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Wear of Dental Restorative Materials

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Abstract

Gradual wear of opposing teeth is a normal phenomenon in human dentition. To ensure a better quality of life through better dental health, there is a need for quality dental restorative materials to repair or replace natural teeth. Several aspects are looked at when designing a proper dental implant. Aesthetics, durability, and integration with the supporting teeth and soft tissues are some key design issues. Several types of materials are available in current dentistry for teeth restoration and replacement, with new materials being introduced every year. The understanding of the wear mechanisms of these new types of dental restorative materials alone or in combinations with either enamel or another dental restorative material becomes important. In this report, work done in the field of analyzing the wear of dental material in the past and present are reviewed.

1. Introduction

Although a number of natural processes could affect the overall dental health person, we are interested in the natural wearing process. Gradual wear of opposing teeth is a normal phenomenon in human dentition. The intra-oral environment can produce loads of 60 to 250 *N* in a moist environment. Higher forces of 500 to 800 *N* are also capable for brief periods. Areas of contact can from 1-4 mm^2. The approximate number of chewing cycles per day is 800 to 1400 [1]. Also as the life expectancy age increases, so does the amount of wear natural teeth must endure. To ensure a better quality of life through better dental health, there is a need for quality dental restorative materials to repair or replace natural teeth.

Several types of materials are available in current dentistry for teeth restoration and replacement, with new materials being introduced every year. Factors to select the proper materials are resistance to wear, compatibility with the surrounding oral tissues, neutrality to oral fluids, and of course the aesthetics are important. Conditions that could affect wear include: types of loading, speed and lubricant used, quantity of the material included, hardness and surface finish, the presence of foreign materials, temperature ad the chemistry of the oral environment. At present, three materials which satisfy these requirements that are commonly used: gold alloy, acrylic resin and porcelain. To understand the wear of these three materials and new types of dental restorative materials alone or in combinations with either enamel or another dental restorative material becomes important.

There are two distinct methods to analyze the wear of dental restorative material alone or in combination, which are, clinical (in vivo) and laboratorial (in vitro) [10]. Clinical test are performed by installing the restoratives in patients and studying the outcome over time, there are problems associated with the type of trial tests. The time necessary for acquiring results is quite extensive (minimum of 2 years [10]). Complete control of the environment impossible since the patients eating and mastication habits, saliva production and overall health vary, patient to patient. There are ethical questions about testing materials without full knowledge of the behavior of installed material.

As for in vitro testing, the ability to have complete control over the variable involved in the wear of the dental restorative materials is a great advantage. Three methods exist to the materials in a laboratory, which range from simple to complex. The first method is a scratch test which looks at the wear due to the sliding of a hard tip. A two-body test employs the relative motion between the sample and another abrasive material. Three-body test include a mediums includes that mimics the mastication and abrasiveness of food. Factors that have been considered are: intermittent contact, movement and contact in an elliptical pattern, controlled force of contact, velocity in the range of the masticatory function, washing of the test field, temperature and chemical reaction. While many have tried to develop a standard to testing the wear of dental restorative materials, none exists as of today, therefore, comparison studies between existing studies is difficult since the methods used by different groups will vary the results group to group.

In this report, work done in the field of analyzing the wear of dental material in the past and present are reviewed. We will focus on types of material tested, method of testing and the need for such testing. A brief review of the future direction of this field will also be included at the end of this report.

2. Laboratory Wear Test in Human Tooth Enamel and Dentin

Human tooth is composed of enamel, dentin-enamel junction (DEJ), dentin and pulp. Figure 1 shows the profile of natural tooth. Enamel is known as one of the hardest tissue in the human body. Compared with enamel, dentin is widely considered to be elastic and soft. Understanding the friction and wear behavior of human teeth would help the clinical treatment for teeth and develop new dental restorative materials.

