AN EVALUATION OF FACTORS INFLUENCING MARGINAL LEAKAGE

OF AMALGAM USING AN AIR PRESSURE METHOD

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ABSTRACT

Factors influencing the in-vitro marginal leakage of dental amalgam
using an air pressure method were investigated. These factors included
alloy type, plasticity of the precondensation mix, and setting dimensional
charge which was measured both axially, (ADA Specification No. 1) and
laterally (Vrijhoef). Within each alloy the leakage value decreased
with increased precondensation mix plasticity. At the same time, the lateral
dimension increased significantly. However, among the alloys tested
at approximately the same plasticity, there were significant differences
in leakage. Lateral rather than axial dimensional change was more signifi-
cantly related to leakage but at any specific lateral dimensional change
the leakage values among alloys was considerably different. The nature
of the alloy particle appeared to have a significant effect on leakage,
where spherical particle alloys exhibited the highest leakage, the dispersant
blends and chip-cut alloys exhibited the lowest leakage.

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INTRODUCTION

Microleakage may be defined as the clinically undetectable passage of bacteria, fluids, molecules or ions between a cavity wall and the restorative material applied to it.[22] Marginal sealing is one of the primary requirements of a restorative material,[6] yet no materials at the present time which are in common usage are truly adhesive.[14,32] Several studies of marginal leakage have demonstrated that initially there is leakage of newly placed dental amalgam to the cavity wall[20,32] but that this leakage decreases with time.[2,3,18,33,36] The reason for this decreased leakage has been attributed to the accumulation of organic material and corrosion products between the restoration and the tooth.[2,3,18,33] However, the leakage during the first few days and weeks is gross[2] and one cannot rule this out from being a cause of post-operative sensitivity. In addition, after some time in service, margins which are sealed by organic materials and corrosion products will be decreased in strength and unsupported by tooth structure.[38] On the other hand, good marginal adaptability can increase retention of the amalgam in the cavity and lead to better resistance of the margin mechanical and electrochemical attack.[20] For this reason, cavity varnishes are used before the amalgam is placed in order to reduce this initial gross leakage.[2,3,5,14]

LITERATURE REVIEW

Many authors have investigated the marginal adaptation of amalgam restorations and a number of influencing factors have been reported. The type of alloy system has been one of interest. Recent evidence has indicated that a dispersed-phase amalgam has better physical properties and more resistance to corrosion than traditional amalgams.[5,25,35] Therefore, the ability of the dispersed-phase amalgam and other non-gamma-2 amalgams to seal their margins has been of some concern. In a radioactive isotope study in 1975, Andrews, et al[2] reported no apparent difference in the sealing ability of a dispersed-phase amalgam and traditional amalgams. Using an air pressure apparatus, Hackman[12] and Biermann[5] have confirmed this result.

The presence of zinc in the amalgam alloy has proven to be a relevant factor. Zinc is used principally as a deoxidizer in the manufacture of alloy and is present in the amount not greater than 1 percent. Even a small amount of zinc has been reported to cause an abnormal expansion of the amalgam in the presence of moisture. Zinc-free alloys compared to zinc-containing alloys show no great differences in mechanical properties but are somewhat more brittle and their pre-condensation mixes have less plasticity.[32] They also exhibit a higher incidence of corrosion and marginal deterioration under clinical conditions. Furthermore, zinc-free amalgams have shown a greater amount of internal porosity, are less plastic in the pre-condensation state, and leaked more than zinc-containing amalgams.[12] Zinc-containing amalgams were also reported to demonstrate reduced surface roughness and better adaptability.[17]

The shape and size of the alloy particles has also been found to affect marginal adaptation. In 1967, Koran and Asgar[23] reported the marginal adaptation of Caulk fine-cut alloy and Kerr spherical alloy. Spherical alloy powders ranging in size from 0-44, 20-44, 30-44, and 44-47 microns were packed in plexiglass disks at less than two pounds force while the fine-cut alloy was packed at eight to nine pounds force. They found that the large and more uniform spherical alloy ranging from 44-47 microns showed the greatest amount of leakage while the spherical alloy powder ranging from 0-44 microns leaked no more than the fine-cut alloy prepared by the regular technique.

