[Original] Matsumoto shigaku, 15 : 27~37, 1989
key words : acrylic resin-dimensional accuracy-literature review

Dimensional Accuracy of Acrylic Resin Denture Bases — Literature Review —

TETSUYA TAKAMATA, HITOSHI ARAKAWA, YOSHIHISA INOUE, SHOHEI SUGITOU, KAZUHIRO KURITA, IKUFUMI KURASAWA and KYOICHI HASHIMOTO

Department of Complete and Partial Denture Prosthodontics, Matsumoto Dental College
(Chief : Prof. K. Hashimoto)

Summary

The more contact there is between the denture base and the cast, the better the fit, resulting in a close adaptation of the denture surface to the oral mucosa and a more retentive denture. Many prosthodontists, however, feel that compression-molded dentures processed with acrylic resins become ill fitting in the mouth because they warp severely during processing and while in service. One of the reasons for this problem is shrinkage of the acrylic resin due to polymerization. This article reviews the studies on accuracy of denture bases using various activation methods for polymerization of acrylic resin.

Introduction

During the past half century heat activated acrylic resin (PMMA) has been the most available denture base material for clinics. It was excellent esthetic properties, adequate strength, low water sorption, and low solubility[1]. In addition, it is free from toxicity, can be easily repaired, can be reproduced accurately, retain indefinitely the details and dimensions of a pattern, and can be used with a simple molding and processing technique for construction of denture bases[2]. Traditionally, these acrylic resins have been processed in brass denture flasks for compression molding of the acrylic resin while it is in the dough stage. The flasks are placed in a temperature-controlled water bath for a specified time to permit resin polymerization. There has always been a problem with shrinkage of the acrylic resin because of the polymerization process. The different coefficient of thermal expansion of the acrylic and the gypsum matrix aggravate this by causing the presence of an internal elastic stress in the cured baseplate[3]. The combination of polymerization contraction, thermal contraction and the strain accompanying stress release during deflasking causes inaccurate adaptation of the denture to the tissue. An accurate fit is relatively important, since the distance between the base and supporting tissues is one of the principal factors in relation and control of the amount of force necessary to dislodge the dentures.

In recent years many attempts have been made to improve the accuracy of the fit of resin dentures by special methods of processing, by specially compounded resins, or by a combination of both, such as light activated resin, microwave activated resin and vacuum-plus-pressure low temper-

(accepted for publication on March 4, 1989)

ature polymerization of resin systems.

This paper presents a review of the literature on dimensional accuracy of heat activated acrylic resins, pourable self activated acrylic reins, microwave activated acrylic resins, and visible light activated resins. Additionally, the methods of evaluating dimensional accuracy of denture bases are discussed.

Overview

I. Heat activated acrylic resins

Many articles and reports have appeared in dental journals and the lay press concerning the physical and mechanical properties of poly (methyl methacrylate) (PMMA). In 1939 and 1942 Sweeney, Paffenbarger and Beall[4,5] measured weight and posterior dimensional changes of complete maxillary dentures on wetting and on drying at 32 per cent relative humidity.

The acrylic resins and the vinyl-acrylic resins lost weight and expanded on wetting. Skinner and Jones[6] showed that dentures made with self-curing acrylic resins also shrank on drying in air. All these reports[4~6] give different values because the test specimens and conditions were not alike. Demonstrations of the relief of strains in dentures and in denture blanks by boiling them in water, and the effect of some techniques on the qualitative amount of strain present were reported by Taylor[7] and Pryor[8].

In 1947 Osborne[9] investigated the possibility of inducing strains into the finished dentures in order to try and determine what extent they might be present in the normal denture and what their immediate and ultimate effects upon that denture might be. He concluded that the internal strain is present in all acrylic resin dentures no matter what processing technique is used. Such strains are mainly concentrated around the teeth, clasps, bars and strengthening wires.

The degree of strain is reduced when the restoration has curvatures in only one plane, and is absent in flat specimens, due to spontaneous relief after deflasking. Harman[10] investigated the effect of time and temperature on the polymerization of a methyl methacrylate resin denture base. He discussed (1) the dimensional change and curing temperature, (2) the effect of cure on dimensional change and water sorption, and (3) the effect of time and temperature of polymerization on the resin and transverse strength. The results of this study were (1) a substantially polymerized, unplasticized methacrylate resin denture base, after two weeks in water at body temperature, has a linear dimensional change of the order of -0.1 per cent, when no correction has been applied for the thermal expansion of the metal mold during curing, (2) it is shown that an effective curing cycle must take into account the mass and form of the sample, the ambient temperature and the rate of temperature rise within the sample, and (3) it is believed that the specification should define the dimensions of the sample from which such test pieces are cut, in order that uniform test results will be obtained in the same material.

