Measurement of Interfacial Porosity at the Acrylic Resin/Denture Tooth Interface

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Abstract

Purpose: Small pores of almost uniform shape and size are common in polymeric materials; however, significant porosity can weaken a denture base resin and promote staining, harboring of organisms such as *Candida albicans*, and bond failures between the artificial tooth and denture base resin. The aim of this study was to investigate the porosity at the interface of one artificial tooth acrylic resin (Trilux, copolymer of polymethyl methacrylate, ethylene glycol dimethacrylate, and color pigments) and three denture base resins: Acron MC (microwave-polymerized), Lucitone 550 (heat-polymerized), and QC-20 (heat-polymerized).
Materials and Methods: Ten specimens of each denture base resin with artificial tooth were processed. After polymerization, specimens were polished and observed under a microscope at 80× magnification. The area of each pore present between artificial tooth and denture base resin was measured using computer software, and the total area of pores per surface was calculated in millimeter square. The Kruskal–Wallis test was performed to compare porosity data ($\alpha = 0.05$).
Results: Porosity analysis revealed the average number of pores (n), area range (S, mm^2), and diameter range (d, μm) for Acron MC (n = 23, S = 0.001 to 0.0056, d = 35 to 267), Lucitone 550 (n = 13, S = 0.001 to 0.005, d = 35 to 79), and QC-20 (n = 19, S = 0.001 to 0.014, d = 35 to 133). The analyses showed that there were no statistically significant differences among the groups ($p = 0.7904$).
Conclusions: Within the limitations of this in vitro study, it was concluded that the denture base resins evaluated did not affect porosity formation at the artificial tooth/denture base resin interface.

Bond failures at the interfacial region between the artificial tooth and denture base resin are still a common clinical problem.[1] Although artificial teeth can be chemically bonded to the denture base, previous studies have shown that of all the repairs carried out in dentures, 20 to 33% continue to be related to artificial teeth breaking off or becoming detached from denture bases.[1-3] In the last case, this is caused by a bond failure in the interfacial region between the tooth and denture base resin. Considering the total amount of time and money spent on denture teeth repairs,[4] bond failures at the interfacial region between artificial tooth and denture base resin must be considered.

Many factors can influence the bond between teeth and denture base resin at the interfacial surface. They include chemical or mechanical preparation on the ridge-lap surface of the tooth,[5,6] processing variables such as resin dough time, and polymerization cycle.[3] In addition, the presence of impurities along the tooth/denture base resin interface due to poor laboratory techniques appears to be a common cause for this type of failure.[3] That could be residual wax[7] because of incomplete elimination or contamination of the ridge-lap surfaces with tinfoil substitutes.[8,9]

Porosity is a complex phenomenon of multifactorial origin.[10-16] It has been reported that significant porosity can severely weaken a denture base resin.[17,18] With regard to hygiene, a denture must be nonporous to resist staining, calculus deposition, adherent substances, and harboring of organisms such as *Candida albicans*.[19,20]

A number of methods have been used for measuring the porosity of polymerized acrylic resin, including microscopic observation.[13,21-27] These studies did not estimate true pore size. In addition, different magnifications were used to check

porosity, and most of the studies do not mention the size of the pores, demonstrating that there is no simple way to characterize pores. Alkhatib et al[21] observed that pores ranged from 10 to larger than 500 μm, using Neophot-21 Metalograph microscopy. Nowlin et al[23] used 8× magnification and did not measure the range size of the pores. They only counted the number of pores. Truong and Thomasz[22] found pores of less than 0.5 mm and up to 4 mm in diameter, under a microscope at 10× magnification. Firtell and Harman[18] also did not mention the size of the pores when using a Boley gauge under a 10× magnifying glass. Xia et al[28] only cited the method used to check the pores; they immersed the acrylic resin specimens in a solution of blue ink, then photographed and examined them under 20× magnification. Faraj and Ellis[29] observed pores with an average diameter of 2.9×10^{-2} mm by photomicrograph and with an average diameter of 50 μm × 109 using a Boley gauge. Reitz et al[24] examined and photographed acrylic resin specimens under 20× magnification. The largest porosity area seen was less than 30 μm in size.

Other studies evaluated porosity differently. Yannikakis et al[13] evaluated porosity of denture base resins under a microscope at 100× magnification and photographed the resins with the microscope's camera. The perimeter of each pore was outlined with a fine-tipped pen, and the area was measured with a digital planimeter. Small pores of almost uniform shape (round) and size (approximately 0.01 mm) were found. Lai et al[27] scanned the polished surfaces of resin blocks and quantified the amount of porosity by percentage. These authors did mention the diameter or the area of pores.