Although microleakage paths are of microscopic dimension, results of investigating macroscopic marginal adaptation may also reflect microleakage of the restorations. In a study by Mitchem and Mahler in 1969[29] two types of lathe-cut amalgams were evaluated. A micro-cut alloy which required 54 percent or more pre-condensation mercury was less well adapted to the proximal margins than a fine-cut alloy which required 51 percent or less pre-condensation mercury.

Wing, et al[40] used lathe cut and spherical amalgams with mercury/alloy ratios of 7/5 and condensed into extracted human teeth to measure with a microscope the space between the amalgam margins and the cavity wall. It was demonstrated that the spherical alloy amalgam is separated from the tooth by a wider space than the lathe-cut alloy amalgam. It was hypothesized that this resulted from the spherical particles tendency to roll away from the condenser. The differences in adaptation between well packed and poorly packed spherical amalgams was slight.

Jorgensen in 1965[19] used an instrument which measured the roughness of amalgam which has been condensed against a polished steel surface to indicate

the adaptability of the amalgam restoration. From this study he concluded that the roughness values were different for different brands of the amalgams. The small particle alloys produced smoother surfaces than large particle alloys and roughness was associated with poor adaptability. An increase in the recommended mercury used in the mix did not significantly alter the roughness, while a small reduction in mercury increased the roughness value.

The influence of condensation has been considered to be a major factor in regard to adaptation of the amalgam restoration.[16,21,30,33,40] In microleakage studies, it was reported that with meticulous attention to condensation technique, a restoration with little or no leakage could be produced.[16,33] In the 1966 study Wing et al[40] demonstrated that good condensation reduced the space between restoration and tooth surface while setting dimensional change had less influence. Jorgensen in 1967[21] reported that good condensation reduced the porosity and increased adaptability. Eames[8] listed the factors involved in the condensation of amalgam to be force, size of condenser, the number and direction of thrusts of the increments, and the time of application of the force. The higher force produced better adaptability of the restoration. A three pound thrust, which conformed to the average force used clinically,[4,27] produced acceptable marginal adaptation. The use of a small condenser, small size of increments and lateral thrust produced better adaptation.[8,39]

The effect of setting dimensional change on marginal adaptation has been investigated because of its presumed relation with the distance of the restoration to the cavity wall. However, dimensional change was reported to be of less importance for marginal seal than the condensation procedure.[21,40] When tests for leakage were conducted by Granath in 1971[13] on nine commercial alloys

condensed in sperm-whale dentin, he was unable to detect a correlation between leakage and setting dimensional change. However, he did find that marginal leakage was related to the plasticity of the amalgam mix. In this study Granath measured plasticity by the difference in Hg content before and after condensation.

Vrijhoef[37] in 1975 stated that the dimensional change test in A.D.A. Specification No. 1 is unsuitable because the outcome of the experiment is highly dependent on experimental variables. He proposed a new method of determining dimensional change during setting by measuring the diameter of cylindrical specimens. Using this method, he showed a high degree of correlation between setting dimensional change and independent adaptation measurements.

In 1976 Oilo[31] reported a relationship between setting dimensional change and marginal defects. The specimens for dimensional change test were condensed in a cylindrical steel mold of 10 mm long a 5 mm in diameter. The initial measurements were recorded two minutes after finishing the condensation by means of a microcater. The amalgams used were different in respect to dimensional change and were condensed in extracted human teeth which was measured after 48 hours. Following the amalgam polishing, the specimens were examined under the microscope. He found that the degree of adaptation was gradually decreased from fillings made of expanding amalgams to those made of contracting amalgams.

A number of methods have been used to investigate the adaptation phenomena of amalgam restorations both in-vitro and in-vivo. Those include the use of radioactive isotopes, dyes, bacteria, and various air pressure systems.[2,5,9,10,12,13,14,24,25] In studies using dyes, bacteria and isotopes the control of penetrants, flow and particle size has presented problems in quantitation and

evaluation of the data. Furthermore, the specimen cannot be used for longitudinal examination.