Several investigators have measured the amount of dimensional change in a processed denture. Woelfel et al[3]. found that the greatest linear change in the posterior region of the denture occurred when the cured dentures were removed from the casts. They showed that linear changes from waxed to finished dentures, when measured molar to molar across the posterior section of the specimens, shrank 0.4 mm (0.877%). A recovery of 0.1 mm (0.219%) occurred after three months of use. Several other investigators[5,11,12] used linear measurements to evaluate the dimensional stability of the denture base materials by placing pins at strategic points in dentures. Fairhurst and Ryge[13], however, stated that the linear measurement across the posterior of a denture blank was not a true

representation or indication of its adaptation. A comparator, which measured dimensional differences and at different pins, was developed by Rupp et al.[14]. They described a technique for measuring changes due to the effect of a different curing cycle on dimensional accuracy of dentures.

Mowery et al.[15] studied the dimensional stability of self-cured and heat-cured dentures. For this purpose measurements of the dimensional changes during processing and during a period of two years of clinical service were made on a series of dentures. They concluded that (1) the magnitude of dimensional changes of both heat-cured and self-cured resins was small, (2) the average processing shrinkage of salf-cured dentures was less than that of heat-cured dentures and the average expansion of self-cured dentures during service was slightly greater than that of the heat-cured dentures, and (3) on the average the greatest change in all dentures occurred during the first month. After two months little significant change occurred.

The early 1960s brought more extensive studies on denture bases. Anthony and Peyton[16] studied the dimensional stability of heat cured resin bases, autopolymerized resin bases, and cast cobalt chromium bases using a modified comparator. The results showed that the most accurately fitting dentures used bases made from autopolymerizing resin. The buccal surface of the alveolar ridge proved to be the most accurately fitting area in the heat cured denture bases. This study was in agreement with that of Skinner and Cooper[17] in which the amount of cooling required after the plastic reached a ridged state in the molds was the principal factor in the observed shrinkage.

Mirza[18] described the degree of dimensional change occurring in dentures and the significance of this change in clinical fit. The clinical fit of autopolymerized dentures was equally as good as that of heat-cured dentures, even though the magnitude of linear dimensional changes of the autopolymerized dentures after 3 months of use was greater than in the heat-cured group.

Woelfel et al.[19] reported on dimensional changes in complete dentures on drying, wetting and heating in water. The changes in molar-to-molar and flange-to-flange distances after wetting, drying, rewetting and heating were measured on 12 sets of thin and 12 sets of thick maxillary and mandibular complete dentures. The denture materials used were : eight types of acrylic resins, one of polystylene, one of vinyl-acrylic copolymer, one epoxy resin and one hard rubber. They concluded that the shrinkage and expansion generally followed the weight changes except that hard rubber expanded on drying and shrank on wetting during drying and rewetting treatment. The thick dentures changed much less in dimension than the thin ones. The average change in per cent of the molar-to-molar and the flange-to-flange distances for individual dentures during the 12 to 35 months' immersion in water ranged from -0.17 to $+0.70$, and on drying for 3 weeks in a desiccator ranged from -0.03 to -0.92.

A pressure-indicator-paste pattern was used to evaluate the fit and function of the dentures[20]. Investigators made duplicate maxillary dentures, one injection molded, using a vinyl-acrylic copolymer, and the other compression molded without trial closure of the flask, using a cross-linked acrylic resin. They made pressure-indicator-paste patterns before the patient wore the dentures, after he wore each one for one week, two years later, and after the patient had been wearing a third denture for 14 months. Clinical and visible evaluation of the dentures showed them to be almost exactly alike in fit and function.

In 1970 Young[21] used a plaster to correlate the denture base-palatal tissue apposition in complete maxillary dentures and to determine if similar biomechanical factors acting on the dentures lead to similar tissue responses. Pressure-Indicating-Paste patterns were also used in this study. The difference between the thickness of the denture base, and the thickness of the denture

base plus the plaster wash indicates the thickness of the space existing between the based surface of the denture and the palatal mucosa while the plaster is in place. A difference in measurement in the same area with the manual and centric occlusion plaster washes indicated a change in position of the denture relative to the tissue. He concluded that there was little correlation of the space existing under specific areas of the basal surface of complete maxillary dentures and the pattern of clinical tissue pathology in the corresponding areas.

