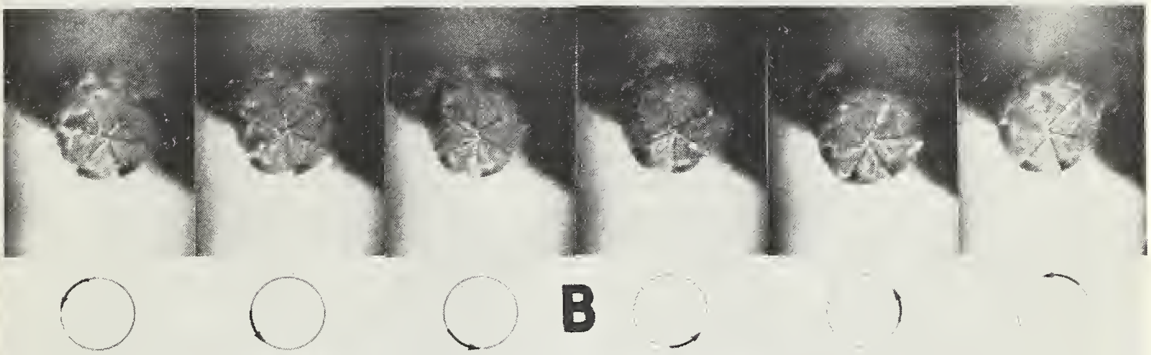
FIG 4. HIGH SPEED MOTION PICTURE CAMERA ON TRIPOD OVER RING OF LIGHTS SURROUNDING BUR TESTING MACHINE.

FIG 5. PRINT FROM A SINGLE FRAME OF 16MM HIGH SPEED MOTION PICTURE FILM OF A STEEL BUR ROTATING AT 2,500 RPM CUTTING HUMAN ENAMEL, 300 GRAM LOAD.



A

559 CARBIDE BUR CUTTING HUMAN ENAMEL



B

559 STEEL BUR CUTTING HUMAN DENTIN

C

559 CARBIDE BUR CUTTING HUMAN DENTIN

THE INSTRUMENTS ABOVE WERE ROTATING AT A SPEED OF 2,500 RPM AT A LOAD OF 300 GRAMS.

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FIG 6. KEY PRINTS FROM 16MM MOTION PICTURE FILM SLOW MOTION STUDIES. THESE WERE SELECTED TO SHOW A CYCLE OF ROTATION OF EACH INSTRUMENT.

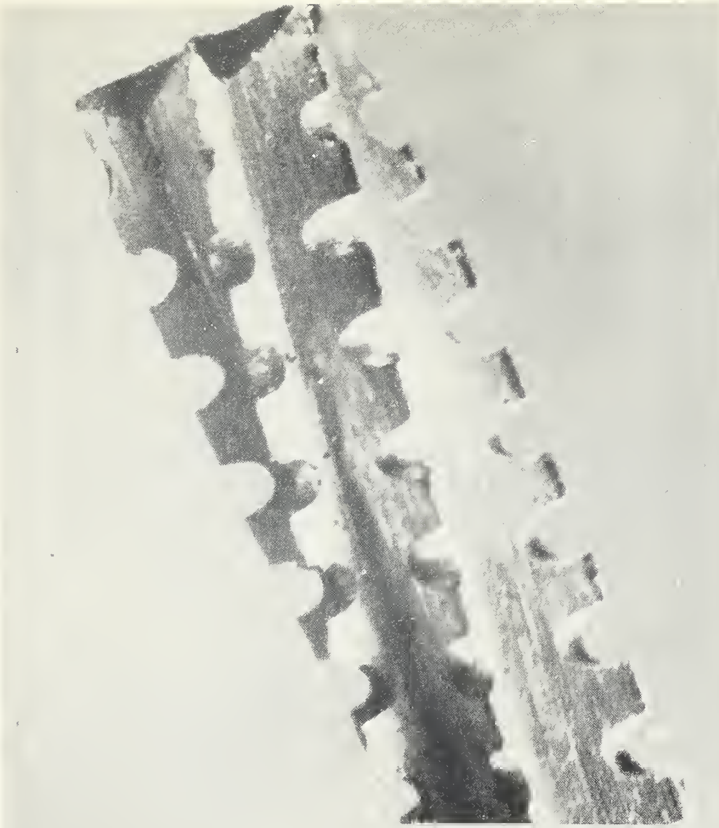

FIG 7. NEW, UNUSED STEEL BUR; NOTE THE CURLED AND DRAWN EDGES.

