NATIONAL BUREAU OF STANDARDS REPORT

5937

Progress Report

on

DIMENSIONAL CHANGES OCCURRING IN ARTIFICIAL DENTURES

DURING AND SUBSEQUENT TO PROCESSING

by

Julian B. Woelfel
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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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DIMENSIONAL CHANGES OCCURRING IN ARTIFICIAL DENTURES DURING AND SUBSEQUENT TO PROCESSING

Abstract

Dimensional changes occurring in technic and clinical complete artificial dentures during processing and for a period of 6 months thereafter were determined for ten resins and the recommended technics for processing them. The resins were seven types of polymethyl methacrylate, one vinyl-acrylic copolymer, one polystyrene, and one epoxy. The processing technics were compression molding with and without trial packing, directional hydraulic compression, injection with both "dry" and "moist" heat, transfer molding, and the pouring method.

Greater linear changes in dimension across the posterior of the dentures usually occurred during processing than subsequently. No significant change in dimension was observed after three months' storage in water or after three months' service in the mouth. Upper dentures changed slightly less than lowers; thick dentures less than thin ones (upper and lowers). The self-cured polymethyl methacrylate and epoxy resins had low curing shrinkages followed by a large expansion when stored in water or when in service. Mean linear curing shrinkage for 105 dentures was 0.5 percent or approximately 0.25 mm.

1. INTRODUCTION

In recent years, many attempts have been made to improve the accuracy of the fit of acrylic resin dentures by special methods of processing and by specially compounded resins or by a combination of both. Vinyl-acrylic copolymers, polystyrene, and epoxy resins with special processing technics have been advocated in place of polymethyl methacrylate. Some processing methods are claimed to produce absolutely accurate, strain-free dentures which have excellent stability of form. One of the new resin compounds is claimed to be the most permanently accurate denture base resin ever produced. It has also been claimed that no change in physical form of the dentures had occurred within a year. Many dentists believe that artificial dentures with an acrylic resin base warp severely in service and cause much of the trouble encountered in the accurate a-position of the denture to the tissues. The primary purpose of this study was the investigation of the foregoing. Although the study is not yet completed, significant trends can be seen and some conclusions can be drawn from the data obtained to date. These preliminary results are presented in this report.

2. REVIEW OF THE LITERATURE

Prosthodontists have been critical of available organic denture base materials since the turn of the century. Hard rubber, widely used for over sixty years, was criticised for its color, opacity, porosity, inability to hold a polish, deterioration with age, and difficulty to process and repair. Linear

curing shrinkage reported for hard rubber ranged from 0.3 percent to 0.5 percent with only a slight change occurring thereafter from sorption of water [1].

Acrylic resins, first introduced in the United States in 1937, soon displaced the other organic denture base materials then in use because of attractive color, ability to take and retain a high polish and because the processing technic was simple. Since 1941, the acrylic resins have dominated the materials used for denture bases.

Linear curing shrinkage was reported as approximately 0.5 percent, or slightly higher than for hard rubber, with an expansion due to water sorption as high as one percent if the denture has been conditioned in air at 32 percent relative humidity before immersing the denture in water [1].

Other reports [2], [3], and [4] give somewhat different values. The differences among the reported values are caused by variation in size, shape, and treatment of the specimens and the composition of the various resins employed. These differences are not large enough to detect clinically. As pointed out by some investigators [3], [4] the linear expansion of acrylic resins caused by water sorption partially compensates for the curing shrinkage.

Reports of severe warpage of acrylic resin dentures on recuring [5] may have led to the persistent belief that acrylic resins readily warp in amounts that have great clinical significance. However, it has been shown [6], [7], and [8] on more

than two hundred clinical and technic dentures some of which were followed for as long as two years that the linear changes are usually less than minus one percent. Across a two-inch molar to molar span this is only 0.5 mm. A change of almost 0.75 mm across the posterior section of a phenol-formaldehyde resin denture has been reported [2] without loss of retention or complaint from the patient.

Rapid tissue changes of a much larger amount have been shown by comparison of the profiles of artificial stone cases [9]. These casts were from alginate impressions of upper and lower edentulous arches: (1) before ill-fitting dentures were inserted and (2) four days after wearing the ill-fitting dentures. This indicates that the oral tissues can change quite rapidly and can change more than any reported changes for acrylic resin dentures.

3. MATERIALS AND METHODS

The trade brand of each resin, included in this report, its general type and subtype, and the processing method used with it are shown in Table 1. The different types of polymethyl methacrylate were: powder-liquid (both uncrosslinked and crosslinked), powder-liquid containing glass fibers, powder-liquid self-curing, and the gel form. In addition to polymethyl methacrylate, a polystyrene, an epoxy resin and a vinyl-acrylic copolymer were used. The major processing methods employed were: compression molding (with and without trail packing), directional hydraulic compression molding, injection molding using both "moist" and "dry-heat," transfer molding, and pouring. All resins were

purchased on the open market in 1957 or 1958. The date of procurement and the lot or batch number are given in Table 1.

Four technic complete artificial dentures were made of each resin listed in Table 1. One set of these technic dentures was thin; the other thick in cross section (Figure 1). All sets of thin dentures were duplicates in size and shape. Likewise, all sets of thick dentures were duplicates. In addition to these technic dentures, clinical dentures (in most cases five complete uppers and three complete lowers) were made of each resin. The same batches of resin, gypsum, and tinfoil substitute were used for both the technic and clinical dentures. The clinical dentures were made for patients who are on the permanent staff of the National Bureau of Standards. With the exception of very recent extractions and immediate dentures, no type of case, regardless of difficulty, was refused.

The following impression technic was used. An individual preformed tray of self-curing polymethyl methacrylate was made for each case. Border molding and postdam were accomplished with green modeling compound. The final impression was a corrective wash of zinc oxide-eugenol paste. Face-bow transfer and beeswax (centric and protrusive) interocclusal records were used to mount cases on a Hanau Model-H articulator. Porcelain anterior and 33° posterior teeth were used. All cases were remounted on the articulator from a new centric interocclusal record taken at the time of insertion. The dentures were processed at the National Bureau of Standards with the exception

of Tilon and Luxene-44 which were processed by the investigators with equipment available in dental laboratories of the Armed Forces or were sent to commercial dental laboratories.

Linear measurements on the dentures (molar to molar and flange to flange) were made at various times (Table 2)* at 22 ± 1° C. (72 ± 2°F) with a toolmaker's microscope to within ± 0.0001 inch. The reference marks were cross lines ruled on polished stainless steel pins and cemented in the dentures as shown in Figure 2. Posterior linear measurements instead of contour measurements were made as previous studies [6], [10] have shown linear changes of significantly greater magnitude occur across the distal portions of a denture than in any other area. Also the changes occurring in the posterior would be the most important in the retention of dentures because of the anatomy of the mouth and the shape of the dentures. Finally, linear measurements can be made with a much higher degree of accuracy than can contour measurements with available instruments.

The necessity of having the measurements as precise and as accurate as possible is shown in Figure 3. With an error of ± 0.005 inch, the data would fall between the outer dotted lines. Many of the linear changes occurring in a denture are smaller than this error. Such gross errors in measurement would seriously affect any comparative results. With a plus error for one denture and a negative error for another, the true picture could be obliterated. However, a skillful observer using a calibrated

* Table 2 includes the schedule for measurements during the continuation of the study.

microscope and excellent reference lines can hold the error in measurement to within ± 0.0001 inch (± 0.005 percent). Differences among various observers increase this error two to three times.

Because the denture base resins have a high coefficient of thermal expansion, (80 ± 10) x 10^{-6} per °C, it is also necessary to have good control of temperature. As stated in Table 2, measurements were made at 22 ± 1°C (72 ± 2°F). Even this latitude of ± 1°C makes possible an error of 0.008 percent.

The high coefficient of thermal expansion of these denture base resins must be considered in interpreting the data obtained at 22 ± 1°C (72 ± 2°F). If the dentures were heated to mouth temperature [37°C (98.6°F)] an increase in dimension of approximately 0.12 percent would be expected.

The experimental design permitted the accurate measurement of linear changes in both technic and clinical dentures during processing and thereafter using a method employed formerly [6]. In addition the effect of the size and shape of the dentures on the dimensional changes during processing, on storage in water and during clinical service could be determined. Also, both the gross and precise differences and relationships in the behavior of technic dentures stored in water and of clinical dentures in service could be learned.

Table 3 shows the average molar to molar changes for dentures of each brand during processing and during the following six months. For most materials averages for processing changes are

based on 5 to 7 upper dentures including 1 thick and 1 thin technic denture and on 3 to 5 lower dentures also including 1 thick and 1 thin technic denture. Averages for dimensional change during service (or immersion in water for technic dentures) represent fewer specimens since many of the dentures have been in service for only a short time. The results show average processing changes near 0.5% for all materials with the exception of Acralite-88 and Epoxolon both of which exhibited somewhat less shrinkage. Average dimensional changes during service (or imersion in water) for six months ranged from approximately -0.1 to +0.4%.