As described, previous researchers have observed pores in the artificial tooth/denture base resin interface at a cross-sectional surface. In the literature, few data on more reliable quantitative and objective methods for the analyses of porosity were found. Mercury porosimetry is regarded as a very reliable method for the determination of pore size. This method measures the extent of mercury penetration into an evacuated solid as a function of the applied hydrostatic pressure.[13] Bafile et al,[29] Compagnoni et al,[30] and Pero et al[31] used a different technique for calculating porosity, by using a method based on Archimedes' principle. The mean percentage porosity was related to the absolute density of the acrylic resin and the weight of the specimen before and after its immersion in water.

The presence of pores at the artificial tooth/acrylic resin interface could also promote an adhesive failure between these two materials, according to Polyzois and Dahl.[32] They found lower bond strength between artificial teeth and microwave-polymerized denture base resin. This finding is of clinical importance, as the choice of polymerization method could influence the risk of acrylic teeth loosening from the denture.

The use of microwave energy for processing acrylic resin has been considered to simplify and to reduce the time for manufacturing dentures; however, the excessive heating promoted by high power, in addition to the exothermic reaction of acrylic resin polymerization, can cause undesirable porosity in this material.[22,33,34] Although researchers have confirmed the similarity of the properties of acrylic resins polymerized conventionally by water bath and those polymerized by microwave energy,[21,24,29,30,33] this polymerization method has still had limited acceptance.[21,32,35,36]

The aim of this study was to investigate the porosity at the interface of one artificial tooth acrylic resin and three denture base resins (two heat-polymerized, one microwave-polymerized). The working hypothesis was that porosity formation would not be affected by the different denture base resins.

Materials and methods

One acrylic resin tooth was chosen for bonding to three denture base resins. Ten specimens were processed for each group. The materials used in this study are described in Table 1.

The specimens corresponded to denture base resin cylinders bonded to the ridge-lap surface of the artificial teeth. All acrylic resin denture teeth were maxillary premolars. First, the ridge-lap surface of the denture teeth was reduced using 320-, 400-, and 600-grit silicon carbide paper (Norton, Saint-Gobain Abrasivos Ltd., Vinhedo, Brazil) in a polishing machine (Arotec Ind. e Com. Ltd., Cotia, Brazil) at 300 rpm to obtain a flat surface for bonding to the denture base resin. The ridge-lap surfaces of the denture teeth were reduced to obtain a flat surface for bonding to the denture base resin.[37] In this study, bonding between acrylic resin teeth to denture base material was not evaluated; however, this adjustment of the ridge lap is established as a standard to obtain a resin surface for bonding.[38]

Next, the teeth were invested in silicone (Zetalabor, Zhermack S.A. Rovigo, Italy), with their flat surfaces exposed (Fig 1A). Silicone patterns (Zetalabor) with circular openings were obtained from a stainless steel mold to standardize the dimensions of the denture base resin cylinders (Fig 1B).

Table 1 Materials used

Material	Manufacturer	Batch number	Type/polymerization cycle*
Acron MC (denture base resin)	GC Lab Technologies, Inc., Alsip, IL	0510121	Microwave-polymerized: 3 min at 500 W
Lucitone 550 (denture base resin)	Dentsply Ind. e Com. Ltd., Rio de Janeiro, Brazil	186120	Heat-polymerized: 90 min at 73°C/163.4°F and 100°C/212°F for 30 min
QC-20 (denture base resin)	Dentsply Ind. e Com. Ltd., Rio de Janeiro, Brazil	6168	Heat-polymerized: 20 min at 100°C/212°F
Trilux (artificial tooth, copolymer of PMMA, EDMA, and color pigments)	RuthiBras Imp. Exp. e Com. de Odontológicos Ltd., Pirassununga, Brazil	6052375784	–

*Polymerization cycles recommended by the manufacturers.