A surface meter was used to evaluate the fit of different denture base materials by Barsoum et al.[22]. The most accurate fit was achieved with the cast aluminum base, followed by self cured resin ; the poorest fit was achieved with heat cured resin.

To evaluate the fit of the denture bases to the oral tissues clinically, Hosoi[23] indicated the use of silicone material. He also used a color analyzer to evaluate the thickness of silicone. The thicker silicone material is the poorer the fit of the denture base to the tissues.

A surface table vernier height gauge and an optical comparator were used by Becker et al.[24]. They compared the dimensional changes due to processing, including the amount and direction of denture flange and palatal distortion and the amount and direction of tooth displacement when processed using a silicone-gypsum molding technique, a fluid-resin system, and an all-gypsum pressure-molding technique (heat-cured). The conclusions of this study were (1) all three of the processing techniques demonstrated three-dimensional change in the position of the teeth and three-dimensional changes of the internal surface of the denture, (2) no single processing technique tested appeared to be superior as far as dimensional stability is concerned, and (3) the choice concerning which of the three processing techniques is most desirable should be based on criteria other than dimensional stability, color stability, surface detail, and hardness.

Barco[25] in 1978 described a method of measuring the adaptation of a maxillary complete denture to a master die. For this in vitro investigation he used silicone impression material which was compressed under a given load between the denture base and master mold and then weighed after curing on an analytical balance to the nearest 0.0001 gram. Mainieri[26], Soyac[27], Shlosberg[28] and Nagata et al.[29] also used this technique to evaluate the fit of denture base materials. According to Barco[25], in vivo, this would give better adaptation resulting in better retention.

Antonopoulos[30] discussed on the dimensional and occlusal changes in fluid resin dentures. The results of this study indicate that the fluid resin dentures underwent more processing shrinkage (0. 617%) than the conventionally processed dentures (0.377%). The excessive reduction in the vertical dimension of occlusion usually observed with fluid resin dentures was minimized.

Hanawa[31] investigated the influence of different methods of mixing and curing of poly (methyl methacrylate) (PMMA) on the amount of residual monomer in denture bases. He examined the mixing methods of monomer and polymer by the use of generally employed edentulous cast, which had been completed-from the arrangement of the artificial teeth to flasking. The amount of residual monomer and heat inside an acrylic resin denture base was measured on each cast by different curing methods. From the results it was concluded that (1) the distribution of polymer size was examined among three kinds of resin-Acron, L-resin and Hircoe-and that the area of their distribution was less than 130μ. Acron had its most distributed area in from 60$\mu$to less than 70μ, L-resin in from 20$\mu$to less than 50μ, and Hircoe in from 50μ to less than 60μ, (2) after surveying monomer and polymer mixing methods of the three cases mentioned above, it was observed that, in order to mix polymer more efficiently, mixing time tended to take 60 seconds rather than 30 seconds, and that when employing vibrators the amount of mixed polymer needed increased in proportion to the

degree of vibration, and (3) the most efficient mixing ratio of polymer and monomer varied from 2 : 1 to 2.5 : 1 in Acron and L-resin, and from 2.5 : 1 to 3 : 1 in Hircoe.

A Starrett (L. S. Starrett Co., Athol, Mass.) measuring device was used to evaluate the changes in vertical dimension of complete dentures by comparison molding with a "pour resin" technique[32]. The investigators concluded that the smallest increase in vertical dimension of occlusion was obtained with compression molding technique.

Tateno[33] reported on the effect of curing temperature and time on curing shrinkage in the preparation of resin base dentures. In this investigation, measurements of linear curing shrinkage were made on heat-cured resins polymerized under 27 curing conditions in which temperatures ranging from 55° C to 100°C was combined with times from 1 hr. to 24 hrs.

In 1982 and 1985 Inanaga et al.[34] and Habu et al.[35] used a three dimensional measurement system (Zyzacs M-400, Tokyoseimitsu Co., Tokyo, Japan) to measure the dimensional change of the injection type cold curing acrylic resin. They also discussed the influence of decreased wax in the alveolar region of waxed up dentures on the dimensional accuracy of the tissue surface and the master cast after polymerization. Habu et al.[35] also reported on the influence of artificial teeth to dimensional accuracy occurring in dentures during processing.

Polyzois et al.[36] studied the examination and compared the linear dimensional changes of three boilable denture resins with a conventional and high-impact heat-cured resin. The results of this investigation indicate that all five denture resins produced dentures that shrink. In addition, measurements between certain teeth showed shrinkages. Linear shrinkages of denture bases and teeth distance were less than 1.0 %. Flange-to-flange and molar-to-molar changes were less than 0.5 mm (1.0 %) and 0.2 mm (0.4 %) respectively. A dial caliper and a depth gauge were used for measurements on denture bases and artificial teeth. Johnson et al.[37] used a binocular microscope for measurements of distortion at the posterior palatal denture border.