Figures 4, 5, 6 and 7 show the molar to molar changes after flasking, packing, and removal of the occlusal stone index on the technic dentures. These changes are small compared with those changes shown on the same dentures in Figures 8, 9, 10, and 11. Here, the dentures were deflasked, removed from the gypsum cast, polished and stored in water for several months. The largest dimensional change occurred when the denture was removed from the cast and was on the average slightly over -0.4 percent (-0.2 mm) in the thin uppers (Figure 8) and -0.6 percent (-0.3 mm) in the thin lowers (Figure 9). These changes are believed to be caused by the release of elastic strain when the dentures were removed from the casts. The strain was probably placed in the denture by the greater contraction of the resin than the gypsum mold during cooling. For example, the two resins showing the least change, Epoxolon and Acralite-88, were processed at

49°C (120°F) and 22°C (72°F), respectively, while the other resins were processed at much higher temperatures in accordance with the manufacturers' directions. (The increase in processing temperatures caused by exothermic heat was not measured).

The dimensional changes after polishing and during immersion of the dentures in water for three months ranged from +0.3 percent for Acralite-88 to -0.1 percent for Luxene-44 on the thin uppers (Figure 8); for the thin lowers (Figure 9) the range was from +0.6 percent for Epoxolon to -0.2 percent for Luxene-44. These dimensional changes were probably caused by sorption of water and the release of some internal strain.

The thick upper and lower technic dentures (Figures 6, 7, 10 and 11) had the same general pattern of dimensional change as the thin upper and lower technic dentures but the average change for the thick dentures was smaller (Figure 12). Each bar in Figure 12, representing data on technic dentures, is the average dimensional change on ten identically shaped dentures each of which was made of a different resin (Table 1).

The thin upper technic dentures shrank 1.7 times as much on the average as the thick upper ones; the thin lower technic dentures over 2.2 times as much on the average as the thick lower ones (Figure 12). These findings were contrary to expectations as the dentures containing the most resin would have the greatest volumetric shrinkage on polymerization. Why then did the bulky dentures show less molar to molar and flange to flange changes than the thin dentures? Probably the dentures with the thicker

cross section were stiff enough to prevent release of some of the mechanical strain when the cured dentures were removed from the casts.

The average dimensional changes during processing of the upper and lower clinical dentures of all ten resins fall in between those of the thick and thin technic dentures (Figure 12). This general relationship has continued after the clinical dentures have been in service for six months and the technic dentures have been immersed in water for six months. The clinical dentures seemed to expand slightly more in service than the technic dentures did while immersed in water. If this relationship continues for several years the construction and measurement of a technic denture in the laboratory would constitute a valid test of the behavior of the denture base resin in service as relates to dimensional changes.

The average molar to molar shrinkage of four technic dentures [thick and thin uppers and lowers of each resin (Table 1)] that occurred during processing, polishing and storage in water for one day are shown in Figure 13. The zero or fiducial observation was taken as the distance from molar to molar on the wax denture flasked to the incisal and occlusal surfaces of the teeth.

The shrinkages of Epololon and Acralite-88 are lower than the shrinkages of the other resins as the temperatures at which Epoxolon and Acralite-88 were cured are much lower than the temperatures at which the other resins were processed. (As explained in the discussion of the data in Figures 6 to 12 there

is less mechanical strain present in dentures processed at comparatively low temperatures). Thus the so-called self-curing resins show less average dimensional change during processing than the heat-curing resins.

The differences in the average molar to molar shrinkages among the other eight resins in Figure 13 are small, barely over 0.1 percent [0.002 inch (0.050 mm) on a 2 inch (50 mm) molar to molar span]. These differences have no practical significance. Thus the choice of a type of resin or a processing method within this group of eight would have to be made on some other basis than dimensional accuracy during processing. In fact, even the differences between the self-curing and the heat-curing types as shown in Figure 13 could not be detected clinically by either the patient or the dentist.

The same dentures that were used for the data shown in Figure 13, were stored in water at 22°C ± 1°C (72 ± 2°F) and measured at intervals up to three months as shown in the schedule in Table 2. These data are presented in Figure 14. Here, the zero dimension is the distance from molar to molar and flange to flange after removal of the cured denture from the gypsum cast, placement of the reference pins in the distobuccal flanges and storage in water for half an hour. Differences between the molar to molar and flange to flange changes indicate the degree of warpage if the changes are expressed in percent of the molar to molar and flange to flange distances. Figure 14 does show some differences but here again they are so small that they cannot

be detected clinically. The largest difference between the molar to molar and flange to flange measurement occurred in the polystyrene dentures but this difference (0.1 percent) has no practical significance.

Most of the dentures expand on storage in water, Figure 14 and Table 3. This expansion generally compensates in part for the curing shrinkages in Figure 13. An exception is the epoxy resin where the expansion on storage in water is greater than the curing shrinkage. While most of the dentures expanded when immersed in water those made of the vinyl-acrylic copolymer shrank. This shrinkage is in addition to the curing shrinkage.

In 1950-1952, a series of clinical dentures of self-curing and heat-curing acrylic resins were made at the National Bureau of Standards and several hospitals of the Veterans Administration. Data on the dimensional changes of these dentures in the first two years of clinical service are soon to be published [7]. A resurvey was made of the available dentures of this series that were suitable after six years of service. Data on these sixteen dentures are in Figure 15. These data show that on the average, during six years' service the heat cured upper dentures changed less in dimension than lower dentures, that the dentures made of self-curing acrylic resins changed more than dentures made of heat-curing resins, that the upper dentures shrank and the lower dentures expanded and that the change in dimension, be it plus or minus, was small. In fact, the greatest average change during six years of service, that in the self-curing acrylic resin upper

and lower dentures, was only 0.3 percent. On a 2.5 inches (63.5 mm) flange to flange span 0.3 percent is only 0.0075 inch (0.19 mm). This evidence as well as all of the evidence in this investigation fails to support the clinical opinion that acrylic resin dentures warp badly in service.

5. WORK IN PROGRESS

The research plan calls for the fabrication of 160 dentures in all or about 50 more than those used in this report. All of these dentures will be followed until apparent equilibrium in dimensional changes is reached. Occlusal processing errors, linear shrinkages in other than distal areas of dentures and comparative changes of both clinical and technic vulcanite dentures are being determined.

The work in progress also includes measurement of water sorption and solubility, color stability, transverse and impact strength, repairability, adhesion to plastic teeth, and warpage of dentures under controlled conditions. An attempt will be made to correlate the physical properties of the resin with the behavior of clinical and technic dentures.

6. SUMMARY AND CLONCLUSIONS

Over 100 technic and clinical dentures were fabricated of ten types of resins under exacting conditions and processed according to the manufacturers' directions. Molar to molar measurements during and subsequent to processing were made on these dentures. Flange to flange measurements were also made after processing.

Shrinkage on Processing. All of the dentures shrank during curing. The mean for the entire group from the wax denture to the polished resin replica was only -0.5 percent with a range of +0.04 percent to -1.1 percent. In the technic dentures the lowers shrank on the average one and one-quarter times as much as the uppers. The thin dentures shrank about two times as much as the thick ones. Therefore, making the denture thinner than necessary is poor practice.

The resins showing the least change during processing, the epoxy and self-curing acrylic resin, were processed at much lower temperatures than the other resins.

The dimensional changes of the upper and lower clinical dentures of all ten resins fall in between those of the thick and thin technic dentures. This may indicate that the average thickness of the clinical dentures was in between that of the thin and the thick technic dentures. However, no determinations of volume were made.

Dimensional Changes Subsequent to Processing. The molar to molar changes during immersion of the technic dentures in water for three months' averages from +0.26 percent for an epoxy resin to -0.14 percent for the vinyl-acrylic copolymer. Average values including the clinical dentures were +0.31 and -0.09, respectively.

Relative Effect of Dimensional Changes. The average differences between the molar to molar distances on wax dentures and their replicas after storage for three months in water range from approximately +0.15 percent for the epoxy type resin to -0.60 percent

for the vinyl-acrylic copolymer (Table 3). Neither the patient nor the dentist could detect these differences in the relative fit or service behavior of the dentures.

The data from this investigation do not support claims for superior accuracy in dimension by processing with special resins and technics or reports of large changes in dimension of dentures in service. The loss or the lack of retention or the failure of artificial dentures in service is caused by factors other than the dimensional changes in resin bases that occur either during processing, storage in water, or in service.