An air pressure technique for amalgam leakage studies was reported as early as 1912 and 1919 by Harper.[15,16] Using a steel die with class II amalgam restorations, he demonstrated initial marginal leakage of air from under the restoration.

Pickard and Gayford in 1965[33] reported a leakage study using air pressure to test class V restorations placed in tap water and connected with air pressure underneath the restoration. Leakage at the margins was assessed with a microscope. The air pressure from beneath the restoration was increased until leakage was established, then was decreased until bubbling just stopped. The leakage pressures in this study were also used to compute the total effective leakage areas of the specimens.

In 1952 Fiascarno and Sherman[9] also used an air pressure method to test the leakage of various restorative materials. They raised the air pressure from an orifice beneath the restoration until an air bubble formed at the cavosurface margin. The pressure was recorded at that point. Only three amalgam samples were tested; two of these showed no leakage at the maximum pressure of the apparatus (50 lbs./sq. in.) and one leaked at 38 lbs./sq. in.

In 1970 Granath and Swenson[12] reported the development of a well controlled one-way-flow air pressure testing system for in vitro samples that provided a reliable, accurate and reproducible means of leakage measurement. In a subsequent paper using his air pressure leakage apparatus, Granath reported low initial leakage with nine different amalgam brands.

Based on Granath's design, Hackman[14] constructed an air pressure leakage apparatus with a few modifications. Modifications were the absence of flow meter and a thermostatically controlled chamber which were considered unnecessary. In testing his apparatus, he found it to be a highly reproducible device for measuring leakage. This apparatus was successfully used in the subsequent year by Biermann.[5]

From these studies, air pressure techniques have proved to be more adaptable to intersample comparison and quantification. Furthermore, the specimens can be evaluated over a period of time.

The purpose of this present sutdy was to investigate, in-vitro, factors influencing the marginal leakage of amalgam using the air pressure method. The factors to be investigated include alloy type, plasticity of the pre-condensation mix, and dimensional change as measured both by the methods of ADA specification No. 1 and Vrijhoef.[37]

MATERIAL AND METHODS

The air pressure testing apparatus used in this study was constructed by Hackman. The test specimen holders to fit the apparatus were made from 902 precision machinable ceramic from Cotronics Corporation. The holders were cut 4.5± 0.1 mm thick and were cut from one-inch diameter rod stock. In the center of these discs 4 mm diameter holes were drilled to simulate a class I cavity. Each specimen was cleaned with water and air-dried to remove machining debris, then marked to designate the alloy and specimen number on top of the disc. The disc was fitted in to a recessed plastic mold to provide a bottom to the cavity when condensing the amalgam.

Four types of alloy systems were used: fine-cut, micro-cut, spherical, and dispersant blends. The alloys selected as representatives for these systems were:

Fine-Cut

New True Dentalloy, S.S. White, batch #1397408

Silver Crown #5

Micro-Cut

Aristalloy, Englehard, batch #0511781

Spherical

Spheraloy, Kerr, batch #3604-08556

Shofu zinc free, batch #177303

Tytin, S.S. White, batch #0627602

Dispersant Blends

Dispersalloy, Johnson & Johnson, batch #4f 125

Micro II, Caulk

The mixing conditions for these alloys are listed in Table I.

Table I

MIXING CONDITIONS FOR THE TEST ALLOYS

Alloy	Initial Hg %			Amalgamator	Capsule & Pestle	Mixing Time
	-2%	ideal	+2%			(seconds)
New True Dentalloy	49	51	53	Wig-L-Bug	S.S. White	15
Silver Crown	49.5	51.5	53.5	Wig-L-Bug	S.S. White	12
Aristaloy	53	55	53.5	Varimix	S.S. White	6
Spheraloy	46	48	50	Varimix	S.S. White	8
Shofu zinc free	42.5	44.5	46.5	Wig-L-Bug	S.S. White	15
Tytin	40.5	42.5	44.5	Varimix	S.S. White	9
Dispersalloy	50.5	52.5	54.5	Varimix	Dispersalloy	13
Micro II	49.5	51.5	53.5	Wig-L-Bug	S.S. White	13

The selection of the test conditions and their rationale were as follows:

Trituration time Each alloy was initially tested for proper trituration time by using a slight dry mix (manufacturer's recommended less 2% Hg). Starting with an undertriturated mix and immediately after trituration, the mix was rolled into a ball. The time was increased until a mix resulted that provided a smooth homogeneous bright after rolling without any fissures. This time was then taken as the proper trituration time.

