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knowledge and skills available to teach those less privileged. Added to our worship of excellence must be a recognition of sharing with our neighbor — be he student, teacher or practitioner.

It has been the prime objective of our Academy to stress excellence of service to our patients through emphasis on the use of the rubber dam and gold foil as a restorative. Many thoughtful, sincere and dedicated members feel strongly that by limiting our emphasis to the rubber dam and gold foil, as fundamental and important as these are, we have reduced our potential of achieving the larger goal of Excellence of Total Service to our patients. This subject has been carefully and thoughtfully studied and is being evaluated.

This message is an invitation to communicate your individual thoughts to the editor, to me, or others who have accepted the responsibility to guide the policies of our Academy. We do not want possible change for change's sake, but change only if we can better serve a necessary mission.

Frida A. Xhonga, D.D.S.

# Direct gold alloys—part II†

The physical characteristics and properties of direct golds currently used in dentistry have been described in Part 1.[1]

At the University of California, Los Angeles, School of Dentistry, investigations have been undertaken, with the technical assistance of the Williams Gold Refining Company,* to effect further improvements on the physical properties of gold without impairing its manipulative characteristics. Contrary to the previous assumptions that gold can be welded or condensed only in a pure state, this research has demonstrated that bonding also takes place between gold alloy particles.

Our basic objective was to obtain a product with increased hardness, and the most effective method of producing a small grain size metal was to resort to powder metallurgy. Condensation, when carried out properly, increases the hardness of the direct gold alloy restoration, equal to a medium hardness cast gold alloy (Brinell hardness 80-90).[2]

The direct gold alloys are produced by electrolytic precipitation. When the sintering temperature (1500-1700° F) and time are carefully controlled, the gold alloy is transformed into an adherent mass

* *Williams Gold Refining Co., Inc., 2978 Main St., Buffalo, N.Y.*

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*Dr. Xhonga is assistant professor of operative dentistry at the University of California, Los Angeles, School of Dentistry. She is a graduate of the University of Minnesota (1956), and of the University of Munich, Germany, where she received her Dr. Med. Dent. degree in 1949. Currently she is president of the UCLA Gold Foil Study Club, and an active member of the American Academy of Gold Foil Operators, and the American Dental Association.* *Computing assistance was obtained from the Health Sciences Computing Facility, University of California at Los Angeles, sponsored by NIH Grant FR-3. This paper was presented before the American Academy of Gold Foil Operators, Annual Meeting, Buffalo, N.Y., October 10, 1969.*

† *This paper consists of two parts : Part one [J.A.A.G.F.O., XIII:17-22, April 1970] summarized the essential physical characteristics and properties of direct golds; Part two deals mainly with the direct gold alloys.*

*Table 1 — Materials Tested*

| | *Gold Type* | *Description* | *Manufacturers* |
|---|---|---|---|
| 1. | Gold Foil | Pure gold cylinders, size ½ gr. | Morgan, Hastings & Co. |
| 2. | Goldent | Pellets of powdered gold, in gold foil envelope, assorted sizes | Morgan, Hastings & Co. |
| 3. | Direct Gold Alloy 97-1-1-1 1500° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1500° F | Williams Gold Refining Co. |
| 4. | Direct Gold Alloy 97-1-1-1 1600° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1600° F | Williams Gold Refining Co. |
| 5. | Direct Gold Alloy 97-1-1-1 1700° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1700° F | Williams Gold Refining Co. |
| 6. | Direct Gold Alloy Au Ca 1500° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1500° F. Williams Electraloy R.V. | Williams Gold Refining Co. |
| 7. | Direct Gold Alloy Au Ca 1600° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1600° F | Williams Gold Refining Co. |
| 8. | Direct Gold Alloy Au Ca 1700° F | Powdered gold alloy, sandwiched between two layers of gold foil, cut into 1-2 mm squares, sintered at 1700° F | Williams Gold Refining Co. |

with adequate porosity needed for ease of manipulation. For convenience of handling, the direct gold alloys can be sandwiched between two layers of gold foil.

## Materials and Methods

Eight different materials selected for testing are listed in Table I. Five members of the School of Dentistry, Operative Division, cooperated in this study. Each operator prepared 24 specimens with eight different type of golds into an ivory block and applied three methods of condensation (Fig. 1). The size of the sample was 2 x 2 mm.

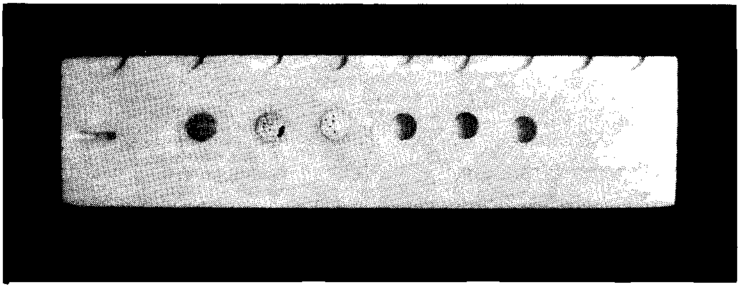

*Fig. 1 — Ivory block, 6 specimens were condensed on each side.*

The method of condensation was as follows: 1) *Hand Condensation:* a packing technique consisting of 6 to 8 lbs. hand pressure, using a .5 mm Baird #3 instrument.* 2) *Hand Malleting:* same instrument was employed as for hand condensation, but the blows were delivered by a hand mallet. 3) *Electromallet:*** the instrument was set at medium frequency and intensity. Straight handpiece with .5 mm round condenser point was used.

A special electric annealer,*** bringing the temperature up to 1200° F., was employed to remove all impurities of the materials used. The degassing, handling, and stepping of the materials were performed as though they were in a dental restoration. All specimens were overfilled, burnished, and then polished under water to a finish of 600 mesh abrasiveness. The surface hardness was measured using a Diamond Pyramid indenter in a Kentron Micro Hardness Tester,**** with a load of 1000 gm, and magnification 20x. Ten readings were taken from

* *The Cleveland Dental Mfg. Co., Cleveland 1, Ohio*
** *McShirley Products, Pasadena, Calif.*
*** The *Cleveland Dental Mfg. Co.,* Cleveland 1, Ohio
**** *Riehle Testing Machines, East Moline, Ill.*

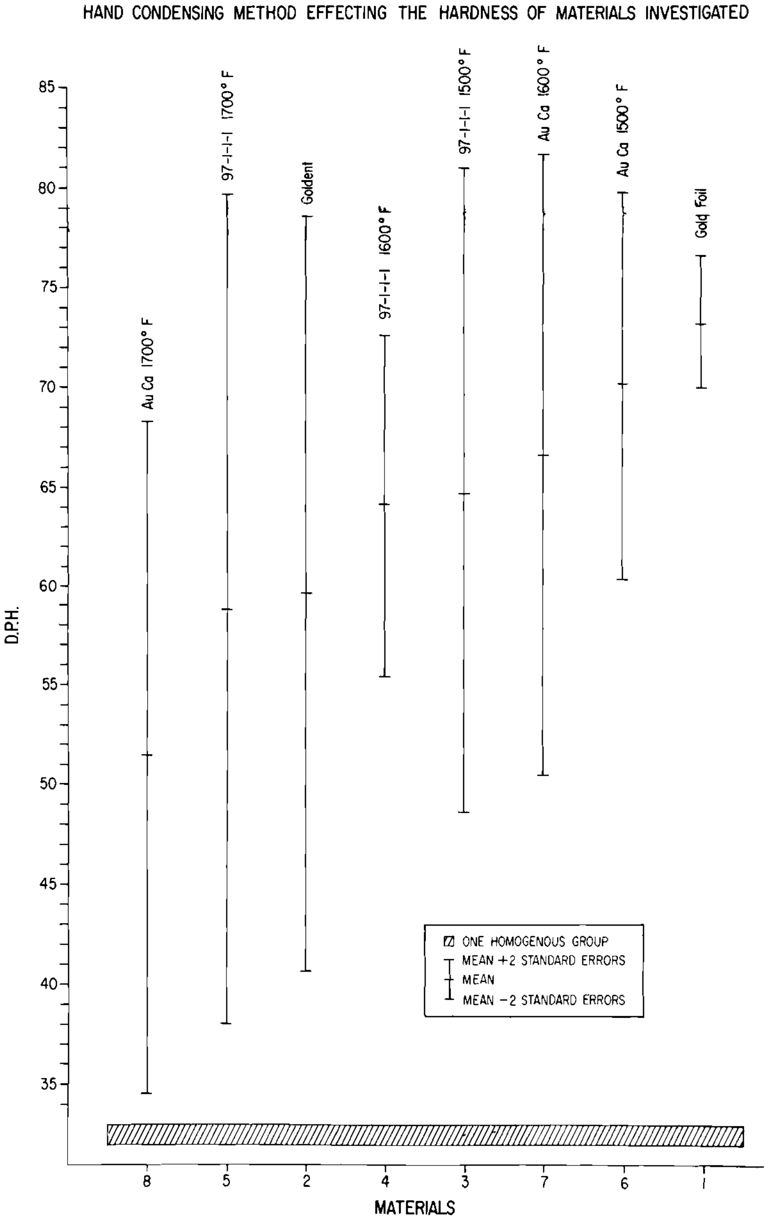


*Fig. 4 — Comparison of hardness obtained by using the hand condensation method.*

each sample, and the average was calculated. The hardness numbers were computed according to the standard formula. This hardness is referred to as Diamond Pyramid Hardness Number = DPHN, or also known as Vickers Hardness Number.

