Compressive Properties of Enamel, Dental Cements, and Gold

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The compressive properties of human enamel and dentin have been reported by Stanford, Paffenbarger, Kumpula, and Sweeney.[1] The elastic modulus of occlusal, side, and cusp enamel was reported to be 1.8, 6.0, and 8.2 $\times 10^6$ psi, respectively. The corresponding values for the proportional limit were 16,800, 21,000, and 34,200 psi and, for the compressive strength, 19,400, 28,300, and 40,200 psi.

An improved procedure for preparing compressive specimens of hard tooth tissues and some restorative materials was published by Stanford, Weigel, Paffenbarger, and Sweeney.[2] The compressive properties of enamel were within the experimental error of the earlier values, and additional values relating compressive properties to environment of development and orientation were reported. In addition, the compressive properties of plastics, amalgam, silicate cement, zinc phosphate cements, and dental golds were listed.

Tyldesley[3] determined the mechanical properties of enamel by using a transverse type of loading system. The elastic modulus of enamel was reported to be 19 $\times 10^6$ psi in bending. The proportional limit and compressive strength were found to coincide at an average value of 11,000 psi.

The published values for the compressive strength of enamel appear low when compared with the values listed for human dentin. Craig and Peyton[4] reported an average compressive strength for dentin of 43,100 psi; Stanford *et al.*[1] gave a value of 50,400 psi; and Tyldesley[3] published a value of 38,800 for the breaking stress. The highest average compressive-strength value of 40,200 psi reported for cusp enamel is, in general, lower than those reported for dentin.[1, 2] These results do not appear reasonable when the hardness and general working characteristics of enamel and dentin are compared.

The principal purpose of this investigation, therefore, was to re-evaluate the compressive properties of proportional limit, compressive strength, and elastic modulus of human enamel, using improved procedures for sample preparation.

In addition, the dental literature included little information concerning the compressive properties of restorative materials measured on specimens approaching the size normally used in dentistry.[2] Investigations of the effect of sample size on the compressive properties of amalgam indicated that higher values were obtained with smaller specimens. The second object of this study, therefore, was to determine the compres-

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sive properties of small specimens of silicate cement, zinc phosphate cement, and dental gold and to compare these values with those obtained on large test specimens.

MATERIALS AND METHODS

Enamel.—Freshly extracted human teeth, generally mandibular first molars, were used as the source of enamel because the enamel is reasonably thick on the buccal portion of these teeth. Since the method of sample preparation is of prime importance in obtaining accurate compressive properties, a detailed description of the procedure will be given.

The teeth were mounted in a cup containing impression compound such that the cusp or side of the tooth selected for sampling was parallel to the proposed axis of the specimen. The cup was designed so that it could be mounted on the tail stock of a jeweler's lathe. A hollow, diamond core was placed in the head stock of the lathe and a cylindrical blank was cut out of the tooth, using water as a coolant. These blanks were approximately 0.060 inch in diameter and consisted of enamel on one end and dentin on the other. The core drill cut into the surface of the tooth at a right angle, and therefore the general direction of the enamel rods was parallel to the long axis of the cylinder.

The enamel end of the specimen was placed in the chuck of the jeweler's lathe, and the dentin end was machined to 3/64 inch (0.0468 inch), using a tungsten carbide tool. The dentin end was then placed in a 3/64-inch collet and the enamel end machined to 1/32-inch (0.0312 inch) in diameter. It was necessary to avoid the use of a center tip on the enamel end because the pressure of the tip caused splitting of the specimens.

After the enamel end had been machined to 1/32 inch diameter, the dentin portion was cut off. The enamel specimen was placed in a 1/32-inch collet and the ends ground off flat and parallel with an India stone and a lathe grinding attachment. The grinding operation was arranged so that it always took place from the edge toward the center of the sample, thus avoiding specimens with chipped edges. All the previous operations were carried out with water as the coolant.

The specimens were examined microscopically for any flaws, and, if none were found, the samples were stored in distilled water until the determination of the compressive properties.

Attempts to prepare enamel specimens with the rod direction perpendicular to the long axis of the cylinder have so far met with failure. Since in normal mastication the compressive forces are generally applied in the direction of the enamel rods or on the ends of the rods, the specimens prepared should yield information related to clinical experience.