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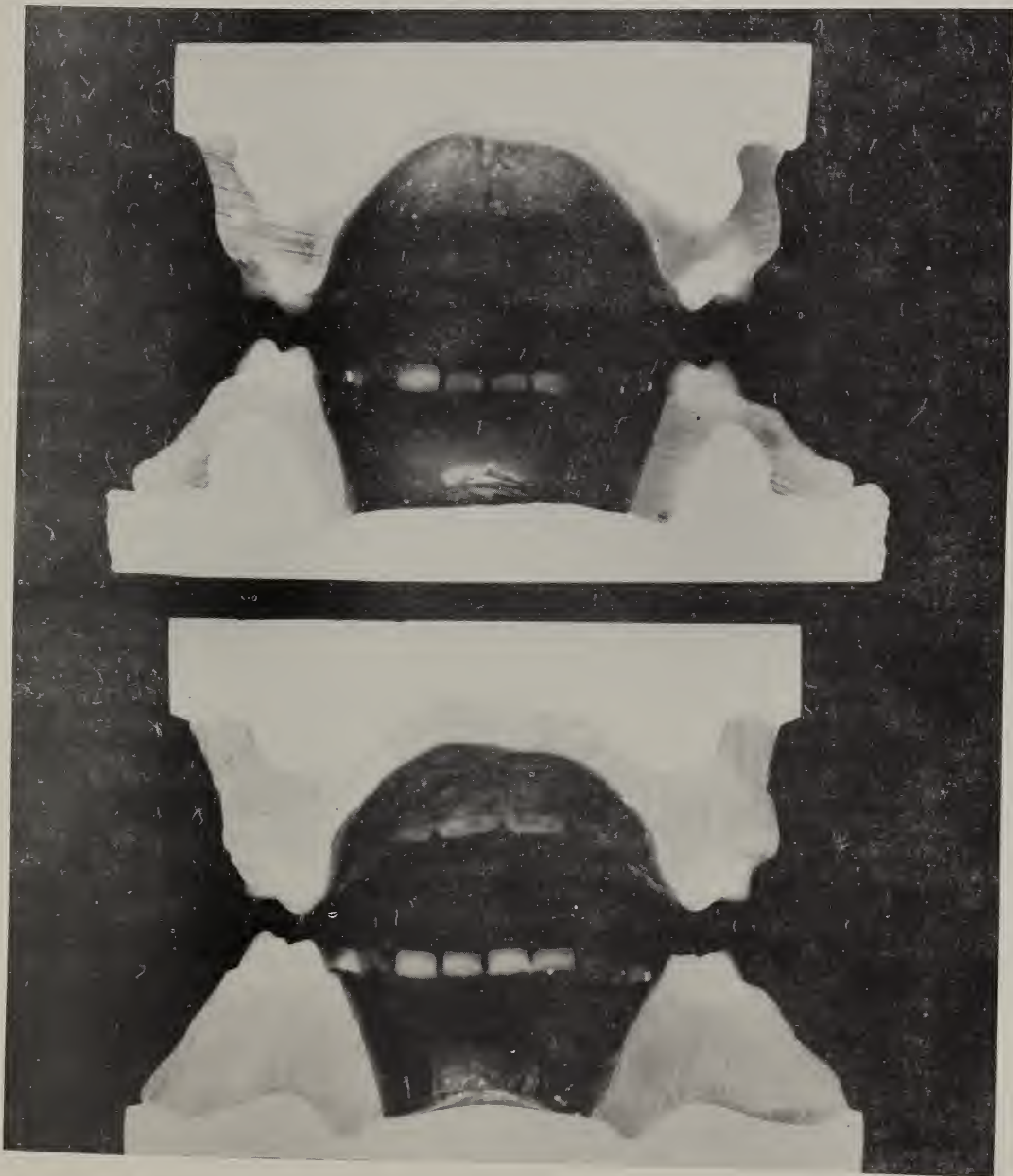

Figure 1. Cross-section of technic dentures.

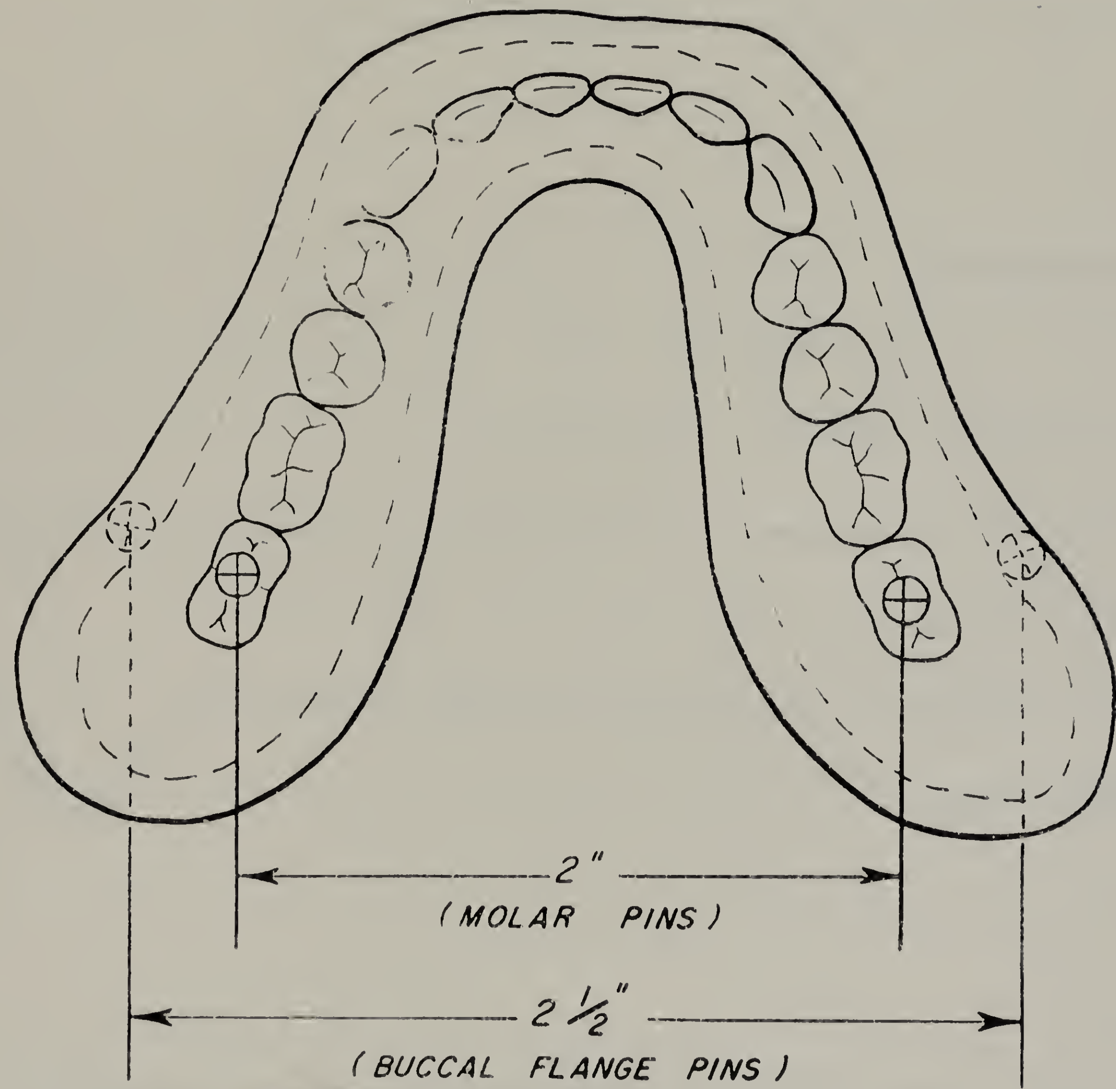

Figure 2. Drawing of denture showing location of stainless steel reference pins.

