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Comparative Wear Resistance of Additive, Subtractive and Prefabricated Resin Denture Teeth: An *In Vitro* Study

Sitham Rungsitsathien[1], *Rasita Kusolphat*[2], *Chaimongkon Peampring*[2]

[1]*Residency Student, Department of Prosthetic Dentistry, Faculty of Dentistry, Prince of Songkla University, Thailand*
[2]*Department of Prosthetic Dentistry, Faculty of Dentistry, Prince of Songkla University, Thailand*

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Corresponding Author:
Chaimongkon Peampring,
Department of Prosthetic Dentistry,
Faculty of Dentistry, Prince of
Songkla University, Songkla
90110, Thailand
E-mail: mongkon.5c@gmail.com

Abstract

Objectives: The purpose of this research is to evaluate the wear volume of resin dentures produced through additive manufacturing, comparing them with conventional acrylic denture options available in the market.

Methods: The study involved three distinct sets of denture samples: 1) prefabricated acrylic dentures, 2) subtractive-manufactured denture teeth, and 3) additive-manufactured denture teeth. All samples were anchored in self-curing acrylic resin for wear assessment. A matching antagonist mimicking a second premolar, crafted from identical material, was developed to interact with the samples. The samples underwent occlusive force testing of 5 kg over 120,000 cycles in a chewing simulator, continuously submerged in distilled water. Measurements of wear volume and depth were obtained through a 3D profilometer. Statistical evaluations were conducted using one-way ANOVA and the post-hoc Tukey's HSD test, maintaining a significance threshold of 0.05.

Results: Significant disparities in wear volume were observed among the groups. The prefabricated acrylic denture group showed no notable difference from the subtractive-manufactured group, nor did the comparison between the additive-manufactured denture teeth. However, both the prefabricated and the additive-manufactured denture teeth groups demonstrated more considerable wear than the additive-manufactured groups ($p<0.05$).

Conclusions: Denture teeth produced from additive manufacturing process showed superior resistance to wear compared to the prefabricated and subtractive-manufactured denture teeth counterparts under conditions simulating mastication.

Keywords: additive manufacturing, chewing simulation, denture teeth, subtractive manufacturing, wear

Introduction

Complete dentures are the standard approach for rehabilitating patients with edentulous arches, comprising two essential elements: the denture base and the denture teeth.[1] For denture teeth to function effectively, they must possess sufficient strength to withstand masticatory forces, resist wear from daily use and cleaning procedures, bond securely to the base, and be biocompatible with oral tissues. Historically, materials such as porcelain, acrylic resin, and composite resin have been employed to fabricate these teeth.[2,3] Traditionally, complete dentures are fabricated through compression molding using heat-polymerized acrylic resin, which often involves multiple visits from the patient and can be associated with shrinking due to polymerization. This has prompted a transition toward digital fabrication techniques, classified as either subtractive (milling) or additive (3D printing) methods. These approaches offer advantages including shorter processing times, reduced likelihood of errors, diminished material waste.[4-8]

Despite the advantages of additive-manufactured complete dentures, their adoption in clinical circumstances is limited due to factors such as higher costs compared to traditional options, the need for specialized equipment (like intraoral scanners and 3D printers), and the necessity for training on these technologies.[8,9] Additionally, research on the properties of additive-manufactured resin materials is still inadequate. Therefore, this study aims to investigate the wear resistance of resin dentures produced through additive manufacturing process, specifically comparing the wear volume in these teeth against commercially available acrylic resin denture teeth.

Materials and Methods

The test specimens were categorized into three groups: prefabricated acrylic resin denture teeth, subtractive-manufactured resin denture teeth, additive-manufactured denture teeth. Each group consisted of nine samples, with the sample size calculated using G*Power version 3.1 to achieve a 95% statistical power based on prior research data, which indicated that a minimum of six samples per group was sufficient.[9] In the prefabricated denture teeth group, test specimens (antagonists) were prepared using commercially available acrylic resin denture teeth (Rivera alpha, Shofu, Tokyo, Japan). The setup included ten upper lateral incisor teeth attached to autopolymerized acrylic resin in a mold with the dimensions of 20 mm in diameter and 15 mm in height, with the labial surface oriented upwards for testing. The simulated chewing abrader was created using second maxillary premolar denture teeth bonded onto a mold measuring 15 mm in diameter and 12 mm in height, also secured with autopolymerized acrylic resin. The palatal cusps were the only cusps that made contact with the antagonist during the wear simulation, while the buccal cusp tips were positioned approximately 2 mm higher than the palatal cusp tips to prevent contact with the test specimen. In the subtractive-manufactured group, artificial teeth were designed featured upper lateral incisors and upper second premolars, and then exported for milling into machinable acrylic resin (Multilayer PMMA Disc, Dentsply Sirona, Bensheim, Germany) using a 5-axis milling machine (350i, imes icore GmbH, Ettlingen, Germany). This process resulted in ten upper lateral incisors and ten second premolars. The milled teeth were then polished by using polishing protocol provided by manufacturer's instruction to create smooth and shine as prepared before being affixed to the denture bases, similar to the procedure used for the acrylic resin group.