II. Pourable self activated acrylic resins

Most acrylic resin dentures are fabricated from heat activated denture base materials. However, cold curing (autopolymerizing, self curing, chemically activated) acrylic denture base materials also produce durable and stable dentures[15] and are readily available to the profession.

The principal difference between heat curing and cold curing acrylic denture base resin in the method used to activate the benzoyl peroxide, catalyst which initiates polymerization of the monomer. With heat cured resins, polymerization is started by free-radicals from the benzoyl peroxide, which are activated by heat. In cold curing resins, a tertiary amine chemical accelerator, usually N, N-dimethyl-p-toluidine in added to the monomer so that polymerization can be completed at room temperature[2].

In 1955 the fluid resin technique, using pourable autopolymerizing acrylic resins and hydrocolloid molds, was developed[38]. Since the development of this technique, Winkler[39] and Shepard[40] have published detailed descriptions, of various fabricating techniques, while other researchers have studied fluid resin dentures and have proposed modifications[30,41-56]. The main advantage of this technique is that it makes processing of dentures less time-consuming as compared to the heat curing technique.

Trudso et al.[57] described a four year follow-up examination of patients with complete dentures processed in either pour resin or heat cured acrylic resin. They compared the two processed materials with regard to some biologic and mechanical properties. They concluded that there were

no serious complaints of the treatment, no significant differences between the groups with regard to the amount of plaque which accumulated on the tissue and polished surfaces. In addition, the pour resin denture base seemed to have poorer physiochemical properties which resulted in an increase in dislodging of teeth from the denture base, more fractures of the denture base, and increased wear of the polished surfaces.

Recently, a new fluid resin for use in removable prosthodontics has been developed[58] that is cured at 45° C in a vacuum assisted pressure chamber. Its manufactures claim that warpage of the denture base is virtually eliminated and that optimal translucency is provided[59].

III. Microwave activated acrylic resin

In 1968 Nishii[60] and Hashimoto et al.[61] published the first reports in which resin materials for denture construction were microwave activated. In 1983 Kimura et al.[62-64] described dough-forming and polymerization of acrylic resins and the surface roughness of acrylic resins polymerized by microwave irradiation. The discrepancies between the hot water bath polymerized denture bases and plaster models were greater than those for denture bases of the same resins polymerized by microwave irradiation. The adaptation at the ridge portion of the denture base was superior to that at the palatal region. As a whole, the resins activated by microwave showed better adaptation than those polymerized in the water bath. Reitz et al.[65] compared some of physical properties, i. e., porosity, hardness and transverse strength, of strips of resin, some of which were polymerized by microwaves and some by conventional water bath heating. Hayden[66] measured the flexural strength of three commercially available brands of acrylic when polymerized by the water-bath procedure and the microwave method. He stated that the processing of denture baseplates in a microwave oven and fiber-reinforced-plastic flasks seemed to polymerize the acrylic in the normal fashion. However, testing under load conditions revealed that the microwaved acrylic did not absorb as much energy before fracture as the conventional water-bath polymerized acrylic. Clerck[67] assessed microwaved polymerization of acrylic resins used in dental prostheses. He concluded that the microwave activated resin has a lower residual monomer to polymer ratio and the same physical properties as a conventionally cured resin. Sanders et al.[68] investigated the porosity in cured blocks of resin. Samples polymerized by microwave followed by bench cooling, by microwave followed by immediate quenching and by conventional water bath heating were compared. Five representative denture base acrylic resins were used. After polymerization, cut specimens were polished and India ink was applied to the cut ends and then repolished. Any ink remaining was used as an indication of porosity. The results were not analyzed statistically, but the authors felt that, using the relatively thick blocks in this study, it was important to select an appropriate resin for the particular technique. Bafile et al.[19] compared the porosity of denture resin cured by microwave energy to denture resin cured using the conventional heat method. The statistical analysis indicated that there were no significant differences in mean porosity between the control group and the four groups processed with microwave energy and Micro Liquid. The two qroups processed with microwave energy and methyl methacrylate showed a significantly higher mean porosity. Shlosberg[28] concluded that the density, dimensional accuracy, transverse strength, hardness and residual monomer levels of a denture base resin polymerized by microwave and by a hot water bath were not different from one another. Within the limits of the testing method no residual monomer was detected in specimens polymerized by either method.

