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The Influence of Re-Polymerization on the Microhardness of Commercial Acrylic Teeth

SUMMARY

Re-polymerization of removable prosthesis and acrylic teeth may affect their hardness, which is the basic factor affecting successful long-term function of removable prosthesis. The aim of this work was to evaluate commercial acrylic teeth microhardness after the standard polymerization process for construction of complete and removable partial dentures, and to compare it with that of the as-supplied teeth.

Vivodent Orthotyp and Vita Vitapan premolars were subjected to re-polymerization in water bath at 90ºC for 12 h in the presence or absence of the acrylic base resin. 12 slice-cut specimens of 1 mm thickness from each tooth type, including as-supplied and re-polymerized teeth, were tested for microhardness with an Anton Paar microhardness tester. ANOVA and Dunnett tests were used to evaluate the level of significance between the microhardness values of all groups of acrylic teeth.

Both Vivodent and Vita acrylic polymer teeth exhibited an either constant or enhanced microhardness value after polymerization in the presence of acrylic resin base material. This is important in order to preserve hardness and abrasion resistance of acrylic polymer teeth after the conventional polymerization procedure for constructing artificial dentures.

Keywords: Acrylic Teeth; Microhardness; Polymerization; Re-Polymerization; Acrylic Resin Base Material

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Introduction

Artificial teeth are produced from acrylic resin, porcelain or composite products and can be exploited for complete and partial denture construction. The mostly utilized artificial teeth for dental prosthesis are the acrylic resin polymer teeth, since their consistency insures the advantages of acrylic resins[1,2]. These comprise acceptable appearance, convenient handling, high toughness and compatibility with the acrylic base resin materials, offering to acrylic resin polymer teeth the lead for dental prosthesis applications[1-3]. Furthermore, the low density of acrylic teeth does not increase considerably the weight of the denture.

The composition of acrylic resin polymer teeth is, basically, poly-methyl-methacrylate (PMMA) beads and colour pigments in a cross-linked polymer matrix. Many manufacturers supply their acrylic teeth with com-polymer or highly cross-linked resin polymers in order to increase their resistance to fracture, abrasion and wear[1-5]. During the construction of acrylic resin polymer teeth, by the moulding technique, the monomer of the cross-linked polymer matrix can penetrate into the beads and the ridge lap area of teeth may be softened[4,6-8]. Although acrylic polymer teeth are supplied polymerized, they should undergo re-polymerization during the conventional process for composing artificial dentures. The presence of the same monomer in the mass of the acrylic resin base material, throughout the standard procedure for the construction of dentures, can act as plasticizer[2,4], affecting appreciably the ridge lap area of acrylic teeth and soften them to some extent, in order to be chemically bonded to the base material[1,2,6]. This could affect the whole mass of acrylic teeth, since the monomer belongs to the organic solvents[1-4,6,7].

Mastication[7-9] occurs on the surface of acrylic teeth[2,3,9], consequently these must be hard enough to resist the abrasive forces and crazing that develop inside the mouth[1-3]. In addition, de-bonding of teeth from the complete or partial dentures should be avoided[7-9]. Hardness is an intrinsic physical property of a material, indicating its resistance to plastic deformation[10-13]. Although the microhardness values of acrylic polymer teeth are, generally, known within the range of 180-200 MPa[1-3], their hardness after polymerization for producing complete or partial dentures is much less studied.

This study **aims** to evaluate the influence of the standard polymerization process on the microhardness of acrylic teeth, as compared to the microhardness of the as-supplied teeth. In addition, the role of the monomer of the acrylic base resin released during re-polymerization is investigated by comparing microhardness of acrylic teeth subsequent to polymerization in the presence or absence of the acrylic denture base material.

Material and Methods

Vivodent (IVOCLAR-Schaan, Liechtenstein) Orthotyp (VO) and Vita (VITA-Zahnfbrik H. Rauter GmbH, Germany) Vitapan (VV) acrylic polymer teeth were tested. 3 groups of each type of teeth were formed as follows:

- 1st group: As-supplied teeth (VOS-VVS).
- 2nd group: Teeth were, initially, set in moulds and inserted in boiling water for 10 min. The moulds were separated and rinsed with soap and boiling water in order to eliminate the presence of wax on the teeth. Then acrylic base resin in dough stage was inserted into the moulds and boiled in water bath for 12 h in 90°C for complete polymerization (VOP-VVP). The acrylic base resin used in this study was the Paladon 65 Kulzer.
- 3rd group: Teeth were boiled in gypsum moulds for 12 h in 90°C, without the presence of acrylic base material (VOB-VVB). This group would verify the influence of the monomer of the acrylic base resin on the microhardness of teeth after re-polymerization.