Freshly extracted molars cut into two halves are samples used in this study. The samples are tested by a reciprocating horizontal tribometer. A normal force of 20 *N*, reciprocating amplitude of 500 μm, and frequency of 2 Hz are used for all the wear tests. Tests up to 5000 cycles are conducted with artificial saliva (Table 1) bath lubrication. The choice of these parameters is based on the clinical experience and literatures.

Two surfaces, occlusal section and axial section, are tested individually. For occlusal section, wear test is performed gradually from the outer enamel to dentin. And for axial section, wear tests are conducted in enamel, DEJ and dentin respectively.

Wear scars are examined both by optical microscope and by laser scanning microscope. Wear depth is measured by a profilometer.

In the occlusal section, from the enamel to the dentin as shown in Figure 2, friction logs describing variations of tangential forces versus displacement amplitude as a function of number of cycles. Enamel layer shows excellent friction behavior. Lower tangential force and coefficient of friction (COF) are observed at the early stage. In Figure 3, the coefficient is about 0.1 and remains constant up to 1600 cycles. For DEJ layer, lower COF only lasts about 50-100 cycles. The COF increases rapidly from the first cycle when friction occurs on the superficial dentin.

In the axial section (Figure 4), COF for both enamel and DEJ increase rapidly at the early stage shown in Figure 5, and then increase gradually to 0.87 and 0.9 respectively after 5000 cycles. However, more fluctuations are found in the dentin zone. The COF fluctuates between 0.3 and 0.5 before 500 cycles and between 0.5 and 0.85 after 500 cycles. Profile measure form Figure 6 shows significant increases both in depth and in area of wear mark from the enamel to dentin for occlusal section. The characteristic of wear in axial section is similar to occlusal section. The main difference of axial section is that the wear depth of the scar in the axial section is bigger than in the occlusal section shown in Figure 7.

3. Laboratory Wear Test of Dental Restorative Materials

Not many clinical tests examine the wear solely of dental restorative materials. Most dental materials will cause wear to the enamel prior to exhibiting wear, itself. The main interest, therefore, is to study wear behavior of dental materials to better predict their abrasion on other materials. The wear due to combinations of different material surfaces and/or enamel is a separate area of research.

New tests for studying wear of dental materials are introduced often in hopes a standard can be established. Wang, DiBenedetto and Goldberg [5] presented a test in Wear journal,"Abrasive wear testing of dental restorative materials", in 1998. A tribometer was modified to form a pin-to-disk type of wear apparatus. In the apparatus the dental restorative material is the pin which ground against a diamond disk. During the test, normal and frictional forces were recorded during a test. Volumetric wear rate was calculated by measuring the change in the pin length. The diameter was chosen to be comparable to the size of a human tooth. The diamond surface was chosen to avoid change in the abrasiveness and to avoid debris buildup. A 'run in' period is still necessary since different materials can increase or decrease the abrasiveness of the grinding disk. A water circulation system was used to wash away debris to maintain a fresh sliding surface. Besides wear rate and frictional coefficient, failure mode can be analyzed using a scanning electric microscope. Three commercial dental restorative products were put through a parameter study using this apparatus and procedure. Effects of filler volume fraction (glass beads in the matrix) and particle size on wear resistance were analyzed. The products were rated according to wear rate and friction coefficient. Studying the surfaces it was observed that the failure behavior was dependent on an inter-particle distance. While the inclusion of fillers may reduce the deformation of the composite, the fillers can also increase damage by propagating of cracks and having filler pull out. Too many particles increased the brittleness of the material. Increasing particle size decreases the chance of the whole particle being pulled out which increases the fracture area. Overall the purpose of developing a test for comparable and reproducible wear of dental restorative materials was achieved.