Precondensation mercury content The mixture of Hg and alloy as recommended by the manufacturer was initially examined using the proper trituration time as determined above. The ideal plasticity was specified as a smooth plastic mix which could be easily smeared with a forefinger in an opposing palm of the hand and which would easily record a fingerprint. The Hg content was changed, if necessary, to provide a mix conforming to these subjective criteria. To represent wet and dry amalgams, two other mixtures of +2% and -2% from the selected ideal Hg content were selected.

Condensation procedure To standardize the condensation technique, all specimens were condensed by one operator. Hand condensation was used with a force of 2½ - 3 lbs. which approximates average clinical conditions. This force was monitored and constant for each amalgam using a calibrated sonic force measuring transducer. This device provides a low and high pitched sound at the low and high load range respectively. Each specimen was prepared using three increments of amalgam with the same amalgam carrier and 12-16 thrusts per increment. A 2-mm diameter flat, round condenser was used for the overpacked using 6-8 thrusts. All samples were condensed within 2½-3 minutes from the end of trituration. Excess amalgam was carefully carved from the top and then the bottom of the sample using a sharp razor blade. The blade was moved from the

edge toward the center of the restoration to prevent packing the margins with carving debris.

Storage condition   Specimens for microleakage test were stored in air in covered crystallizing dishes for 24 hours to allow completion of the setting reaction.

Air pressure leakage test   Using the protocol established by Hackman[14] the test procedure was conducted as follows: first the specimen was placed in the apparatus, top toward the high pressure. Then the holder was closed and tightened. Second, the air pressure valve was turned on and the pressure was allowed to equalize in the manometer at 300 mm mercury. Then the water level was adjusted in the measuring burrette to a minus four reading. Then the air pressure, room and line temperature was checked and recorded. The bypass valve was opened to release enough air to bring the level in the measuring burrette to a minus one reading and then the valve was tightly closed. When the next bubble was released the stop watch was started and the number of complete bubbles released in two minutes was recorded. Finally, the main air valve was turned off, the sample removed and the protocol repeated for the next sample. The number used as a measure of leakage was the number of bubbles (0. cc) released over a two minute time period.

Dimensional change test   Setting dimensional changes were measured on all eight amalgams. Three specimens of each mix were made and tested according to A.D.A. Specifications by the same operator except that instead of the mechanical condensation as described in this specification, the condensation procedure used was the same as in the preparation of the specimens tested for leakage. In addition, the lateral dimensional change was determined as described by Vrijhoef[37], i.e.,

at 24 hours, and the diameter of the set cylindrical specimens was measured in two perpendicular positions with a micrometer. The measurement was taken to the nearest 1 micron and the dimensional change recorded as micron/cm. The fiducial diameter of the test specimen prior to setting was taken to be 3980 microns.

Table 2

LEAKAGE VALUE (.05^{ml}/unit)