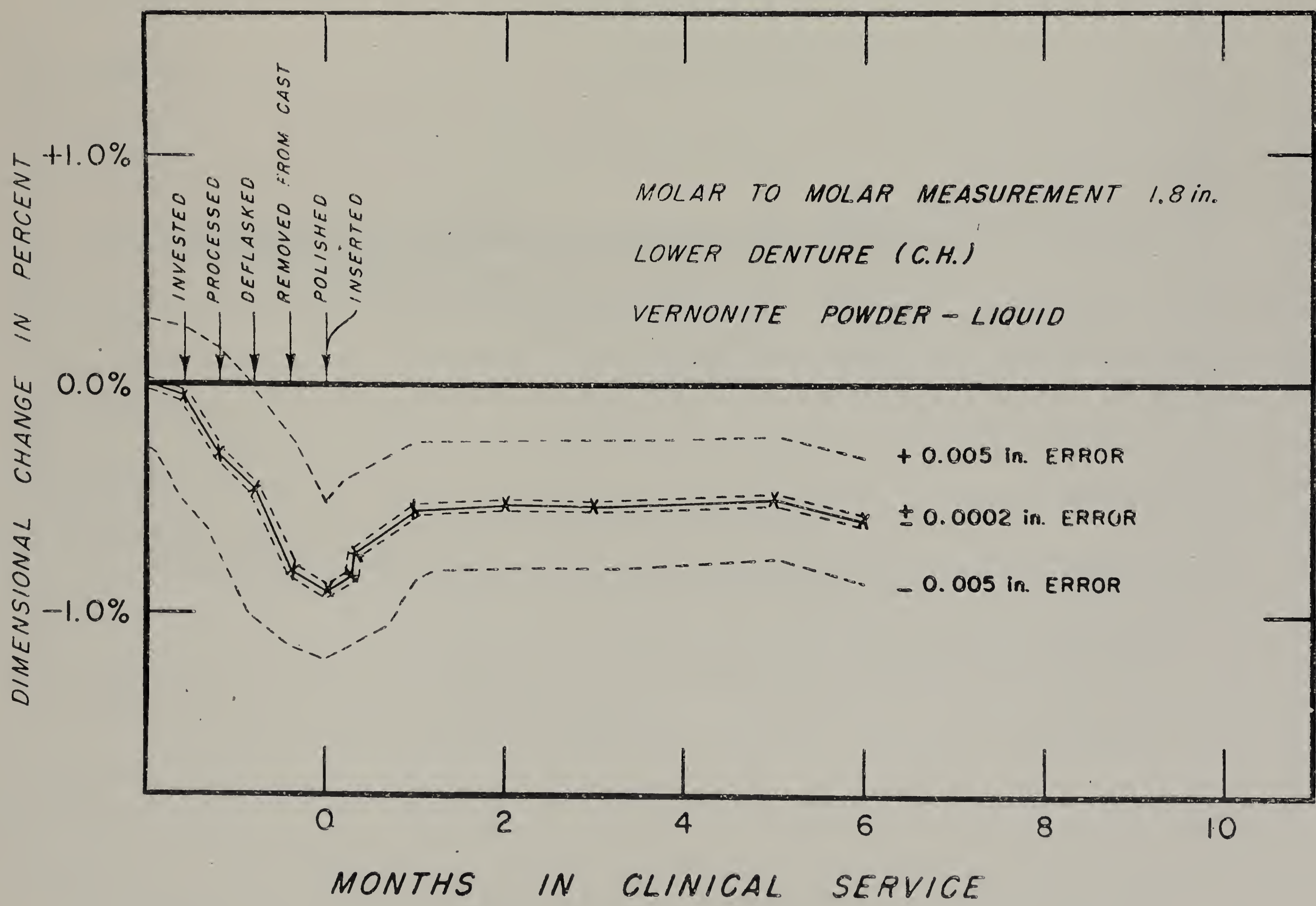

Figure 3. Effect of measurement error on data.

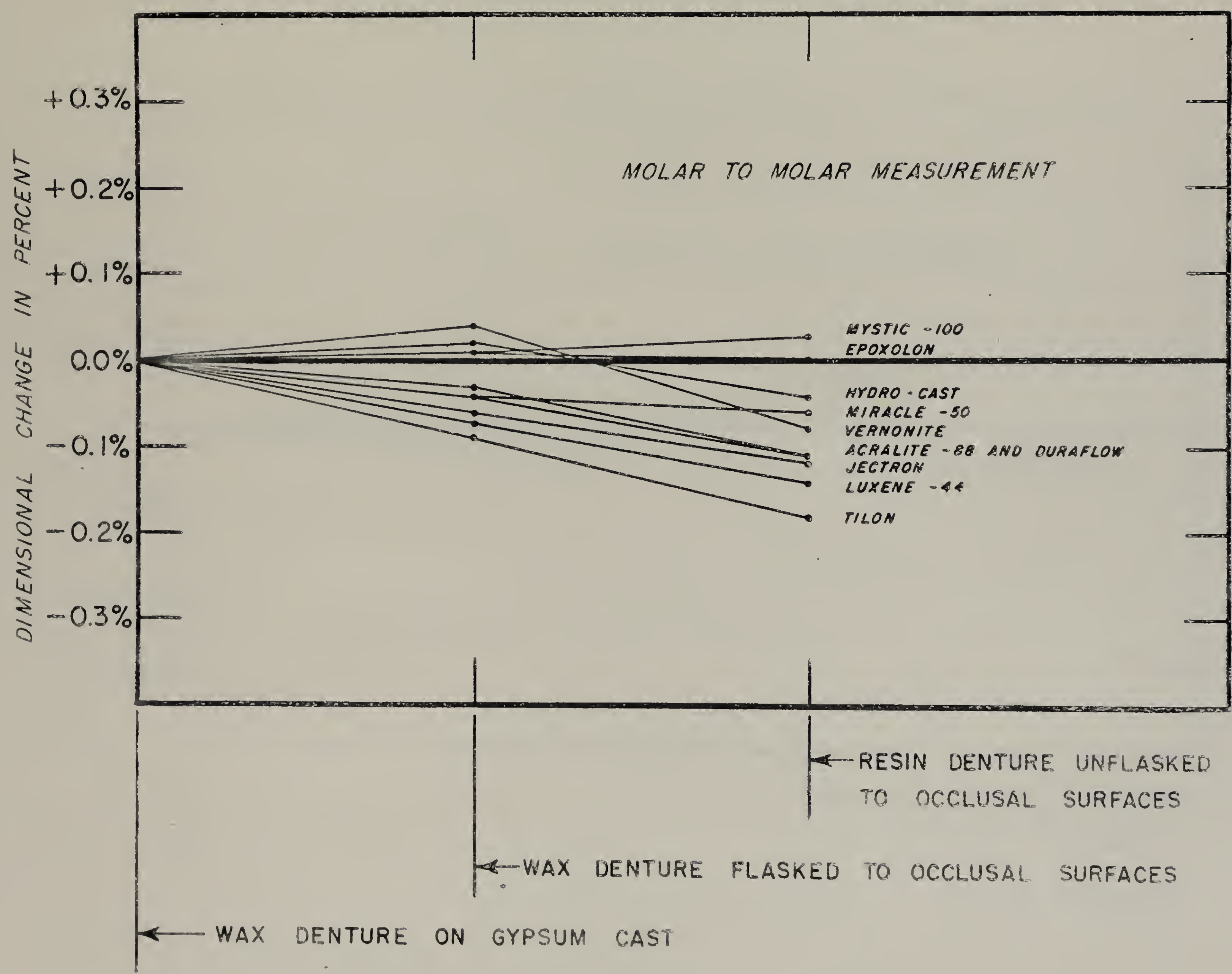

Figure 4. Linear changes of identical thin upper technic dentures during flasking, packing and deflasking procedures.