Silicate and zinc phosphate cements.—A tapered, single-unit, stainless-steel mold was used to prepare blanks for silicate and zinc phosphate cement specimens. The mold yielded specimens that were about ⅛ inch in diameter and 11/16 inch long. Cylinders were prepared from these blanks in a manner similar to that described for enamel. The finished silicate cement specimens were ⅛ inch (0.0125 inch) in diameter and varied from 5/16 to ⅜ inch long; filling porcelain* was used with a powder/liquid ratio of 1.43 gm/0.4 cc.

* S. S. White Co., Chicago, Ill.

The zinc phosphate samples were more difficult to prepare than the silicate cement samples, and therefore the diameter was increased to 5/16 inch. The specimen length again was approximately ⅜ inch. The cement* was used in two consistencies. Inlay-consistency mixes were prepared with 1.1 gm. of powder for 0.5 cc. of cement liquid, and the base-consistency mixes contained 1.85 gm. of powder for 0.5 cc. of cement liquid.

Gold.—Castings were prepared from partial denture gold,† using the water-added casting procedure. The gold was quenched when the sprue button ceased to show a red glow. Gold cylinders, 0.080 inch in diameter and ¾ inch long, were cast. Specimens were machined from the cylindrical blank with the jeweler's lathe and a tungsten-carbide tool. The dimensions of the specimens were 0.078 inch in diameter and 0.28 inch in length. It was not possible to use the grinding procedure in preparing the ends of the cylinders because of smearing of the gold. The ends were machined with the tungsten-carbide cutting tool.

The partial denture gold specimens were subjected to the following hardening heat-treatment procedure. The specimens were placed in a 50–50 $NaNO_3$-KNO_3 bath for 15 minutes at a temperature of 350° C.

Compression testing.—The proportional limit, compressive strength, and elastic modulus of the various samples were determined by the procedure described by Craig and Peyton[4] in a study of human dentin. The specimens were placed between two steel plungers, the deformation was obtained from optical strain gauges, and the load indicated by a Reihle Testing Machine. Corrections were applied to the measured strain for the deformation resulting from the shortening of the steel plungers and foundation effects as previously described.[4]

The stress-strain curves for enamel were obtained, using a discontinuous loading rate. The load was increased in increments and the strain measured at these intervals. This procedure was possible, since no flow of enamel was observed, as had been the case with human dentin.

The deformation rate used in the determination of the compressive properties of silicate cements was 0.015 inch/minute. The deformation rate for the zinc phosphate cements and gold specimens was 0.01 inch/minute.

RESULTS

Enamel.—The compressive properties of human cusp enamel are listed in Table 1 and those for side enamel are reported in Table 2. In each case, the general direction of the enamel rods was parallel to the long axis of the cylinder. Also listed in the tables are the length/diameter ratios of the various samples. The majority of the length-to-diameter ratios for cusp enamel was greater than 2, since the enamel in the cusp portion of a tooth is reasonably thick. The side enamel specimens, however, all had ratios less than 2 because of the thinner enamel layer on the side of a tooth. It was possible, however, to obtain ten specimens having a length-to-diameter ratio greater than 1.4; the remaining seven specimens had ratios ranging from 1.06 to 1.36.

The proportional limit of cusp enamel varied from 30,600 pounds/square inch (psi) to 64,800 psi, and an average value of 51,200 psi was obtained for specimens having a

* L. D. Caulk Co., Milford, Delaware.

† J. F. Jelenko & Co., Inc., New York, and the J. M. Ney Co., Hartford, Conn.

TABLE 1

COMPRESSIVE PROPERTIES OF HUMAN ENAMEL

SAMPLE	CUSP ENAMEL			LENGTH/ DIAMETER
	Proportional Limit (Psi)	Ultimate Compressive Strength (Psi)	Elastic Modulus (Psi $\times 10^{-6}$)	
1..........	53,900	55,200	12.3	3.00
2..........	40,900	44,200	11.1	2.63
3..........	48,800	59,000	12.5	2.37
4..........	62,200	66,700	13.2	2.32
5..........	30,600	33,200	9.6	2.14
6..........	57,400	63,800	13.6	2.08
7..........	64,800	74,400	12.7	2.01
8..........	....	48,800	12.8	2.00
9..........	....	67,100	10.9	1.88
10..........	33,400	39,000	9.1	1.85
11..........	39,500	43,400	11.3	1.68
12..........	41,200	50,700	13.9	1.56
Av.*....	51,200	55,700	12.2×10^6 $\pm0.9\times10^6$	....

