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Clinical Oral Investigations

ISSN 1432-6981

Clin Oral Invest
DOI 10.1007/
s00784-011-0572-5

Springer

Clin Oral Invest
DOI 10.1007/s00784-011-0572-5

ORIGINAL ARTICLE

Clinical performance of a light-cured denture base material compared to polymethylmethacrylate—a randomized clinical study

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Received: 25 October 2010 / Accepted: 19 May 2011

Abstract The aim of this study was to evaluate the clinical long-term performance of a visible light-cured resin (VLCR) denture base material and to compare it to a well-established polymethylmethacrylate (PMMA)-based denture acrylic in a randomized split-mouth clinical long-term study. One hundred removable partial dentures in 90 patients, with at least two saddles each, were investigated. One saddle was made of VLCR, while the other was made of PMMA at random. Plaque adhesion, tissue reaction, and technical parameters of the dentures were assessed 6, 12, and 18 months after treatment. Statistical analysis was performed using the Wilcoxon rank-sum test. Though VLCR showed higher plaque adhesion than PMMA after 6, 12, and 18 months ($p<0.001$), there were no important differences with regard to tissue reaction. Concerning plaque adhesion, surface quality with regard to the lower side, interfaces between denture acrylic and metal and the boundary between denture acrylic and denture tooth PMMA was rated higher than VLCR. The surface quality of the upper side of the denture saddles showed no significant differences ($p>0.05$). Neither VLCR nor PMMA showed discoloration at any point in time ($p>0.05$). It can be concluded that VLCR is a viable alternative for the production of removable dentures. Especially in patients with hypersensitivities to PMMA, VLCR is particularly suitable for clinical use.

Keywords Denture acrylics · Removable partial denture · Light-curing denture base material · Plaque adherence

Introduction

Removable dental prostheses (RDPs) which are often used for the treatment of partially edentulous patients are known to have great influence not only on patient satisfaction and quality of life but also on oral tissue health [1, 2]. Wearing RDPs may lead to pressure sores and to denture stomatitis which is characterized by an inflammatory response of the mucosa in the region of the prosthesis bed that mainly occurs in conjunction with maxillary prostheses [3]. The etiology of denture stomatitis is multifactorial and comprises both local and systemic factors [4–7]. Accumulation of microbiological plaque on the top of the denture plays a crucial role since it promotes change from a symbiotic to a pathological oral flora [8]. It is hence desirable for dental materials to have a low susceptibility to adhesion of oral microorganisms since the formation of plaque on tooth surfaces and dental restorations favor the development of denture stomatitis and caries as well as periodontitis of the remaining teeth. Numerous in vitro and in vivo studies show that dental materials differ in their susceptibility to adhesion of oral microorganisms due to differences in the surface roughness of the substrate and/or the free surface energy [9].

On the other hand, plaque accumulation is decisively influenced by the quality of denture hygiene. Up to now—to the knowledge of the authors—no information is available with regard to the impact of different types of

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Published online: 08 June 2011

denture hygiene instructions on plaque formation given to the patient.

Usually polymethylmethacrylate (PMMA) either autopolymerized or heat cured is used as denture base material. Depending on the curing mode, an undesirable amount of residual monomer is left in the material. Hiromori [10] reports a residual monomer content of 1.81–1.85% in heat-cured PMMA. In autopolymerisates, a residual monomer content of 2–6% has to be expected [5]. Although PMMA shows low water solubility, residual monomer may diffuse into the oral environment. The small quantity that is dissolved results from nonpolymerized monomer and water-soluble additives (colorant constituents etc.). Fisher [11] reports that methylmethacrylate monomer may cause soft tissue reactions when in contact with skin or mucosa. Tanoue et al. reported about an increasing number of patients with hypersensitive reactions to PMMA [12].

As an alternative to the traditional PMMA, several visible light-cured resins (VLCR) based on dimethacrylates are now available for some years. Due to their chemical nature, VLCR materials in contrast to conventional PMMA do not contain monomethymethacrylates. Instead VLCR are comparable to restorative composite-based resins with an equal amount of residual monomer which can be reduced by using a high-intensity and a suitable light exposure time [5]. Especially in patients who have so far reacted sensitively to residual methacrylate monomer, VLCR could be a viable alternative to conventional PMMA denture base resins. However, very little information is available with regard to the clinical performance of VLCR materials. Technical parameters have been investigated merely by Pfeiffer and Faot [7, 13]. Thus the aim of the study was to investigate the clinical effectiveness of a VLCR composite denture base material compared to a conventional PMMA in a prospective longitudinal randomized clinical study.

