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Non-linear 3D finite element analysis of full-arch implant-supported fixed dentures

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ABSTRACT

Despite the necessity for faster clinical protocols for immediate loading of implant-supported dentures, there is a lack of biomechanical studies to confirm the rigid splinting effectiveness. We compared the stress in mandibular full-arch implant-supported fixed dentures under immediate loading through three-dimensional finite element analysis. Edentulous human mandible models were restored with a 4-implant fixed denture. Implants were splinted with a metallic framework and submitted to conventional loading (group A—control), with acrylic resin and submitted to immediate loading (group B), with a metallic framework and submitted to immediate loading (group C), and with acrylic resin and a prefabricated distal bar and submitted to immediate loading (group D). Models were supported by masticatory muscles. A 100-N oblique load was applied on the first molar. Group A presented the lowest stress and implant displacement values, whereas group D showed the highest values. In bone, groups under immediate loading exhibited the highest stress, whereas the group experiencing conventional loading showed an approximately 50% reduction. All groups submitted to immediate loading presented similar stress values in peri-implant bone. The loading protocol influenced the stress and implant displacement, but the design of the fixed denture did not affect the stress in the peri-implant bone. Rigid splinting of implants submitted to immediate loading is not essential for treatment success.

1. Introduction

Functional and esthetic rehabilitation of edentulous patients is the aim of implant treatment. The absence of occlusal contact during the healing phase (4–6 months) in the 2-step surgical protocol is important for osseointegration [1]. However, the healing period is uncomfortable for the patient and has been empirically determined [2]. Shortening the period between implant placement and prosthesis insertion is an alternative for a less time-consuming treatment [3,4]. The term immediate loading has been used to characterize implants submitted to occlusal loading immediately after surgical insertion [5].

Several studies of the immediate loading of implants have been published during the last decade, with success rates reaching 100% [1,6–11]. Despite the high success rate for implants inserted in edentulous mandibles, loss of peri-implant marginal bone is still reported and considered a negative factor by patients and professionals [12]. These failures are related to poor hygiene; biomechanical factors including implant design, length, diameter and surface treatment; and patient's characteristics such as bone quality and volume, masticatory load and general health [13]. In addition, the factors related to biomechanical failure of implants are not completely understood, and the literature remains inconclusive [14].

Several studies of biomechanics [15–21] have demonstrated that implant overloading might be the main cause of bone resorption because stress is directly transferred to the bone tissue during functional loading [22]. Several factors may influence the stress transfer, such as the load type, the material properties, the implant design and surface type, the bone quality and volume, and the bone-implant interface [23].

The biomechanical behavior of dental implants has been investigated by different techniques such as strain-gauge analysis, photoelastic stress analysis and finite element analysis (FEA) [24]. FEA was first used in the engineering area and has proven to be an efficient instrument for dental implant biomechanics [23] and a less time-consuming process in experimental research [25]. Non-linear FEA is considered a potent approach to calculate strain, stress and displacement of structures in a realistic condition that might not be possible using linear modeling [25]. FEA can also be used to optimize implant designs and to create new implant systems [23].

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Previous studies [5,26–30] reported an efficient method to convert provisional partial dentures or complete dentures into provisional implant-supported dentures and to shorten the treatment length through immediate loading of edentulous arches. According to this protocol, the abutments are captured with an autopolymerizing acrylic resin, and the space between the abutments and prosthesis is filled with additional acrylic resin. This technique is a low-cost and simple alternative for immediate loading of edentulous arches. The provisional prosthesis facilitates the evaluation of the esthetics, function and oral hygiene prior to fabrication of the final fixed denture [31].

Rigid splinting of implants in provisional restorations for immediate loading of implant-supported fixed dentures is uncertain. Although splinting has been suggested to limit implant micromovement and ensure osseointegration, Cooper et al. [32] demonstrated a success rate of 100% for edentulous mandibles rehabilitated with provisional restorations in acrylic resin without a metallic framework among 10 patients treated with 5 to 6 implants. Peñarrocha et al. [33] found an implant success rate of 100% after a 12-month follow-up of provisional mandibular full-arch implant-supported and implant-retained dentures without splinting submitted to immediate loading.