* Includes samples with l/d equal to, or greater than, 2.

TABLE 2

COMPRESSIVE PROPERTIES OF HUMAN ENAMEL

SAMPLE	SIDE ENAMEL			LENGTH/ DIAMETER
	Proportional Limit (Psi)	Ultimate Compressive Strength (Psi)	Elastic Modulus (Psi $\times 10^{-6}$)	
1..........	31,300	36,300	11.7	1.97
2...	60,300	64,200	10.6	1.74
3..........	49,700	59,900	12.2	1.64
4..........	44,800	46,600	11.8	1.64
5..........	48,100	49,400	10.3	1.58
6..........	48,800	51,300	10.8	1.55
7..........	57,000	60,900	12.8	1.54
8..........	49,700	54,100	10.9	1.41
9..........	37,000	53,700	11.5	1.40
10..........	60,200	62,800	10.7	1.40
11..........	37,500	41,900	10.4	1.36
12..........	44,600	45,300	12.4	1.31
13..........	37,800	39,100	10.3	1.31
14..........	65,800	88,200	12.1	1.25
15..........	62,400	81,900	10.7	1.23
16..........	51,000	56,800	10.0	1.10
17..........	62,800	78,500	12.6	1.06
Av.*....	48,700	53,900	11.3×10^6 $\pm0.7\times10^6$	....

* Includes only samples with l/d equal to, or greater than, 1.4.

length/diameter (l/d) ratio equal to, or greater than, 2. The values obtained on specimens with ratios from 1.56 to 1.88 were, however, not significantly different from those with l/d ratios greater than 2.

The ultimate compressive strength for samples with l/d greater than 2 ranged from 33,200 to 74,400 psi, and an average figure of 55,700 psi was calculated. From these data it may be seen that a wide variation in strength was obtained, possibly because of actual variations in the specimens or imperfections in the samples. There is, therefore, some question as to what an average value for the proportional limit or compressive strength represents, although it does serve as a general indication of these values for enamel. Of particular interest is the relatively small difference between the proportional limit and compressive strength for any single specimen. This means that human enamel does not become permanently deformed until shortly before fracture of the specimen.

The elastic-modulus values for cusp enamel ranged from 9.1×10^6 to 13.9×10^6 psi. The average elastic modulus was 12.2×10^6 psi, and the average deviation from the mean was calculated to be $\pm 0.9 \times 10^6$ psi. When the samples having l/d ratios less than 2 were included in the average, the elastic modulus was lowered slightly to 11.9×10^6 psi.

The compressive properties of side enamel, reported in Table 2, are within the experimental error of those obtained for cusp enamel. The average values for the proportional limit, compressive strength, and elastic modulus were 48,700, 53,900, and 11.3×10^6 psi, respectively. Specimens having l/d ratios of less than 1.4 were not included in these averages. The proportional limit and compressive-strength values obtained with specimens having l/d ratios of less than 1.3 were considerably higher than those having larger l/d ratios.[5] This increase is probably due to the samples approaching a disk, where the apices of the cone-shaped stress patterns are closer together than in longer specimens. Since the stress in the cone-shaped volume is less than in the remainder of the specimen and since in short samples the cone volume is a larger portion of the total specimen volume, short samples are able to withstand higher stress than long specimens.

The elastic moduli of the short specimens do not alter the average value when they are included. The observation that the elastic modulus is less affected by the length-to-diameter ratio than are the proportional limit and compressive strength is a typical finding in compression testing.

Silicate and zinc phosphate cements.—The compressive properties of silicate cements, 24 hours and 7 days after preparation, are given in Table 3. The proportional limit, ultimate compressive strength, and elastic modulus of the 24-hour specimens averaged 19,600, 25,600, and $3{:}25 \times 10^6$ psi, respectively. The corresponding values for the 7-day specimens were 24,300, 32,100, and 3.58×10^6 psi. Considering the errors involved in the measurements, these data indicate a small but definite increase in the compressive properties of the 7-day specimens. As in the case of enamel and other brittle materials, the proportional limit is nearly as high as the compressive strength. This indicates that little permanent deformation of the material is possible before rupture occurs. The average 7-day compressive strength of 32,100 psi was higher than the value of 28,500 reported by the manufacturer. Also it should be noted that the 24-hour strength of 25,600 psi exceeds the A.D.A. Specification No. 9 requirement of 23,000 psi.