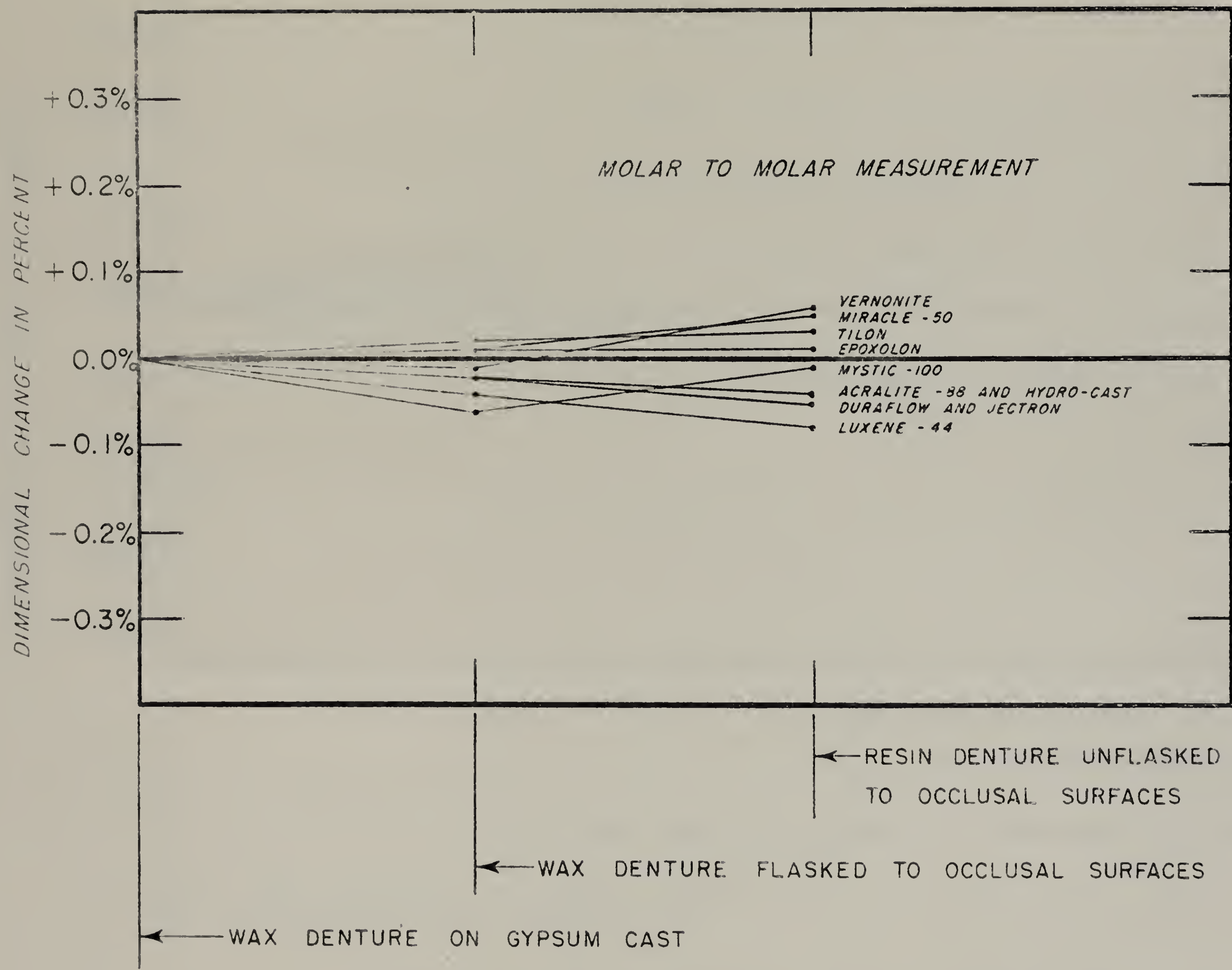

Figure 5. Linear changes of identical thin lower technic dentures during flasking, packing and deflasking procedures.

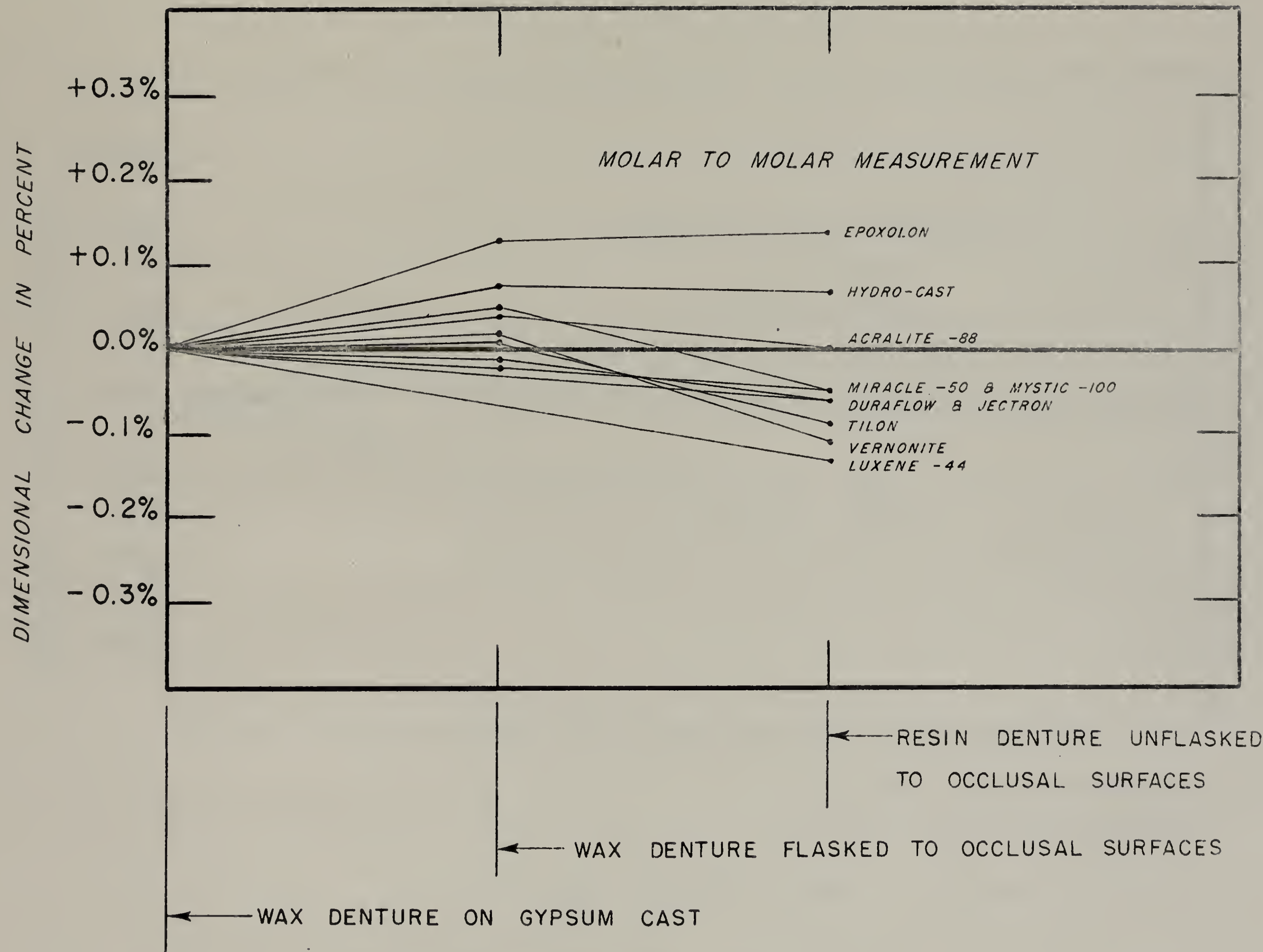

Figure 6. Linear changes of identical thick upper technic dentures during flasking, packing and deflasking procedures.

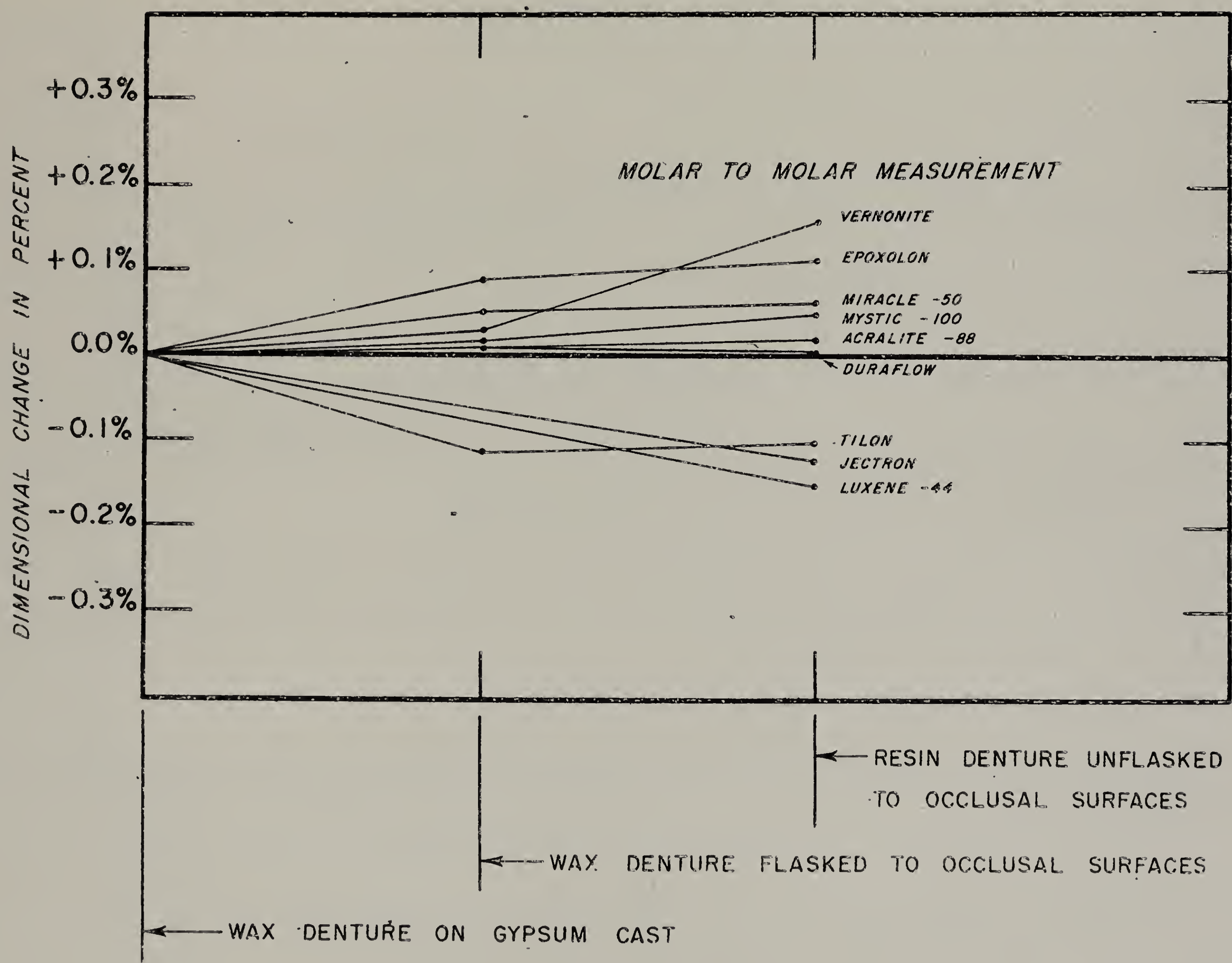

Figure 7. Linear changes of identical thick lower technic dentures during flasking, packing and deflasking procedures.