Acrylic teeth of all groups were cut in cross-section slices with a diamond wafer blade, in a Buhler cutting machine, under a load of 0.4 kg at 300 rpm. The load and rotation speed of the cutting were kept as low as possible in order to produce the smallest damage to the teeth slices. 4 1.5 mm thick sliced specimens were cut from each tooth. Internal cross-section slices of teeth were selected as specimens for microhardness measurements since the effect of polymerization on the whole mass of teeth was investigated. Subsequent to cutting, specimens were mechanically thinned, on both sides, using silicon carbide grinding papers of 1200 and 2000 grade and a final mechanical polish was accomplished using 10 μm and 0.3 μm alumina (a-Al_2O_3) pastes. A final thickness of 1 mm for each slice was reached prior to microhardness testing. Mechanical grinding and polishing were necessary for elimination of cutting damages and production of smooth surfaces for microhardness testing. Microhardness values of all 3 groups of specimens were evaluated using an Anton Paar MHT-10 microhardness tester loaded on a Zeiss "Axiolab A" optical microscope. After the indenter came to rest, indentation prints were projected to a monitor through a CCD camera attached to the microscope. The diagonals of the indentation prints were then determined using image-processing software. Due to the difference in structural characteristics of 2 types of teeth, both Knoop and Vickers indenters were used for microhardness measurements. The Knoop microhardness values were calculated from the following expression:

$$H_K = 14{,}229\ P/d^2, \qquad (1)$$

where P is the loading force in gf (1 gf $\cong 10^{-2}$ N), d is the longer diagonal of the indentation print in μm and H_K is the Knoop microhardness value. Correspondingly, the Vickers microhardness values were calculated from the following expression:

$$H_V = 1{,}854\ P/d^2, \qquad (2)$$

where P is the same with previous case, d is the mean value of the indentation diagonals in μm and H_V is the Vickers microhardness value in kgf/mm^2. In the literature, both methods are considered to produce equivalent microhardness values for the same indentation loads; consequently they can be used concurrently.

Results

Anova and Dunnett tests ($P<0.005$) indicated a significant difference between all groups of Vita Vitapan acrylic teeth. The same tests indicated significant difference between VOS(1) and VOB(3) at Vivodent orthotyp acrylic teeth, while no significant difference between VOP(2), VOS(1) and VOB(3) at a p value of 0.005. These are in agreement with the calculated values of standard deviations listed in tables 1 and 2.

Applying equation (1), Knoop microhardness measurements performed under a loading force of 0.3 N on the Vivodent Orthotyp teeth resulted in the following: a) The as-supplied teeth (VOS) exhibited a mean microhardness value of 196.81.1 MPa, which is within the range expected for acrylic polymer resin teeth; b) VOS teeth after re-polymerization with the acrylic base (VOP) presented, virtually, identical mean microhardness value with the VOS teeth, i.e. equal to 197.8±5.2 MPa; c) VOS teeth polymerized without the presence of the acrylic base resin (VOB) showed a slightly increased mean microhardness value of 204.5±3.9 MPa, which was not significant. All 10 measurements for each group of Vivodent teeth are depicted in table 1.

Table 1. Knoop microhardness measurements and mean microhardness values of the Vivodent acrylic teeth

Vivodent Orthotyp	Knoop microhardness HK (MPa)										Mean values (MPa)
VOS	194.6	198.6	196.7	196.7	197.8	197.8	195.9	196.7	196.7	196.7	196.8±1.1
VOP	199.5	199.5	205.9	195.9	196.7	205.9	194.3	189.9	193.3	196.7	197.8±5.2
VOB	200.3	209.7	200.3	202.2	202.2	202.2	208.0	209.7	208.0	202.5	204.5±3.9

Table 2. Knoop microhardness measurements and mean microhardness values of the Vita acrylic teeth