## Results

A three-way analysis of variance on materials, condensation methods, and operators was conducted.[3] Highly significant differences ($P < .01$) were found between the materials and methods, *i.e.*, $F = 4.22$ on 7 and 28° of freedom, and $F = 9.07$ on 2 and 8° of freedom respectively. A substantial interaction between materials and methods could not be established; $F = 1.50$ on 14 and 56° of freedom.

To discover the reasons for the significant differences mentioned above, the means and variability for each material and method were examined. Figures 2, 3, and 4 present the malleting methods which influence the hardness of the materials tested. The marks in the middle of the floating bars indicate the mean values of hardness in Diamond Pyramid Hardness Number, while the upper and lower marks represent the plus and minus of two standard errors of means.

Duncan's New Multiple Range Test[3] was employed to find homogeneous sets of materials according to their hardness for each of the three methods used. The horizontal bars show the homogeneity of various groups of materials tested.

In Figure 2, the electromalleting method exhibits the highest mean values of 90.18 DPHN by AuCa alloy. The lowest reading of 70.90 DPHN was shown by gold alloy 97-1-1-1. The greatest variability can be seen here by AuCa alloy. In Figure 3, the hand malleting method exhibits the highest mean values of 86.02 DPHN by AuCa alloy. The lowest reading was obtained by gold foil of 72.34 DPHN. Great variability was displayed by the AuCa alloys and Goldent.* In Figure 4, the hand condensation method exhibits, in general, low mean values and great instability.

Table II presents a summary of the mean values for the hardness, standard deviations, and standard errors on the eight types of gold tested by the five operators. This statistical table reflects the data obtained, when specimens were condensed by electromallet. Hand condensation and hand malleting, in general, were not very consistent and were largely dependent upon the ability of the operators involved. The Standard Deviations for the two methods mentioned above were higher than for the electromalleting technique, which is considered to be the standardized procedure for condensing the direct golds.

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* *Morgan Hastings & Co., 2314 Market St., Philadelphia, Pa.*

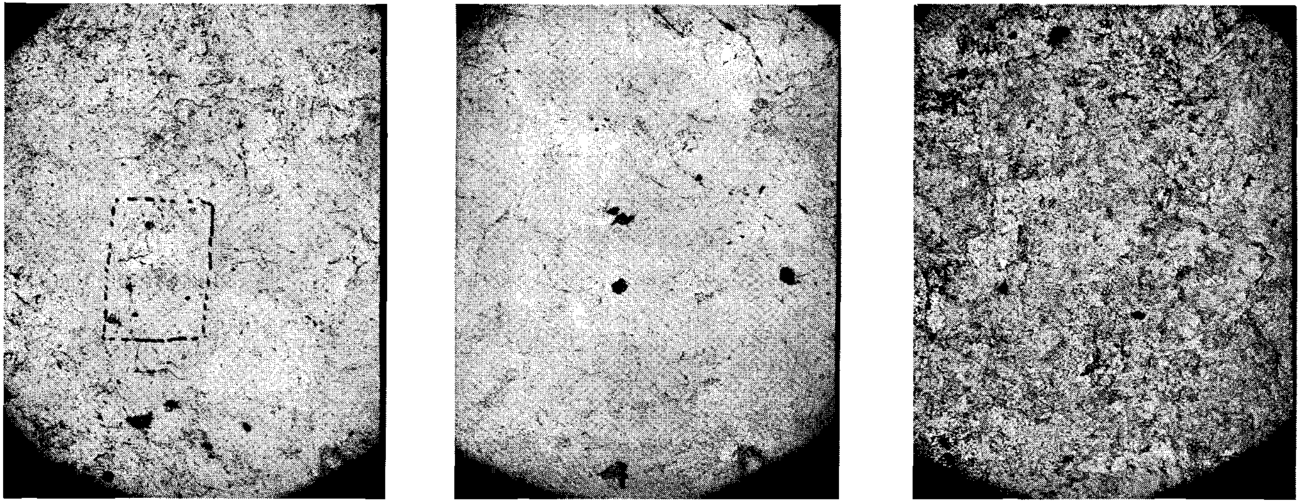
*Table II — Mean Values, Standard Deviation, and Standard Error of the Mean for the Hardness Tests Performed on 8 Types of Golds Condensed by Electro Mallet*

| Materials Tested | Diamond Pyramid Hardness | Standard Deviation | Standard Error |
|---|---|---|---|
| 1. Gold Foil | 72.44 | 6.67 | 2.98 |
| 2. Goldent | 74.52 | 2.64 | 1.18 |
| 3. 97 1-1-1 1500° F | 77.20 | 4.86 | 2.17 |
| 4. 97 1-1-1 1600° F | 75.40 | 8.41 | 3.75 |
| 5. 97 1-1-1 1700° F | 70.90 | 6.73 | 3.00 |
| 6. Au Ca 1500° F | 90.18 | 12.88 | 5.75 |
| 7. Au Ca 1600° F | 85.54 | 5.18 | 2.31 |
| 8. Au Ca 1700° F | 83.38 | 3.42 | 1.53 |

## Discussion

From the data compiled, it is shown that the method of condensation affects the hardness considerably. Specimens prepared by hand condensation showed the lowest mean values. Samples condensed by electromallet or hand malleting revealed definite improvement in hardness over those by hand condensation. The hardness, when condensed by electromallet, of 77.2 DPHN for the gold alloy 97-1-1-1, 1500° F, as compared to 72.44 DPHN for gold foil, is probably due to the solid solution strengthening; but it is more difficult to give an explanation for the high hardness of 90.18 DPHN of the AuCa alloy, 1500° F.

The information on the gold-calcium phase diagram is sparse and contradictory. The solid solubility of calcium in gold is small and has been estimated to be less than 0.3 wt% Ca at 1472° F.[4] According to the same reference, this solid solution is in equilibrium with an intermetallic compound, $AU_4Ca$ (4.8 wt% Ca), which has a melting point of 1616° F. More recent investigations[5] indicate, however, that the probable composition of this compound is $Au_5Ca$ (3.9 wt% Ca), and that it has a cubic structure (F4 3 m) with a lattice parameter a = 7.747 angstrom units. In this case, a gold alloy containing 2 wt% calcium should consist of two phases: gold and a sizeable fraction (30 to 50%) of the intermetallic compound.



*Gold foil* *Goldent* *AuCa Alloy*

*Fig. 5 — Three specimens condensed by electromallet. Magnification 75 X.*

Light microscopic studies were carried out on the following specimens: AuCa 1500, 1600, and 1700° F., gold foil and Goldent, all condensed by electromallet. In order to distinguish the several structural details, a suitable etching reagent was selected, capable of discriminating the various constituents of the microstructure. Specimens were repolished and then electrolytically etched with 5% potassium cyanide (Fig. 5).

The direct gold and direct gold alloys are characterized by dense masses, with adjacent area containing voids. Porosities are present because of incomplete contact and welding between the individual particles of gold. The amount of voids depends on the skill of the operator. Here, again, the direct AuCa alloy appears to display the least porosity.

X-ray diffraction tests, which indicate the co-existence of two phases in an eutectic structure and aids in their identification, were conducted on the AuCa at 1500° F. However, neither the light microscopic inspection nor the X-ray diffraction analysis showed any evidence for the presence of an intermetallic compound. The explanation for this surprising fact was found later on a spectrographic analysis showing that the AuCa alloy in the powdered form contained only approximately 0.1 wt% calcium. Evidently, during the manufacturing process, most of the calcium was being lost. This explains also why the sintering treatments at 1500, 1600, and 1700° F. did not lead to formation of a liquid phase.

According to Hansen[4], the eutectic between gold and the first intermetallic compound is at 1480° F., and 3 wt% Ca, and an alloy with 2 wt% Ca should form a considerable amount of liquid when heated above the eutectic temperature. The question in which way the remaining calcium influences the hardness of the gold remains to be answered.

Possible mechanisms are: solid solution strengthening, and, if the solubility limit is exceeded, direct dispersion strengthening through the presence of the finely dispersed intermetallic compound.[6]

Another strengthening effect can be the retardation of recrystallization, referred to as indirect dispersion strengthening.

More work, especially electron microscopy and electron microprobe studies, would be needed in order to clarify these questions.

## Conclusion

Direct AuCa alloys possess many properties that are desirable in a dental restorative material. When compared with gold foil and Goldent, the direct gold calcium alloy exhibited superior strength, and great ease of manipulation. From a clinical standpoint, adaptation to cavity walls by direct gold alloys appears excellent.

All the operators who cooperated in this study unanimously agreed that direct AuCa alloys handled with greater ease than the other materials tested. Auxiliary alloying agents seem to have an important role in improving the gold hardness and in influencing its physical properties.

This investigation has proven that the introduction of auxiliary metals, in particular calcium to gold, helps to stabilize the atomic arrangement, preventing the slip and increasing the hardness. In addition, this study has demonstrated that gold alloys can be welded or condensed as well as pure gold.

## Acknowledgement

The author wishes to express her gratitude to the participating members of the Operative Division for their cooperation, and to Williams Gold Refining Co., Inc., Buffalo, New York, for their generous contributions of gold alloys for this study. Acknowledgement is also due Dr. Robert B. Wolcott and Dr. James P. Vernetti for their counsel, and to Dr. Earl W. Collard for his participation in the testing procedures.

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Jack L. Hartley, D.D.S., M.S.
Morton Amsterdam, D.D.S.
Rex Ingraham, D.D.S.