IV. Visible light activated acrylic resins

Little experimental work has been reported with reference to the use of visible light activated resins for dentures. Ogle et al.[70] evaluated the clinical use of Triad reliner material, noting some physical properties of and bacterial adherence to the light activated Triad as well as an ordinary heat activated and an autopolymerized (chemically activated) methyl methacrylate. Goto et al.[71] investigated and reported the transverse deflection, transverse strength, tensile strength, water sorption and change in Rockwell hardness of a light activated resin. They concluded that the visible light activated resin has less values than conventional heat activated resin in regards to mechanical properties. Aoyama et al.[72] and Umi et al.[73] studied the physical properties and fit of visible light activated resin. In these studies, the fit of the denture base (no teeth) was better when the resin sheet form was divided into a few pieces prior to placement and polymerization compared to a one-piece placement of the sheet form. They used a metallugical microscope for measurement of space between denture bases and casts. Ishigami et al.[74-76] were concerned with the junctional strength between the visible light activated resin base and the resin artificial teeth. They also studied the coefficient of viscosity of relining material of this type, trying to make a relining material free from bitterness or an amine-like odor before curing, using cyclophosphazene monomer (4 PN-$(TF)_2$-$(EMA)_6$). It was concluded that the relining material was well suited for clinical use, being tasteless and odorless and having a lower viscosity coefficient and greater liquidity than the light activated resin then being marketed by Dentsply. Kahn et al.[77] described the staining characteristics of a visible light activated denture base material. They stated that the Triad system possessed satisfactory mechanical properties but its staining potential may be a limiting factor in its suitability as a denture base material. Nimmo[78] stated a technique for the chairside correction of the posterior palatal seal using a visible light curing resin.

Discussion and Conclusions

During a half century a heat activated acrylic resin (PMMA) has been most available denture base material for clinics. It has been well known, however, that compression-molded dentures processed with acrylic resins become ill fitting in the mouth because the warp severely during processing and while in service[3]. Phillips[79] have stated that "since the acrylic resins exhibit certain unavoidable dimensional changes, the dentist should appreciate these limitations so that he will not expect the impossible." In recent years many attempts have been made to improve the accuracy of the fit of resin dentures by special methods of processing, by specially compounded resins, or by a combination of both, such as light activated resin, microwave activated resin and vacuum-plus-pressure low temperature polymerization of resin systems. Although many investigators have reported that processing shrinkage of conventional heat activated resin due to thermal and polymerization contractions may result in the lack of the dimensional accuracy, no detailed study has been reported on these new methods.

Recently, the authors[80] tested to evaluate the dimensional stability of a conventional heat activated acrylic resin (PMMA), a new pour resin, a visible light activated resin and microwave activated acrylic resin, all used for denture bases. We found the results of this study to be interesting and useful for clinicians ; the results are in press. However, we feel that more studies are needed in relation to porosity, physical properties and discoloration on these new activated resins and methods.

Acknowledgment

The authors gratefully acknowledge Dr. James C. Setcos, Department of Dental Materials, School of Dentistry, Indiana University and Mr. Arthur Bingham, Matsumoto Dental College, for their helpful counselling and encouragement.