Jahanmir and Dong [4] developed a method for studying the wear mechanisms of a dental glass-ceramic in 1995. The wear behavior of a mica-containing glass ceramic used for replacement of occlussal surfaces was studied. A ball-on-flat tribometer was designed and constructed for this evaluation. High purity aluminum balls with a roughness of 0.01 μm were used for this study. The samples of mica were prepared taking into account the effect machining can have on crack propagation. Final surface roughness of mica ranges from 0.55 to 0.75 μm. Through the experiment a low speed of 1.44 $mm\ s^{-1}$ was maintained to reduce thermal effects. A load of 4.9 N was used and tests were conducted for an hour. Friction coefficient for three samples was measured and ranged from 0.7 to 0.77. Wear volume was measured using a stylus profilometer. These profiles were taken perpendicular to the sliding direction. The wear track was examined using a SEM. Wear debris was seen in the track which was not strongly attached to the surface. Upon cleaning, it could be seen that cracks initiate and propogate along the mica plates. Since the cracks are controlled by the mica plates, wear could possibly be controlled by mica size and distribution in the glass matrix. These results compared well with a Hertzian contact study performed previous to the experiment.

Using a similar ball-on-flat tribometer Yap, Teoh and Chew conducted a fatigue analysis of the loading on occlusal contact area of composite restoratives [13]. The specimens were subjected to wear testing at 20 *MPa* with an artificial saliva lubricant. Wear depth was measured every 20,000 cycles up to 120,000 cycles. Fatigue wear mechanisms were studied using an SEM. For all materials wear increased with increasing number of cycles. Effect of cyclic loading was material dependent. Some materials exhibit fatigue wear while others exhibited deep microcrack formation with extended cycling loading. This behavior is a major design consideration.

The next paper emphasizes the different loading situation that dental restorative materials encounter.

Chimello, Dibb, Corona and Lara [6] investigated the wear and surface roughness of different composites after tooth brushing. Six commercial resins wear tested. Eight disks 12 mm in diameter and 1 mm thick were prepared for each sample. These samples loaded into a machine designed by University of Sao Paulo to simulate tooth brushing. Samples were subjected to brushing with toothpaste under a weight of 0.2 kgf, which traveled a course of 3.8 cm for a cycle of 100 min. For each sample the toothbrush and toothpaste were changed. Afterwards samples are dried and weighed to measure mass loss. Surface roughness were taken perpendicular to the brushing motion and compared to data taken before the tests. In general, the materials experienced some mass loss with an increase in surface roughness.

4. Laboratory Wear Test for Combination of Dental Restorative Materials including Enamel

Restoration or replacement of masticatory surfaces is one objective in the treatment of oral pathologic conditions. An individual natural tooth may be restored with silicate cement, acrylic resin, gold inlay, amalgam, or one of the various forms of crowns. Therefore, to determine what materials should be placed in occlusion, a laboratory wear analysis is needed. Gold, porcelain, acrylic resin, and enamel in all combinations are evaluated. They are gold-gold, acrylic-gold, porcelain-gold, enamel-gold, acrylic-acrylic, porcelain-acrylic, enamel-acrylic, porcelain-enamel, enamel-enamel, and porcelain-porcelain.

The samples are tested with an abrading apparatus which is designed to simulate the occlusal environment. Factors considered are: intermittent contact, movement and contact in an elliptical pattern, controlled force of contact, velocity in the range of masticatory function, and washing of the test field. Sample is rotated with 48 rpm and a 60 N force is applied normally to the sample A to against sample B. The samples are weighted on an analytical balance and then tested for 485 minutes. After the pressure cycles, the samples are reweighed and the weight loss is calculated.Figure 8 and Figure 9 illustrate the total percent weight loss and total volume loss respectively. The gold-gold combination appears to be the most resistant to wear. Wear rates of various combinations can be divided into three categories. The first group which includes gold-gold, acrylic-gold, enamel-gold, and porcelain-gold has the lowest wear value. The second group which includes acrylic-acrylic, porcelain-acrylic, and enamel acrylic shows a slightly higher wear rates. The third group which includes enamel-porcelain, enamel-enamel, and porcelain-porcelain has significantly high wear rates.