For the additive-manufactured group, the designed artificial teeth featured upper lateral incisors and upper second premolars were printed using additive-manufactured liquid composite resin (Optiprint temp, DENTONA GmbH, Singen, Germany), resulting in the production of twenty upper lateral incisors and twenty upper second premolars with a 3D printer (Asiga MAX; Asiga, Sydney, Australia). The printing layer thickness was set to 50 micrometers. After printing, the samples were then light-cured to complete the reaction using an Otoflash (Otoflash G171 Curing Light, Fona Dental, Kastrup, Denmark) for 2000 cycles under nitrogen gas, after which the artificial teeth were secured to the bases, consistent with the previous group.All samples were polished using silicon carbide wet sanding paper with grits of 600 and 1200 for one minute per piece, utilizing a rotary polishing machine (Buehler, Metaserve, Buehler Ltd., Lake Bluff, Illinois, USA). Lists of materials used in this study were shown in Table 1.

All samples were then soaked in distilled water maintained at 37°C for 24 hours prior to wear testing using a chewing simulator (CS-4.4; SD Mechatronik GmbH, Friedrichshafen, Germany). During testing, the machine moved vertically by 5 millimeters and horizontally by

2 millimeters, applying a chewing force of 5 kilograms with a frequency of 0.8 cycles per second. This setup simulated approximately six months of mastication by subjecting the samples to 120,000 chewing cycles in distilled water.[10,11] The wear of the samples was measured using a 3D laser profilometer (Keyence VR6000 series, Keyence Corporation, Osaka, Japan). The samples were scanned post-testing to calculate the lost volume and height. Data collection and analysis involved comparing the volume and height of the lost artificial teeth across the three groups. The data were analysed using One-way ANOVA and post-hoc comparisons (Tukey's HSD) using a significance level of 0.05.

Results

Following the simulation of 120,000 chewing cycles, the wear volume of the artificial teeth in all three groups was measured (Table 2). One-way ANOVA analysis demonstrated statistically significant differences in wear volume among the groups at a 0.05 significance level. Subsequent post-hoc testing with Tukey's HSD revealed that there was no significant difference in wear volume between the prefabricated denture teeth group and the subtractive-manufactured denture teeth group. However, both the prefabricated acrylic resin group and the subtractive-manufactured denture teeth group showed significantly greater wear depth and volume compared to the additive-manufactured denture teeth group at the same level of significance.

Discussion

The objective of this study was to examine the wear behavior of various denture teeth types used in complete denture construction, including a prefabricated acrylic resin group representing conventional complete denture fabrication, a subtractive-manufactured acrylic denture teeth group, and an additive-manufactured resin denture teeth group, illustrating digitally fabricated dentures. Prior research has shown that denture wear is affected by the materials employed in their construction and their opposing counterparts.[12,13] When different materials come into contact under identical conditions, they produce differing levels of wear. The results of this study reject the hypothesis that wear volume would remain unchanged when using the same material for opposing surfaces during wear simulation. The type of material influenced the extent of denture tooth wear, owing to differences in their structural and compositional properties. The acrylic resin and subtractive-manufactured acrylic denture teeth groups showed no significant difference in wear, likely due to their similar composition of polymethylmethacrylate (PMMA), which is processed under high heat and pressure to achieve comparable strength.[14] The additive-manufactured denture teeth group demonstrated the least wear, since this material contains dimethacrylate monomers, a critical component for UV-cured resins, and include inorganic fillers that enhance mechanical performance. This aligned with prior research indicating that composite-structured dentures possess superi-

Table 1: Lists of material used in this study.

