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Fabrication of a radiopaque fit-testing material to evaluate the three-dimensional accuracy of dental prostheses

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ABSTRACT

Objectives. The objective of this study was to fabricate a radiopaque prosthetic fit-testing material, and to develop methodology to evaluate the fitting accuracy of prostheses three-dimensionally (3D) using a combination of the silicone replica technique and micro-computed tomography (μCT).

Methods. Eight types of prototype specimens of fit-testing materials were prepared by adding contrast agents (zirconia, alumina, and barium-glass) to a commercially available fit-testing material. These specimens were evaluated on their mechanical properties, X-ray absorption coefficients, reproducibility of cement space, and suitability for 3D analysis by μCT. Then, silicone replicas made from prototype specimens were assessed for accurate 3D morphology. Subsequently, color-mapping analyses of the silicone replicas were performed according to replica thickness, and the results were compared with stereomicroscopic images.

Results. The mechanical properties, X-ray absorption coefficients, and reproducibility of the cement space demonstrated that prototypes containing 20 wt% zirconia (Zr-20) or barium glass (diameter 2 μm; Ba2-20) were useful as fit-testing materials. However, the morphology of the Ba2-20 silicone replica was unable to be accurately described using μCT because of its low X-ray absorption threshold. Zr-20, however, could be clearly observed on μCT imaging. Furthermore, color-mapping analysis of the μCT images demonstrated that Zr-20 was the most suitable for 3D observation of prosthetic fit.

Significance. This method could allow any professional to evaluate the fit of any type of dental prosthesis, such as inlays, crowns, and fixed and removable dentures. This study demonstrated that the technique presented in the current study is able to accurately describe the abutment–crown prosthetic discrepancy based on silicone replicas.

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1. Introduction

Ceramic materials have been used for dental restorations and prostheses in recent years because of the progression of their mechanical properties and adhesion techniques [1,2]. In addition, advancement in computer-aided design/computer-aided manufacturing (CAD/CAM) technology has also played an important role in the prevalence of ceramic materials containing zirconia. A large portion of zirconia used for dental applications is yttria-stabilized tetragonal zirconia polycrystal (Y-TZP), which possesses high mechanical strength [3,4]. Y-TZP is increasingly being used in the dental field because of the prevalence of CAD/CAM technology [5,6].

Accurate marginal and internal fitting of dental prostheses result in a more favorable prognosis [7]. When the fit of a prosthesis is inaccurate, it may lead to recurrent caries, marginal discoloration, periodontal disease, or debonding of the restoration [8,9]. Various studies evaluating methods to assess the fitting accuracy of prostheses have been undertaken over the past few decades [10–16]. One method involves evaluating the abutment–prosthesis discrepancy based on a thin slice, which is prepared while the prosthesis is attached to the abutment [10,11]. Another method involves direct observation of the marginal gap between the prosthesis and abutment using a stereomicroscope [12,13]. Furthermore, the silicone replica method, in which an impression of the discrepancy between the abutment and prosthesis is taken using a light-bodied silicone material, has also been developed [14,15]. By using the silicone replica technique, the fit of the prosthesis can be evaluated from a thin section prepared from the replica [16]. However, these methods allow us to observe marginal and internal fit only in one (1D) or two dimensions (2D), but the three dimensional (3D) fit of the prosthesis cannot be precisely evaluated using these methods. The 3D internal fit is generally non-uniform within a prosthesis [5,6,17]; therefore, 1D and 2D observation are unsuitable for accurate evaluation of prosthetic fit. In addition, 3D observation of fit allows us to simultaneously evaluate multiple areas, such as buccal and mesial surface at a time.

Recently, several approaches evaluating 3D prosthetic accuracy have been developed [18]. Moldovan et al. [19] reported a method whereby a silicone replica was converted to digital data, and the thickness of the replica was then measured using an optical system for evaluating the internal gap. However, using this method, it was difficult to evaluate the correct fit because of image artifacts generated by optical scanning. Schaefer et al. [20] developed an evaluation system that scanned images of the abutment surface and inner surface of the prosthesis using CAD software, and then measured the discrepancy to determine the prosthetic fit. Because this method estimated the prosthetic fit based only on digital images, the results did not reflect the true fit of the prosthesis.

Wakabayashi et al. [21] reported that the fit of glass–ceramic crowns could be evaluated using micro-computed tomography (μCT); however, this technique was complex. Additionally, the fitting accuracy of prostheses prepared from more radiolucent materials (*e.g.* glass–ceramic and alumina) could be evaluated using this method, whereas more radiopaque materials (*e.g.* zirconia) generated image artifacts, which made assessment of the prosthetic fit difficult.

Table 1 – List of novel fit-testing materials used in this study.

Sample	Powder	Mean diameter (μm)	Powder content (wt%)
Al-20	Alumina	0.7	20
Al-30	Alumina	0.7	30
Zr-20	Zirconia	1.5–2.5	20
Zr-30	Zirconia	1.5–2.5	30
Ba1-20	Barium glass	1.0	20
Ba1-30	Barium glass	1.0	30
Ba2-20	Barium glass	2.0	20
Ba2-30	Barium glass	2.0	30

It was hypothesized that the fit of radiopaque prostheses could be evaluated using a combination of the silicone replica technique and a radiopaque fit-testing material. Furthermore, using this technology, it was expected that the 3D prosthetic fit could be evaluated precisely and non-invasively. Therefore, the purpose of this study was to select an appropriate contrast agent to be added to a fit-testing material, and to assess whether prosthetic fit can be evaluated using μCT in combination with this radiopaque fit-testing material.

2. Materials and methods

2.1. *Preparation of fit-testing materials containing contrast agents*

Prototype fit-testing materials were prepared by mixing a commercially available fit-testing material (Fine Checker; Shofu, Kyoto, Japan) with various contrast agents. Each contrast agent was added to the fit-testing material at quantities of 20 wt% or 30 wt%, which were determined based on the results of preliminary experiments. These composites were stirred for 3 min in a vacuum mixer. In total, eight prototype materials were prepared for this study (Table 1). A scanning electron microscope (SEM; JSM-6390, JEOL, Tokyo, Japan) was used to obtain the images of contrast agents (Fig. 1).

2.2. *Characteristics of prototype fit-testing materials*

The dispersibility of the contrast agents in the matrix was investigated by SEM observation and measurement of density. The base and catalyst agents for each prototype material were kneaded and cured for 5 min, and then molded into a cylindrical form using a steel frame (diameter: 6.2 mm, height: 2.0 mm). These samples were mounted on copper seat, sputter coated with gold, and observed by SEM at 15 kV.

To measure the densities of the prototypes, the mixtures of base and catalyst agents were poured into a 2.4-mL plastic mold. The weights of the prototype materials were measured with an electric balance (ML104, Mettler Toledo, OH, USA; $n = 5$).

Consistencies of the fit-testing materials were investigated according to ISO 4823:2000. Briefly, the base and catalyst agents of the prototypes were kneaded for 20 s, and then 0.5 mL of the mixture was placed onto a glass plate. Vertical