Wear rates are greatly influenced by which combinations of materials should be used for the occlusal surface .At the lower wear stand point of view; all materials tested against gold could be the most satisfactory in restoration.

A general conclusion that the rate of wear varies depending on the surface finish of the porcelain, As a result , a variety of procedures for treating porcelain restorations have been investigated. Nevertheless, an objective analysis is needed to understand how surface finish affects the tooth wear.

This test is conducted by an intermittent sliding apparatus driven by a 30 rpm gear motor. A vertical force of 1 lb. is applied at the point of attachment of the specimens. All specimens are immersed under artificial saliva solution during test. The artificial saliva solution consists of 5 % (by weight) high-molecule-weight dextran, 2.5 % (by weight) egg albumin and sufficient water to make 5000 ml.

Porcelain samples are divided into four groups. The first group is glazed to a grit 240 surface and is referred to as “porcelain glazed 240.” The second group is glazed and then finished to a 240 grit surface. These specimens are referred as to “porcelain rough.” The third group is finished to 240 before glazing and is glazed and subsequently finished to a 400 grit surface, these are referred as to “porcelain polished.” The four group is finished before glazing to 400 grit surface, then glazed, and is referred to as “porcelain glazed 400.”

Table 2 indicates a definite correlation between the roughness of the porcelain surface and the resultant rate of tooth wear after 12 hours test. Glazing of rough ground porcelain is not adequate to minimize tooth wear. Only be fine polishing and porcelain can achieve this objective.

Additional experiment is run for a total of 24 hours using enamel against “porcelain rough.” This test is interrupted and weight loss is measured at 3, 6, 12, and 24 hours in order to determine how wear rate varies with duration of testing.

Figure 10 shows that the initial high wear rate of the porcelain specimens tends to decrease with time, eventually approaching to zero. This decrease is accompanied by polishing of the porcelain surface, and it indicates that most of the wear on the porcelain results from the removal of the rough fractured surface layer. The wear of opposing tooth samples also decreases but not as dramatically as the porcelain does.

The goal in restorative dentistry should program occluding surface that not only resist wear but do not wear opposing surfaces. In the zeal to provide esthetics dentistry, advertisements address the esthetics and wear resistance of these materials. Unfortunately long term clinical effects of these products have largely been ignored.

In clinical examination, the most common finding is inadequate tooth preparation. 1.5 *mm* of tooth reduction is required for adequate metal, opaque, and porcelain thickness that will allow for proper contours and adjustments. Inadequate tooth reduction results in the restoration being more abrasive, weaker, and unaesthetic.

Proper evaluation of the occlusion, to include the patient’s parafunctional habits and centric relation-maximum intercuspation discrepancy is essential. Interpreting the patient’s occlusal wear patterns for potential damaging side shifts is also important. The destructive consequence of ignoring these factors causes that a patient’s posterior porcelain occlusal restorations and opposing ceramometal crowns suffered irreparable damage after 2 and half years restorative treatment.

The placement of porcelain occluding against porcelain theoretically presents an idea wear-resistant system. If only the anterior component is considered, then porcelain occlusion is acceptable. Posterior reconstruction requires a material that must be non-brittle, easily adjustable, and withstand potential clenching and bruxism force. However porcelain doesn't meet these requirements. To have an ideal dental restoration, the aim should not be merely the meticulous restoration of which is missing or unaesthetic, but also the perpetual preservation of that which remains.

