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A comparative finite elemental analysis of glass abutment supported and unsupported cantilever fixed partial denture

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ABSTRACT

Objective. The purpose of this study was to investigate and compare the load distribution and displacement of cantilever prostheses with and without glass abutment by three dimensional finite element analysis. Micro-computed tomography was used to study the relationship between the glass abutment and the ridge.

Methods. The external surface of the maxilla was scanned, and a simplified finite element model was constructed. The ZX-27 glass abutment and the maxillary first and second premolars were created and modified. The solid model of the three-unit cantilever fixed partial denture was scanned, and the fitting surface was modified with reference to the created abutments using the 3D CAD system. The finite element analysis was completed in ANSYS. The fit and total gap volume between the glass abutment and dental model were determined by Skyscan 1173 high-energy spiral micro-CT scan.

Results. The results of the finite element analysis in this study showed that the cantilever prosthesis supported by the glass abutment demonstrated significantly less stress on the terminal abutment and overall deformation of the prosthesis under vertical and oblique load. Micro-computed tomography determined a gap volume of 6.74162 mm^3.

Significance. By contacting the mucosa, glass abutments transfer some amount of masticatory load to the residual alveolar ridge, thereby preventing damage to the periodontal microstructures of the terminal abutment. The passive contact of the glass abutment with the mucosa not only preserves the health of the mucosa covering the ridge but also permits easy cleaning. It is possible to increase the success rate of cantilever FPDs by supporting the cantilevered pontic with glass abutments.

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1. Introduction

Because of patient preference, many dentists have used a fixed partial denture (FPD) with free-end pontics for several years with low success rate [1]. The estimated 10-year failure rate is 18.2% for cantilever FPDs. During this period, several biological, mechanical and technical failures, such as abutment crown and/or root fractures, abutment crown loosening, and fractures of the FPD, are common [2]. Most of these failures are undiagnosed until there is caries or fracture with pulp involvement causing pain. The principle cause for the high failure rate in cantilever FPD is because of the compromised harmony between the mechanical factors, such as load transfer, and biological factors, such as periodontal health.

Conventional FPD replacing one or more missing teeth gains complete support from one or more abutment teeth situated on both the mesial and distal ends of the edentulous ridge. In contrast, a cantilever FPD gains support from one end by one or more abutments and the other end remains unsupported [2]. Because the cantilever FPD is supported at only one end, the functional load distribution from the cantilevered pontic to the abutment differs from that of a conventional FPD. Hence, the success of the treatment depends on the health and number of abutments supporting cantilever FPD, the functional load applied on the cantilevered units, the type of occlusion [3–6] and oral hygiene [7]. Cantilevered pontics generate tilting and rotational forces on the terminal abutments, unlike in natural dentition, where the forces are transferred along the long axis of the tooth [8]. These oblique forces cause stress-induced microdamage to the supporting periodontium [9]. This damage is even pronounced when a cantilever FPD replaces posterior teeth because the muscles of mastication exert the strongest masticatory load in the posterior segment of the dental arch. To reduce this damage, single cantilevered pontics must be supported by at least two periodontally healthy abutments [3,10].

Placement of one or more implants to support the cantilevered end is also an option that is recommended by many experts [11–17]. Proper case selection, implant placement and prosthesis design based on biological and mechanical aspects can better distribute the masticatory load and preserve the health of the abutment [16,17]. However, not all cases can be treated with implants because a number of factors, such as (i) medical health of the patient, (ii) morphology of the ridge, (iii) anatomy of the bone, (iv) age and (v) financial aspects, may prevent patients from opting for implant treatment. Hence, there is a need to develop a cost-effective and suitable system that meets these important parameters, and researchers have developed a glass abutment system that will improve the force distribution from cantilevered pontics.

Glass abutments are fabricated to rest on the edentulous ridge to support the cantilevered pontics. By resting on the ridge, some of the masticatory load generated on the cantilevered pontic is transferred to the ridge, thereby reducing the damage to the abutment caused by vertical and oblique forces [18]. However, active contact of the glass abutment and the masticatory forces transferred directly to the ridge can adversely affect the health of the mucosa over the edentulous ridge. Therefore, the objective of this research was to study and compare the functional load distribution and displacement of the cantilever FPD with and without glass abutments using 3D finite element analysis. This analysis was preferred over 2D analysis because 3D analysis provides an actual representation of the stress behavior of the supporting alveolar bone. Furthermore, for the first time, micro-computed tomography (micro-CT) was used to study the relationship between the glass abutment and the ridge.

Table 1 – Elastic properties of the materials used for the finite element analysis model.

	Young's modulus (MPa)	Poisson's ratio
Cortical bone	1340	0.30
Cancellous bone	150	0.30
Enamel	80, 000	0.30
Dentin	15, 000	0.31
ZX-27 Glass	69, 000	0.19
Nickel chromium alloy	200, 000	0.29
Periodontal ligament	6.9	0.45 [35]
Pulp	5.4	0.44 [35]
Oral mucous membrane	7.5	0.45 [36]

2. Materials and methods

The external surface of the dry human maxilla, which was edentulous in the right posterior area, was scanned using a 3D laser scanner (Exascan, Creaform Inc., rue St-Georges, Levis, Quebec) to construct a simplified finite element model of the maxillary bone. The ZX-27 glass abutment and maxillary first and second molars were created and modified following the fundamental principles of fixed prosthodontics [19,20] using a 3D CAD system (Catia V5). The modified molars with 3 roots consisted of three co-axial cylinders. The inner most cylinder represented the pulp with a diameter of 1 mm, the middle cylinder represented dentin with a diameter of 2 mm, and the outer cylinder represented enamel, with a diameter of 1 mm. The ZX glass abutment was created to rest on the soft tissue adjacent to the maxillary second molar (Fig. 1). The solid model of the three unit nickel chromium cantilever FPD was scanned using a 3D laser scanner, and the fitting surface was modified with reference to the created abutments using a 3D CAD system (Catia, v5) (Fig. 1). The entire STL (Stereo Lithography) file was imported to ANSYS 5.0 (ANSYS, Inc. Southpointe, Canonsburg, PA). The elastic properties of the cortical bone [21], cancellous bone [21], enamel [22], dentin [22], pulp, periodontal ligament, oral mucous membrane, glass abutments [23] and cantilever nickel chromium alloy [24] FPD are tabulated in Table 1. The model with the glass abutment had 995,030 nodes and 635,738 elements, and the model without the glass abutment had 991,894 nodes and 634,039 elements. The thickness of the gingiva was 2 mm, and the thickness of cortical bone was 3 mm. The finite element model was subjected to simulated masticatory forces with a vertical and oblique surface load. A vertical static surface load of 448 N [25] was distributed over and perpendicular to the occlusal table to simulate the natural functional load along the long axis of the cantilever FPD. To simulate the lateral functional load during eccentric mandibular movements, an oblique static surface load of 300 N [26] was distributed at an angle of 45°