# Ultraspeed instrumentation for atraumatic removal of tooth structure

There is increased concern for the incidence of pulpal reactions which may possibly be attributed to the mechanical procedures necessary for the removal of tooth structure. Although it is generally accepted that healing cannot occur without an initial inflammatory reaction, it is suggested that not all teeth which become post-operatively asymptomatic are necessarily healthy. Acute episodes, requiring endodontic treatment have occurred shortly after, six months or even 10 years after a restorative session.

Much of the pulpal damage has been properly attributed to the preoperative existence of a pathosis which was clinically non-symptomatic. There is no diagnostic instrument which will indicate a "half-sick" tooth. Heat, harsh medicaments, toxic restorative materials, leaking margins and improper functional occlusion have been extensively reported in the literature as contributing factors. Good studies, particularly on heat production and control, have appeared to conflict and present evidence both for and against the need for a cooling mist.

There is little question concerning the relationship between the depth of cut, specifically the remaining dentin, and the degree of pulpal injury. This relationship holds, whether the preparation is intra-

*Dr. Hartley is director of Consultants International, San Antonio, Texas, clinical associate professor of dentistry at the University of Missouri, visiting lecturer in periodontics at the University of Pennsylvania, and associate professor of fixed prosthodontics and consultant in dental materials at the University of the Pacific, San Francisco, Calif. Dr. Amsterdam is professor of removable prosthetics, University of Pennsylvania. Dr. Ingraham is chairman of operative dentistry, University of Southern California, Los Angeles, Calif.*

coronal and relatively small, but may be deep, or extracoronal and relatively shallow, but does involve a large percentage of the tooth. Here, the duration of the stressful input may be a factor.

Relatively less work has been accomplished on the possible input of stress to the pulp by the forces necessary to disrupt the molecular bond of enamel and dentin. The classic work of Kasloff revealed cracking and crazing of enamel by all types of rotating instruments. The ultraspeeds produced the least; diamond instruments at these speeds less than carbide burs. They did not attempt to relate this to pulpal histology or clinical significance.

Brannstrom related hydromechanical shock of cutting to pain, and high frequency movement of the tubular contents to pulp damage. Mumfold reported that hydrostatic pressure applied to human dentin produced an electric potential across the dentin with a low frequency or constant pressure. Rapid application and a higher pressure increased the potential difference. This leads us to postulate that not only amplitude, but frequency of the vibration or hydromechanical-hydrostatic shock can be a contributing factor of stress.

The condensation of gold foil, a low frequency input to the pulp was found to be biologically sound by Thomas, Stanley, and Gilmore. Their cavity preparations were at 3,000 to 5,000 rpm, with an intermittent pressure, a low frequency procedure.

To study the vibration and shock factors of dental milling and grinding, and to record actions occurring too rapidly for the eye, a high speed motion picture camera slowed actions which took place in less than 0.8 micro second, revealing that all blades of a bur rarely touch the tooth during a single rotation. As a single blade formed a chip of enamel or dentin, the resulting force caused the instrument to bounce away from contact, frequently completing a full rotation before retouching the tooth. In less violent excursions, two or three blades may strike the tooth before it again bounces. The chuck was rigid and concentric; the eccentricity while cutting could only be attributed to the bur. Cutting with a diamond did not show this bounce.

Further studies with the high speed camera were accomplished to determine the chuck effectiveness of major brands of air and ball bearing ultraspeed handpieces. These studies showed, by chucking the same centerless ground shaft of tungsten carbide in all handpieces, that those with plastic chucks were eccentric. Those with split metal chucks less, but not acceptable. The air bearing handpieces exhibited not only radial eccentricity, but vertical excursions when in contact with a tooth. The most concentric handpieces were those employing multiple jaws that placed and maintained a centering force upon the instrument while free-running and under vertical and radial loads.

A new technique accomplished by synchronizing the one-millionth second high intensity flash of a repeating strobe to the shutter of a sound motion picture camera synch-pulse generator permits a "real-time" study of ultraspeeds. The high speed motion picture camera records action which takes place only for a fraction of a second.

Stroboscopic macrocinephotography clearly shows the blades and diamond particles of instruments rotating at the ultraspeeds. In this study, burs and diamonds were recorded as they cut enamel, dentin, amalgam and gold. Eccentricity was greater when cutting with a bur than when grinding with a diamond. Eccentricity was greater when the instrument was chucked in a worn, dirty, improperly designed or flexible chuck-bearing assembly, which results when plastic or rubber is used to damp or reduce noise by isolating the bearing group from the handpiece.

A bone conduction microphone, placed over the mid-frontal bone of a human patient, recorded the amplitude and frequency of a known load, and the vibrations transmitted through the skull produced by cutting the same tooth with all types of handpieces. This was displayed on an oscilloscope. A determination of the approximate force required to break into enamel and dentin was then possible. The point of a carbide at ultraspeed is approximately 150 foot pounds per second/per second. A single diamond at the ultraspeeds is 30 foot pounds per second/per second. This may explain why we break burs and can snap off the lingual cusp of a bicuspid. An eccentric handpiece increases this force.

It appears to be possible for these forces to be great enough to constitute a definite hazard to the pulp through the mechanism of hydromechanical or hydrostatic transmission to the dental pulp.

Further work will be accomplished to attempt correlation with histopathological responses. It is not improbable that certain pathologic entities described in the literature as having been due to another input of stress or toxic reaction may have, in fact, been caused by the instrumentation employed to make the initial preparation for study.

To minimize mechanical shock: 1) select a ball bearing air turbine with a multiple-jawed chuck; there should be no lateral play of the chuck-bearing mechanism; 2) employ diamonds whenever possible; 3) when use of a bur is mandatory, select the smallest possible; 4) when closest to the pulp, use the lowest possible speeds or hand instruments.

Richard J. Elderton, B.D.S., L.D.S.
Alan Boyde, PhD., B.DS., L.D.S.

# Morphological observations of some direct filling golds

The direct filling of cavities in teeth with small pieces of gold has been practiced for several hundreds of years. Throughout this period the gold has been in the form of leaf or foil, though crystalline gold was being used as far back as 1853. While direct filling golds have been developed continuously, it appears that only since 1956, when Koser and Ingraham[1] published the technic of using mat gold for building up the bulk of restorations, have cohesive golds other than in foil form been widely accepted. This acceptance has since increased with the introduction of Goldent* in the United States in 1961[2] and may go further with the new Electraloy RV** which was presented to the profession in 1969.[3]

Classified by the shape of the gold particles, there are currently three main forms of 24 karat gold in widespread clinical use for compacted gold restorations These are gold foil, crystalline gold and powdered gold. The light microscope has been used to study these materials in both the non-compacted and compacted states[2,4,5,6,7] but the limitations of this instrument preclude the obstainment of clear pictures on account of poor depth of focus and limited resolution. The scanning electron microscope overcomes these problems[8]. Illustrations of the morphology of commercially available golds of the three types mentioned form the basis of this report.

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* *Morgan, Hastings and Co., Philadelphia, Pa.*
** *Williams Gold Refining Co., Buffalo, N.Y.*

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*Dr. Elderton is a lecturer at the Dental School, London Hospital Medical College, London. During 1966 to 1968 he taught at the State University of New York at Buffalo in the Operative Department. He is a member of the AAGFO, British Dental Association and British Society for Restorative Dentistry.*
*Dr. Boyde is with the Department of Anatomy, University College, London. He is a member of the IADR, Royal Society of Medicine and many other prominent professional societies.*

## MATERIALS AND METHODS

Specimens of gold were examined with the Cambridge Stereoscan scanning electron microscope and representative photo micrographs were recorded. The golds were examined in the condition they were received from the manufacturers except for the hand formed gold foil which was first prepared from No. 4 gold sheet* according to the method described by Gilmore[9]. In addition the outer foil coverings of the Goldent and Electraloy RV were teased open so as to enable examination of the material within.

## OBSERVATIONS

*Gold Foil.* The appearances of different forms of gold foil are shown in figures 1-4. Figure 1 shows the end view of a conventional manufactured cylinder*. In the higher magnification, in addition to porosity, grooving of the gold is visible, which was presumably imparted by the instrument that was used to cut the cylinder to length. Hand rolled gold (Fig. 2) has a more plain though crumpled appearance; the lack of machine marks (and consequent work hardening of the gold) may be one reason why this gold appears to be softer to condense and is therefore favored by those operators who have mastered the technique of rolling it from sheets.

A gold foil cylinder intended to be used in the non-cohesive state and wound from 32 thicknesses of No. 4 gold is shown at low magnification (in Fig. 3A). At higher magnification, a view across the laminations of laminated gold foil is shown (Fig. 3B). This represents a section through a cylinder, as laminated foil is folded from a sheet in the same manner but then cut to size with scissors instead of being formed into cylinders. Cutting marks and tearing of the gold are evident. The individual laminations are clearly visible, approximately 1 micron thick, and so correspond to the calculated dimension for No. 4 gold.

A cylinder of platinized gold** is shown in figure 4. As the gold and platinum are welded together during manufacture,[10] it is not surprising that the layers of the two metals cannot be differentiated with any degree of certainty.

