RESEARCH AND EDUCATION

Analysis of behavior of the wear coefficient in different layers of acrylic resin teeth

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Occlusal and incisal wear can contribute to the failure of removable dentures with acrylic resin teeth. Excessive wear of a group of teeth might cause inadequate occlusal contact, loss of vertical dimension, masticatory inefficiency, and unfavorable horizontal maxillomandibular relationships. In addition, acrylic resin teeth respond poorly to parafunctional dental habits and can easily result in poor esthetics.[1]

The wear resistance of acrylic resin teeth has been enhanced by introducing manufacturing sophistications such as the incorporation of agents that improve the proportion of cross-linkage,[2-4] inorganic components, different polymers that enable the production of teeth made of composite or nanocomposite resin materials,[4] and interpenetrating polymer networks (IPN).[2,3] The effectiveness of these enhancements has been tested with clinical trials comparing the wear of acrylic resin among

ABSTRACT

Statement of problem. Analysis of the wear coefficient (k) of the superficial and deep layers of acrylic resin teeth can help predict denture durability, but little has been published on the wear coefficient of denture teeth.

Purpose. The purpose of this in vitro study was to determine the k value for the superficial and deep layers of the acrylic resin teeth of 6 different brands by using the fixed-ball microabrasive wear method.

Material and methods. Six artificial tooth specimens of 4 commercial brands were tested: Artiplus IPN (Ar), Biotone IPN (Bi), Magister (Ma), Premium (Pr), Trilux (Tr), and SR Vivodent (Vi). Two specimens from each brand were created, one for the superficial layer and the other for the deep layer. The test was performed on fixed-ball microabrasive wear equipment set to operate at a constant normal force of 0.5 N and a rotation speed of 100 rpm. The test time periods were 5.00, 8.33, and 11.66 minutes. The characteristics of the wear craters were measured by using an optical microscope at a magnification of ×50 and Leica Microsystems software. Wear coefficient (k) values were deduced by using the Archard equation for abrasive wear, $Q=k \cdot N$, and were analyzed by using 1-way analysis of variance, complemented by the Tukey HSD test (α=.05). A different analysis was used for each layer.

Results. The analysis of variance of the wear coefficient revealed significant differences among the groups regarding the superficial layers (P=.009). The Tukey HSD test showed that the k values for the superficial layers of Artiplus specimens were significantly lower than those of the Vivodent and Magister specimens.

Conclusions. One brand (Ar) presented significantly lower wear coefficient value for the surface layer. No difference in wear coefficient values was found among the tooth brands for the deep layer. (J Prosthet Dent 2019;121:967.e1-e6)

brands[5-7] and with laboratory tests[4,8-13] that provide more rapid results by simulating clinical situations. To mimic actual clinical conditions, laboratory tests often distance themselves from the standardization idealized

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Clinical Implications

Analysis of the wear coefficient of acrylic resin denture teeth can help predict denture durability. Preservation of the surface layer is important during polishing and occlusal adjustment to improve tooth performance against abrasion. The acrylic resin of all tooth brands has similar abrasive behavior when wear reaches the dentin layer.

by tribologists, leading to the use of different parameters in their analyses and ultimately precluding a reliable comparison among different studies.[14] Furthermore, because laboratory experiments do not replicate actual clinical conditions, their results have been questioned by clinicians. However, there seems to be a consensus among tribologists that the methods of laboratory analysis that best mimic actual wear conditions are those that reproduce the same wear mechanisms, regardless of whether they mimic the external conditions (such as geometry and kinematics of relative movement) in which wear occurs clinically.[15] The main phenomena related to tooth wear and to the performance of restorative materials under clinical conditions are complex.[16] Unfortunately, controlled studies determining the mechanisms of wear of artificial teeth in vivo are lacking; nevertheless, it seems reasonable to assume that abrasive materials such as food particles cause grooving and rolling of artificial teeth in vivo.

The selection of artificial teeth may be based on esthetics, but satisfactory wear performance is also expected. The performance of materials against abrasion is usually predicted with tests that determine the coefficient of wear: the higher the coefficient, the greater the expected wear, provided the tribological system is the same.