The zinc phosphate cement had slightly lower compressive properties than the silicate cement. Since the zinc phosphate cements are used as inlay cements and as base cements, the compressive properties of mixes of both consistencies were investigated and are reported in Table 4. The values listed for the inlay consistency mixes after 1, 7, and 28 days showed a gradual improvement in compressive properties from the time of mixing. The proportional limit, compressive strength, and elastic modulus increased from 8,600, 14,400, and 1.64×10^6 psi, respectively, after 1 day to 13,900, 21,700, and 2.36×10^6 psi, respectively, after 28 days.

TABLE 3

COMPRESSIVE PROPERTIES OF SILICATE CEMENTS*

Sample	Age (Days)	Proportional Limit (Psi)	Ultimate Compressive Strength (Psi)	Elastic Modulus (Psi $\times 10^{-6}$)
1	1	....	25,300	3.13
2	1	18,300	25,400	3.57
3	1	17,900	26,000	3.17
4	1	20,400	25,400	3.34
5	1	21,200	25,800	3.03
Av.	....	19,600 $\pm$1,400	25,600 $\pm$300	3.25×10^6 $\pm 0.17 \times 10^6$
6	7	26,900	29,900	3.76
7	7	....	32,400	3.66
8	7	23,200	27,400	3.41
9	7	26,100	37,800	3.45
10	7	20,900	32,700	3.61
Av.	....	24,300 $\pm$2,200	32,100† $\pm$2,700	3.58×10^6 $\pm 0.12 \times 10^6$

* S. S. White Improved Filling Porcelain, 1.43 gm. cement powder for 0.4 cc. of cement liquid.
† The manufacturer's value was 28,500 psi.

The compressive properties of the zinc phosphate cement base-consistency mixes, measured 1 and 7 days after preparation, indicated only a slight increase in strength over this period. The base-consistency mixes had higher strengths than the inlay mixes, as shown by the average proportional limit, compressive strength, and elastic modulus values of 13,900, 26,400, and 3.40×10^6 psi, respectively.

Gold.—A type I and a type IV gold were used in a limited investigation of the compressive properties of dental golds, and the results are reported in Table 5. The average proportional limit of the type I gold was 17,700 psi, and the elastic modulus was 11.2×10^6 psi. No value could be obtained for the compressive strength, since the large permanent deformation prevented any true rupture of the specimens in compression. The proportional limit in compression of 17,700 psi was considerably higher than the value of 12,000 psi measured in tension by the manufacturer. The value of 11.2×10^6 psi for the elastic modulus in compression, however, was in excellent agreement with the tension value of 11.0×10^6 psi.

The partial denture gold specimens were tested in the hardened condition. An average value of 74,600 psi was established for the proportional limit, and a figure of 14.4×10^6 psi was found for the elastic modulus. The values obtained on individual specimens were in close agreement with the average values. The proportional limit in compression of 74,600 psi was again higher than the manufacturer's value of 72,000 psi obtained in tension. No figure was listed for the elastic modulus in tension. As in the case of the type I gold, it was impossible to obtain a true ultimate compressive strength for the partial denture gold.

DISCUSSION

The compressive properties of cusp and side enamel have been shown to be essentially equal. The average values for the proportional limit, compressive strength, and elastic modulus of 51,200, 55,700, and 12.2×10^6 psi, respectively, are considerably