References

1) Skinner, E. W. and Chung, P. (1951) The effect of surface contact in the retention of a denture. J. Prosthet. Dent. **1**:229—235.
2) Winkler, S. (1984) Denture Base Resins. Dent. Clin. North Am. **28**: 287—297.
3) Woelfel, J. B., Paffenbarger, G. C. and Sweeney, W. T. (1960) Dimensional changes occurring in dentures during processing. JADA, **61**: 413—430.
4) Sweeney, W. T. (1939) Denture base material: acrylic resins. JADA, **26**: 1863—1873.
5) Sweeney, W. T., Paffenbarger, G. C. and Beall,J.R. (1942) Acrylic resins for dentures. JADA, **29**: 7—33.
6) Skinner, E. W. and Jones, P.M. (1955) Dimensional stability of self-curing denture base acrylic resin. JADA, **51**: 426—431.
7) Taylor, P. B. (1941) Acrylic resins: their manipulation. JADA, **28**: 373—387.
8) Pryor, W. J. (1943) Internal strains in denture base materials. JADA, **30**: 1382—1389.
9) Osborne, J. (1947) Internal strains in acrylic denture base materials. Brit. Dent. J. **16**: 204—212.
10) Harman, I. M. (1949) Effects of time and temperature on polymerization of a methacrylate resin denture base. JADA, **38**: 188—203.
11) Skinner, E. W. (1949) Acrylic resins: an appraisal of their use in dentistry. JADA,**39**: 261—268.
12) Stafford, G. D., Bates, J. F., Huggett, R. and Handley, R. W. (1980) A review of the properties of some denture base polymers. J. Dent. 8: 292—306.
13) Fairhurst, C. W. and Ryge, G. (1954) Tin foil substitute: Warpage and glazing of acrylic resin. J. Prosthet. Dent. **4**: 274—287.
14) Rupp, N. W., Dickson, G., Lawson M. E. and Sweeney, W. T. (1957) A method for measuring the mucosal surface contour of impression, cast, and dentures. JADA, **54**: 24—32.
15) Mowery, W. E., Burns, C. L., Dickson, G. and Sweeney, W. T. (1958) Dimensional stability of denture base resins. JADA, **57**: 345—353.
16) Anthony, D. H. and Peyton, F. A. (1962) Dimensional accuracy of various denture-base materials. J. Prosthet. Dent. **12**: 67—81.
17) Skinner, E. W. and Cooper, E. N. (1943) Physical properties of dental resins. Part 1. Curing shrinkage and water sorption. JADA, **30**: 1845—1852.
18) Mirza, F. D. (1961) Dimensional stability of acrylic resin dentures: clinical evaluation. J. Prosthet. Dent. **11**: 848—857.
19) Woelfel, J. B., Paffenbarger, G. C. and Sweeney, W. T. (1962) Dimensional change in complete dentures on drying, wetting, and heating in water. JADA, **65**: 495—505.
20) Woelfel, J. B. and Paffenbarger, G. C. (1965) Pressure-indicator-paste patterns in duplicate dentures made by different processing technics for the same patients. JADA, **70**: 339—343.
21) Young, J. M. (1970) A study of the accuracy of the apposition of palatal tissues to complete dentures. J. Prosthet. Dent. **23**: 136—147.
22) Barsoum, W. M., Eder, J. and Asger, K. (1968) Evaluating the accuracy of fit of aluminum-cast denture bases and acrylic resin bases with the surface meter. JADA, **76**: 82—88.
23) Hosoi, N. (1976) Studies on the fitness test for the denture base. Tsurumi Shigaku, **2**: 111—134.
24) Becker, C. M., Smith, D. E. and Nicholls, J. I. (1977) The comparison of denture-base processing techniques. Part II. Dimensional changes due to processing. J. Prosthet. Dent. **37**: 450—459.
25) Barco, M. T. Jr. (1978) Maxillary complete denture stability: Part 1 : In vitro dimensional accuracy. Part 2 : In vivo stability. Master's Thesis, Indiana University School of Dentistry.
26) Mainieri, E. T. (1979) Tooth movement and dimensional change of denture base materials using two different type of investing. Master's Thesis, Indiana University School of Dentistry.

