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Analysis of Polymerization Time on Abrasive Wear of Dental Resins

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An evaluation was made of the abrasive wear of six composite thermofixed dental resins subjected to different polymerization times. The method of evaluation was based on sharpness measurements to quantify the abrasive wear resistance of the resins. To this end, a test bench was built, consisting of a rotating porcelain cylinder that wears out a resin-coated cylinder placed above it, thus causing vertical displacement of the contact as the wear progresses. The values of vertical displacement, i.e., the input variables, were read and recorded by means of a computer program to obtain the sharpness values. These data indicated that the resins displayed different behaviors as a function of the polymerization times applied, reinforcing the importance of using a practical and rapid method of analysis in order to ensure that the behavior of new materials is fully understood before they are launched on the market.

Keywords: *composite resins, abrasive wear, photopolymerization time, sharpness*

1. Introduction

Humans are always in search of better opportunities in life. The valuation of facial esthetics in today's society has been a primary factor that has driven advances in the area of new synthetic materials for Dentistry. The new formulations of photopolymerizable composite resins widely employed as restorative materials for anterior and posterior teeth are particularly conspicuous, especially as replacements for amalgam.

Among the various factors that motivate dentists to use composite resins is the easy handling and wide availability of colors, which more often than not closely resemble the coloring of human teeth, rendering them practically imperceptible after their application.

However, an indispensable characteristic for these resins to be considered perfect restoratives is wear resistance as high as dental enamel, a feature that is rarely found in practice. The mechanical forces of mastication and teeth brushing lead to marked wear that can culminate in the early replacement of the restoration.

Innumerable researches have focused on the wear resistance of restoratives and, based on the recommendations of the American Dental Association[1], two lines of study have been widely used: the clinical (in vivo) and the laboratory (in vitro) lines.

The clinical method basically involves making restorations in a given number of patients and, after a certain period of time, usually more than two years, evaluating the resin's wear. The lack of control of important variables such as the force employed in mastication, the patient's diet, or biological factors (oral), undoubtedly limit such studies.

Miranda et al.[2] and Wendt & Leinfelder[3] demonstrated the unacceptable behavior of resins as restorative materials for application in posterior teeth due to the high occlusal wear and consecutive loss of anatomical shape when compared with other materials such as amalgam. Moreover, after eight years of analysis, Collins et al.[4] reported a far higher rate of failures in resin restorations than in amalgam.

In laboratory assays performed on test benches or simulators, using carefully prepared test specimens, the analysis of wear resistance is both faster and more accurate, but shows little correlation with clinical evaluations.

Many devices have been developed to simulate the wear that occurs in the human mouth. To exemplify, Mair et al.[5], Yap et al.[6], Condon & Ferracani[7], and Momoi et al.[8] used devices that reproduce the wear of composite resins in a complex interaction of the mechanisms of erosion, corrosion, adhesion, abrasion and impact. Deterioration can also be accelerated through mechanical fatigue.

As reported by Venhoven et al.[9], Vieira et al.[10], Abate et al.[11] and Halvorson et al.[12], polymerization is another factor that interferes in the final quality of composite resins, and the process is controlled by several variables. Photopolymerization equipment is used preferentially in the preparation of test specimens for lab assays.

Kurachi et al.[13] found lower hardness values in resin samples polymerized by LED (light-emitting diode) devices than in resins polymerized with a halogen lamp at a typical polymerization time of 40 seconds.

Tsai et al.[14] concluded that the LED polymerization diodes available in the market achieve adequate polymerization and microhardness values for resin thicknesses of less than 2 mm. For greater thicknesses, they found that polymerization with conventional high-intensity halogen lamps was more effective.

In a comparison of composite resins of various commercial brands, Carvalho Júnior[15] found that all of them showed increased hardness and solidification contraction (stiffening) seven days after polymerization, characterizing the transitory behavior of these characteristics intrinsic to the process.

Based on the above reviews, we have sought to demonstrate that both the evaluation of wear of composite resins used in dentistry as well as aspects of polymerization have been the focus of intense

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interest in researches, despite the paucity of scientific information of a comparative nature.

The present research work offers data on the abrasive wear of commercial dental resins polymerized for different lengths of time and evaluated by an experimental method developed specifically for this purpose.

2. Materials and Methods

Our experiments involved testing six brands of composite thermofixed resins, i.e., Fill Magic®, Suprafill®, Tetric Ceram®, Xrv-Herculite® and Z100®, color A2, for use in dental restorations, polymerized with a halogen lamp for 10, 20 and 40 seconds.

