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Original article

Load distribution on abutment tooth, implant and residual ridge with distal-extension implant-supported removable partial denture

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ABSTRACT

Purpose: The aim of this study was to evaluate the effect of implant location on load distribution in the abutment tooth, implant and residual ridge with a distal-extension implant-supported removable partial denture (ISRPD).
Methods: A mandibular unilateral distal-extension edentulous simulation model was used. Implants were inserted at the second premolar (mesial implant) and second molar (distal implant) positions in the edentulous area. An experimental ISRPD was fabricated of acrylic resin with a cobalt-chromium alloy framework. Loads on the implants and abutment tooth were measured with piezoelectric force transducers. The load on the residual ridge was measured with pressure-sensitive film. A vertical load of 100 N was applied at the first molar region. Measurements were made under the following three conditions: with conventional removable partial denture (CRPD), with mesial-implant-supported removable partial denture (MISRPD), and with distal-implant-supported removable partial denture (DISRPD). In each condition, the unused implants were made inactive by eliminating contact with the inner surface of the denture.
Results: The load on the abutment tooth was greatest with DISRPD, followed by CRPD and MISRPD ($P < 0.01$). The load on the implant was greater with DISRPD than with MISRPD ($P < 0.01$). The load on the residual ridge was lowest with DISRPD, followed by MISRPD and CRPD ($P < 0.01$).
Conclusions: This experimental study provided quantitative data regarding the effect of implant location on load distribution with ISRPDs. Further investigation regarding the effect of denture design on the load distribution is needed for determining the proper implant location of ISRPD.

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1. Introduction

Implant-supported removable partial dentures (ISRPDs), which can transform a tooth/tissue-supported mandibular Kennedy class I or II removable partial denture into a pseudo-Kennedy class III, have become a popular prosthodontic treatment option in recent years [1–3]. Compared with conventional removable partial dentures (CRPDs), ISRPDs offer maximum denture stability [4,5] and greater occlusal force [6], and facilitate functional recovery [6,7]. ISRPDs also offer excellent maintainability, because they have removable superstructures [8]. Additionally, ISRPDs have a high implant survival rate of 95–100% [3,8,9] and high patient satisfaction [1,9,10]. On the other hand, mechanical complications, such as breakage or loosening of the implant attachments and fracture of the denture components, have been also reported with the use of ISRPDs [9,11,12]. However, there is still no evidence-based research regarding the ISRPD [2,3]. In terms of implant-supported complete overdnture, it was reported that the stress concentration on the residual ridge at the posterior ends of the mandible can be correlated with clinically measured bone resorption [13]. In addition, an inadequate RPD design, which causes the unbalanced load distribution, can lead to an increase in abutment tooth mobility [14,15]. Those concerns regarding the bone resorption in the residual ridge beneath the denture base and the mobility of abutment tooth in the RPD are also applicable to the ISRPD. Therefore, the load distribution on the supporting structures of ISRPD, such as abutment tooth, implant and residual ridge can thus be significant factors to prevent several complications and to consider the appropriate design of the ISRPD.

Because of some limitations, such as applying the measuring devices or the ethical problems, it is still difficult to conduct *in vivo* experimental studies on load distribution to the supporting structures of ISRPD. Several *in vitro* and *in silico* studies have investigated the biomechanics of ISRPDs. In model-based studies, Ohkubo et al. [4] and Sato et al. [5] showed that implant placement at the distal edentulous residual ridge prevented displacement of the distal extension base of the ISRPD. Stress distribution in the bone around the abutment tooth and in the distal supporting implant of ISRPDs has been evaluated with a photoelastic model [16] and with two-dimensional finite element analysis (FEA) [17–20]. These studies evaluated the effects of implant size and the attachment system on stress distribution. Shahmiri et al. [21] used three-dimensional (3D) FEA to reveal the potentially destructive mismatch in strain distribution between the acrylic resin and the metal framework of ISRPDs. That group also investigated the effect of the framework's occlusal rest position on the distribution of stress on the denture components of ISRPDs [22]. In terms of the implant location, despite the benefits of a distally implant, in some clinical cases the implants were placed mesially because of inadequate posterior alveolar bone volume [9,23,24]. Therefore, we should also understand the biomechanical behavior of mesially placed implant in ISRPD. However, although there are a few studies investigated the effect of the implant location on stress distribution [20,25], results of those studies were inconsistence, with much ongoing debate. Therefore, further studies are still needed to evaluate the most effective position of the implant [2].

In the present experimental simulation model study, 3D measurements of the loads on the abutment tooth, the implant, and the residual ridge beneath the denture were made under different implant-support configurations. The aim of this study of ISRPDs was to investigate the effect of implant position on the distribution of loads on the abutment tooth, implant, and residual ridge beneath the denture base, and to determine the appropriate biomechanical design of ISRPDs.

2. Materials and methods

2.1. *Experimental device development*

The mandibular unilateral partially edentulous model missing the second premolar, first molar and second molar was modified based on the commercial simulation epoxy resin model (D50-520; Nissin, Kyoto, Japan) (Fig. 1(a)). Two 4.1×10 mm implants (Standard RN; Straumann AG, Basel, Switzerland) were inserted in the edentulous residual ridge vertical to the occlusal plane, one at the second premolar location (mesial implant) and one at the second molar location (distal implant) for comparing the biomechanical effect of different implant location.

To measure the 3D load on the implants, experimental ball abutments with the same form as the anchor abutment (Straumann AG) were fabricated to fit accurately onto piezoelectric 3D force transducers (Kistler Instruments AG, Winterthur, Switzerland) [26,27]. The inferior portion of the ball abutment was configured to fit the superior end of the implants. An anchor and transducer pair was fastened to the implant with a titanium screw to serve as an abutment (Fig. 2(a)) [28].

The artificial right first premolar, chosen as the direct abutment tooth for the experimental denture, was also modified to allow measurement of abutment tooth loads. Its crown was removed and the superior portion of an implant (Standard RN) was inserted approximately 1/3 of the way into the root and fixed with an adhesive resin cement (Super Bond C&B; Sun Medical, Shiga, Japan). An artificial periodontal ligament approximately 0.5 mm thick, made of silicone impression material (Fit-checker, GC, Tokyo, Japan) [4,5], was inserted around the root. A gold-platinum alloy crown was fabricated and placed onto the piezoelectric force transducer. Both the alloy crown and the transducer were fastened to the implant embedded in the artificial first premolar with a titanium screw (Fig. 2(b)) [26,27].

Artificial mucosa approximately 2 mm thick made of silicone impression material (Exahiflex injection-type, GC, Tokyo, Japan) was affixed to the edentulous area of the mandibular simulation model [28]. A pressure-sensitive tactile sensor film (I-SCAN; Nitta, Osaka, Japan) was placed on the artificial mucosa between the distal and mesial implants (Fig. 1(a)) [28,29]. The artificial mucosa was molded by initially fixing the sensor film to the basal surface of the experimental ISRPD, followed by polymerization of the silicone while a 5-N load was applied to the occlusal surface of the ISRPD [28].

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