*Crystalline Gold.* Mat gold*** is shown in figure 5, and Electraloy RV in figure 6. These materials, produced by the same company, were formed by electrolytic precipitation. They are very similar in appearance though the former is pure gold and the latter an alloy of gold and calcium (approximately 0.5%).[3] The dendritic structure of mat gold was not observed to be particularly treelike as described by Skinner and Phillips,[11] but perhaps resembles more the links of a chain. By compari-

(text continued on page 28)

* *Claudius Ash, Sons and Co. Ltd., London, England.*

** *Morgan, Hastings and Co., Philadelphia, Pa.*

*** *Williams Gold Refining Co., Buffalo, N.Y.*

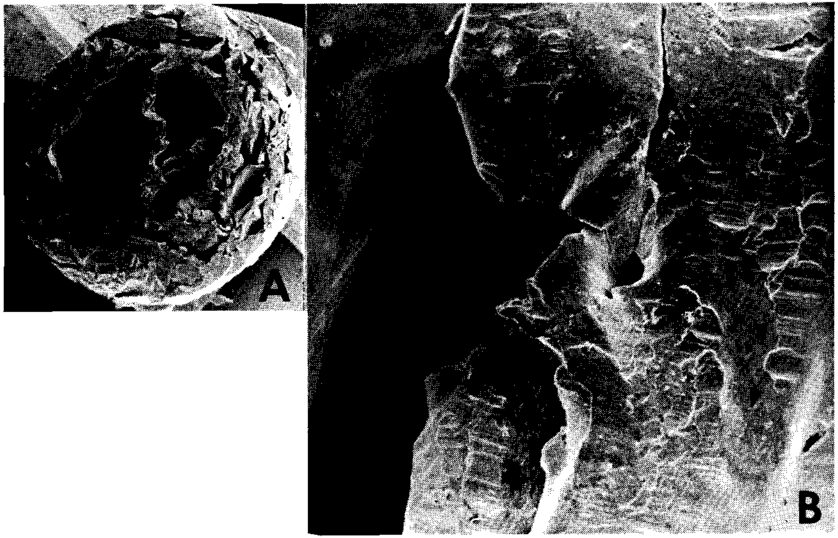


*Fig. 1 — End view of manufactured gold foil cylinders, A (above), x15; B (right), x2100.*

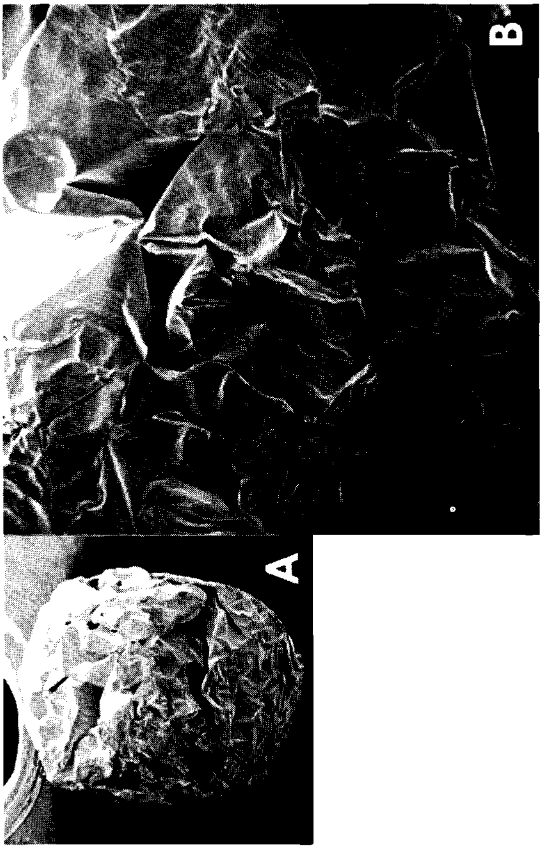


*Fig. 2 — Hand rolled gold foil pellet, A (above), x17; B (right), x105.*

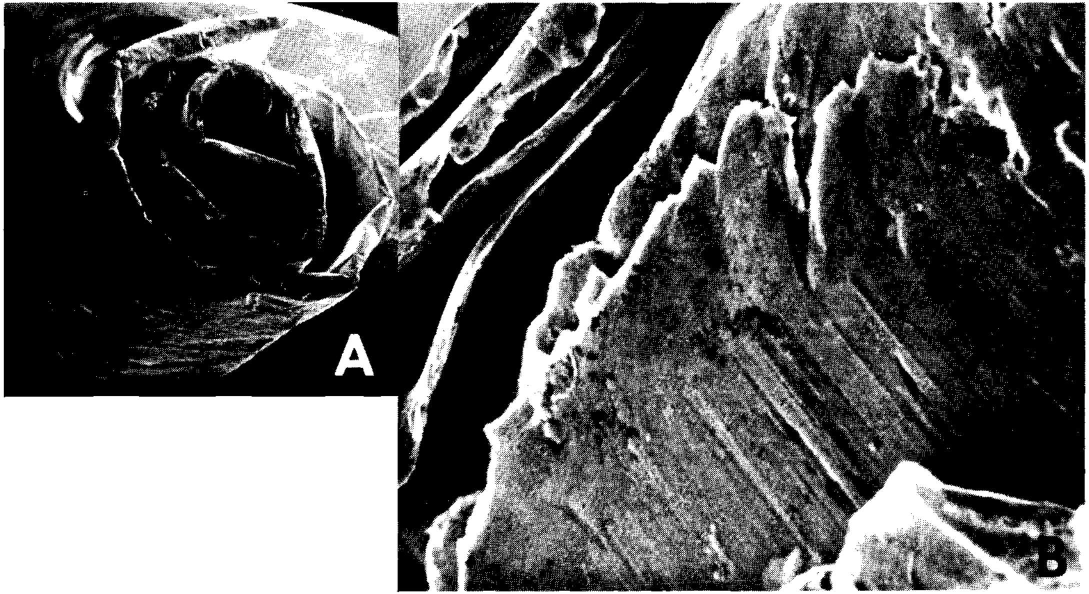


*Fig. 3 — 3A (above), Gold foil cylinder for non-cohesive use, x15; B (right), section through laminated gold foil, x2140.*

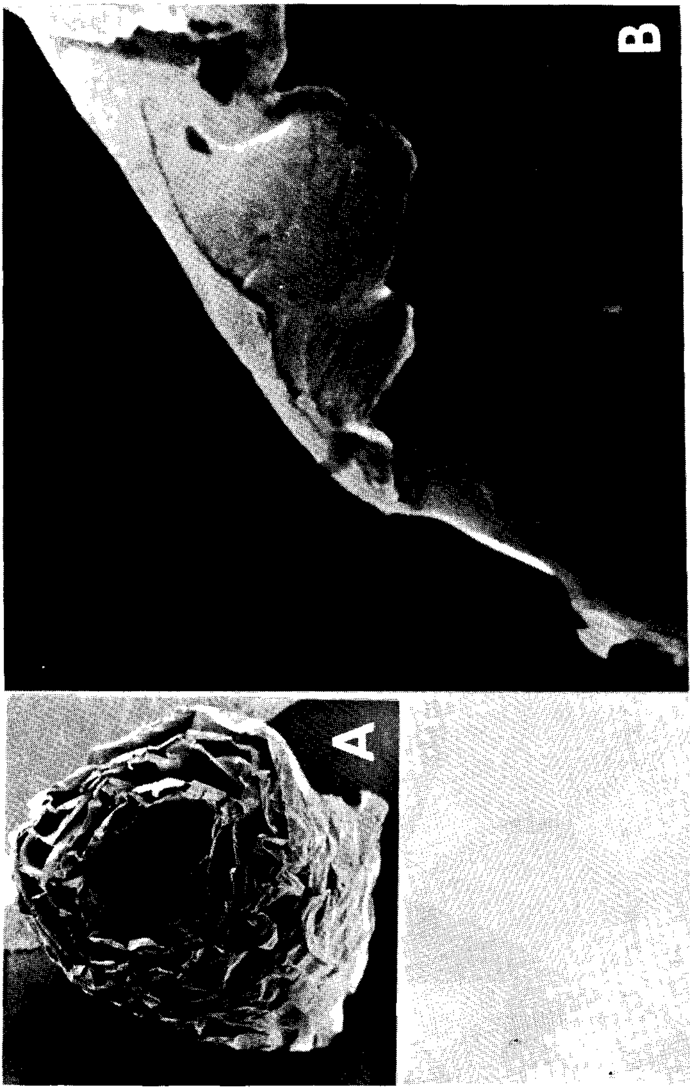


*Fig. 4 — End view of platinized gold foil cylinder, A (above), x15; B (right), x5100.*