In 1996, Rutherford and Hutchings[17] introduced the ball-cratering abrasion test. This test assesses the wear volume and wear mode on the surface of the material when a rotating sphere is forced against the material in the presence of a slurry of abrasive particles. The wear is evaluated by the diameter of the wear crater generated during the test. This method enables the calculation of the rate of wear and the wear coefficient of the material by using a tribological system, which makes it possible to predict—or at least estimate and compare—the abrasive wear resistance of different materials under actual working conditions. The wear rate (Q) is defined as the quotient of the wear crater volume (V) and the sliding distance (S) between the sphere and the specimen. The coefficient of wear (k), stated in $mm^3 \cdot Nm^{-1}$, considers the value of Q and the normal force between the sphere

and the test specimen.[18] This method has been considered appropriate for evaluating dental materials such as composite resin and amalgam.[19]

Some denture teeth manufacturers claim that their products are made from resins more resistant to abrasion, particularly in the surface layer, and that this characteristic would improve the clinical durability of dentures. The authors are unaware of studies that determine the wear coefficient of acrylic resin teeth according to the brand and the layer, namely a superficial (enamel) or deep (dentin) layer. Although teeth having suffered severe wear during function should be replaced, the wear coefficient of deeper layers should be determined because they can be exposed to mastication during prosthesis fabrication, when space is lacking or when occlusal adjustment is necessary. Therefore, the purpose of this in vitro study was to compare the wear coefficient of the superficial and deep layers of 6 different brands of acrylic resin teeth by using the fixed-ball microabrasive wear method. The null hypothesis was that no difference would be found in the wear coefficient values of the denture tooth brands tested, either in the deep or superficial layer.

MATERIAL AND METHODS

A minimum sample size of 5 specimens per group was calculated, considering a power of 85%, a type I error of 5%, a standard deviation of 7.0 units of k ($mm^3 \cdot Nm^{-1}$), and the possible detection of a difference of 18 units of k. This difference was considered adequate for the test to detect differences corresponding to approximately half of the maximum k values found in the exploratory tests with the 6 tooth brands evaluated. Therefore, 6 artificial tooth brands of 4 commercial brands were tested (Table 1).

Analysis of the superficial layer was conducted by embedding maxillary central incisor denture teeth in half-inch polyvinyl chloride tubes (Tigre) with autopolymerizing acrylic resin (Jet; Clássico), leaving the facial aspect of the denture tooth exposed to the microabrasive wear device. Analysis of the deep layer was performed by sectioning maxillary lateral incisor denture teeth buccolingually along their long axis and then embedding them with the sectioned aspect facing the surface. The surfaces of the specimens were polished by using a sequence of 320, 400, 500, 600, 800, 1200, and 2000 grit abrasive papers (Norton). The specimens were washed for 30 seconds in running water at each grit change. Five specimens of each of the 6 tooth brands were prepared for analysis of their superficial layer and 5 for their deep layer (n=5) for a total of 60 specimens.

The abrasive suspension consisted of 5% (w/w) pumice (Asfer) wet sieved to a grain size corresponding to a 400+ mesh and 95% distilled water. The pumice particles had a nanohardness of 907 ±123 HV (measured

Table 1. Characteristics of artificial tooth brands studied

Model/Initials	Lot Number	Characteristics	Brand
Artiplus IPN (Ar)	386952; 772563; 772493	PMMA; BADMA; high-quality INPEN material	Dentsply Sirona
Biotone IPN (Bi)	988223; 967463; 011121; 967463	PMMA; high-performance density cross-linked resin	Dentsply Sirona
Magister (Ma)	1211316405; 1211244149; 1211398912; 1111069366	PMMA; INCOMP technology	Kulzer GmbH
Premium (Pr)	1311784768; 1311817492; 1311789803; 1311742549	PMMA; MPM; microfiller combined with a viscoelastic nanofiller (Nano Pearls); INCOMP technology	Kulzer GmbH
Trilux (Tr)	0000037214; 0000038022	PMMA; DCL; OMC; EDMA[20]	Vipi Ind Com Ltda
SR Vivodent PE (Vi)	022013; 201402	PMMA	Ivoclar Vivadent AG

BADMA, butylene glycol dimethacrylate; DCL, double cross-linking; EDMA, polymerized ethylene glycol dimethacrylate; INCOMP, technique of injection and compression of layers; MPM, multiple polymer matrix; OMC, organically modified ceramics; PMMA, polymethyl methacrylate.