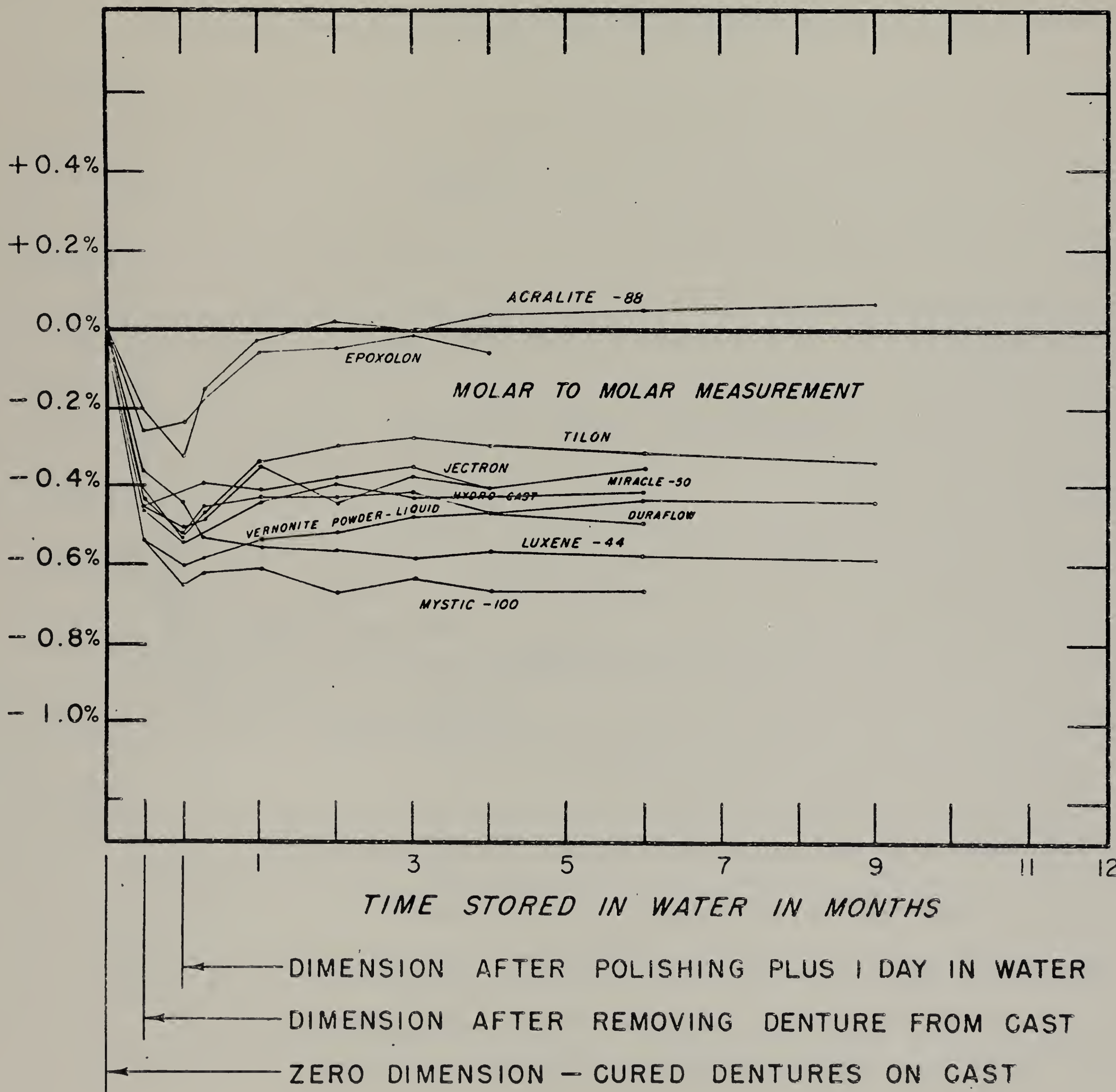

Figure 8. Linear change in identical thin upper technic dentures.

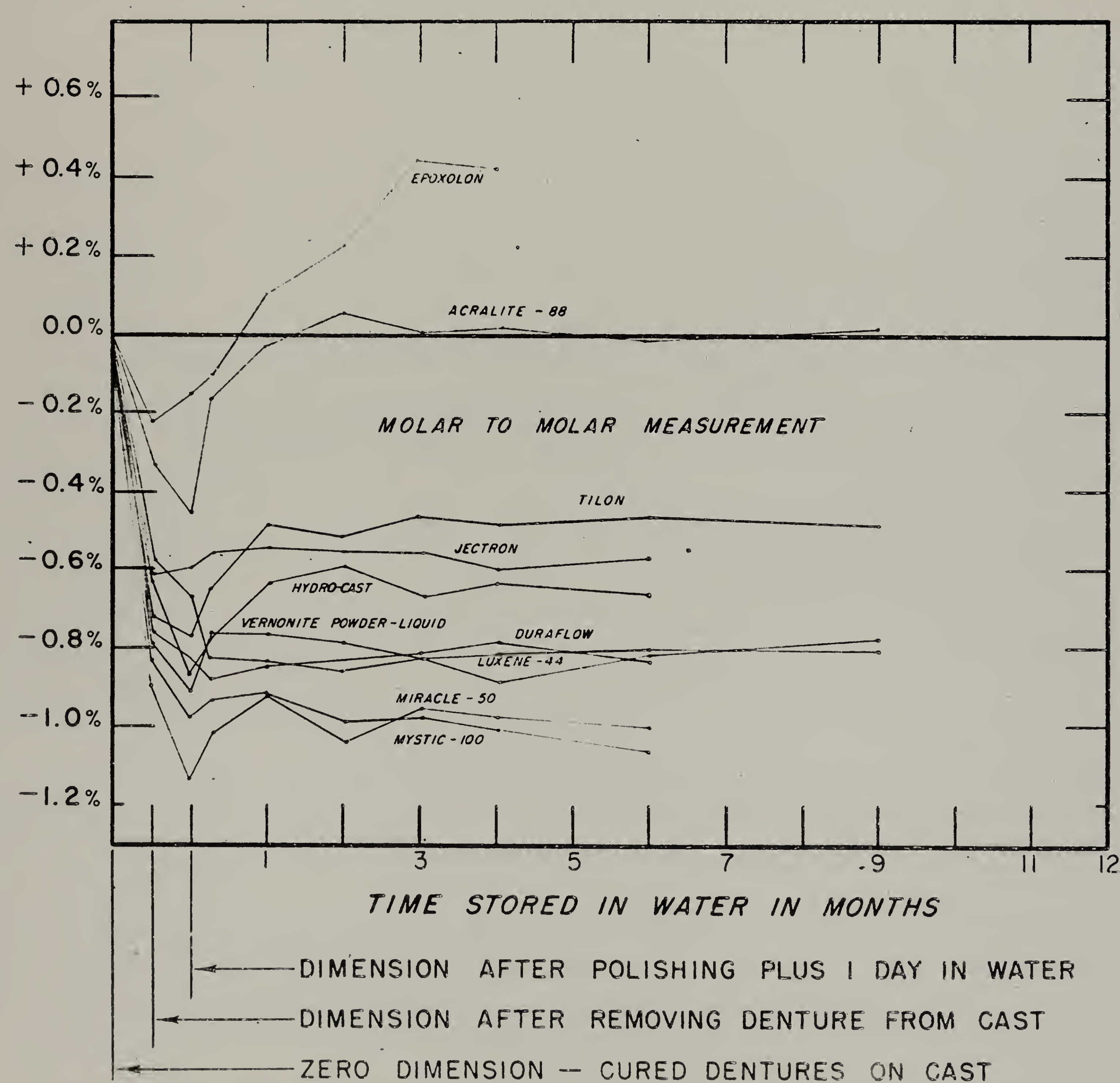

Figure 9. Linear change in identical thin lower technic dentures.