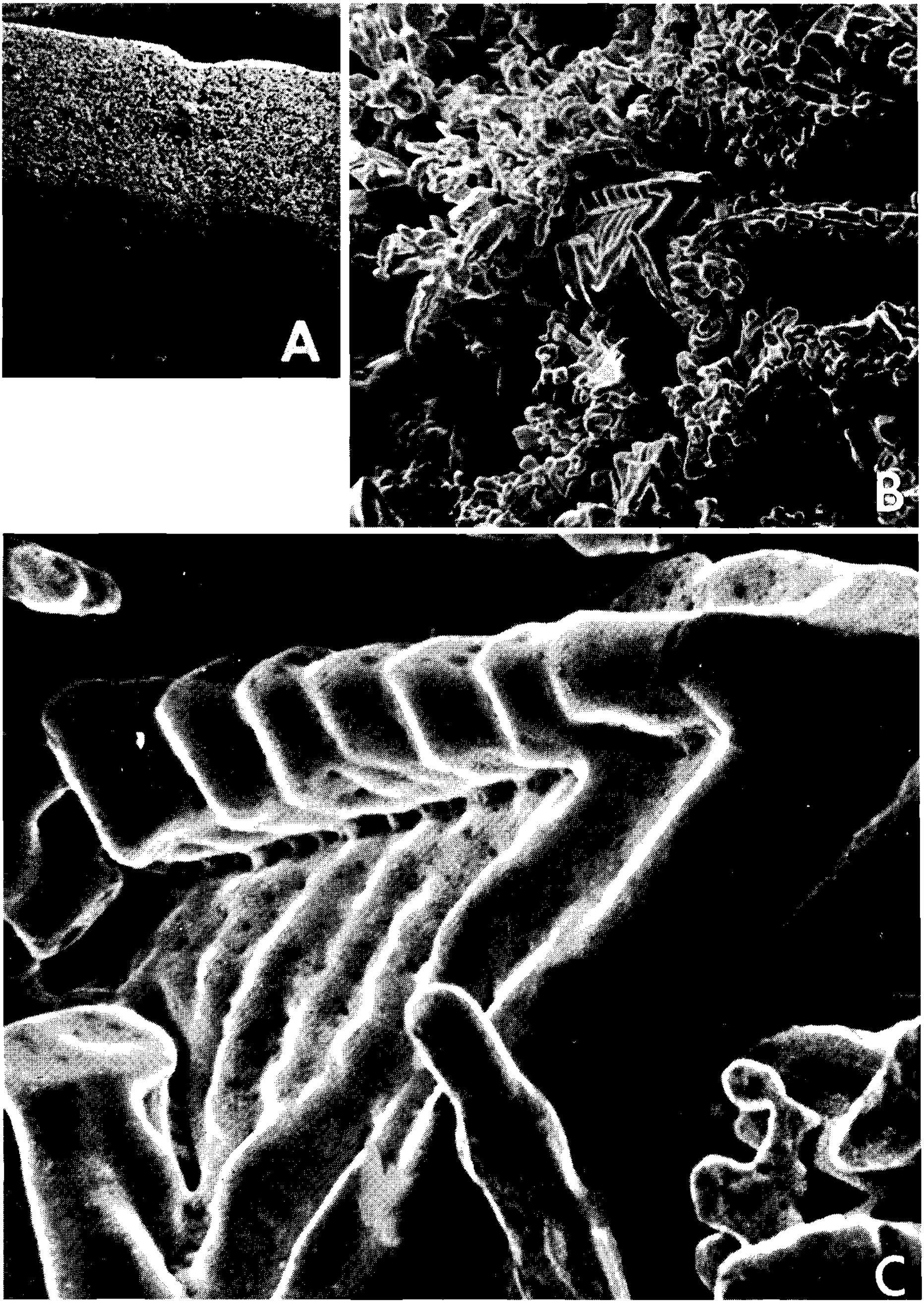


*Fig. 5 — Mat gold, A (above), x12; B (right), x440; C (below), x3200.*

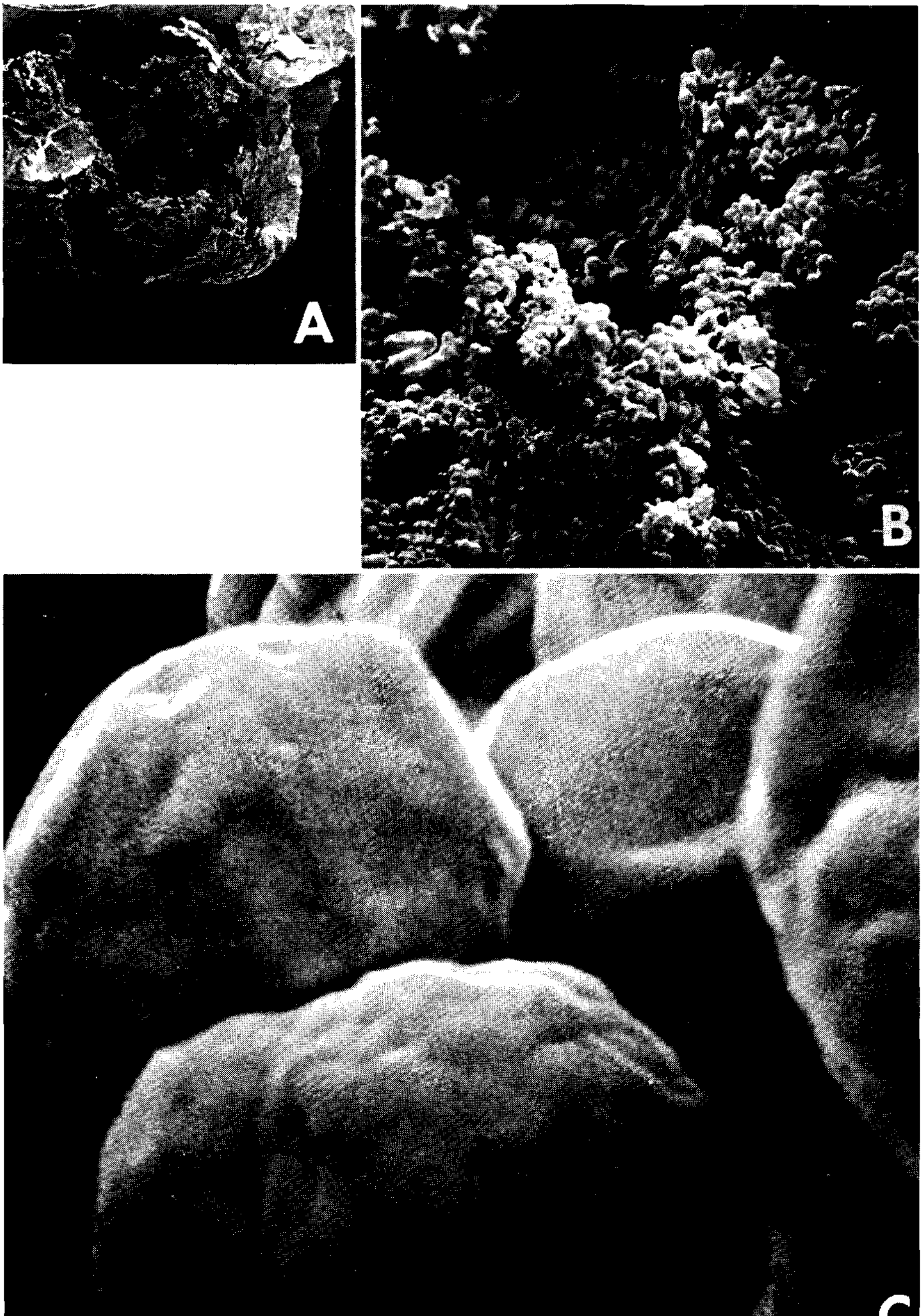


*Fig. 6 — Electraloy RV, A (above), x27; B (right), x830; C (below), x7500.*

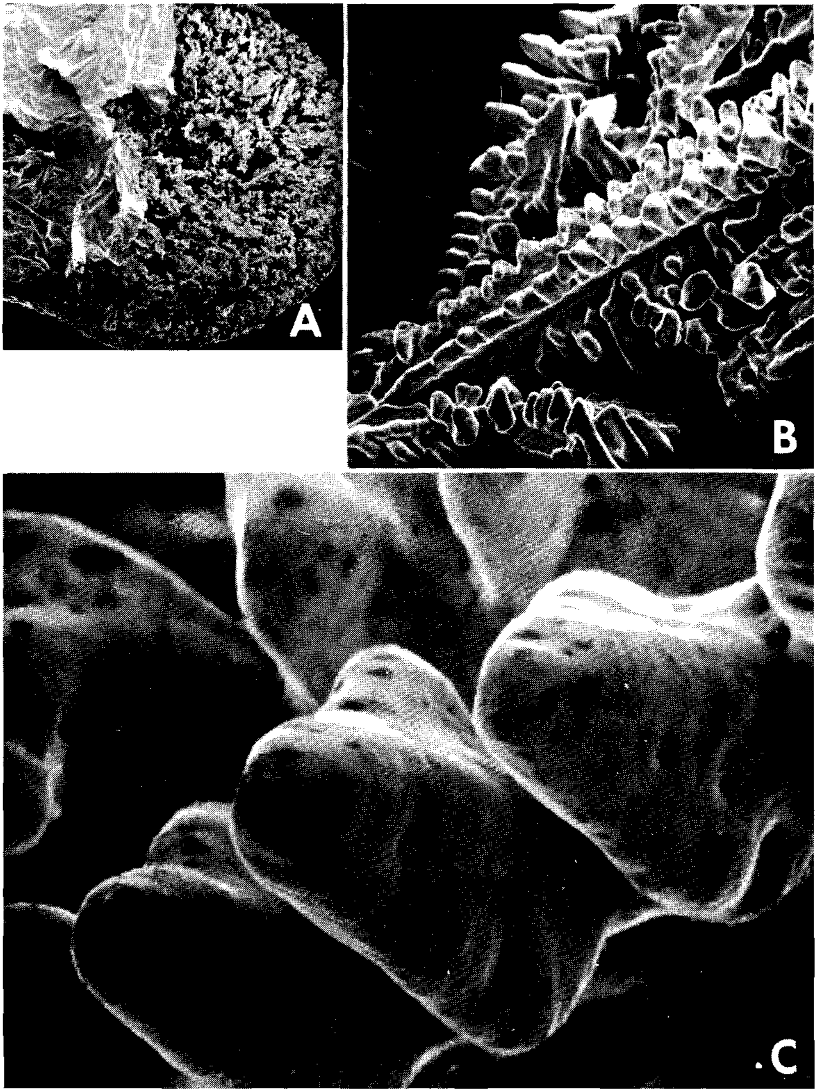


*Fig. 7 — Goldent, A (above), x12; B (right), x410; C (below), x15000.*

(continued from page 20)

son, the Electraloy RV has a more ordered appearance. The dendrites are more perfectly formed and the crystals have coalesced to a lesser extent. Pitting of the surface of both of these golds is clearly visible, probably resulting from gas evolution during formation.