In a split-mouth human model, the following null hypothesis was tested:

(a) The plaque formation on denture bases made of conventional PMMA does not differ from the plaque formation on denture bases made of VLCR resin.
(b) The plaque accumulation is not affected by the type of denture hygiene instruction (written form or illustrated by a dentist) given to the patient.

Materials and methods

Ninety partially edentulous patients (47 male/43 female, age >18 years) who received a new RDP in the department of prosthodontics of our clinic took part in the study. Patients with known allergies to PMMA, medication or narcotics, infectious diseases, as well as malignant tumors and prior radiotherapy were excluded. Pregnancy was also an exclusion criterion. The patients were informed about all important aspects of the study in a detailed and generally comprehensible informative way and gave their written consent. A total of 100 RDPs with a minimum of two different saddles were fitted [these comprised 93 telescopic retained partial dentures (TRDPs) and seven clasp-retained removable partial dentures (RDPs)]. The study was set up in terms of a split-mouth model. The right and left saddles were allocated to the materials VLCR or PMMA at random by means of "randomization envelopes." In cases with a third mesial tooth-bound gap, the denture saddle was made from VLCR, but not included in the evaluation. Versyo.com (Heraeus Kulzer, Germany) was used as VLCR and compared to a traditional PMMA (PalaXpress; Heraeus Kulzer, Germany; Table 1).

For VLCR application the base of the artificial teeth was conditioned (Versyo.bond; Heraeus Kulzer, Germany) and polymerized (Heralight Pre; Heraeus Kulzer, Germany). VLCR was delivered from a dispenser and applied in layers which were subsequently light polymerized (Heraflash, UniXS; Heraeus Kulzer, Germany). For finishing conventional rotary instruments and polishing brushes were used until a glossy surface was achieved.

PMMA liquid and powder were mixed according to the manufacturer's instruction (10 g powder to 7 ml liquid) to obtain a pourable consistence. Polymerization was carried out at 55°C and 2 bars. Subsequently the surface was finished with rotary instruments and polished in the same way as VLCR. Overall 2×100 saddles in 90 patients were investigated. Forty-four dentures were fitted in the maxilla and 56 in the mandible.

After conclusion of treatment, three follow-up investigations were scheduled at 6-month intervals. The treat-

Table 1 Components of Versyo.com and PalaXpress (according to the manufacturer)

Versyo.com	PalaXpress
Aliphatic polyestertriurethantriacrylate	Powder
Dodecandioldimethacrylate	Methylmethacrylate copolymer
Bisphenol-A-ethoxylate(2) dimethacrylate	1-Benzyl-5-phenylbarbiturate
2,2-Dimethoxy-1, 2-diphenyl-ethan-1-on	Pigments
	Liquid
	Methylmethacrylate
	Trioctylammonium chloride
	Coinitiators, stabilizers

ment flow is shown in Fig. 1. The following target variables were investigated on the basis of a four-stage evaluation scheme (Table 2) at all follow-up appointments by a single blinded examiner who was calibrated before the beginning of the study:

- Plaque accumulation (visual evaluation before and after staining with erythrosin)
- Tissue reaction (visual evaluation based on presence of tissue irritations)
- Technical state of the denture (visual evaluation):

  Surface quality of the top and bottom side of the denture, changes in color, interfaces in the resin/metal base transition, and resin/denture tooth

In a further randomization step ("randomization envelopes"), the respective form of denture hygiene instruction was assigned to the patient at the beginning of the study. The randomization envelopes were opened only after completion of the denture. Half of the patients received detailed instructions for oral and denture hygiene and as well as demonstrations provided by a dentist ("cleaning demonstration"). The oral hygiene was monitored at each follow-up appointment and—if denture or teeth were not plaque free—the instructions were repeated anew. On the other hand, the other half of the patients were merely handed an information sheet with care instructions ("instruction sheet") at the end of the treatment phase (Fig. 1). The written care instructions called on the patients to cleanse the denture after each meal under tap water as well as to clean it with toothbrush and toothpaste at least once a day. Additionally the patients were instructed to brush their remaining teeth also with toothbrush and toothpaste. In the cleaning demonstration group, the patients were shown how to clean their dentures and teeth as described on the instruction sheet.