The wear evaluation of these resins was based on a study originally made by Coelho[16], involving the sharpness of grinding wheels in the grinding of steel workpieces.

The required adaptations, illustrated in Figures 1 and 2, consisted basically of keeping a driving metal cylinder coated with porcelain rotating under a sample holder containing the test resin and coupled to a gauge which measures the vertical displacement caused by the wear of the resin.

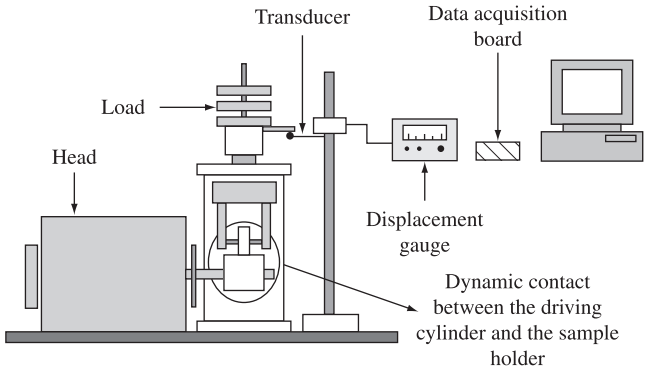

Figure 1. Schematic diagram of the test bench developed for this study

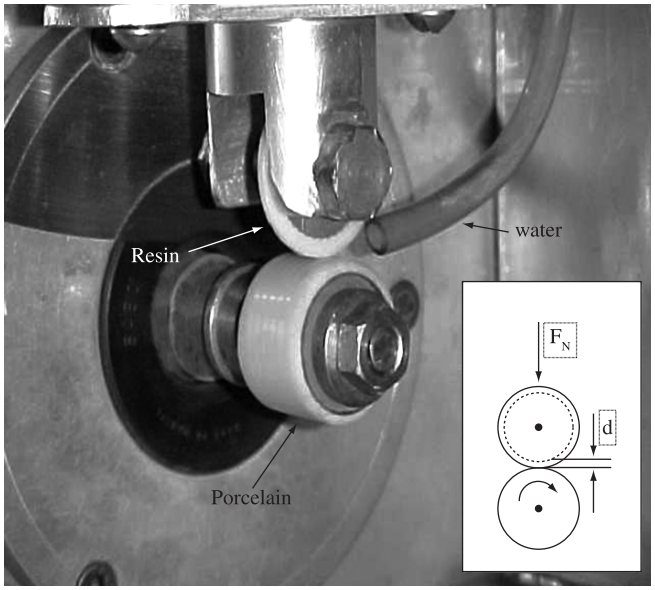

Figure 2. Detail of the dynamic contact between the porcelain-coated driving cylinder and the resin-coated sample holder to be tested (lower portion of the test bench).

Under these conditions, Ulhôa[17] demonstrated that sharpness can be determined as follows in Equation 1:

$$k = \frac{2b\sqrt{4r}}{3F_n}(a_1)^{2/3} \quad (1)$$

where k is the sharpness, given in (mm^3/N.s), F_n is the normal applied force, in (N), b and r correspond to the width and radius of the elements in contact with each other, both in (mm), and a_1 is the angular coefficient of linear regression obtained from the ratio of vertical displacement of the contact (d) to the testing time ($t^{2/3}$).

The porcelain used was Duceram, color C4, recommended for dental substitution prostheses. The metal cylinder was manufactured of NiCr cast alloy, which is recommended as the substrate for the aforementioned porcelain.

The porcelain was applied by hand on the metal cylinder in layers of about 2 mm, the first of which consisted of the opaque formulation of porcelain. Figure 3 illustrates this procedure. After each layer was deposited, the coated cylinder was heat-treated in a furnace at 950 °C and allowed to cool for 90 minutes. At the end of the procedure, the excess material was removed by grinding, and the resulting porcelain-metal cylinder had an external diameter of 24 mm.

The sample holders were fabricated by assembling a steel cylinder, two metal washers and two Teflon washers, joined together with a longitudinal screw, as depicted in Figure 4. The external surface of this cylinder was scored to ensure the optimal adhesion of the resins, while the 8 mm spacing between the Teflon washers served as the matrix for the resins' application and subsequent polymerization.