*Powdered Gold.* Goldent is shown in figure 7. This gold is formed by atomization followed by sintering to cause the particles to clump together. Most of the granules have an overall spherical shape, though under the highest magnification an indented appearance is evident. In 1963 Baum, Collard and Lund[2] gave an average particle size of 15 microns (range: 2 to 150 microns), as measured with a comparator microscope. Under the scanning electron microscope we observed spherical particles in the range of 1 to 10 microns. A few larger particles were present (up to 25 microns) but these were of irregular shape. No surface pitting of the gold was observed.

## CONCLUSIONS

The scanning electron microscope provides a means by which the morphology of direct filling golds may be determined. Examination of golds in current clinical use has provided basic information about these materials and shown differences in morphology which are clearly related to the different methods of manufacture. The currently described observations are being applied to work which is at present underway involving the study of restorations after their removal from the cavities into which they were condensed. It is hoped that this will form the basis of a further report.

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Harold R. Stanley, B.S., M.S., D.D.S.

# The protective effect of reparative dentin and how it compares to man-made liners

Nature usually seals cut, damaged, or diseased dentinal tubules at the pulpal surface with endogenously formed reparative (irregular, atubular) dentin. The pulp tissue beneath such dentin is generally safe from most subsequent dental procedures (Fig. 1). When one is in doubt as to the uniform presence of reparative dentin beneath an area of restoration, exogenous substances must be employed to seal or plug opened dentinal tubules peripherally. Few exogenous products can match the qualifications of reparative dentin, tubule for tubule, for performing this task. But how to predict the completeness of the reparative dentin barrier is a real problem.

Frequently in younger patients, regeneration of odontoblasts will lead to such differentiation of mesenchymal cells that new dentinal tubules will again form. Empty vascular spaces, once supporting capillaries that formerly provided nourishment to an area where matrix formation was taking place, will also persist and permit the penetration of subsequently placed toxic products into the subjacent pulp. Carious penetration can also be so devastatingly rapid that the potential for the continual regeneration of odontoblasts to form reparative dentin is either partially or completely aborted and the quality of the matrix formed is so inferior that a potential barrier does not really exist. However, teeth that have been abraded or eroded over a period of years, or have possessed restorations for long periods of time will have had sufficient time to produce a solid wall of reparative dentin that is capable of resisting the most irritating episodes, whether physical or chemical (Fig. 2). One must not compare a thin and porous reparative dentin bridge formed in several weeks from a calcium hydroxide application with similar barriers which have thickened over a period of years. Certainly isotope or dye perfusion

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*Dr. Stanley is Chairman, Division of Oral Pathology, College of Dentistry, University of Florida.*
*This paper was presented at the meeting of the American Dental Association in New York, October 1969.*

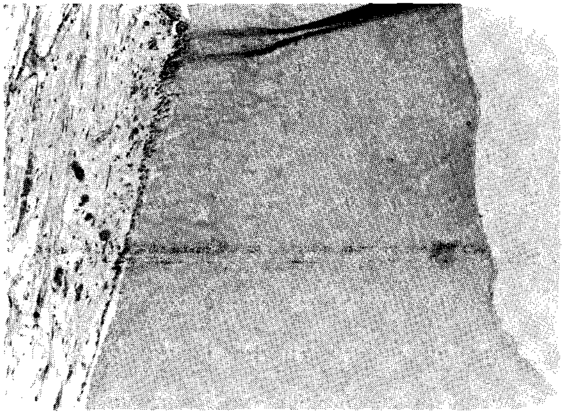

*Fig. 1 — Preoperatively formed reparative (irregular) dentin has prevented the development of a pulpal response six days after a Class V cavity preparation with a #37 diamond stone and an air-water spray at 20,000 rpm and ZNOE restoration. Some tubular formation can be observed in the reparative dentin. The thickness of remaining dentin, including both primary and reparative types, is approximately 0.5 mm.*

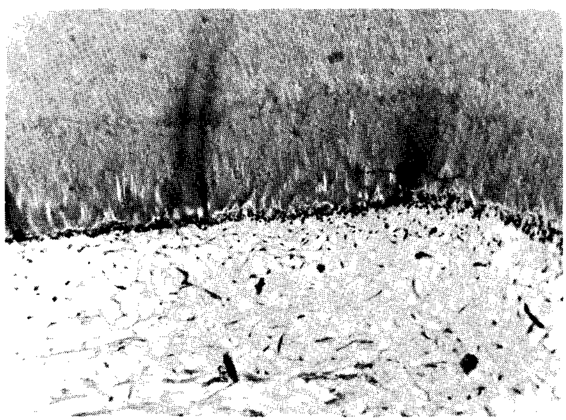

*Fig. 2 — Preoperatively formed reparative (irregular) dentin has prevented the development of a pulpal response three days after a Class V cavity preparation with a #35 inverted cone carbide bur and an air-water spray at 300,000 rpm and silicate restoration. No cavity liner or base was placed before the insertion of the silicate cement. Some tubular formation can be observed in the reparative dentin. The thickness of remaining dentin, including both primary and reparative types, is approximately 0.6 mm.*

studies will show the inadequacy of dentinal bridges formed during brief postoperative periods.

Despite the controversy regarding the barrier potential of reparative dentin, the modern clinician and especially those performing full-mouth care have found that postoperative pulpitis and pulp death result less frequently if they temporize fixed restorations for several months with zinc oxide-eugenol cement before the final cementation with zinc phosphate cement. The rationale for this thinking is attributed to the belief that the permanent cementation should be delayed until reparative dentin forms beneath the patent dentinal tubules which were cut at the time of preparation. The seepage of irritating substances like phosphoric acid into the pulp tissue will thus be prevented. This problem has become more significant during the high speed era because the mildly traumatic high-speed, water-cooled cutting technics have greatly decreased the incidence rate of reparative dentin formation.[1]

The full-mouth rehabilitationist is the one who complains that the unrestored tooth is the one that succumbs to crowning, rather than the old much restored tooth. The pulp of the repeatedly restored tooth is almost completely covered with reparative dentin, whereas the pulp of the unrestored tooth prepared for crowning presents millions of patent tubules capable of transporting toxic products directly into the pulp tissue.

Statistical analysis has substantiated the fact that the amount of remaining dentin beneath the cavity preparation plays the most important role in the incidence and the intensity of pulp responses to cutting procedures.[2]

The point should be stressed again that the response to cutting and restorative procedures occurs mainly in areas beneath freshly cut dentinal tubules not lined with reparative dentin. Generally, 2.0 mm of primary dentin thickness between the floor of the cavity preparation or the surface of a crown preparation and the pulp will provide an adequate insulating barrier against the more traumatic thermogenic cutting technics and several restorative materials. As this dentin thickness decreases in value the pulp response increases.[3] Occasionally, the condensation of amalgam or gold foil and the application of silicate cement can overcome the protective effects of this thickness of remaining dentin. The effluent from the self-curing composite resins can readily penetrate all remaining dentin regardless of thickness[4] and on rare occasion even reparative dentin (Fig. 3).

Reparative dentin, acting as an additional protective barrier, is capable of scattering excessive frictional heat to the point that burn lesions do not occur. Even when the floor of the cavity preparation rests within the reparative dentin itself, a near pulp exposure, the response to cutting procedures is still minimal.[5] When lacking tubular structures or cellular or vascular inclusions, reparative dentin also prevents the penetration of the majority of the toxic components of restorative materials.

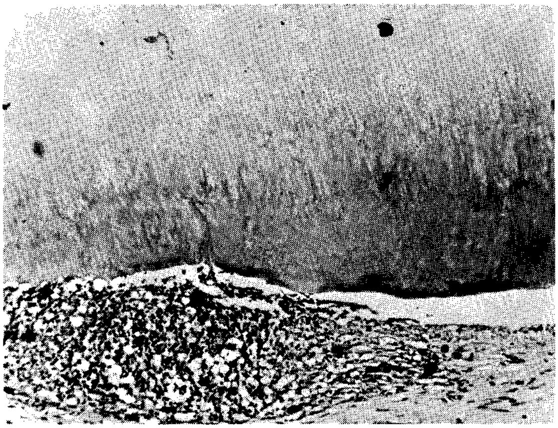

*Fig. 3 — Preoperatively formed reparative (irregular) dentin has not prevented the development of a prominent pulpal response three days after a Class V cavity preparation is a #34 carbide bur, #557 and # 1/2 steel burs and air at 4-6,000 rpm and restoration with a composite restorative material without a liner material. This cutting technique produced little or no pulpal reaction beneath primary dentin when preparation was restored with ZNOE. Evidence of tubular formation in the reparative dentin is very minimal. The thickness of remaining dentin, including both primary and reparative types, is approximately 0.5 mm.*

Age in itself, as manifested in the form of tooth hardness, sclerosis or decreased permeability, apparently provides no obvious protection to the pulpal tissues subjacent to cavity preparation except in older teeth where the pulpal horns or occlusal portions of the pulp chambers are filled with reparative dentin. The contribution of the aging process is too slight to be recognized when one considers the overwhelming effects of remaining dentin thickness. When reparative dentin is not found in older teeth, the intensity of the response is not modified as compared to younger teeth.[6]

Therefore, dentists should have a concerned interest in the incidence and rate of reparative dentin formation resulting from various restorative procedures. In a study evaluating the incidence of reparative dentin formation from cavity preparation, with low and high-speed technics, the incidence for any high speed, water-cooled technique ranged from 8.5 to 33.3% with an average rate of 18.7%.[1] The greater the thickness of the remaining dentin beneath the cavity preparation the less the chance of reparative dentin being formed. Any high speed drilling technic leaving behind a millimeter or more of primary dentin produced an incidence of less than 15.0%. If the initial trauma was not severe enough to destroy the primary odontoblasts either by inflammation or degeneration, reparative dentin formation was not found as late as six months after cavity preparation. If the injured pulp is not stimulated to form reparative dentin within the first fifty days reparative dentin will not form that particular traumatic episode, whether due to cutting procedures or restorative procedures.[1]

A recent human study demonstrated that little reparative dentin occurs in man before a postoperative period of 30 days.[7] Only in three instances did reparative dentin occur earlier, one at 19 days and two at 27 days. Since no reparative dentin was found prior to 19 days it is possible that this amount of postoperative time is the minimum time required for undifferentiated mesenchymal cells to differentiate into matrix forming odontoblasts.