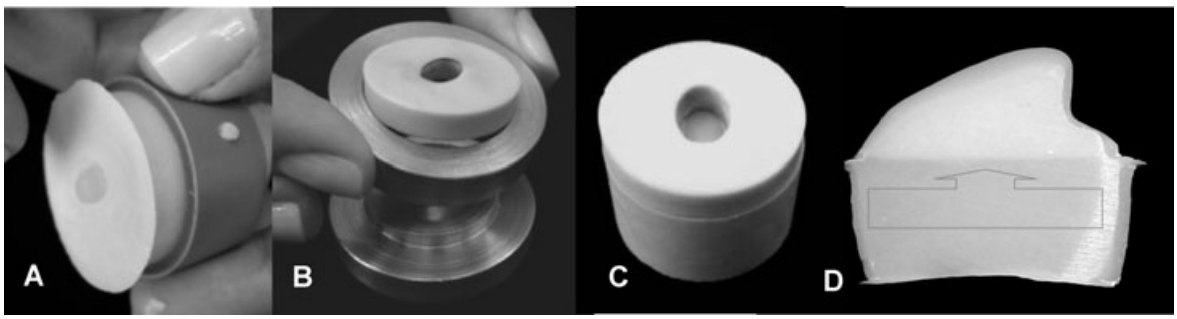

Figure 1 (A) Artificial tooth included in silicone using a PVC tube; (B) Stainless steel mold used to obtain the silicone pattern with the circular opening; (C) Silicone pattern opening coinciding with the flat tooth surface; (D) Specimen after polishing. The arrow indicates the artificial tooth/denture base resin interfacial surface.

Each silicone pattern obtained from the stainless steel mold was fixed with an instantaneous adhesive (Super Bonder, Loctite Henkel Ltd., Diadema, Brazil) on the surface of each silicone-included tooth, so that the silicone pattern opening coincided with the flat tooth surface (Fig 1C). After that, the circular opening of the silicone pattern was sealed with high fusion modeling compound (Sybron Kerr Industry and Commerce Ltd., Guarulhos, Brazil) before proceeding with the investing.

The silicone-included tooth fixed to the silicone pattern was invested in denture flasks using dental stone (Herodent, Vigodent S.A. Ind. Com., Rio de Janeiro, Brazil). Standard metal flasks and plastic flasks were used for heat polymerization and microwave polymerization, respectively. After the dental stone was set, the flask was opened, and the compound was carefully removed from the silicone pattern circular opening. Microwave- and heat-polymerized denture base resins were packed into the silicone pattern circular opening and processed in accordance with the manufacturers' instructions (Table 1). After polymerization, each flask was bench cooled at room temperature overnight.

Each specimen was carefully deflasked, and its proximal surface was polished in a polishing machine (Arotec Ind. e Com. Ltd.) using 320-, 400-, and 600-grit silicon carbide paper (Norton), so the artificial tooth/denture base resin interface was adequately displayed (Fig 1D) to allow viewing under the microscope. This procedure was done under running water coolant to avoid overheating of the acrylic resin,[5,39] to prevent damage to its physical and mechanical properties and to ensure that debris would not fill up pores and obscure them. Next, the specimens were stored in distilled water at 37°C for 50 ± 2 hours.[40]

The presence of pores was evaluated by a visual method using a computer program (Image Processing Analysis System, Leica Imaging Systems Ltd., London, UK), which, by means of color contrasts, selected the areas corresponding to the pores and quantified them in millimeter square. The computer that contained the Leica program was connected to an optic microscope, through which the regions in the specimen were selected for analysis.

First, a standard scale supplied by the microscope manufacturer was used to convert 1 pixel to 0.0106 mm. Each surface was observed under the microscope at 80× magnification, which produced an effective resolution of 12.5 μm as a 1 mm distance in the image, and each image was captured. For each specimen, five images of different fields were captured. For each image, the perimeter of each pore was outlined on the computer, and the total area was measured by the software and expressed in millimeter square. An effort was made to measure the porosity with maximum accuracy. At the beginning of the experiment, a pilot study was conducted. For the same image, the same pore was outlined ten times, and its area was measured until the method demonstrated good repeatability. All observations were made by one investigator.

Data were submitted to statistical analysis by Kruskal–Wallis test at a 5% level of significance. Only 10 specimens were used per group based on previous studies of porosity evaluation and the statistical procedure, which did not detect need of sample size increase.

Results

Pores were found in all experimental groups. The number of pores and the area and diameter range for each group are shown in Table 2. Kruskal–Wallis test was performed to compare porosity data in this study ($\alpha = 0.05$). Area data collected were converted to ranks and grouped in one data set. The comparison of the groups was carried out by means of the average of the ranks. The results indicated no significant differences among the three evaluated denture base resins ($p = 0.7904$). Figure 2 shows the box-plot graph that indicates the distribution of porosity values (area, mm^2) for the three experimental groups.

Table 2 Total number of pores, area, and diameter range of pores in specimens by group

Group*	Number of pores	Area range (mm^2)	Diameter range (μm)
Acron MC	23	0.001–0.056	35–267
Lucitone 550	13	0.001–0.005	35–79
QC-20	19	0.001–0.014	35–133

*n = 10 per group.