5. Future Work and Conclusion

The wear mechanisms solely attributed to tribological effects compares well to existing contact models. The papers above have documented this fact. On the other hand, the contribution of corrosion to the wear of natural, restorative and prosthetic teeth is not well developed. The acidic environment and micro-particle abrasion can have significant effect on the wear. Little work if any has been carried out to study this effect or develop a model representing the contribution of corrosion [3]. In 2001, a clinical study was carried out by Young [7], which studied over 500 cases of excessive tooth wear. Saliva protects the teeth from external and internal acids. The study correlated risk of erosion to people who have work and sports dehydration, caffeine addiction, gastro-esophageal reflux, asthma, diabetes or any other health factor which could cause salivary hypo function. From this study, it is apparent that there exists a need to model the effects of corrosion. A smaller but still significant problem is bridging the gap in the nomenclature dentists and engineers use to describe erosion [3]. Wear or erosion in the world of dentistry refers to both mechanical and corrosive effects, where as, engineers only consider the mechanical effect. This makes comparison between the two communities difficult.

Figure and Tables

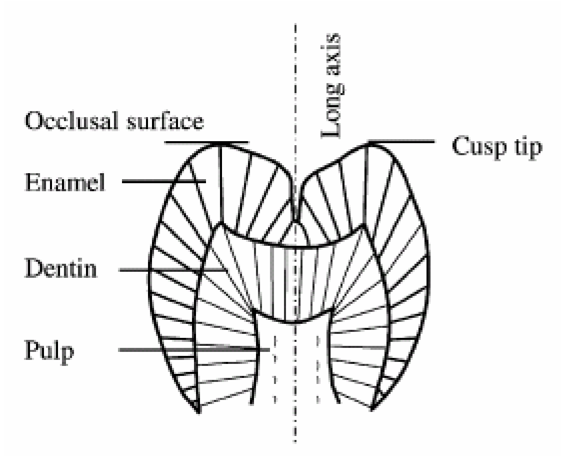

Fig. 1 Profile of the natural tooth.

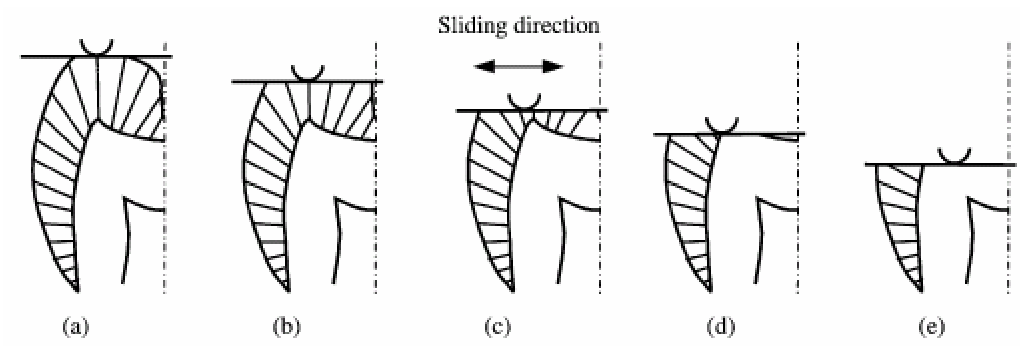

Fig. 2 Contact position for different wear test in occlusal section.

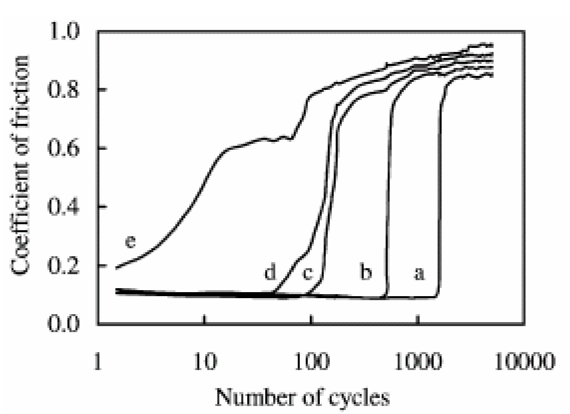

Fig. 3 Variation of the friction coefficient at different contact position for occlusal section.