Vita Vitapan	Knoop microhardness HK (MPa)										Mean values (MPa)
VVS	228.8	229.8	237.8	236.7	226.4	240.3	219.9	224.4	230.8	225.4	230±6.5
VVP	251.6	259.2	267.6	245.1	271.9	258.0	247.8	265.0	279.5	252.8	259.9±11.1
VVB	285.5	296.7	288.1	284.9	295.2	279.5	311.7	282.9	295.2	281.5	290.1±9.8

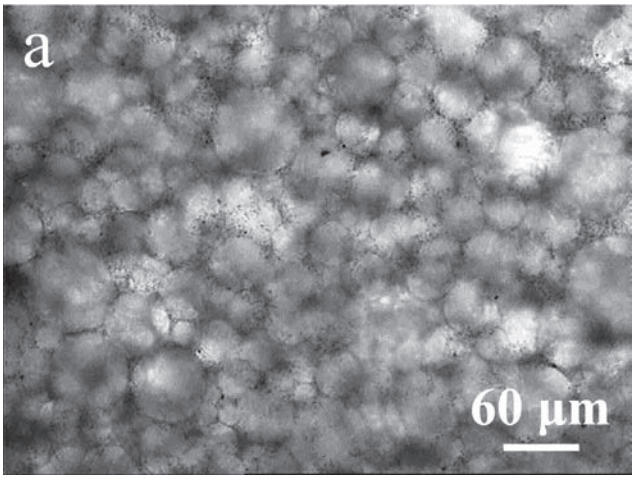

Figure 1a. Optical micrograph depicting the morphology of the as-supplied Vivodent inner teeth. An overall homogeneous structure is observed, where the PMMA beads cannot be clearly distinguished inside the polymer matrix

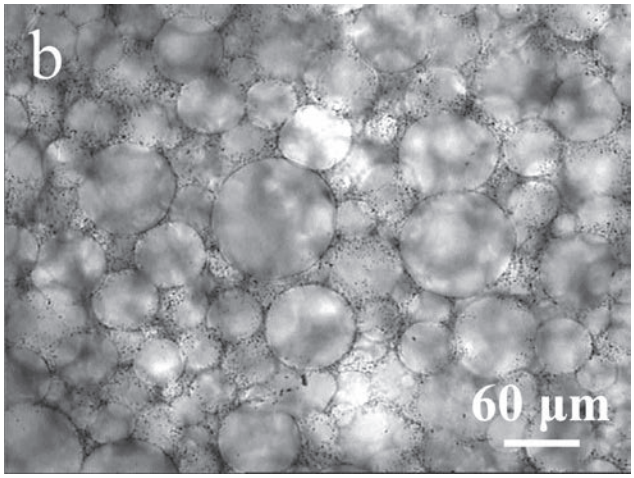

Figure 1b. Optical micrograph illustrating the morphology of the as-supplied Vita inner teeth. The PMMA beads are, here, well defined and clearly distinguishable within the cross-linked polymer matrix

Morphology of the as-supplied inner Vivodent teeth is illustrated in the optical micrographs of fig. 1a - an overall homogeneous structure is observed, where the PMMA beads cannot be clearly distinguished inside the polymer matrix. The homogeneity of the structural characteristics of Vivodent teeth is verified from the low values of the standard deviations in the mean microhardness values.

The corresponding Knoop microhardness measurements for the Vita Vitapan teeth can be summarised in the following: a) the as-supplied teeth (VVS) presented a mean microhardness value of 230±6.5 MPa, appreciably higher than VOS; b) Teeth polymerized in the presence of the acrylic base (VVP) exhibited an unpredictably high mean microhardness value of 259.9±11.1 MPa; c) Teeth polymerized in the absence of the acrylic base resin (VVB) showed an even more enhanced mean microhardness value of 290.1±9.8 MPa. The measurements are summarised in table 2.

Morphology of the as-supplied Vita teeth is illustrated in figure 1b, where the difference with the previous case is evident. The PMMA beads are, here, well defined and clearly distinguishable from the cross-linked polymer matrix. All groups of Vita teeth exhibited unpredictably high mean microhardness values, which are linked, however, with rather high standard deviations. These deviations in the microhardness values suggest anisotropy of the overall sliced teeth surface concerning microhardness. This anisotropy most likely arises from hardness differences between the PMMA

beads and the cross-linked polymer matrix. Since the Knoop indenter produces a rhombic print that has a long diagonal, it is difficult to isolate the indentation inside a PMMA bead or within the matrix to detect differences in microhardness values. Thus, Knoop indentations resulted in the average microhardness value of the beads and the matrix. Alternatively, a Vickers indenter was used for these particular indentations, since it produces a square print, which can be imprinted inside a bead. In order to have a small imprinted area, Vickers microhardness measurements were performed under 0.1 N and 0.3 N loads. Both loads belong to the plateau area of the Indentation Size Effect (ISE) curve[10-12] that were recorded for Vita teeth (Fig. 2), and thus the Vickers hardness values calculated are considered to be highly plausible.