TABLE 4

COMPRESSIVE PROPERTIES OF ZINC PHOSPHATE CEMENT*

Sample	Age (Days)	Mix Type	Proportional Limit (Psi)	Ultimate Compressive Strength (Psi)	Elastic Modulus (Psi $\times 10^{-6}$)
1..........	1	Inlay†	8,600	15,100	1.56
2..........	1	Inlay	8,100	14,200	1.55
3..........	1	Inlay	8,700	14,100	1.63
4..........	1	Inlay	8,800	13,300	1.66
5..........	1	Inlay	8,900	15,200	1.78
Av......	....	....	8,600	14,400	1.64×10^6
6..........	7	Inlay	11,500	18,500	2.23
7..........	7	Inlay	13,500	17,200	1.96
8..........	7	Inlay	14,400	17,500	1.94
Av......	....	....	13,100	17,700	2.04×10^6
9..........	28	Inlay	13,100	23,800	2.56
10..........	28	Inlay	14,100	24,200	2.59
11..........	28	Inlay	14,300	21,400	2.16
12..........	28	Inlay	13,900	20,500	2.36
13..........	28	Inlay	13,900	18,500	2.10
Av......	....	....	13,900	21,700	2.36×10^6
14..........	1	Base‡	13,900	25,900	2.99
15..........	1	Base	14,100	25,600	3.24
16..........	1	Base	13,700	24,700	3.20
17..........	1	Base	14,200	24,700	3.05
Av......	....	....	14,000	25,200	3.12×10^6
18..........	7	Base	13,600	25,200	3.56
19..........	7	Base	13,900	26,300	3.16
20..........	7	Base	14,300	27,800	3.44
21..........	7	Base	13,700	26,200	3.43
Av......	....	....	13,900	26,400	3.40×10^6

* Tenacin Cement, L. D. Caulk Co., Milford, Delaware.

† 1.1 gm powder/0.5 cc cement liquid.

‡ 1.85 gm powder/0.5 cc cement liquid.

greater than the corresponding figures of 24,200, 43,100 and 2.65 $\times$ 10^6 psi previously reported for human dentin.[4]

The proportional limit of cusp and side enamel was reported by Stanford *et al.*[1, 2] to be 32,500–34,200 and 21,000–27,000 psi, respectively. The compressive strengths for comparable positions of enamel were 37,800–40,200 and 28,200–34,600 psi, respectively. These values are from 28 to 59 per cent lower than those found in the present research. Since the length-to-diameter ratios of Stanford's specimens varied from 1.3 to 2.1, the sample size should not have markedly affected the results. Lower ratios should give, in any case, higher, rather than lower, proportional limit and compressive-strength values.

The elastic modulus of cusp and side enamel was reported by Stanford *et al.*[1] to be 8.2 $\times$ 10^6 and 6.0 $\times$ 10^6 psi, respectively. More recent values by Stanford *et al.*[2] list

TABLE 5

COMPRESSIVE PROPERTIES OF DENTAL GOLD

Sample	Type	Proportional Limit (Psi)	Elastic Modulus (Psi $\times 10^{-6}$)
1..........	I*	20,800	11.5
2..........	I	16,300	11.1
3..........	I	16,900	10.5
4..........	I	17,000	11.8
Av.....	....	17,700	11.2$\times 10^6$
5..........	IV†	74,400	14.5
6..........	IV	76,300	14.8
7..........	IV	73,700	14.0
8..........	IV	74,000	14.3
Av.....	....	74,600	14.4$\times 10^6$

* Jelenko Special Inlay; yield strength given as 12,000 psi, and elastic modulus as 11.0 $\times$ 10^6 psi, J. F. Jelenko & Co., Inc., N.Y.

† Ney G-3 ORO, hard condition; proportional limit listed as 72,000 psi, the J. M. Ney Co., Hartford, Conn.

these values as 6.7 $\pm$ 0.7 $\times$ 10^6 and 4.7 $\pm$ 0.6 $\times$ 10^6 psi, respectively. These values are substantially lower than the figures of 12.2 $\times$ 10^6 and 11.3 $\times$ 10^6 psi found in the present study.

The lower values for these properties possibly indicate imperfections in the enamel specimens, since any flaws would result in lower compressive properties. The lack of agreement between the results of the studies also may be due to differences in the method of preparing the very small specimens or to variations in the surface finish of the samples.

The higher compressive-strength properties of enamel compared with dentin, observed in the present investigation, correlate with the known properties of these materials. Higher compressive properties for dentin compared with enamel, found by Stanford *et al.*,[1] are difficult to reconcile with the general differences between these materials.

The elastic modulus and strength in bending of 19 $\times$ 10^6 and 11,000 psi, respectively, reported by Tyldesley,[3] are in disagreement with the current values for the compressive properties of enamel. It is questionable whether the results observed in bending, for a non-isotropic material such as enamel, can be compared with those in compression, particularly since the bending specimens were a composite of enamel and dentin.