Alloy	Hg %	Sample Size	Mean	Variance	S.D.	S.E.
NTD	D 49.00 I 51.00 W 53.00	5 5 5	6.00 3.60 1.80	.50 1.80 1.20	.70 1.34 1.09	.31 .60 .48
Silver Crown	D 49.50 I 51.50 W 53.50	5 5 5	24.80 20.00 4.20	17.70 17.00 2.70	4.20 4.12 1.64	1.88 1.84 .73
Aristaloy	D 53.00 I 55.00 W 57.00	5 5 5	3.40 2.20 1.40	1.80 .20 .80	1.34 .44 .89	.60 .19 .39
Spheralloy	D 46.00 I 48.00 W 50.00	5 5 5	62.60 12.80 3.20	64.30 24.20 1.20	8.00 4.90 1.09	3.58 2.20 .48
Shofu	D 42.50 I 44.50 W 46.50 W 48.00 W 50.00	5 5 5 5 5	97.00 91.00 45.00 22.00 10.00	283.00 202.30 134.20 8.50 1.80	16.80 14.20 11.70 2.90 1.34	4.50 6.36 5.23 1.30 .60
Tytin	D 40.50 I 42.50 W 44.50 W 46.00	5 5 5 5	13.80 9.20 3.80 2.00	1.70 1.70 1.70 .00	1.30 1.30 1.30 .00	.58 .58 .58 .00
Dispersalloy	D 50.50 I 52.50 W 54.50	5 5 5	4.80 2.20 1.80	.70 .20 .20	.83 .44 .44	.34 .19 .19
Micro II	D 49.50 I 51.50 W 53.50	5 5 5	2.80 1.00 1.00	1.70 .00 .00	1.30 .00 .00	.58 .00 .00

Table 3

ANALYSIS OF VARIANCE

Source	D.F.	Sum of Sq.	Mean Sq.	F Ratio	F Prob
Between Groups	7	14.150	2.021	186.211	00.0
Within Groups	32	.347	.011		
Total	39	14.497			

Table 4

AXIAL DIMENSIONAL CHANGE (M/cm)

Alloy	Hg %	Sample Size	Mean	Variance	S.D.	S.E.
NTD	D 49.00	3	-21.38	-16.43	4.05	2.34
	I 51.00	3	-21.26	2.45	1.56	.90
	W 53.00	3	-16.10	31.82	5.64	3.25
Silver Crown	D 49.50	3	-30.67	4.79	2.18	1.26
	I 51.50	3	-28.44	.07	.27	.16
	W 53.50	3	-29.22	2.23	1.49	.86
Aristaloy	D 53.00	3	-1.53	.17	.41	.24
	I 55.00	3	-.94	.67	.81	.47
	W 57.00	3	-.54	4.40	2.10	1.20
Spheralloy	D 46.00	3	-10.19	.90	.94	.54
	I 48.00	3	-9.28	.02	.14	.08
	W 50.00	3	-6.84	1.52	1.23	.71
Shofu	D 42.50	3	-14.53	.24	.49	.28
	I 44.50	3	-13.71	.59	.77	.44
	W 46.50	3	-13.90	.59	.74	.44
	W 48.00	3	-12.21	.01	.10	.05
	W 50.00	3	-12.30	.16	.40	.23
Tytin	D 40.50	3	-11.41	1.14	1.08	.62
	I 42.50	3	-10.81	3.30	1.82	1.05
	W 44.50	3	-11.26	.91	.958	.55
	W 46.00	3	-4.21	1.44	1.33	.76
Dispersalloy	D 50.50	3	-1.16	.30	.55	.31
	I 52.50	3	.98	1.23	1.10	.64
	W 54.50	3	2.68	1.35	1.16	.67
Micro II	D 49.50	3	8.55	.43	.65	.37
	I 51.50	3	14.56	2.80	1.67	.96
	W 53.50	3	16.34	15.29	3.90	2.25

Table 5

LATERAL DIMENSIONAL CHANGE (M/cm)