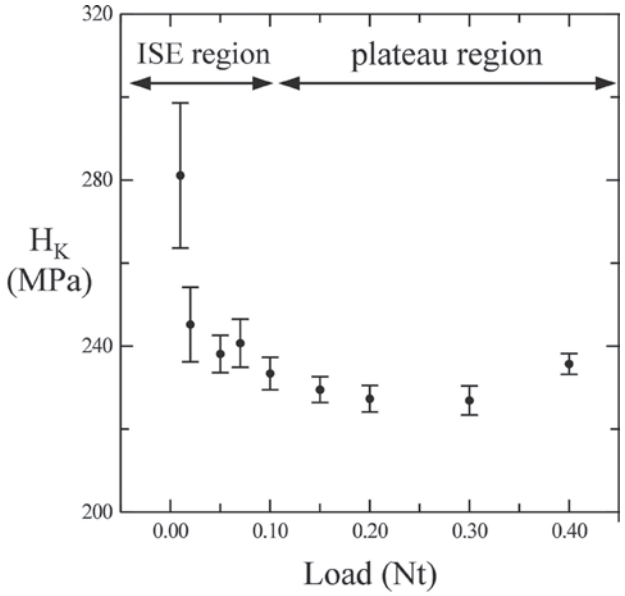

Figure 2. Schematic illustration of Vickers microhardness (Hv) as a function of the applied load, where the ISE and the Plateau areas are depicted for the VVS beads. The error bars represent the mean standard deviations

Vickers measurements performed on the PMMA beads of Vita teeth revealed the following: a) VVS beads present a mean microhardness value of only 198±3.9 MPa, whereas the corresponding matrix value is of the order of 440 MPa; b) VVP beads exhibit a mean microhardness of 205.5±8.4 MPa, which is practically equal to that of the VOS beads, and the corresponding matrix value is of the order of 470 MPa; c) VVB beads exhibit the highest mean microhardness that is of the order of 236.9±6.1 MPa and the corresponding matrix value is of the order of 490 MPa. Variation in the mean microhardness value of the cross-linked polymer matrix is mainly caused from the heterogeneity of its structural elements. In addition, the microhardness value of the matrix is difficult to be precisely determined, since the areas between beads are small for clear indentation prints. The substantial difference between the microhardness values of the PMMA beads and the matrix is undoubtedly illustrated in figure 3, where 2 Vickers indentation prints, performed under the same loading force on a PMMA bead and on the matrix of a VVP tooth are shown. Since the particle and the matrix areas have a different contrast, the percentage of the total area they cover can be easily calculated with digital image processing. For the application of image processing, 10 sections of 25 mm^2 were used to assess the corresponding areas mean values. The area covered with matrix is estimated to be the 20% of the total area. Taking this into account, a good approximation of the average microhardness value (H_{Vav}) can be resolved by adding the relative microhardness "weight" of each component as follows:

$$H_{Vav} = W_b \times H_{Vb} + W_m \times H_{Vm} , \quad (3)$$

where W_b and W_m are the relative "weights" of the PMMA beads and the matrix respectively, and H_{Vb}, H_{Vm} the corresponding Vickers hardness values. Applying equation (3), we find the following average microhardness values for Vita teeth: i) In VVS H_{Vav} = 246.4 MPa; ii) in VVP H_{Vav} = 258.4 MPa; and iii) in VVB H_{Vav} = 287.5 MPa.

These are, practically, equivalent with the microhardness values obtained from the Knoop measurements.