Table 2. Mean k coefficient values of surface layer of different brands of artificial teeth

Tooth Model	k (×10⁻⁴) (Mean ±Standard Deviation)
Ar	22.6 ±13.8^a
Bi	36.1 ±5.9^{ab}
Ma	47.8 ±13.8^b
Pr	30.2 ±6.5^{ab}
Tr	35.2 ±7.0^{ab}
Vi	43.1 ±10.8^b

Ar, Artiplus IPN; Bi, Biotone IPN; Ma, Magister; Pr, Premium; Tr, Trilux; Vi, SR Vivodent. Means followed by same letters are not significantly different (*P*>.05). Statistically different means (*P*≤.05) are indicated by different superscript letters.

Table 3. Mean k coefficient values of deep layer of different brands of artificial teeth

Tooth Model	k (×10⁻⁴) (Mean ±Standard Deviation)
Ar	23.4 ±7.8^a
Bi	29.6 ±5.2^a
Ma	34.8 ±9.4^a
Pr	36.8 ±11.6^a
Tr	23.3 ±8.2^a
Vi	34.0 ±8.5^a

Ar, Artiplus IPN; Bi, Biotone IPN; Ma, Magister; Pr, Premium; Tr, Trilux; Vi, SR Vivodent. Means followed by same letters are not significantly different (*P*>.05). Statistically different means (*P*≤.05) indicated by different superscript letters.

with a 7-mN load indentation and a Berkovich penetrator) and ranged from 20 μm to 700 μm, with a mean size of 110 μm.

The test was performed by using a fixed-ball microabrasive wear device, designed for a research project conducted in the Department of Mechanical Engineering, Polytechnic School, University of São Paulo.[21,22] Each wear crater was created for each of the sliding distances, without intermediate stops, and test sites were arbitrarily chosen within each layer. A 25.4-mm-diameter AISI 52100 steel sphere was used. Rotation speed was set at 100 rpm (surface velocity of approximately 0.15 m/s), and the normal force was set at 0.5 N. The test time periods assigned to the sliding distances (S) were t=5 minutes for 40 m, t=8.33 minutes for 66.5 m, and t=11.66 minutes for 93 m. In all, 3 craters were created for each test, with 5 repetitions for each condition.

Wear crater diameter was measured by using an optical microscope (BX60M; Olympus Corp) at a magnification of ×50 and Leica Microsystems software (Leica Microsystems GmbH). The wear rate (Q) was derived from the Archard equation for abrasive wear, $Q = k \cdot N$, where k (m³·Nm⁻¹) is the wear coefficient and N is the normal force. The wear coefficient was calculated by using the ball-cratering equation $k = V/N \cdot S$, where S is the sliding distance and V is the loss of volume calculated with the equation $V = \pi \cdot d^4/64 \cdot R$, where R is the radius of the test ball and d the diameter of the crater.[21,23]

Mean values were compared by using the 1-way analysis of variance (ANOVA) test complemented by the Tukey HSD test (α=.05). The analyses for the superficial and deep layers were performed separately. The wear coefficient values considered for the analyses were those obtained under a 93-m sliding distance condition (t=11.66), which determined the permanent wear phase in which the coefficient is constant throughout the test.[18] The wear coefficient values obtained for the other sliding distances, corresponding to t=5.00 and t=8.33, were not considered in the statistical analyses. A statistical software program (Piface 1.76 Rus Lenth and MedCalc 18.6; MedCalc Software bvba) was used for the calculations.

RESULTS

The Kolmogorov-Smirnov test showed that the enamel and dentin data had normal distribution (*P*>.10). The Levene test showed that the variances found for the enamel (*P*=.516) and dentin data were similar (*P*=.903). One-way ANOVA of the wear coefficient revealed significant differences between the tooth groups regarding the superficial layers (*P*=.009). The Tukey HSD test showed that the k value for the surface layers of the Ar specimens was significantly lower than that of the Vi and Ma specimens (Table 2).