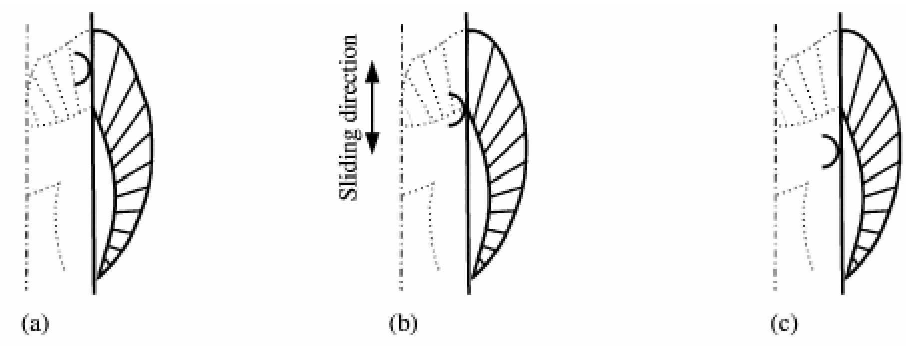

Fig. 4 Contact position for different wear test in axial section.

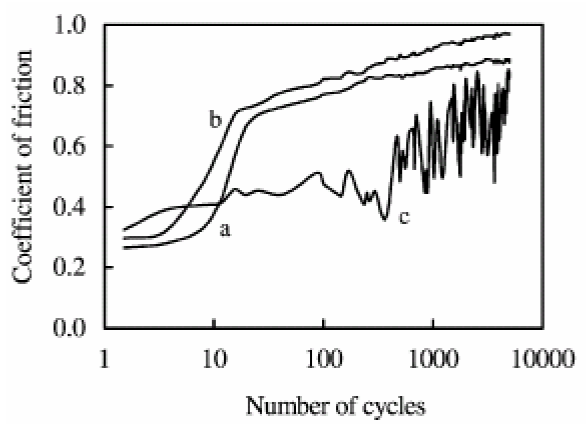

Fig. 5 Variation of the friction coefficient at different contact position for axial section.

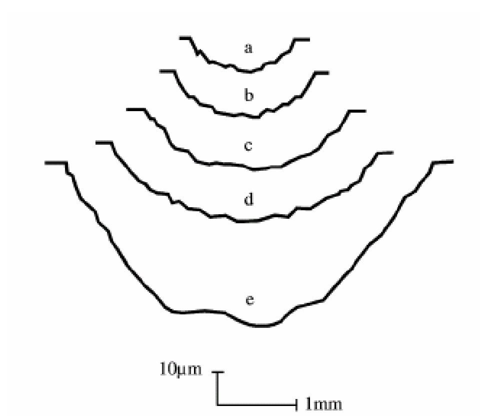

Fig. 6 Profile measurement on wear scars parallel to the occlusal section from the enamel to dentin zone.

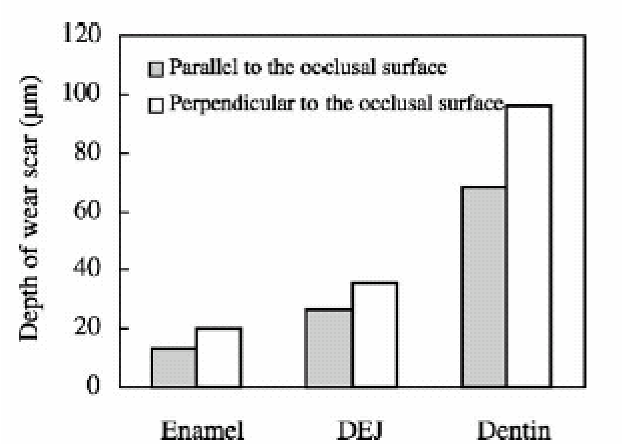

Fig. 7 A comparison of wear depth between different contact zones for two different orientations.