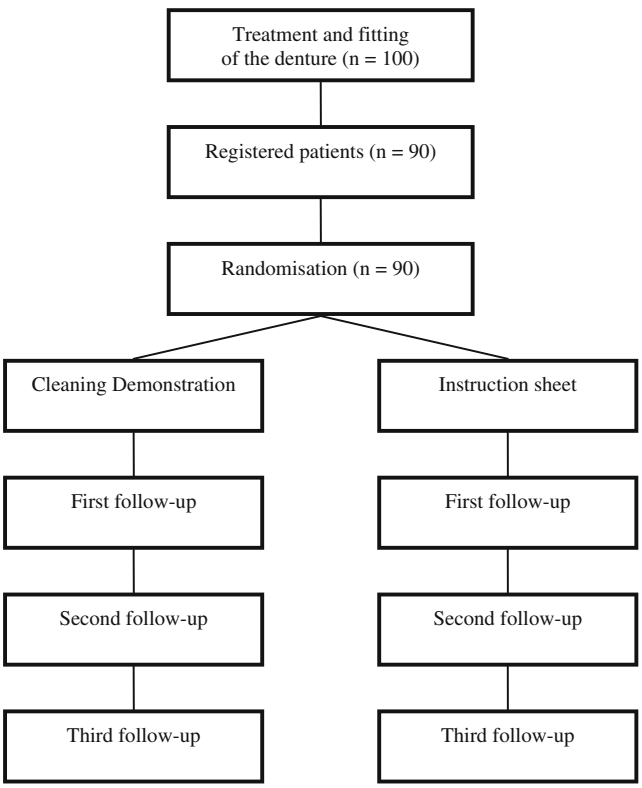

Fig. 1 Treatment flow diagram

Owing to the nature of the data deriving from *ordered metric scales* [14] (ordinal values, not normally distributed), statistical analysis was performed using nonparametric procedures using SPSS Win 12.0. Since VLCR and PMMA were compared in a split-mouth model, the Wilcoxon signed-rank sum test for linked random samples was used. Nevertheless for a better overview, the mean scores are reported as a relative measure.

The study was approved by the ethics commission of the Justus-Liebig University in Giessen (File no. 65/01) and was conducted in accordance with the current version of the Helsinki treaty. The study is also registered in the German Register for Clinical Studies (Registration no. DRKS 00000159).

Results

The results for the variables investigated—except color change—and the different oral hygiene groups are listed in Tables 3 and 4. Overall VLCR showed worse results for plaque accumulation on the denture base than PMMA at all three follow-up investigations (Table 3). Every time the overall plaque accumulation for PMMA was close to one score better than for VLCR and a highly significant difference between the two materials was observed ($p<0.001$). Thus part (a) of the null hypothesis had to be rejected.

In terms of denture hygiene (cleaning demonstration and instruction sheet), PMMA also performed better. A higher plaque accumulation was shown for VLCR than for PMMA for both hygiene groups at every follow-up investigation. Considering the materials separately, with regard to plaque coating, PMMA attained lower ratings in the group that received a cleaning demonstration than the group that merely received an instruction sheet. This was not the case for VLCR. After 12 and 18 months, there was a highly significant difference ($p<0.001$) between the two denture resins in both oral hygiene groups, and a significant difference ($p<0.05$) after 18 months for the patient group that received an instruction sheet. Accordingly, part (b) of the null hypothesis also had to be rejected.

Table 2 Representation of the four-stage evaluation schedule

Principal variable	Score (1)	Score (2)	Score (3)	Score (4)
Plaque coating	Plaque free	Plaques revealed by staining	Visible soft removable plaques	Visible soft plaques and dental calculus
Reactions of the oral mucosa	No irritations	Slight pressure point	Pressure point with erythema	Ulceration
Technical conditions				
◦Surface quality	Smooth surface	–	Uneven surface, correctible	Highly uneven surface, not correctible
◦Change in color	No difference in color as compared to test specimen	–	–	Difference in color as compared to test specimen
◦Interfaces	Smooth transition	–	Discernible crevice	Discernible crevice with chippings

With regard to the oral mucosa, there were no significant ($p>0.05$) differences between VLCR and PMMA though PMMA performed slightly better than VLCR. Interestingly the oral hygiene group which received an instruction sheet showed slightly better results than the group which got a cleaning demonstration. However, no significant difference between the two denture base resins was found at any time ($p>0.05$).

After 6 months the surface quality of the upper side of the denture saddles were scored 1 (smooth, perfect surface) for all saddles in both materials. Rough surfaces were only observed in the VLCR group with instruction sheet after 12 and 18 months. However, there was no significant difference with regard to the surface quality between PMMA and VLCR ($p>0.05$) at any time.