One-way ANOVA of the deep layers revealed no statistically significant difference (*P*=.093). A comparison of the mean k coefficient values performed with the Tukey HSD test is shown in Table 3. A post hoc power analysis showed that differences of 13.7 units of k were detected for the superficial layers and 15.6 units of k, for the deep layers.
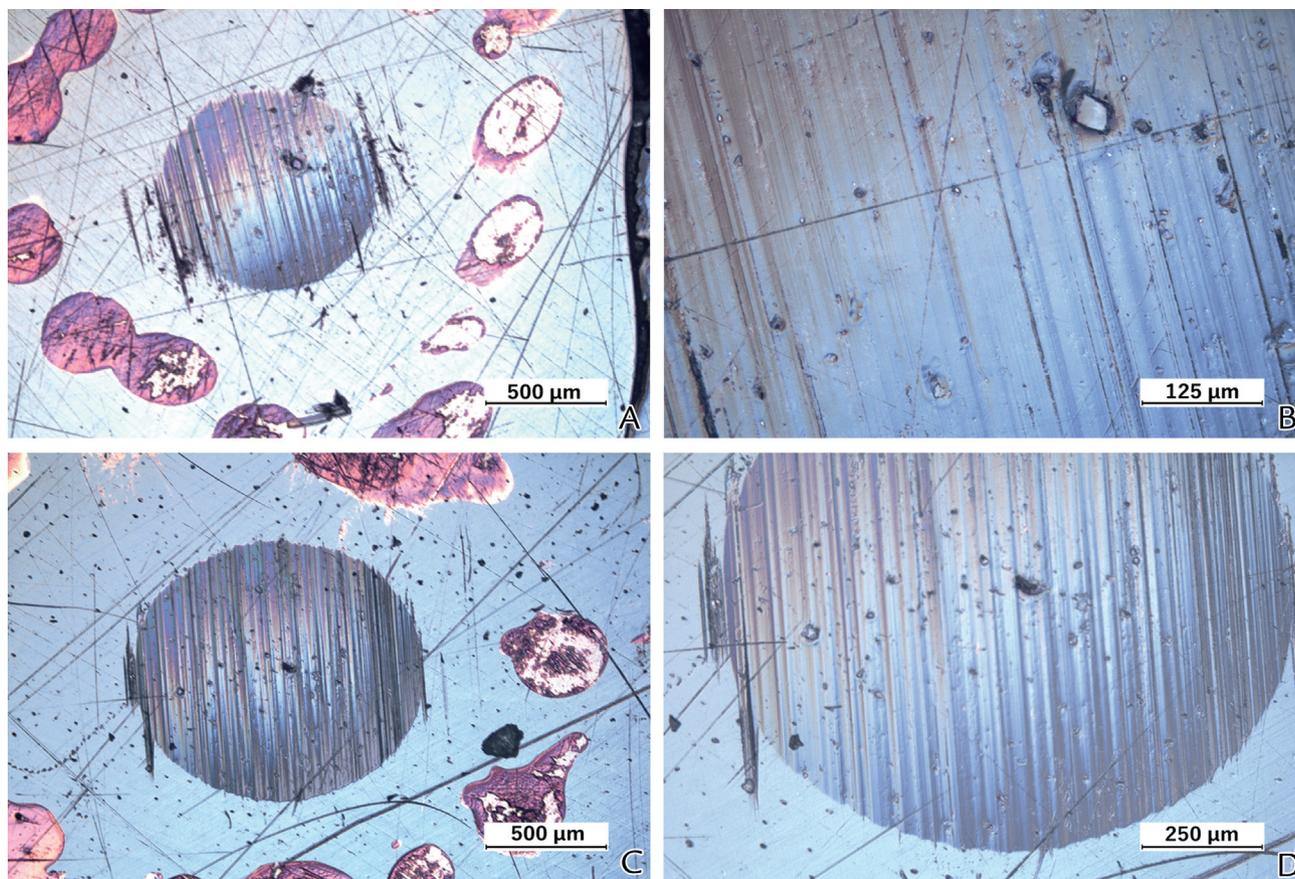
Figure 1. A, Artiplus, deep layer, t=11.66, ×5 magnification. B, Artiplus, deep layer, t=11.66, ×20 magnification. Inlaying of large abrasive particle evident (approximately 50 µm). C, Trilux, superficial layer, t=11.66, ×5 magnification. D, Trilux, superficial layer, t=11.66, ×10 magnification.

The edges of the craters had a regular circular boundary, which characterizes a centered movement of the sphere. The surfaces of the wear craters were marked by well-defined grooves, which characterize the wear mode as grooving wear or 2-body abrasion (Fig. 1).[24]

DISCUSSION

Although no difference was observed among the studied tooth brands regarding the deep layers, the results showed that the wear coefficient values for the superficial layers of Ar specimens were significantly lower than those of the Vi and Ma specimens. Therefore, the null hypothesis was rejected.

This significant difference on the superficial layer seems clinically relevant because it indicates that better wear performance can be expected from Ar just before complete wear of the superficial layer. Nevertheless, once the superficial layer is worn away, all the tooth brands studied will likely perform similarly. As a result, when the teeth are ground during an occlusal adjustment, the clinician should be particularly concerned if Ar is used,

considering that the material most resistant to wear is being removed. The same does not apply to the other artificial teeth.