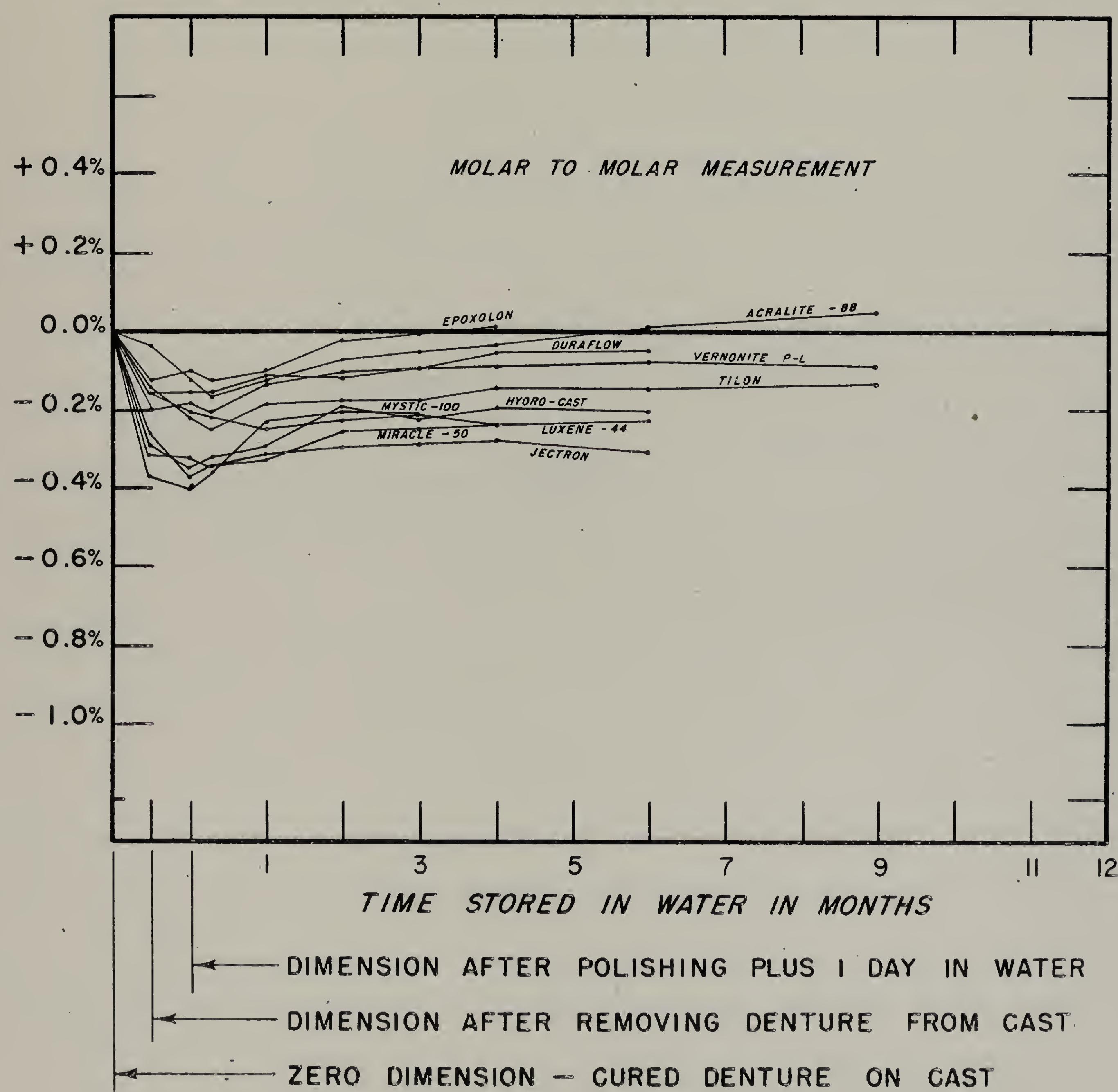

Figure 10. Linear changes in identical thick upper technic dentures.

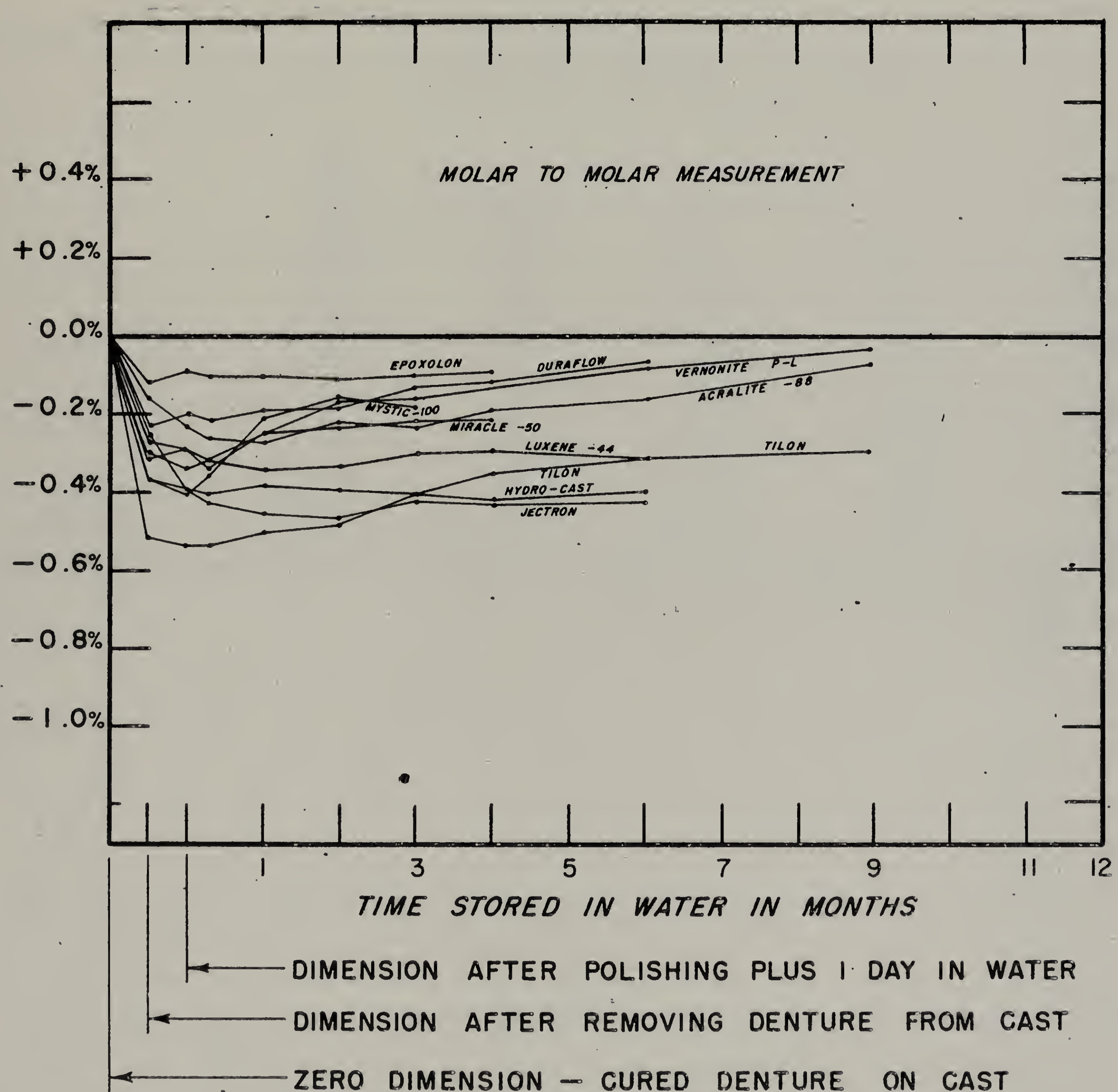

Figure 11. Linear changes in identical thick lower technic dentures.