In contrast to the upper side of the denture, the VLCR saddles received fewer positive ratings for their tissue adjacent side than did the PMMA saddles. Within each denture hygiene group and also in the overall analysis, there was a highly significant difference ($p<0.01$) between the two denture base resins. In all three follow-ups, VLCR attained very much lower ratings than PMMA (Table 4).

With regard to the changes in color, both VLCR and PMMA were color stable within the entire observation period. Not a single discoloration was observed. From the beginning—and consequently at all follow-up investigations—PMMA was better adapted to the metal framework of the denture than VLCR (sign., $p<0.05$) and also to the acrylic teeth (Table 4).

Discussion

In the present randomized clinical study, a VLCR and PMMA denture base material was compared in a split-mouth model in RDPs. All investigations were carried out by a single blinded investigator in order to eliminate the variable "investigator." On the other hand, this has the disadvantage as the results might be generally biased which may be considered a weakness of the study. To overcome this problem, the investigator was calibrated before the beginning of the study. As this calibration revealed a good reproducibility of the assessment, we abstained from the alternative to involve different investigators. This approach had required double investigations and thus had exaggerated the already high workload for this study. Furthermore the different scores for the variables evaluated were defined with

Table 3 Overview of the evaluations for plaque accumulation and oral mucosa

Variable		Versyo[a] score (mean)			PalaXpress[a] score (mean)		
	Recall	Cleaning demonstration	Instruction sheet	Total	Cleaning demonstration	Instruction sheet	Total
Plaque accumulation	First recall, $n=91$	2.76a	3.00b	2.87c	1.58a	2.00b	1.92c
	Second recall, $n=88$	2.68d	3.38e	3.00f	1.68d	2.41e	1.95f
	Third recall, $n=73$	2.56g	2.88H	2.82i	1.50g	2.12H	1.84i
Oral mucosa	First recall, $n=91$	1.11	1.05	1.08	1.13	1.02	1.08
	Second recall, $n=88$	1.21	1.13	1.17	1.21	1.03	1.14
	Third recall, $n=73$	1.25	1.12	1.15	1.13	1.00	1.08

Letters indicate statistical differences in between groups marked with the same letters (H, Wilcoxon <0.05) respectively, Wilcoxon <0.001 denoted by lowercase letters

[a] Score 1–4

Table 4 Overview of the evaluation for surface quality and interfaces

Variable		Versyo[a] score (mean)			PalaXpress[a] score (mean)		
	Recall	Cleaning demonstration	Instruction sheet	Total	Cleaning demonstration	Instruction sheet	Total
Surface quality, upper side	First recall, n=91	1.00	1.00	1.00	1.00	1.00	1.00
	Second recall, n=88	1.00	1.06	1.02	1.00	1.00	1.00
	Third recall, n=73	1.00	1.12	1.03	1.00	1.00	1.00
Surface quality, lower side	First recall, n=91	1.51J	1.91k	1.70l	1.04J	1.09k	1.07l
	Second recall, n=88	1.65M	2.13n	1.77o	1.12M	1.06n	1.07o
	Third recall, n=73	1.88P	2.06q	1.74r	1.13P	1.00q	1.11r
Plastic–metal interfaces	First recall, n=91	1.70	1.43	1.57S	1.21	1.23	1.22S
	Second recall, n=88	1.88T	1.63	1.72U	1.18T	1.50	1.30U
	Third recall, n=73	1.94	1.83	1.77V	1.50	1.47	1.44V
Plastic–plastic tooth interfaces	First recall, n=91	1.06	1.25	1.15W	1.00	1.00	1.00W
	Second recall, n=88	1.24	1.44X	1.28Y	1.00	1.00X	1.00Y
	Third recall, n=73	1.37	1.12	1.30Z	1.19	1.00	1.04Z

Letters indicate statistical differences in between groups marked with the same letters (J,..., Z; Wilcoxon <0.05) respectively, Wilcoxon <0.001 denoted by lowercase letters

[a] Score 1–4

high discriminatory power (e.g., soft removable plaque vs calculus).

A significant difference between the two denture resins VLCR and PMMA was shown with regard to the plaque coating. Though in this study only one VLCR material and one PMMA material was investigated, it is assumed that the results obtained are also valid for other materials of the same type, especially as all VLCR materials available rely on the same basic chemistry [12, 15, 16].

More deposition of plaque was found on the VLCR saddles than those made of PMMA. The amount of plaque accumulation depended on the denture resin as well as the type oral hygiene instruction given to the patient. Differences with regard to bacterial colonization between denture resin materials of different chemical compositions were observed in numerous studies [9, 17, 18]. However, to the author's knowledge, up to now, no clinical study compared PMMA and VLCR in a split-mouth model in a long-term setup.