27) Sayoc, A. M. (1983) Effect of sterilization techniques on plastic maxillofacial implant materials. Master's Thesis, Indiana University School of Dentistry.
28) Shlosberg, S. R. (1987) Microwave curing of Poly (methyl methacrylate) denture base resin. Master's Thesis, Indiana University School of Dentistry.
29) Nagata, K., Sato, M., Nakabayashi, N. and Masuhara, E. (1987) Polymerization shrinkage and fitness of denture. J. Jpn. Soc. Dent. Appar. Mater. **19**: 153—158. (in Japanese)
30) Antonopoulos, A. N. (1978) Dimensional and occlusal changes in fluid resin dentures. J. Prosthet. Dent. **39**: 605—615.
31) Hanawa, Y. (1978) Clinical studies on the heat curing methods of acrylic resin dentures: The influence of different methods of mixing and curing on the amount of residual monomer in denture bases. J. Jpn. Prosthodont. Soc. **22**: 328—341. (in Japanese)
32) Dukes, B. S., Fields, H. Jr., Olson, J. W. and Scheetz, J. P. (1985) A laboratory study of changes in vertical dimension using a compression molding and a pour resin technique. J. Prosthet. Dent. **53**: 667—669.
33) Tateno, H. (1985) A study on dimensional accuracy of heat-cured resin for denture base. Tsurumi Shigaku, **11**: 89—107. (In Japanese)
34) Inanaga, A., Miyaguchi, H., Oka,K., Habu, T., Kawaguchi, M., Miyazaki, K. and Horibe, T. (1982) Studies on denture base resin: Part 2. The dimensional accuracy of Intopress (injection type cold curing acrylic resin) in a denture base area. J. Fukuoka Dent. Coll. **9**: 215—226. (In Japanese)
35) Habu, T., Inanaga, A., Takeuchi, T., Sawamura, N., Kawaguchi, M., Miyazaki, K. and Horibe, T. (1985) Studies on dimensional change of dentures during polymerizing process: Part 1. Three dimensional investigation in the denture base area of maxillary complete dentures. J. Jpn. Prosthodont. soc. **29**: 310—318. (In Japanese)
36) Polyzois, G. L. (1987) Dimensional stability of dentures processed in boilable acrylic resins; A comparative study. J. Prosthet. Dent. **57**: 639—647.
37) Jhonson, D. L. and Duncanson, M. G. Jr. (1987) The plastic postpalatal denture seal. Quint. Int. **18** (7): 457—462.
38) Fairchild, J. M. and Kelly, E. K. (1969) Centrifugal casting process for resin base dentures. J. Prosthet. Dent. **21**: 607—612.
39) Winkler,S. (1967) Pour technique for denture base processing. Dental Digest, **5**: 200—203.
40) Shepard, W. L., (1968) Denture bases processed from a fluid resin. J. Prosthet. Dent. **19**: 561—572.
41) Goodkind, R. J. and Shulte, R. C. (1970) Dimensional accuracy of pour acrylic resin bases. J. Prosthet. Dent.**24**: 662—668
42) Civjan, S., Garder, T. V., Worthen, D. F. and Simon, L. B. (1968) Evaluation of a "fluid" denture base resin. Abstracted, IADR Program and Abstracts no. 233.
43) Inge, W. A. Jr and Taylaor, D. F. (1970)Dimensional changes in dentures processed by the fluid resin technique. Abstracted, IADR Program and Abstracts no. 273.
44) Pickett, H. G. and Appleby, R. C. (1970) A comparison of six acrylic resin processing techniques. JADA, **80**: 1309—1314.
45) Winkler, S., Ortman H. R., Morris H. F. and Plezia, R. A. (1971) Processing changes in complete dentures constructed from pour resins. JADA, **82**: 349—353.
46) Grant, A. A. and Atkinson, H. F. (1971) Comparison between dimensional accuracy of dentures produced with pour-type resin and with heat-processed materials. J. Prosthet. Dent. **26**: 296—301.
47) Winkler, S., Morris, H. F., Thongthammachat, S. and Shorr, J. H. (1971) Investing mediums for pour resins. JADA, **83**: 848—851.
48) Kraut, R. A. (1971) A comparison of denture base accuracy. JADA, **83**: 352—357.
49) Winkler, S. (1972) The current status of pour resins. J. Prosthet. Dent. **28**: 580—584.
50) Winkler, S., Henig, L. C. and Ortman, H. R. (1972) Centrifuging pour resins. JADA, **85**: 1338—1343.
51) Civjan, S., Huget, E. F. and de Simon, L. B. (1972) Modifications of the fluid resin technique. JADA, **85**: 109—112.
52) American Dental Association (1972—1973) Guide to Dental Materials and Devices, ed 6. Chicago. 98—99.