FIG 8. NEW, UNUSED CARBIDE BUR; NOTE THE CLEAN-CUT EDGES.

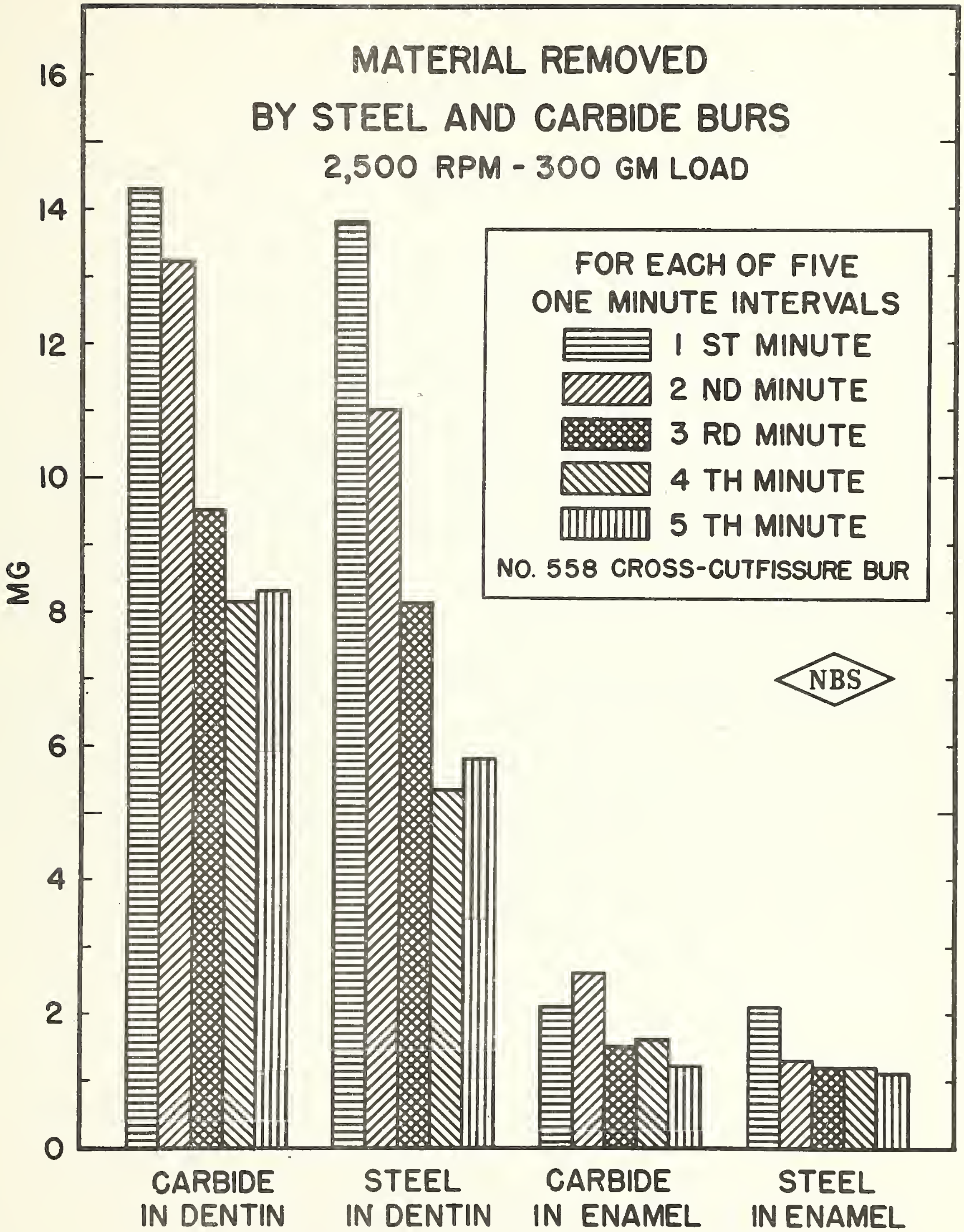

FIG 9. RELATIVE CUTTING RATES OF STEEL AND CARBIDE BURS IN HUMAN ENAMEL AND DENTIN DETERMINED BY CONVENTIONAL LABORATORY METHODS.

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