It has also been reported that microbial surface properties influence bacterial adhesion to solid surfaces [4]. The initial adhesion of microorganisms to oral surfaces is reversible and mainly depends on electrostatic and van der Waals forces. The more specific interactions such as coadhesion and coaggregation that follow later lead to irreversible binding of microorganisms to substrate surfaces [9]. A reason for the higher deposition of plaque on VLCR might be its surface properties. In a study of Tan et al. [19], an increased amount of porosities was found in light-activated denture resin. This may be due to the fact that the polymerisation of light-activated denture resin is not possible under pressure for the time being. As reported by Theughels et al. [20], the adhesion of microorganisms depends particularly on the roughness of the surface. A surface roughness of less than 0.2 μm does not affect the adhesion of microorganisms [21]. Though the surface roughness of the denture bases was not metrically assessed in this study, it can be assumed that a glossy surface has a roughness of at least less than 0.1 μm. Thus it is hypothesized that the observed differences in plaque formation were not related to the physical quality of the surface. Besides the difficulties of metrically assessing the surface roughness in a clinical study, an in vitro approach seems to be more viable for quantitative analyses of surface roughness and plaque formation on VLCR materials. To our knowledge this has not been investigated so far.

A further important factor for adhesion is the free surface energy which is known as an important factor for adhesion [20]. Bacterial strains with a high free surface energy such as *Streptococcus mutans* adhere preferentially to hydrophilic substrates since they show high free surface energy [4]. Adhesion of *S. mutans* to the surface of PMMA tends to be slight, since PMMA is hydrophobic and only shows low fee surface energy [22].

In this study higher plaque coating in VLCR did not have any negative effects on the oral tissue. A significant difference (p>0.05) between the two denture resins VLCR and PMMA with regard to the oral mucosa could not be found at any time. This is interesting, since VLCR did not provoke decisively more tissue reactions compared to PMMA even in patients with decisively higher plaque deposition. Since VLCR is a single-component system, it evinces the fundamental advantage that there is a preset consistency and polymerization can therefore be controlled. However, it should be pointed out to patients in whom VLCR is used

that there is an increased risk for plaque deposition, so that they should accordingly observe oral hygiene instructions.

With regard to the technical state of the dentures, PMMA was rated better than VLCR in respect of the quality of the upper surface of the denture which indicates that the surface of VLCR can be worked well, similar to conventional PMMA. On the other hand the tissue adjacent surfaces (normally only carefully finished) of VLCR saddles showed poorer results than PMMA ($p<0.001$). This indicates that sparsely or unpolished VLCR appears to be more prone to bacteria colonization than does PMMA. How far this is related to an increased roughness of the unpolished VCLR surface in comparison to PMMA cannot be answered at this time. Keyf et al. [6] report that food residues and other deposits adhere to rough denture surfaces and that such surface also lose their shine. Smooth denture surfaces are easier to clean and have more esthetic appearance than rough denture surfaces. Since Tan et al. [19] detected increased porosities in VLCR, this might explain the poorer rating of the surface quality of the underside of the denture in the case of VLCR as compared to PMMA.

The material color change was also assessed. In contrast to Khan et al. [23], inspecting color change showed no differences between the investigated materials. Khan et al. [23] report more intense coloration of a light-activated denture base resin after storage in tea solution as compared to conventional PMMA. This may also be attributable to more frequent occurrence of porosities in light-activated denture base resins [19]. Since no discoloration was observed in this study, VLCR does not appear to be subject to this problem.

The evaluation of the tissue adjacent surface also included observation of the interfaces and chippings. In a study of Diaz-Arnold et al. [24], it was shown that light-activated denture base resin shows a high flexural strength and only little elasticity indicating a high brittleness. In addition, it was also reported that the presence of internal porosities contributes to the formation of microfissures [25]. These characteristics may explain the problems to adapt VLCR to the metal framework and the acrylic teeth, thus requiring a more precise and time-consuming technical procedure than in PMMA-based dentures.

Conclusion

VLCR seem to be a suitable alternative to PMMA denture base materials though PMMA was higher rated compared to VLCR—especially for plaque adhesion—in this study. However, since no differences between the two test materials were found with regard to tissue reactions, VLCR can be recommended especially for patients with hypersensitivities to PMMA.

Conflict of interests We have no conflict of interests. The study was supported by Heraeus-Kulzer, Hanau, Germany. We have no further financial relationship with the manufacturer. The results and conclusion presented are solely our own work and have not been influenced.

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