During the first three weeks of matrix production, the rate of daily deposition averaged 3.5 microns. For the next three weeks the daily rate averaged 0.74 microns and the next eight weeks 0.23 microns. After this period further deposition was not detectable. The average daily rate for the entire study was 1.49 microns.[7] This means that if the cutting technic used left more than one millimeter of remaining dentin, that technic should produce an incidence of reparative dentin formation of 15%. If the particular tooth under treatment happens to represent the right tooth (the one in six or seven statistically), to form the reparative dentin, then after 119 postoperative days (approximately four months) a reparative dentine barrier of approximately 150 microns (0.15 mm) would have formed. Remember that only 100 days of the 119 postoperative days represent actual time for potential matrix formation.

Since the incidence of reparative dentin is so low with the high speed, water-cooled technics, even after extended periods of time, dentists are being unrealistic to wait for reparative dentin to form, especially when only one tooth in six will probably do so. The biologic variation concerned with reparative dentin formation is too great to permit an educated guess as to which tooth will be the one to form the reparative dentin. A more practical approach is to apply an adequate and effective cavity lining material.

According to Going[8] a cavity lining material should 1) protect the pulp from thermal shock, 2) insulate against the galvanic action inherent in all amalgam restorations, 3) inhibit the penetration of mercury from silver amalgam restorations into the underlying dentin and thus prevent discoloration of the tooth, 4) provide an anodyne effect on the pulp, 5) provide some degree of antibacterial activity to sterilize the underlying dentin and the residual decay of deep carious lesions, 6) neutralize the acid of silicate cements and finally 7) reduce marginal leakage around restorations, thus limiting also the diffusion of bacterial toxins and soluble ions of all types into the underlying dentin and pulp. One can readily appreciate that a barrier of reparative dentin is capable of fulfilling many of these criteria.

Calcium hydroxide is thought most effective in neutralizing the free acid from the silicate gel. Because there is some question as to how completely this is accomplished, some clinicians propose that both calcium hydroxide and zinc phosphate cement be used under the silicate restorations.

Copal resin varnish (Copalite)* is the most effective liner under amalgam, limiting marginal penetration of all radioisotopes to a superficial depth and thus eliminating dentin penetration completely. Mizzy Poly-liner** and calcium hydroxide liners are effective in preventing penetration of radioactive ions into the dentin and the pulp, but zinc oxide and zinc phosphate cements are not.

Gilmore[9] states that cavity varnish when used with amalgam acts as an inert layer and a mechanical plug and together with the formed oxides, decreases leakage, postoperative sensitivity and inflammation. Cavity varnish is too thin for thermal insulation, but in cementing procedures it is capable of preventing the "sting" of phosphoric acid.

In 1964 Going[8] said that calcium hydroxide liners should be confined to the deepest portion of the cavity preparation and that the adjacent dentin be coated generously with Copalite varnish. However, with the advent of the self-curing composite resins which dissolve cavity varnish, it is now necessary to coat all dentin with calcium hydroxide agents[9]. The new calcium hydroxide compounds are slightly alkaline and have a high degree of flow. Manipulation of preparations of calcium hydroxide is quite easy because small tubes of catalyst and base are used. The compounds are detectable on radiographs, are water soluble, and exhibit low strength. Only a thin layer is placed since thick applications can crumble.

In a study to evaluate the effect of crown cementation on primary dentin with patent tubules, previously unrestored teeth received full crown preparations with a nontraumatic, high speed, water-cooled drilling technic[10]. Aluminum shell crowns, or self-curing resin crowns, were cemented over the prepared teeth. The control specimen crowns were cemented with zinc oxide-eugenol; the experimental specimens with zinc phosphate cement of silicate cement. Some preparations were first coated with either Pulpdent** liquid or Copalite.

When the crowns were cemented with zinc phosphate or silicate cement directly over the freshly cut primary dentin, without the use of an appropriate liner, moderate to severe lesions occurred with considerable involvement of the deeper tissues. When either Pulpdent liquid or Copalite was used as a lining material, the pulp response was either greatly reduced or remained similar to the control specimens.

A cavity lining material (No. 1930)* was also developed by the 3M

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* *Harry J. Bosworth Co., Chicago, Ill.*

** *Pulpdent Co. of America, Boston, Mass.*

Company[4] to protect the pulp from potentially harmful ingredients in Addent.** This liner is a film forming synthetic vinyl copolymer dissolved in acetone which is impermeable to water and the monomeric and catalytic fractions of the composite resin. The Addent cavity lining material seemed to provide some protective function to the pulp tissue but not enough to guarantee the desired protection.

Addent and similar composite resin products can be used safely in old cavity preparations where reparative dentin has previously formed. It may also be used in preparations involving virgin tubules when calcium hydroxide lining materials are used to seal all the newly opened dentinal tubules prior to insertion of such restorative materials.[11]

## SUMMARY AND CONCLUSIONS:

1. Generally, pulpal tissue beneath preoperatively formed reparative dentin is safe from most subsequent dental procedures.
2. Clinically, however, one cannot predict the completeness of the reparative dentin barrier. Therefore, liners and bases (or cavity lining materials) must be employed.
3. The unrestored tooth, lacking reparative dentin and being utilized as an abutment, is more subject to the damaging effects of chemical agents because of patent dentinal tubules.
4. Although 2.0 mm of primary dentin between the floor of the cavity preparation and the pulp is usually a sufficient protective barrier against cutting technics, the condensation of amalgam and gold foil and the effluent of cements and self-curing resins can over-come this thickness of protection.
5. Age changes of themselves, without the concomitant production of reparative dentin in the involved area, is of no recognizable benefit to the pulp.
6. High speed, water-cooled, cutting technics produce an average incidence of reparative dentin formation of only 18.7%. Less is produced if more than one millimeter of primary dentin remains beneath the cavity preparation.
7. If reparative dentin does not form within the first 50 days following a restorative procedure reparative dentin will not form from that particular episode.
8. A minimum of 19 postoperative days is required for new odontoblasts to differentiate and produce reparative dentin matrix. On the average, 100 productive days of matrix formation is required to produce a reparative dentin barrier of 0.15 mm.
9. Considering these biologic conditions clinicians no longer need to temporize for months before final cementation if the reason for

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* *Minnesota Mining and Manufacturing Co., St. Paul, Minn.*
** *Mizzy Inc., Clifton Forge, Va.*

waiting is to allow time for reparative dentin to block patent dentinal tubules. The use of cavity lining materials is a reasonable substitute solution.

10. Varnish and calcium hydroxide lining materials appear very capable of protecting the pulp tissue when appropriately used.

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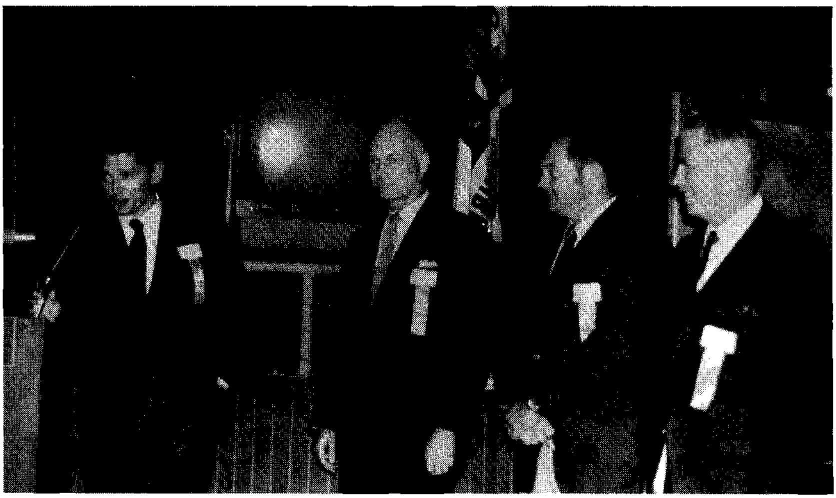
# Annual Meeting


*Mr. John Wooden, famous basketball coach of the UCLA Bruins, was the featured speaker at the Annual banquet of the Academy held in Los Angeles. Pictured also is Mrs. Robert Caldwell, wife of the Dean of the School of Dentistry at UCLA.*