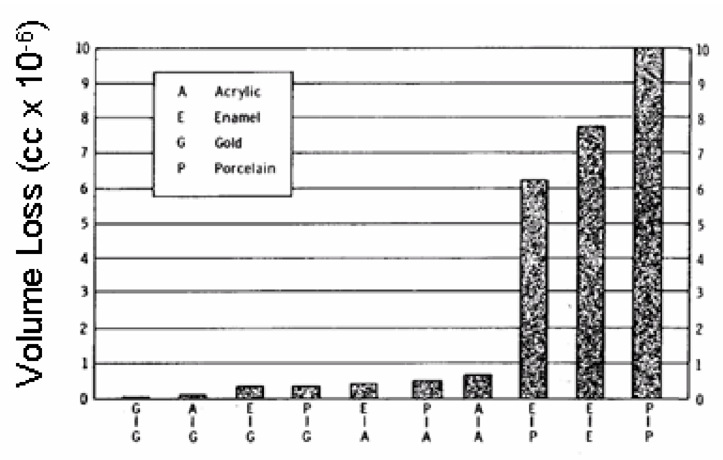

Fig. 8 Bar graph of the total mean volume loss ($ccx10^{-6}$)

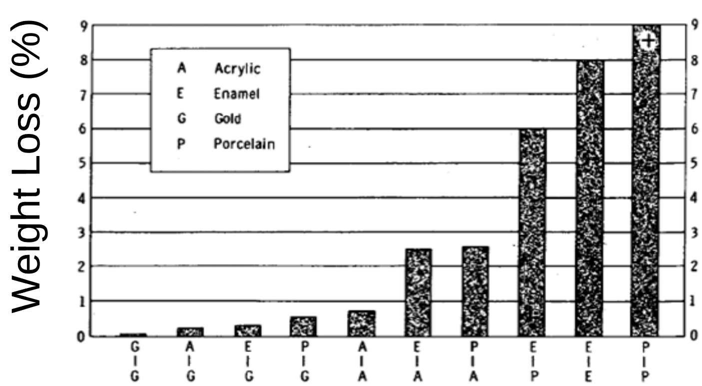

Fig. 9 Bar graph of the mean total percent weight loss.

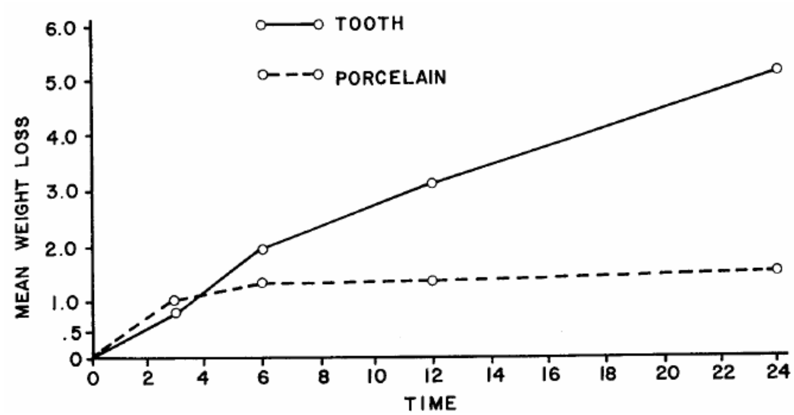

Fig. 10 An illustration of time versus weight loss for porcelain and tooth structure.

Table 1 Composition of artificial saliva solution

NaCl	KCl	$CaCl_2 \cdot 2H_2O$	$NaH_2PO_4 \cdot 2H_2O$	$Na_2S \cdot 9H_2O$	Urea	Distilled water
0.4 g	0.4 g	0.795 g	0.78 g	0.005 g	1 g	1000 ml

Table 2 Mean weight loss and standard deviation

Samples	*Mean weight loss (mg.)*	*Standard deviation*
Tooth	2.18	±2.65
Porcelain glazed 400	0.65	±0.22
Tooth	3.73	±2.41
Porcelain polished	0.48	±0.16
Tooth	3.87	±2.00
Porcelain glazed 240	0.82	±0.09
Tooth	4.77	±2.54
Porcelain rough	0.73	±0.13

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