The proportional limit, compressive strength, and elastic modulus of silicate cement (24,300, 32,100, and 3.58×10^6 psi) were of the same order of magnitude as the corresponding values for dentin (24,200, 43,100, and 2.65×10^6 psi). The elastic modulus of silicate cements in compression is also in good agreement with the modulus in tension of 3.1×10^6 psi, reported by Bowen and Rodriguez.[6] It is also interesting to note the good agreement between the elastic modulus of 2.8×10^6 psi for dentin in tension[6] and the value of 2.65×10^6 psi for the modulus in compression.[4]

The compressive properties of the zinc phosphate cement specimens prepared from inlay-consistency mixes were lower than those for silicate cements and dentin. When a base-consistency mix was tested, the compressive properties were within reasonable agreement with those obtained on silicate cements. The greatest difference between the zinc phosphate cements and silicate cements was the markedly lower proportional limit of the zinc phosphate cements. The compressive properties of silicate and zinc phosphate cements reported by Stanford *et al.*[2] are in reasonable agreement with the 1-day values obtained in the present study. The elastic modulus of the 28-day inlay-consistency zinc phosphate cement samples was essentially the same as the values for human dentin. The base-consistency zinc phosphate cement and the silicate cement samples had elastic modulus values between 3.40 and 3.58×10^6 psi compared with an average value of 2.65×10^6 for human dentin.

The compressive properties of the dental gold specimens showed that these materials had elastic moduli similar to human enamel. The proportional limit of the type I gold, however, was 35 per cent less than that for enamel, and the value for the type IV gold was 50 per cent greater. Thus considerable difference exists between gold and enamel in respect to the stress at which permanent deformation will result. There is also a great difference in the amount of permanent deformation tolerated before rupture.

In general, it was observed that the proportional limits and compressive strengths of the small specimens used in this study were higher than those reported for larger specimens. This relationship between strength and specimen size has been previously observed by Taylor, Sweeney, Mahler, and Dinger[7] in a study of the factors influencing the crushing strength of dental amalgam. This relationship should be kept in mind when comparing literature data.

SUMMARY

The compressive properties of enamel, silicate cement, zinc phosphate cement, and dental gold were determined.

Cusp and side enamel were shown to have similar compressive properties, which were substantially higher than those for dentin.

Silicate and zinc phosphate cements were found to have compressive properties of the same order of magnitude as that determined for human dentin. The age of the

specimens and the powder-to-liquid ratio affected the compressive properties of the cements.

Type I gold had a proportional limit substantially lower than tooth structure, while type IV gold, in the hardened condition, had a proportional limit considerably higher than enamel or dentin. The elastic moduli of type I or IV gold, however, were comparable to values obtained for human enamel.

The compressive properties obtained for the various materials showed that higher values were obtained for the proportional limit and compressive strength when small, rather than large, specimens were utilized.

The proportional limit and compressive-strength values for enamel were found to be higher than usual when the length-to-diameter ratios of the cylindrical specimens were less than 1.3.

REFERENCES

1. Stanford, J. W., Paffenbarger, G. C., Kumpula, J. W., and Sweeney, W. T. Determination of Some Compressive Properties of Human Enamel and Dentin, *J.A.D.A.*, **57**:487, 1958.
2. Stanford, J. W., Weigel, K. V., Paffenbarger, G. C., and Sweeney, W. T. Compressive Properties of Hard Tooth Tissues and Some Restorative Materials, *J.A.D.A.*, **60**:746, 1960.
3. Tyldesley, W. R. The Mechanical Properties of Human Enamel and Dentine, *Brit. D. J.*, **106**:269, 1959.
4. Craig, R. G., and Peyton, F. A. Elastic and Mechanical Properties of Human Dentin, *J. D. Res.*, **37**:710, 1958.
5. Cook, M., and Larke, E. C. Resistance of Copper and Copper Alloys to Homogeneous Deformation in Compression, *J. Inst. Metals*, **71**:371, 1945.
6. Bowen, R. L., and Rodriguez, M. M. Tensile Strength, Testing Method and Values for Some Dental Materials. Presented at the I.A.D.R. Dental Materials Group Annual Meeting, March 17–20, 1960.
7. Taylor, N. O., Sweeney, W. T., Mahler, D. B., and Dinger, E. S. The Effects of Variable Factors on Crushing Strengths of Dental Amalgams, *J. D. Res.*, **28**:228, 1949.