Material	Compositions	Manufacturer
Rivera alpha	Cross-linkedPMMA	Shofu, Kyoto, Japan
Multilayer PMMA	Polymethylmethacrylate, Double Cross Link.	Dentsply Sirona, Benshiem, Germany
Optiprint temp	Aliphatic difunctional methacrylate 2,2'-ethylenedioxydiethyl dimethacrylate Aliphatic urethane Acrylate Phosphine oxide	DENTONA, Germany

Table 2: The average wear depth and volume loss, as well as the standard deviation of each type of material after undergoing chewing simulation.

Group	Mean wear depth ± SD (mm)	Mean volume loss ± SD (mm^3)
Prefabricated denture teeth	0.187 ± 0.022^{A}	0.286 ± 0.073^{a}
Subtractive-manufactured teeth	0.205 ± 0.093^{A}	0.215 ± 0.064^{a}
Additive-manufactured teeth	0.076 ± 0.006^{B}	0.087 ± 0.019^{b}

The same uppercase letter in the Mean wear depth column indicates no statsistically significant difference.
The same lowercase letter in the Mean volume loss column indicates no statsistically significant difference.

or wear resistance compared to traditional acrylic resin denture teeth, due to the inorganic fillers that improve their mechanical properties and overall strength.[15,16]

The wear volume and depth across all groups followed a consistent pattern, which contrasts with earlier studies that reported no significant differences in wear resistance between 3D-printed resin dentures and prefabricated denture teeth.[9,17] However, many of these previous studies focused on experiments involving metal or zirconia opposing surfaces, which may not accurately represent the conditions of complete mouth denture use. Moreover, there is limited evidence regarding how digital manufacturing techniques like subtractive manufacturing or additive manufacturing compare to conventional methods in terms of wear behavior.

This research excluded prefabricated composite resin dentures as a test group. This decision was made because the inability to standardize the shape and occlusal inclination of the opposing teeth would have led to inconsistent wear results. To simplify the measurement process, the wear simulation tests were performed on flat surfaces. The design of the wear simulation in this study was distinct from previous experiments, as it was developed to more closely imitate the conditions of actual complete denture use. Based on prior findings that 30,000 cycles equate to roughly 1.5 months of oral function[18], this study used 120,000 cycles to simulate six months of chewing. A force of 5 kg (49 N), representing the average human chewing force, was applied.[10,11] The chewing motion was mimicked using a 5 mm vertical and 2 mm horizontal movement. Throughout the simulation, distilled water was used to clear debris from the sample surfaces. However, limitations in the research equipment prevented the use of thermal cycling (alternating heating and cooling).

During the experiment, one sample from the additive-manufactured denture teeth group was excluded after it broke mid-test. The failure was characterized by both adhesive failure (separation between the different materials) and cohesive failure (fracturing within the material itself). This breakage likely resulted from inadequate adhesion between the two types of materials and a weaker bond between the individual printed layers compared to the strength within each layer. This finding aligns with research by Lim *et al.*, which reported that the bond between 3D-printed resin and self-cure acrylic resin is weaker than its bond with Bis-acryl composite resin.[19] The probable cause is that methyl methacrylate does not copolymerize effectively with bifunctional monomers or light-cured resins. Thus, to improve the bonding strength for denture repairs or reinforcements, it may be necessary to enhance the mechanical and chemical surface properties of additive-manufactured parts.

The chewing simulation in this study focused on two-body wear, which involves the direct abrasive contact between two identical materials.[20,21] This models the wear on complete dentures, especially those with bilaterally balanced occlusion, that occurs during functions like chewing and swallowing. Although food can introduce three-body wear, its effect was considered minimal because modern diets are typically soft, making abrasion from food less impactful than direct tooth-on-tooth contact.[15] Therefore, the experiment was designed to measure two-body wear. The results clearly indicate that additive-manufactured denture teeth offer significantly superior wear resistance compared to traditional denture materials for complete denture applications.

Conclusions

Based on this study's findings, additive-manufactured (3D-printed) denture teeth demonstrated superior resistance to wear compared to traditional options. Following a simulated six-month period of use, the 3D-printed teeth had significantly less material loss than teeth made from subtractive-manufactured (milled) or prefabricated resin. The wear performance of the subtractive-manufactured and prefabricated acrylic resin teeth was comparable, with no statistically significant difference observed between them.

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Conflict of Interest

Authors declared no conflict of interest.

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