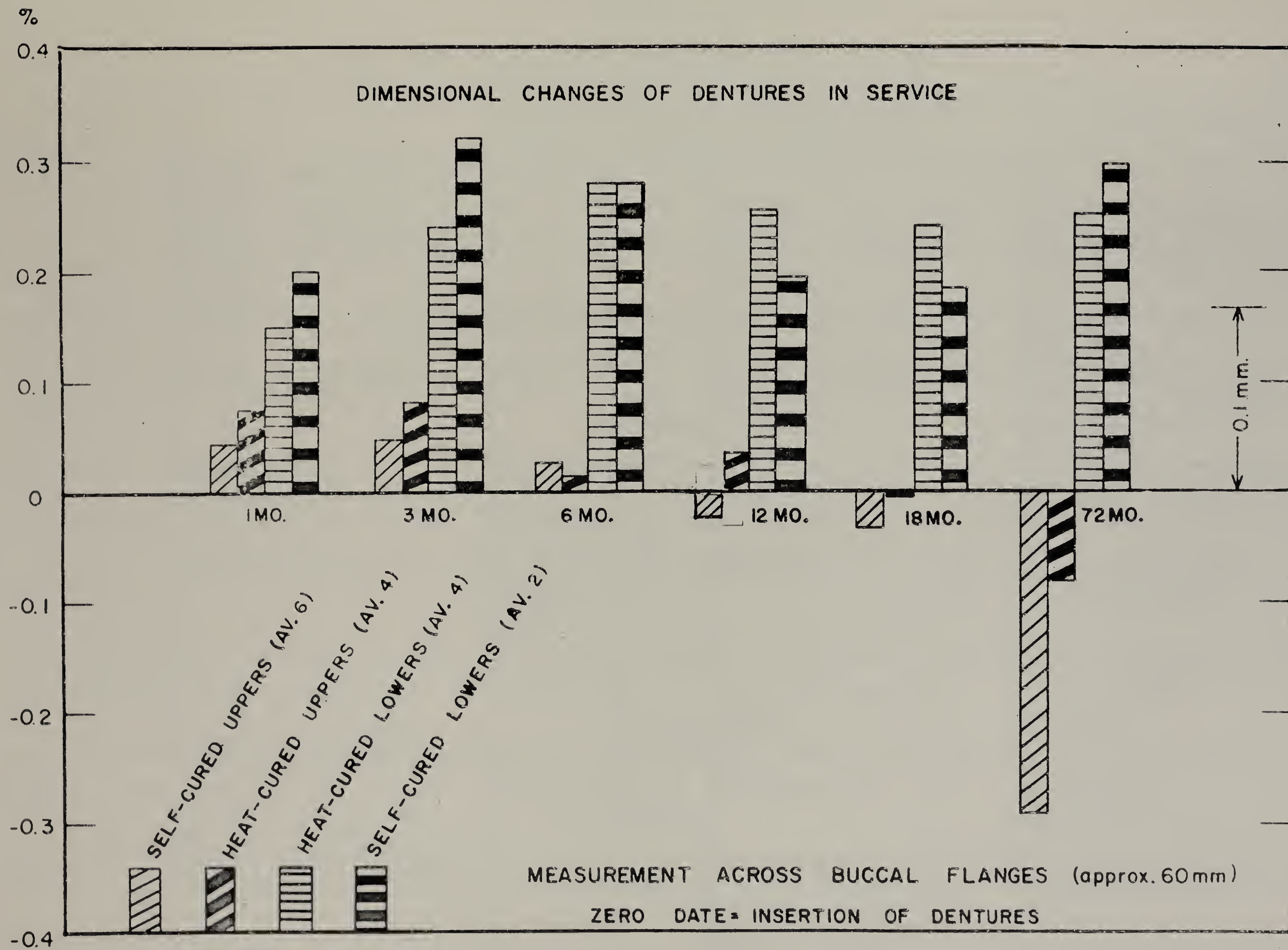

Figure 15. Average flange to flange changes on heat-curing and self-curing acrylic resin dentures during six years of service.

TABLE 1

RESINS AND PROCESSING TECHNICS INVESTIGATED

BRAND	TYPE OF RESIN	DATE REC'D	BATCH NO.	MANUFACTURER OR DISTRIBUTOR	PROCESSING METHOD
Acralite-88	Methyl methacrylate, powder-liquid, cross-linked, self-curing	8-1-57	190	Acralite Co., Inc. New York, New York	Compression molding (room temperature)
Duraflow	Methyl methacrylate, powder-liquid, cross-linked	9-16-57	0657E	Product Research Laboratory, Inc. Cambridge, Mass.	Compression molding (no trial packing)
Epoxolon	Epoxy, slurry-liquid	11-8-57	Lot #78	Surgident Ltd., Los Angeles, Cal.	Pouring (dry low heat cure)
Hydro-Cast	Methyl methacrylate, powder-liquid	12-17-57	NO BATCH NUMBER	Kay-See Dental Mfg. Co., Kansas City, Missouri	Directional hydraulic compression ("Hydro-Cast" technic)
Jectron	Polystyrene, pre-cured bar	11-1-57	75	Jectron Co., Toledo, Ohio	Injection ("Transfer molding" technic)
Luxene-44	Vinyl-acrylic copolymer, gel	Processed by licensed commercial laboratory, 1957 & 1958 in Washington, D.C.		Luxene, Inc. New York, New York	Injection-moist heat ("Pressure Cast" process)
Miracle-50	Methyl methacrylate, powder-liquid, containing 14% glass fibers by weight	10-8-57	NO BATCH NUMBER	American Consolidated Manufacturing Co., Inc. Philadelphia, Pa.	Compression molding
Mystic-100	Methyl methacrylate, powder-liquid, containing 21% glass fibers by weight	10-8-57	NO BATCH NUMBER		Compression molding
Tilon	Methyl methacrylate, uncrosslinked, gel	1-1-57	A6A6	Ticonium Div. of Consolidated Metal Products Corp., Albany, N. Y.	Injection dry heat ("Unidirectional Curing")
Vernonite	Methyl methacrylate, powder-liquid, uncrosslinked	7-1-57	492	Vernon-Benshoff Co. Pittsburgh, Pa.	Compression molding

TABLE 2

Measurement Schedule for Dentures*

MOLAR TO MOLAR MEASUREMENTS ONLY	MOLAR TO MOLAR AND FLANGE TO FLANGE MEASUREMENTS
Wax denture in lower half of flask	Denture removed from cast and stored in water
Wax denture flasked to occlusal and incisal surfaces of teeth	Polished and stored for 24 hours in water
Processed resin denture with occlusal investment removed	After storage in water or in use for 8 days, 29 days, 2, 3, 4, 6, 9 months, and 1, 1-1/2, 2, 3, 4, 5 years
Resin denture on cast with flasking investment removed**	

* All measurements and water storage were at 22 ± 1°C (72 ± 2°F).

** A small portion of the cast in the disto-buccal region was removed at this point on 45 dentures so that flange to flange measurements could be made before the denture was removed from the cast on which it was processed.

TABLE 3. AVERAGE MOLAR TO MOLAR DIMENSIONAL CHANGE OF DENTURES DURING PROCESSING AND SERVICE

Material		Processing Change*			Cumulative Change in Service**									Total Change at 6 Months***		
					1 month			3 months			6 months					
		No. of Dentures	Change	Av. Dev.	No. of Dentures	Change	Av. Dev.	No. of Dentures	Change	Av. Dev.	No. of Dentures	Change	Av. Dev.	No. of Dentures	Change	Av. Dev.
			%	%		%	%		%	%		%	%		%	%
Duraflow	Upper	6	-0.43	0.19	6	0.05	0.02	4	0.15	0.06	3	0.11	0.05	3	-0.40	0.20
	Lower	5	- .50	.24	5	.08	.08	4	.19	.15	3	.16	.14	3	- .44	.31
Hydro-Cast	Upper	8	- .44	.16	5	.13	.05	4	.16	.04	3	.18	.06	3	- .25	.13
	Lower	5	- .52	.03	5	.19	.11	4	.22	.12	3	.28	.15	2	- .16	.20
Miracle-50	Upper	3	- .48	.08	3	.05	.07	3	.08	.03	1	.10	--	1	- .46	--
	Lower	3	- .59	.33	3	.12	.06	3	.14	.03	1	.13	--	1	- .95	--
Mystic-100	Upper	3	- .51	.06	3	.04	.06	3	.04	.07	1	- .02	--	1	- .63	--
	Lower	3	- .65	.22	3	.11	.06	3	.10	.08	1	- .08	--	1	-1.06	--
Tilon	Upper	6	- .63	.24	6	.18	.11	4	.16	.10	2	.14	.07	2	- .36	.13
	Lower	6	- .65	.26	6	.13	.10	4	.20	.13	2	.19	.11	2	- .42	.01
Vernonite	Upper	6	- .42	.07	6	.06	.02	5	.11	.03	3	.10	.01	2	- .34	.16
	Lower	5	- .57	.26	5	.14	.09	4	.22	.12	3	.21	.08	3	- .42	.33
Average all heat cured methyl methacrylate	Upper	32	- .48	.16	29	.09	.07	23	.12	.06	13	.13	.06	12	- .37	.17
	Lower	27	- .58	.23	27	.13	.10	22	.18	.11	13	.19	.12	12	- .48	.31
Acralite-88	Upper	7	- .22	.08	7	.17	.11	6	.30	.12	4	.32	.10	4	.08	.10
	Lower	5	- .36	.18	4	.08	.19	3	.23	.18	2	.26	.18	2	- .10	.04
Luxene	Upper	7	- .50	.08	7	- .08	.04	5	- .08	.05	4	- .07	.04	4	- .58	.12
	Lower	5	- .55	.14	5	- .09	.04	4	- .10	.04	3	- .11	.06	3	- .69	.16
Jectron	Upper	5	- .50	.07	7	.03	.04	7	.05	.04	2	.06	.02	2	- .40	.04
	Lower	5	- .53	.09	5	.03	.05	5	.03	.04	2	.00	.03	2	- .58	.04
Epoxolon	Upper	7	- .15	.08	6	.15	.05	5	.32	.13	3	.34	.20	3	.23	.18
	Lower	5	- .18	.09	5	.02	.11	4	.30	.18	2	.38	.38	2	.32	.30

* Change from wax denture through one day after polishing resin denture.

** Change from one day after polishing to time indicated.

*** Processing change plus six months' service change.

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
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