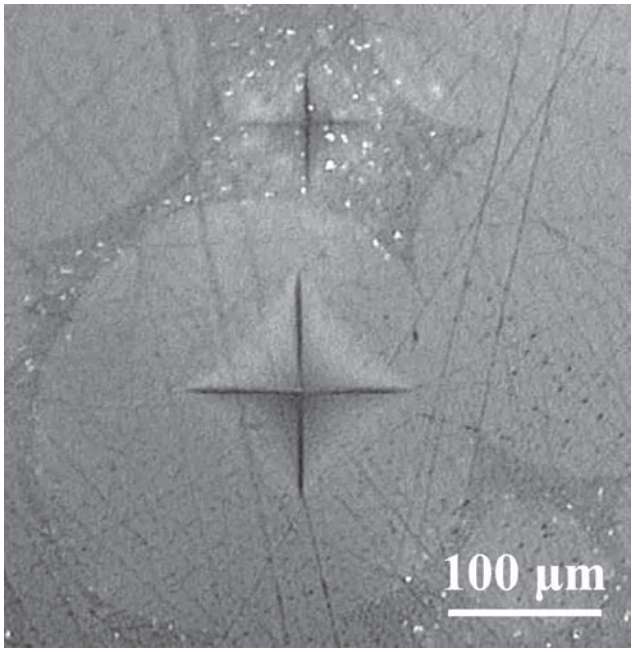

Figure 3. Vickers indentation prints, performed under the same loading force, on a PMMA bead and on the matrix of a VVP tooth. The difference in diagonals of the indentation prints is indicative of the difference in microhardness

Discussion

2 vital parameters that influence the quality of microhardness measurements are the loading force of the indenter and the duration of the indentation. The indentation load should be selected to be high enough, so the measurements will not be influenced from the Indentation Size Effect (ISE), which is responsible for the apparent enhanced microhardness values obtained with indentations belonging to the low-load region[10,12,14,15]. Furthermore, the indentation duration should be long enough to produce plastic deformation but simultaneously, short enough to eliminate the possibility of undesirable external vibrations. For Knoop measurements we have used already published data[16], whereas for Vickers measurements loads belonging to the plateau of figure 2 were utilized.

Vivodent acrylic polymer teeth presented a homogeneous morphology of the inner teeth, exhibiting an almost constant microhardness regardless re-polymerization with or without the presence of acrylic resin base material. Due to the lack of apparent boundaries between the PMMA beads and the polymer matrix, it seems that there is no influence of the monomer on the hardness of the material. This is verified from the fact that microhardness values of teeth boiled in the absence or presence of acrylic resin were practically equal.

Conversely, Vita acrylic resin polymer teeth exhibited an enhanced microhardness value after re-polymerization in the presence of acrylic resin base material. Furthermore, their hardness increased even more when boiled without the presence of acrylic resin. Since the morphology of the inner Vita teeth is heterogeneous, showing clear boundaries between the PMMA beads and the polymer matrix, microhardness was measured separately for the 2 components. The results revealed an increase in the microhardness value of the PMMA beads after the conventional procedure for constructing artificial dentures, while matrix microhardness remained, practically, constant. In the absence of the acrylic resin base the enhancement of the PMMA beads microhardness is noticeably higher. This allows us to deduce that monomer of the acrylic resin base during re-polymerization penetrates into the boundaries between the 2 components and softens the PMMA beads[6]. This softening, however, is by no means important given that microhardness of PMMA beads after re-polymerization in the presence of the acrylic resin base is considerably higher than that of the as-supplied teeth.

Conclusions

The influence of the standard polymerization process on microhardness of acrylic teeth was evaluated and compared to the microhardness of the as-supplied teeth. The role of the monomer of the acrylic base resin released during re-polymerization was also investigated by comparing the microhardness of acrylic teeth subsequent to polymerization in the presence or absence of the acrylic denture base material.

Both Vivodent and Vita acrylic polymer teeth exhibited an either constant or enhanced microhardness value after re-polymerization in the presence of acrylic resin base material. This is crucial in order to avoid softness, crazing and preserve abrasion resistance of acrylic polymer teeth after the conventional re-polymerization procedure for constructing artificial dentures.

Softening of the PMMA beads in Vita teeth during polymerization seems to be directly related to the diffusion of the monomer, present in the mass of the acrylic base resin, within the boundaries between PMMA beads and the polymer matrix. This does not, however, influence significantly the overall microhardness of the teeth that remains higher than the corresponding of the as-supplied teeth. Due to their homogeneous morphology Vivodent teeth are not influenced by the presence of the monomer.

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