*New offiicers were presented at the Annual Meeting by Bruce Smith, first President of the Academy. From left to right: Ian Hamilton, president-elect; Hunter A. Brinker, secretary-treasurer; George W. Ferguson, president.*

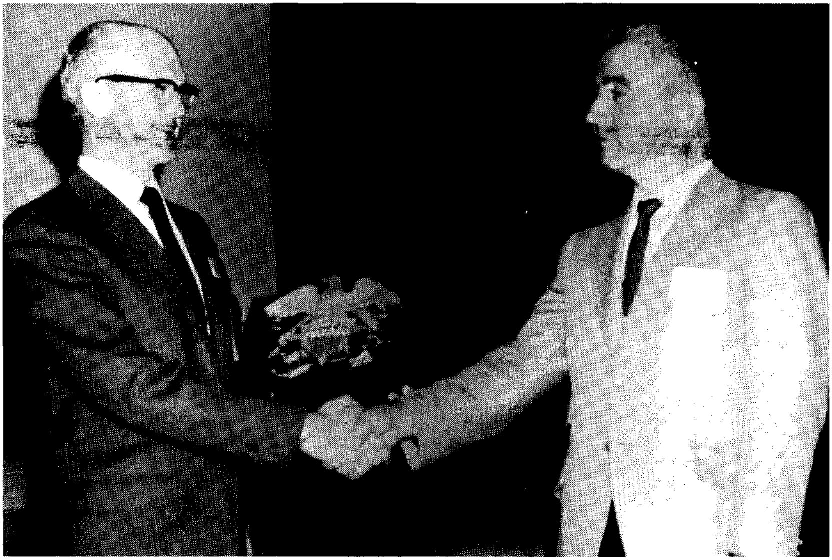
# Honors

Honoring Ralph Edgerton Plummer, D.M.D., F.A.C.D.

In recognition and appreciation of his devotion to the advancement of Science and Arts of Dentistry . . . especially for his many years in the field of gold foil instruction . . . his patience and unselfishness in assisting others to perfect operative techniques . . . his devotion to the teaching and guiding of those who seek his wise and ready counsel.

*Presented by* the G. V. Black and University Ferrier Seminar Groups at the Annual Meeting of Associated Gold Foil Study Clubs of Washington and British Columbia, May 1, 1970.

# Awards



Dr. Gerald D. Stibbs, Head of Operative Dentistry, University of Washington, was honored at the Annual Meeting by his former students, now graduates serving in the Naval Dental Corps. The officers presented him with a plaque in appreciation of his skill and leadership in their education in restorative dentistry, which has contributed to the advancement of naval dentistry. Dr. L. V. Hickey, DC, USN, Head, Operative Dentistry Department, Naval Dental School, National Naval Medical Center, Bethesda, made the award.

*The name of the student listed below was inadvertently omitted from the list of Recipients of Student Awards in the previous issue:*
*James Jay Mangle — University of Illinois*

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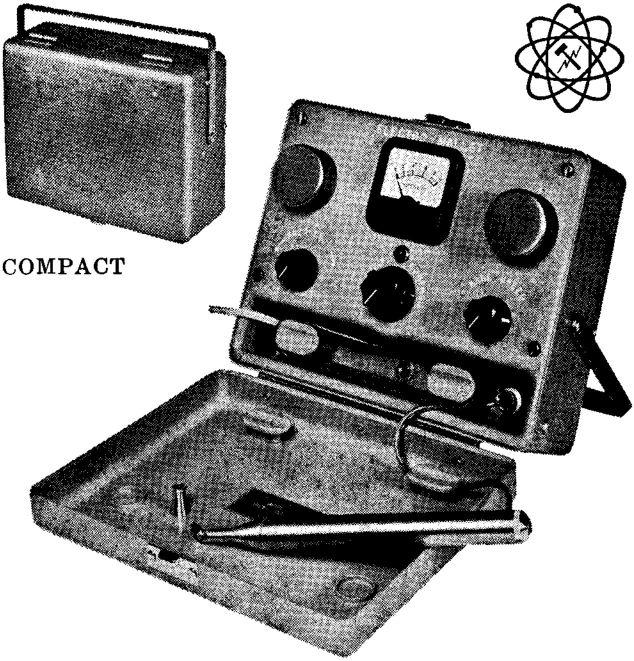
## CATEGORICAL INDEX

# ELECTRO - MALLET

## *The Electronic Foil Condenser*



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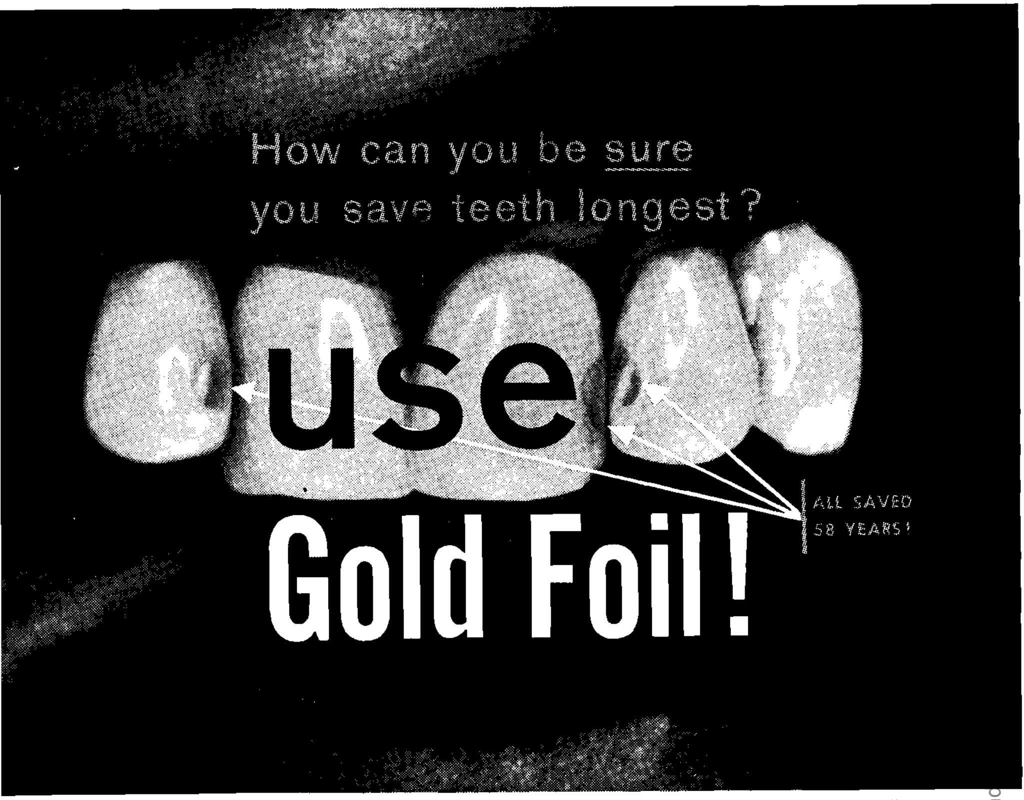


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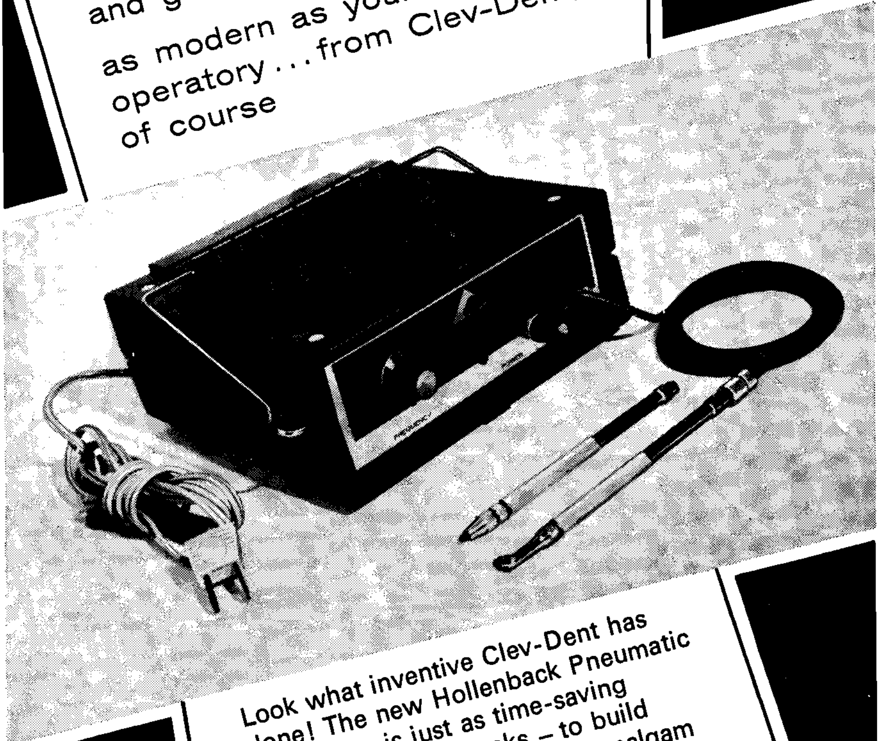

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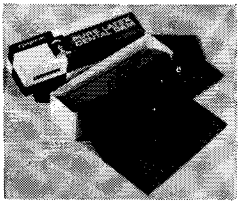

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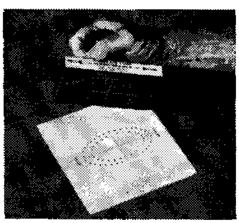

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