The photopolymerization device was a Kondortech CL-K50 photopolymerizer with irradiation of the light source made by means of a halogen lamp, previously calibrated, providing a satisfactory light intensity of over 300 $mW.cm^{-2}$.

After polymerization, the samples were immediately immersed in deionized distilled water and stored for 24 hours before being

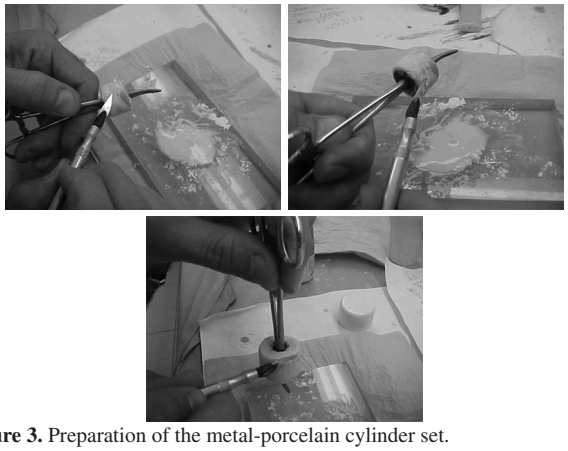

Figure 3. Preparation of the metal-porcelain cylinder set.

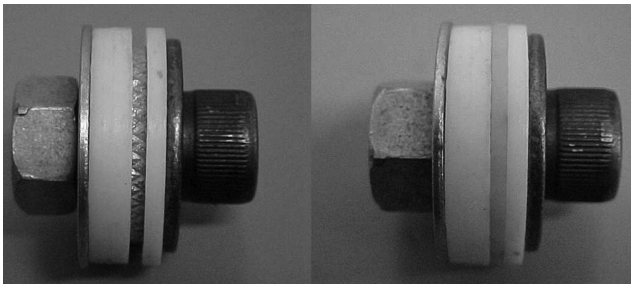

Figure 4. Sample holder with and without the polymerized test resin.

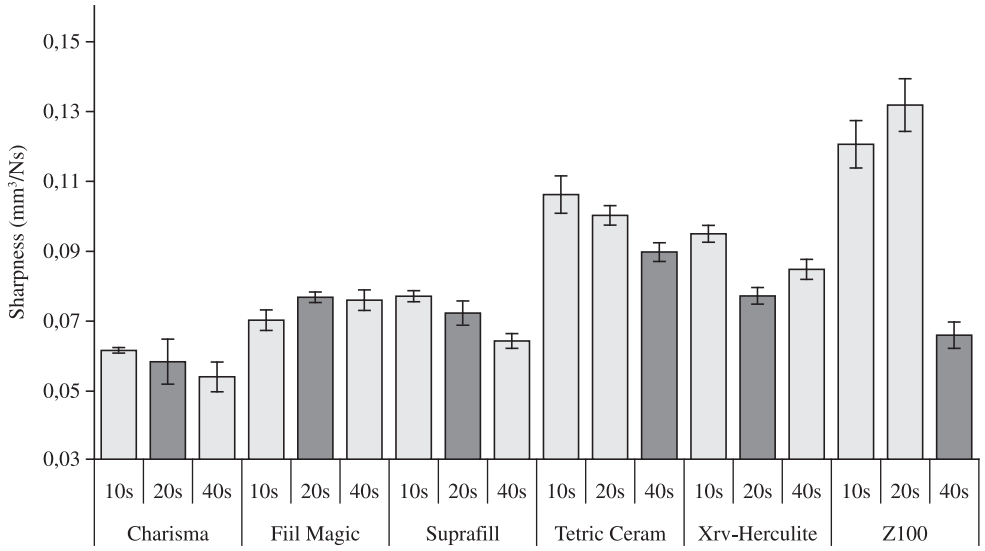

Figure 5. Sharpness results obtained in the assays.

subjected to grinding with a white aluminum oxide (Al_2O_3) grinding wheel to bring them down to a nominal diameter of 24 mm. The post-polymerization time prior to the abrasive wear test was the same for all the samples.

The test parameters, which were established in preliminary tests, were: cutting speed of 18 m/s and constant vertical contact load of 16N. The micrometric measurements of vertical displacement of the sample holders at the point of contact were carried out with an electronic transducer coupled to a Tesatronic TT60 electronic gage.

The recorded data were processed using a program generated by LabView® software, producing a $d(t^{2/3})$ regression curve to calculate the angular coefficient (a_1) and, hence, to determine the sharpness (k) at the resins, according to the Equation 1.