The wear method used in this study has been classified as "3-body abrasion" because a particulate abrasive was interposed between the surface under study and the surface that propelled it.[19] However, this arrangement of the abrasive system is currently considered as "2-body abrasion" because the observed wear mode is grooving. Grooving characterizes a 2-body system in which the abrasive is fixed to the surface of the counter body, thus preventing it from actually rolling. Another study has suggested that the terms "grooving wear" and "rolling abrasion" should be used to describe the mechanisms of abrasive wear because the terms "2-body abrasion" and "3-body abrasion" could be misleading.[24]

The present research aimed at studying the wear coefficient of different layers of different brands of artificial teeth, considering that the lower the k value of a specimen is, the better it is expected to resist 2-body abrasive wear. According to Kato,[25] wear coefficient is not a property of the material because it depends on the test conditions and/or the tribological system involved.

The tribological system used was the AISI 52100 steel sphere, which has a hardness of 9.9 GPa. This could be considered a limitation of this study because the hardness of dental enamel is approximately 2.9 GPa and that of acrylic resin teeth is approximately 0.26 GPa. This indicates that the trial was severe according to the severity chart developed by Adachi and Hutchings[26,27] and confirms the involvement of a grooving mechanism. Other factors that may have contributed to the severity of the test were the hardness of 8.9 GPa and the faceted shape of the abrasive used.[24] Since severe tests reduce the ability to distinguish small differences in wear resistance, the results of the present study would be more applicable to patients for whom the tribological system also causes severe wear. In other words, the use of the Ar model could initially benefit patients who rapidly wear out artificial teeth; however, once the superficial layer is worn away completely, the benefit is lost. A tribological system that could replicate the wear mechanisms found in artificial teeth would be convenient, but the authors are unaware of studies that have conducted this type of investigation.

Most in vitro wear studies have focused on ranking various dental materials by using wear machines that simulate oral conditions, whereas others have simulated wear mechanisms. None of the experimental teeth used for wear simulation reproduce actual intraoral interactions because wear is a complex process that involves several biologic factors that are difficult to simulate.[10] Typically, the tribological systems used in artificial tooth wear studies tend to produce severe wear because these systems are likely inspired by preexisting tests developed for materials that are more resistant to abrasion. Another study evaluated the 2-body wear resistance of dental materials by using a double-axis mastication simulator (Willytec) and steatite ceramic balls. The results showed that microfilled and nanofilled composite resins resist wear better than artificial teeth (PMMA resin, IPN resin, TCR resin, DCL resin, and PMMAu resin). However, no significant difference in wear resistance was found among the acrylic resin teeth studied.[28] A study by Stober et al[4] analyzed the wear resistance of 9 artificial teeth brands (MPMA-PMMA, IPN-PMMA, INPEN-PMMA, ISOSIT, PMMA-inorganic fillers, and nanocomposite) and an experimental material (PMMA-inorganic fillers). The apparatus used to produce 2-body wear was a mastication simulator (Willytec) with a 4.8-mm-diameter Al_2O_3 antagonist sphere (Degussit). The artificial teeth tested showed different wear resistance values, but no relationship was identified between the chemical composition and the wear resistance of the artificial teeth.

According to Heintze,[9] all the wear test methods lack clinical relevance because prospective studies that correlate in vitro with long-term in vivo results for identical materials are lacking. Therefore, the extrapolation of data from in vitro wear studies to clinical wear behavior should be considered with caution. In vitro wear processes should be further investigated to enhance understanding of the mechanisms involved, such as in vivo failure patterns,[29] as well as to support appropriate comparisons and contrast analyses of different situations of lubrication and friction. Most importantly, further investigation could improve the understanding of the characteristics of abrasive food particles in the oral environment.

CONCLUSIONS

Based on this in vitro study, the following conclusions were drawn:

1. Considering the tribological system used in this study, only the Ar artificial tooth model presented a superficial-layer wear coefficient significantly lower than that of the other brands assessed and, therefore, better microabrasion performance.
2. No significant difference in the deep-layer wear coefficient was found among the tooth brands studied.
3. The wear mode observed in all the specimens was grooving wear, indicating that the test conducted was a 2-body microabrasion test.
4. The "fixed rotating sphere" test proved adequate to understand the microabrasive phenomena; however, new studies with other parameters and wear mechanisms should be performed to improve the understanding of the different tribological systems present in the intraoral environment.

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