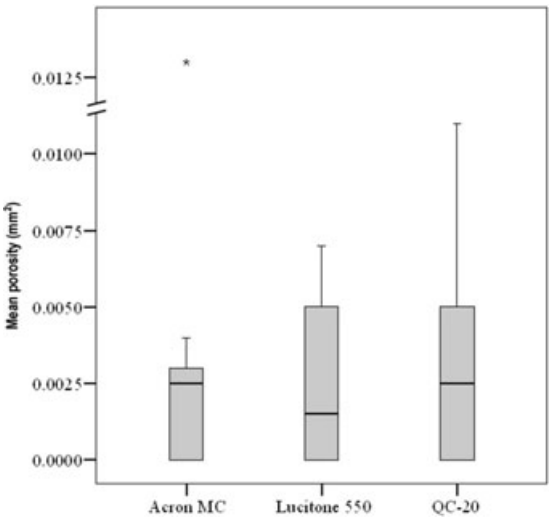

Figure 2 Box-plot graph indicating porosity area (mm^2) for the three denture base resins used in this study. Boxes represent 50th percentile (horizontal line) with 25th and 75th percentiles of observed data (top and bottom of box). Error bars represent the maximum value and the asterisk indicates an extreme value.

Discussion

The working hypothesis that the presence of pores would not be affected by the denture base resin was accepted, since the three denture base resins evaluated produced statistically similar porosity at the artificial tooth/denture base resin interface. Given the vast range of tooth and denture base products on the market, our results cannot be extrapolated to assess the porosity of each combination, since only one type of acrylic tooth was evaluated. In addition, a number of methods have been used for measuring the porosity of polymerized acrylic resin, meaning there is no standardization for porosity evaluation in the different studies.

The present study demonstrated no difference in porosity results among the three denture base resins evaluated. Our results are in agreement with Bafile et al,[29] Compagnoni et al,[30] and Lai et al.[27] These authors also observed that the polymerization cycle did not interfere in the porosity of the evaluated denture base resins.

The results of the present study are consistent with the hypothesis that pore formation does not depend only on the type of acrylic resin. Porosity is a complex phenomenon with a multifactorial origin[14] and has been attributed to a variety of factors that include the following: polymerization cycle, air entrapped during mixing, monomer contraction during polymerization, monomer vaporization associated with the exothermic reaction, degree of polymerization, and the presence of residual monomer.[12-16]

The method used for porosity measurement in the present study did not result in a significant difference among the denture base resins. All denture base resins evaluated in this study are heat-polymerized, and the chemical similarity among these materials might explain our results.

Previous studies have measured pore formation.[13,14,18,20,22,24,29] Our results demonstrated pores ranging from 35 to 267 μm in diameter. A direct comparison between the results of the present study and those of others is somewhat difficult because there has been no standardization of measuring porosity in the dental literature and because of the variety of materials and methods used. In addition, different magnifications were used to check porosity, which can demonstrate that there is no simple way to characterize pores. The American Dental Association specification for the porosity of denture base polymers states, "There shall be no bubbles or voids when viewed without magnification." This statement reinforces that it is difficult to determine a clinically acceptable amount of porosity.

A limitation of this study is that only one type of artificial tooth was used. The type of teeth evaluated in previous studies[2,4,5,37-44] may be a factor interfering with bond strength between tooth/denture base resin. Given the vast range of tooth and denture base products on the market, it would be an immense undertaking to assess the bond strength of each combination. There are, however, strong indications that highly cross-linked teeth do have reduced bond strength. Suzuki et al[43] explained that the size of the polymer chain networks in highly cross-linked polymers becomes too small for interpenetration of MMA monomer from the denture base into the matrix and results in poor bonding between the highly cross-linked plastic denture teeth and the denture base resin. In this work, the products were restricted in range and more emphasis was placed on technique rather than material structure.

It can be considered that the occurrence of pores at the artificial tooth/denture base resin interface continues to be a clinical problem; however, the present study did not simulate clinical conditions. Despite these limitations, the materials evaluated in this study are expected to perform similarly in the oral environment. Further studies are suggested to investigate the formation of pores at the artificial tooth/denture base resin interface, using other types of artificial teeth and denture base resins.

Conclusion

Within the limitations of this study, it could be concluded that the porosity at the artificial tooth/denture base resin interface was statistically similar among the three denture base resins evaluated ($p = 0.7904$).

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