3. Results and Discussion

Figure 5 presents the mean values and standard deviations determined for the sharpness at the assayed resins, each tested five times at the aforementioned polymerization times. The Figure also shows the polymerization time specified by each resin manufacturer.

Assuming a direct correlation between sharpness and abrasive wear, the global comparison of the assayed resins revealed that the brand Charisma showed the best wear resistance performance and the brand Z100® the worst, at polymerization times of 10 and 20 seconds.

Considering the effect of the polymerization times adopted, including the reference times of the manufacturers, we found that the Charisma resin showed a slightly higher wear resistance with increased polymerization time. A similar result was found for the resins Suprafill® and Tretic Ceram®, but with higher sharpness values. In contrast, the resin Xrv-Herculite showed higher wear resistance at 20 seconds, while the polymerization time was found to exert little influence on the wear of the resin Fill Magic®. Among all the resins, only the brands Tetric Ceram®, Xrv-Herculite and Z100® showed low wear in the polymerization time specified by the manufacturers.

In the Z100® resin, as observed earlier herein, the marked increase in the sharpness value at 10 and 20 seconds prompted us to carry out a complementary dynamic mechanical thermal analysis (DMTA) of samples polymerized at these two times in order to better understand the structural characteristics of this resin as a function of temperature. The DMTA tests were carried out in a three-point flexure module

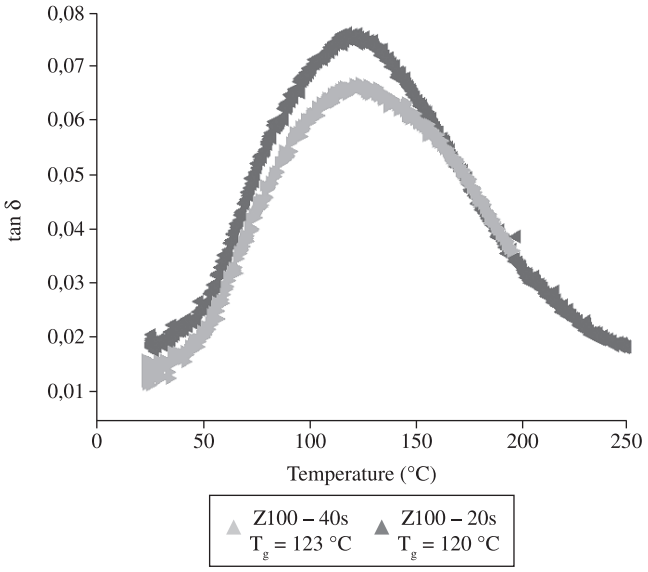

Figure 6. Results of the determination of tan δ for the samples of Z100® resin polymerized for 20 and 40 seconds.

with an oscillation frequency of 64 μm and scanning from room temperature to 250 °C, using properly prepared samples.

According to Young and Lovell[18], the viscoelastic regime of polymers depends on the frequency of mechanical loading as a function of temperature, and can be represented by the following Equation 2:

$$E^* = E' + iE'' \quad (2)$$

where E' and E'' are, respectively, Young's elastic and viscous moduli, related to the phase angle (δ) between the stress and strain imposed (Equation 3):

$$\tan\delta = \frac{E'}{E''} \quad (3)$$

The temperature at the maximum value of E'', or of tan δ, is the glass transition temperature (T_g) and the area under these two maximum values is associated with the polymer's molecular mobility.

Figure 6 depicts the performance obtained in the DMTA tests of the Z100® resin, demonstrating that the maximum value of tan δ was slightly higher for the sample polymerized for 20 seconds, in correlation with a temperature (T_g) slightly lower than the polymerization at 40 seconds. This finding indicates a higher molecular mobility or, similarly, a lower incidence of structural reticulation for the polymerization in 20 seconds. In terms of mechanical properties, this may mean lower mechanical strength, to an extent sufficing to impair the wear resistance for polymerization in 20 seconds.

4. Conclusions

Based on the results obtained in the assays, the following conclusions were drawn:

- The test bench proved effective in evaluating the effect of the polymerization time of composite resins for use in dentistry;
- The repeatability of the tests, allied to the accuracy of the measurements, ensured low values of standard deviation, allowing us to reaffirm the importance of applying the method to this class of materials prior to their commercialization;
- The resins studied here yielded distinct responses of wear resistance intensity depending on the polymerization time.

Acknowledgements

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