Alloy	Hg %	Sample Size	Mean	Variance	S.D.	S.E.
NTD	D 49.00 I 51.00 W 53.00	3 3 3	-13.40 -6.70 4.18	6.90 3.68 3.70	2.62 1.92 1.92	1.51 1.10 1.11
Silver Crown	D 49.50 I 51.50 W 53.50	3 3 3	-13.41 -5.90 -2.51	2.11 2.01 1.57	1.45 1.40 1.25	.84 .82 .72
Aristaloy	D 53.00 I 55.00 W 57.00	3 3 3	-2.09 2.08 4.18	.52 .52 .52	.72 .72 .72	.41 .41 .41
Spheralloy	D 46.00 I 48.00 W 50.00	3 3 3	-5.46 6.61 19.63	3.66 3.18 2.10	1.91 1.78 1.44	1.10 1.03 .83
Shofu	D 42.50 I 44.50 W 46.50 W 48.00 W 50.00	3 3 3 3 3	-10.90 -8.80 -3.78 1.25 2.90	.52 .00 1.65 1.56 .52	.72 .00 1.28 1.25 .72	.41 .00 .74 .72 .41
Tytin	D 40.50 I 42.50 W 44.50 W 46.00	3 3 3 3	-7.11 -4.60 2.09 7.95	.53 .52 2.10 .52	.73 .72 1.44 .72	.42 .41 .83 .41
Dispersalloy	D 50.50 I 52.50 W 54.50	3 3 3	-3.35 2.09 6.69	.52 .52 .52	.72 .72 .72	.41 .41 .41
Micro II	D 49.50 I 51.50 W 53.50	3 3 3	.83 6.69 12.96	3.64 3.68 3.60	1.90 1.90 1.91	1.10 1.10 1.10

RESULTS AND DISCUSSION

The mean leakage values for the dry, ideal and wet mixes of eight alloys are presented in Table 2. The variance within each alloy system indicates the effect of sample preparation on initial leakage. It was observed that within each alloy, the leakage decreased with increasing precondensation mix plasticity. This result confirms in part Granath's results where he used the amount of Hg removed during condensation as a measure of plasticity and showed that alloys experiencing the greatest amount of Hg removal (greatest plasticity) exhibited the least amount of leakage.

To examine the effect of plasticity across alloys, the leakage of each of the alloys at their respective "Ideal" plasticities is shown in bar graph form in Figure 1. Because of the non-homogeneity of variance (small variances associated with small means, and large variances associated with large means), a log transform was performed on the leakage data. Analysis of variance followed by Tukey's multiple comparison test was used to determine differences among alloys. This computation is shown in Table 3. The horizontal lines in Figure 1 connect leakage values that are not different at the 95% confidence level. Since these leakage values were measured on the eight alloys prepared at approximately the same plasticity and since significant differences are shown, Granath's hypothesis[12] cannot be confirmed when comparing different alloy systems. Thus, in addition to precondensation mix plasticity, other factors influencing leakage should be examined for relevancy. The relationship of leakage to dimensional change was examined even though previous reports have shown no relationship[5,12,14] in this regard.

In Tables 4 and 5 are presented the results of dimensional change measurements, both axial and lateral respectively. Within each alloy the axial dimensional changes show only modest increases with increasing precondensation mix plasticity, while the lateral dimensional changes show very significant increases as the plasticity increases. This result confirms Vrijhoef's contention that lateral rather than axial dimensional change is a better measure of adaptation of the amalgam to the cavity wall.[37] One explanation of this phenomenon could be the presence of excess Hg at the lateral walls of the mold due to the direction of condensation which is parallel to these walls.

In Figure 2, leakage versus lateral dimensional changes are plotted at different plasticities. Regression lines for each alloy have been drawn. It is obvious from the slopes of the lines drawn in each of these figures that within each alloy, leakage decreases as dimensional change increases.

Furthermore, the almost parallel slopes of these lines indicates that all alloys are responding similarly in regard to the relationship between leakage and lateral dimensional change. However, the separation of these lines suggests a strong alloy effect on leakage patterns. At any specific lateral dimensional change, the leakage values for certain alloys are considerably different.

Thus, at either a constant plasticity or at a constant lateral dimensional change, leakage values among alloys are not the same.