53) Winkler, S. (1973) Clinical evaluation of complete dentures constructed from pour resins. JADA. **87**: 131—133.
54) Winkler, S., Henig, L. C. and Ortman, H. R. (1972) The effect of pressure changes on pour resins. Abstracted, IADR Program and Abstracts No. 574. March
55) Koblitz, F. F., Smith, R. A. and Wolfe, H. E. (1973) Fluid denture resin processing in a rigid mold. J. Prosthet. Dent. **30**: 339—346.
56) Craig, R. G. and Peyton, F. A. (1975) Restorative Dental Materials, ed 5. 411—412. St. Louis, The C V Mosby Company.
57) Trudso, H., Budtz-Jorgensen, E. and Bertram, U. (1980) A four-year follow-up study on processed pour acrylic resins. J. Prosthet. Dent. **44**: 495—496.
58) Prothesenherstellung mit dem Inkovac-Polymerisationssystem. Dental-Labor Heft. **9**: 1129—1132.
59) PERform DENTURE SYSTEM, Technical Manual.
60) Nishii, M. (1968) Studies on the curing of denture base resins with microwave irradiation: With particular reference to heat-curing resins. J. Osaka Dental University, **2**: 23—40.
61) Hashimoto, H., Nishii, M. and Kato, Y. (1968) Studies on the curing of denture base resin with microwave, Preliminary report. J. Jap. Res. Soc. Dent. Mater. Appli.**17**: 46. (in Japanese)
62) Kimura, H., Teraoka, F., Saito, T., Ohnishi, H. and Yato, M. (1983) Applications of microwave for dental technique (Part 1): Dough-forming and curing of acrylic resins. J. Jap. Soc. Dent. Appar. Mater. **2**: 253—257. (in Japanese)
63) Kimura, H., Teraoka, F., Ohnishi, H., Saito, M. and Yato, M. (1983) Application of microwave for dental technique (Part 2): Adaptability of cured acrylic resins. J. Jap. Soc. Dent. Appar. Mater. **2**: 253—257. (in Japanese)
64) Kimura, H., Teraoka, F., Ohnishi, H., Saito, T. and Yato, M. (1983) Application of microwave for dental techique (Part 3): Surface roughness of cured acrylic resins. J. Jap. Soc. Dent. Appar. Mater. **2**: 772—776. (in Japanese)
65) Reitz, P. V., Sanders, J. L. and Levin, B. (1985) The curing of denture acrylic resins by microwave energy. Physical properties. Quint. Int. 8: 547—551.
66) Hayden, W. J. (1986) Flexural strength of microwave-cured denture baseplates. General Dent. **34** (5): 367—371. Sept.Oct.
67) De Clerck, J. P. (1987) Microwave polymerization of acrylic resins used in dental prostheses. J. Prosthet. Dent. **57**: 650—658.
68) Sanders, J. L., Levin, B. and Reitz, P. V. (1987) Porosity in denture acrylic resins cured by microwave energy. Quint. Int. **18**: 453—456.
69) Bafile, M., and Graser, G. N. (1988) Porosity of denture resin cured by microwave energy. Abstacted, IADR Program and Abstracts No. 2096. March.
70) Ogle, R. E., Sorenson, S. E. and Lewis, E. A. (1986) A new visible light-cured resin system applied removable prosthodontics. J. Prosthet. Dent. **56**: 497—507.
71) Goto,H., Umi, T., Aoyama, Y., Ishizaki, T., Umezu, N., Ishigami, K., Sato, Y., Anzai, M. and Ohki, K. (1986) A basic study on visible light resin for denture base: Part 1. The property of mechanism. J. Jpn. Prosthodont. Soc. **30**: 387—391. (in Japanese)
72) Aoyama, Y., Umi, T., Goto, H., Nakamura, Y., Anzai, M. and Ohki, K. (1986) A basic study on visible light resin for denture base: Part 2. The physical properties and fitness. J. Jpn. Prosthodont. Soc. **30**: 719—723.(in Japanese)
73) Umi, T., Aoyama, Y., Goto, H., Umezu, N., Ishizaki, T., Ishigami, K., Sato, Y., Anzai, M. and Ohki,K. (1986) A basic study on visible light resin for denture base: Part 3. The practice of fitness. Nihon Univ. Dent. J. **60**: 410—414. (in Japanese)
74) Ishigami, K., Rhirane, M., Aoyama, Y., Miura, M., Miyata, T., Nagai, F., Sato, Y., Yuda, M., Anzai, M. and Ohki, K. (1986) Basic studies on visible light-curing resin as a denture base: Part 4. Its strength in the repair of fractured parts of heat-curing denture base resin. J. Nihon Univ. Sch. Dent. **28** (4): 287—293.
75) Ishigami, K., Aoyama, Y., Umi,T., Saito, A., Miura, S., Maeda, M., Takeda,T., Hayakawa, J., Anzai, M. and Ohki, K. (1987) Basic studies on visible light curing resin as a denture base: Part 5. Its junctional

strength with resin teeth. J. Nihon Univ. Sch. Dent. **29** (1): 35—41.

76) Ishigami, K., Aoyama, Y., Umi,T., Saito, A., Miura, S., Maeda. M., Takeda, T., Hayakawa, J., Anzai, M. and Ohki, K. (1987) A basic study on visible light-curing resin as a denture base: Part 6. Use as a trial relining material. J. Nihon Univ. Sch. Dent. **29** (2): 221—227.

77) Kahn,Z., von Frunhofer, J. A. and Razavi, R. (1987) The staining characteristics, transverse strength, and microhardness of a visible light-cured denture base material. J. Prosthet. Dent. **57**: 384—386.

78) Nimmo, A. (1988) Correction of the posterior palatal seal by using a visible light-cured resin: A clinical report. J. Prosthet. Dent. **59**: 529—531.

79) Phillips, R. W. (1982) Skinner's Science of Dental Materials, p195, 8th ed. Philadelphia, W. B. Saunders Co.

80) Takamata, T., Setcos, J. C., Schnell, R. J., Phillips, R. W. and Boone, M. E. Adaptation of acrylic resin dentures as influenced by the activation mode of polymerization. JADA, in press (accepted for publication)