Of the alloys tested, those exhibiting the highest leakage patterns were predominantly spherical particle alloys while those exhibiting the lowest leakage were dispersant blends and chip cut alloys. This suggests a possible influence by the nature of the alloy particle.
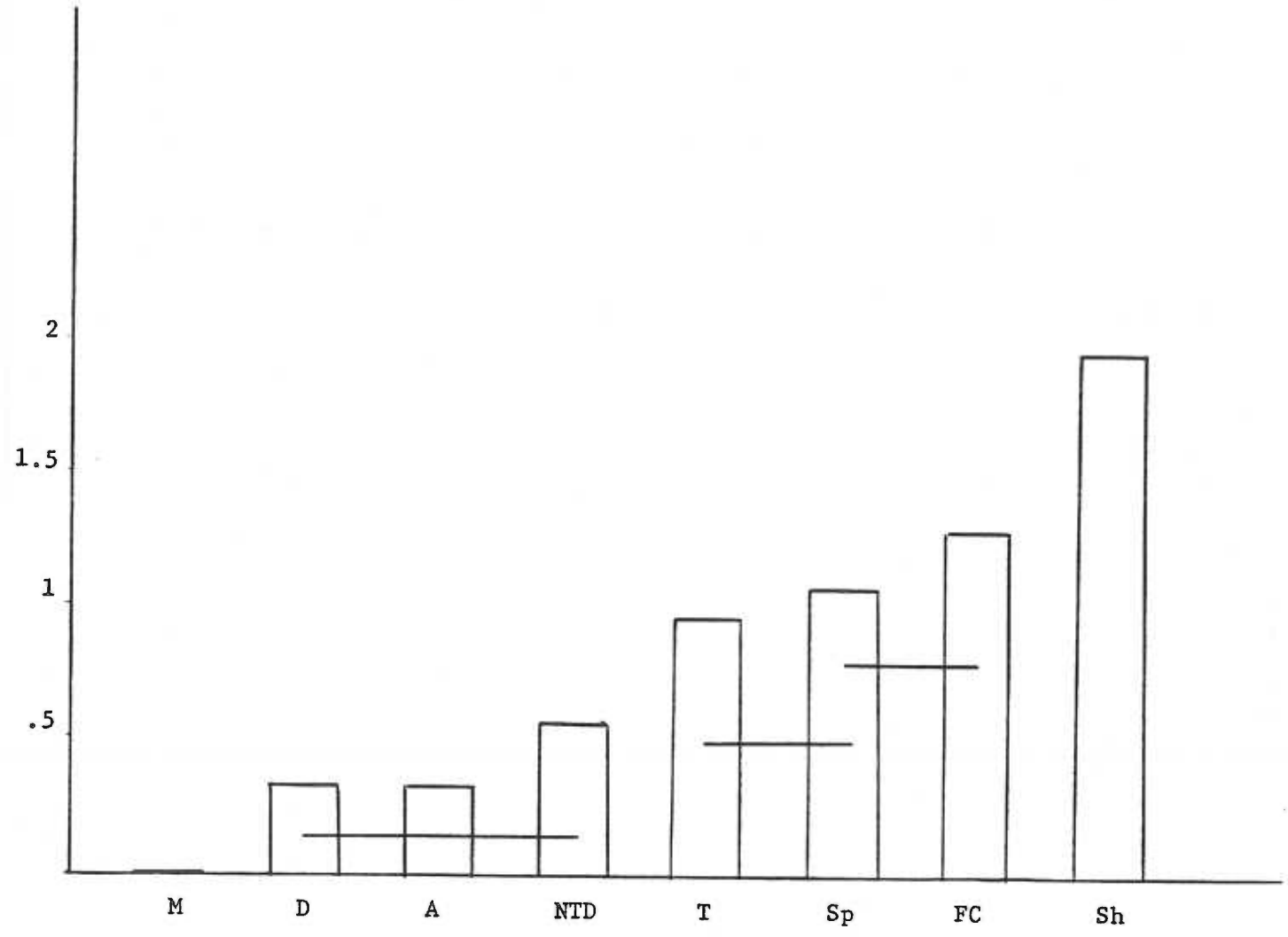
Fig. 1 Leakage Volume vs. Amalgams. Amalgams connected by the line are considered not significantly different by "Tukey's" multiple comparison test at the 95% confidence level.
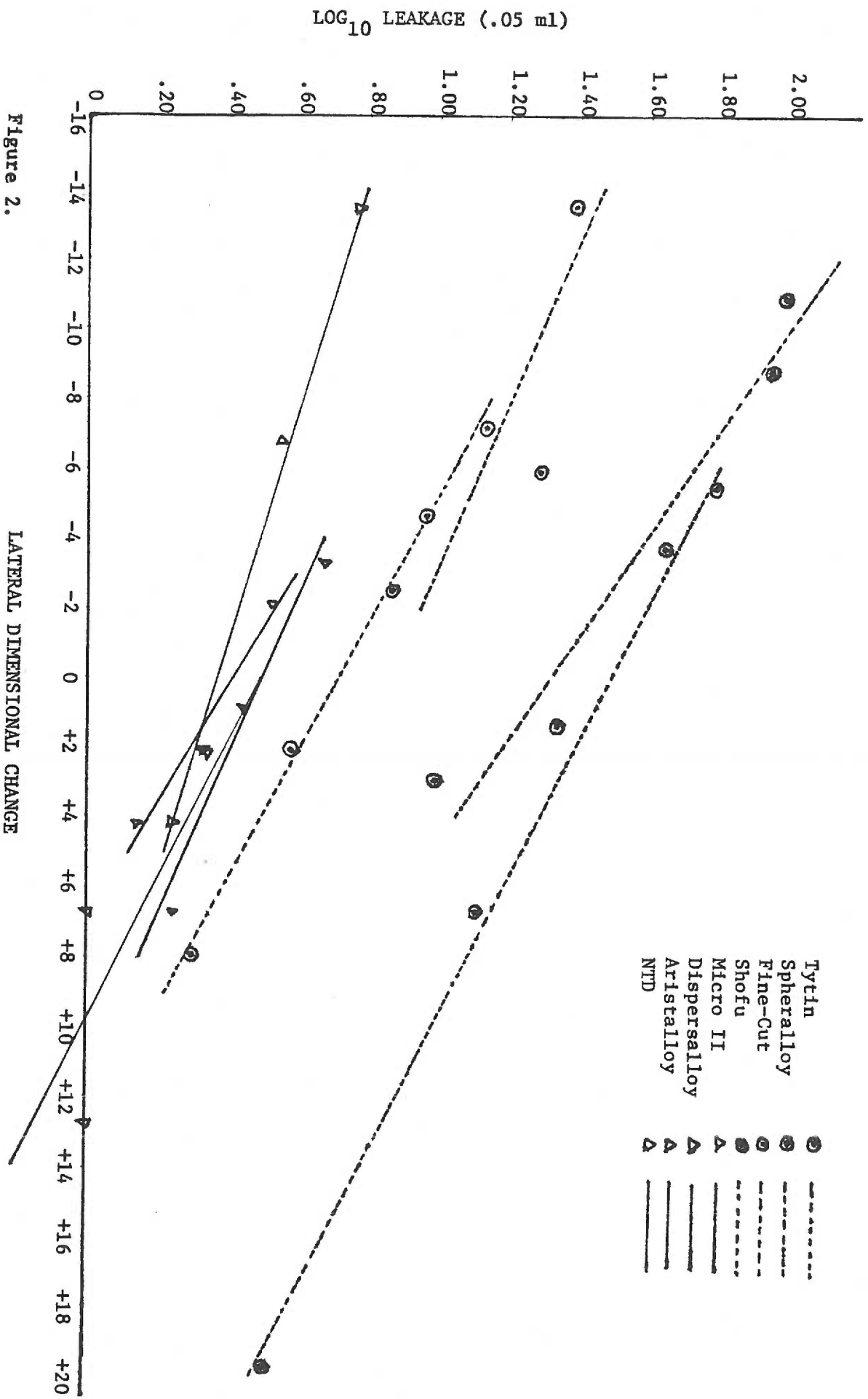
Figure 2.

CONCLUSIONS

The following conclusions were drawn from this study:

1. Within each alloy, as the plasticity of the precondensation mix was
   increased--

   a. leakage decreased.

   b. lateral dimensional change increased markedly.

   c. axial dimensional change increased only slightly.

2. Across alloys, leakage was significantly different--

   a. at the same plasticity.

   b. at the same lateral dimensional change.

3. The nature of the alloy particles appeared to influence leakage,
   where the spherical particle alloys investigated in this study showed
   more leakage than alloys having chip-cut or dispersant blend particles.

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