Despite the necessity for faster clinical protocols for immediate loading of implant-supported fixed dentures in edentulous patients, there is a lack of biomechanical studies to confirm the effectiveness of rigid splinting by a metallic framework. Thus, the aim of this study was to compare the stress between 3 mandibular full-arch implant-supported fixed dentures submitted to immediate loading with different splinting designs and a conventional two-step surgical protocol through non-linear three-dimensional finite element analysis (3D FEA). The null hypothesis assumed that dentures submitted to immediate loading would exhibit the highest stress in the bone tissue and that the lack of implant rigid splinting would represent the worst scenario.

2. Material and methods

2.1. Study design

Four finite element models of the edentulous human mandible were fabricated and restored with different designs of full-arch implant-supported fixed dentures. The models were divided into four groups: Group A (control) — implants were rigidly splinted with a metallic framework and submitted to a conventional loading protocol after two surgical steps, Group B — implants were non-rigidly splinted (acrylic resin splinting) and submitted to immediate loading, Group C — implants were rigidly splinted with a metallic framework and submitted to immediate loading, and Group D — implants were non-rigidly splinted (acrylic resin splinting) and submitted to immediate loading with a prefabricated distal bar inserted in the cantilever region (Fig. 1).

2.2. Model fabrication

The mandible was fabricated based on computed tomographic scans (I-Cat Cone Beam Volumetric Tomography and Panoramic Dental Imaging System, Imaging Sciences International, Hatfield, PA, USA) of the edentulous mandible of a 60-year old male patient. The intercondylar distance, mandibular bone height and bone thickness were determined according to the computed tomography (CT) to simulate a real clinical scenario. The patient signed an informed consent form according to the Research and Ethics Committee of Aracatuba Dental School — UNESP, Brazil (#2008-00939). The patient was rehabilitated with conventional complete dentures, and the mandibular denture was duplicated in a colorless autopolymerizing acrylic resin mixed with barium sulfate (3:1) to provide radiopacity during the CT scan.

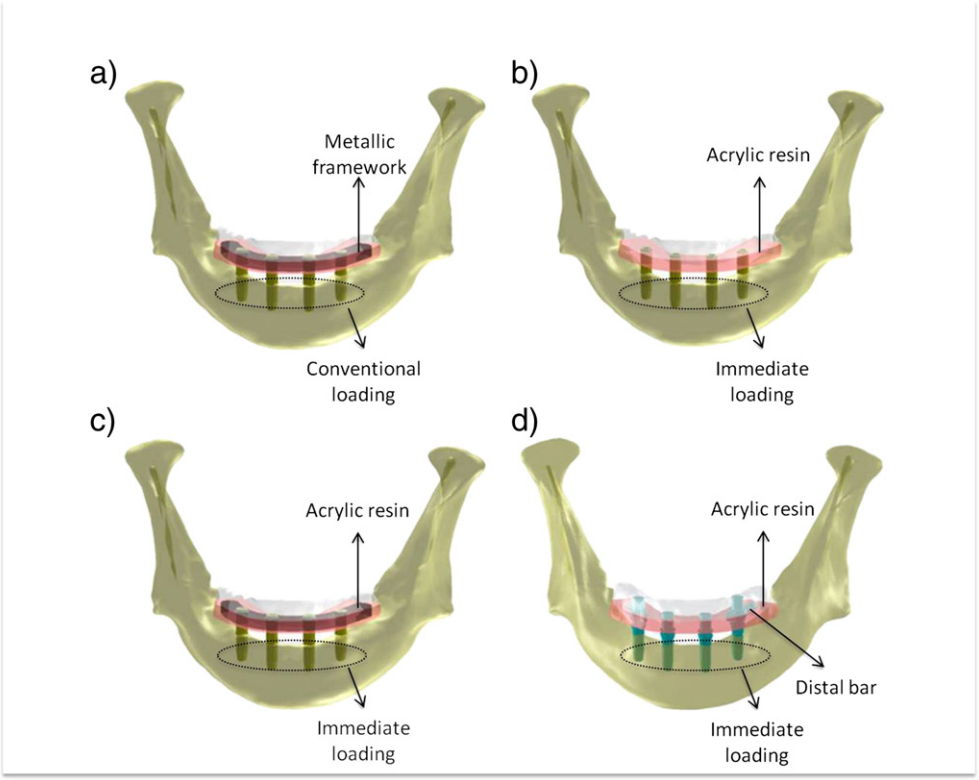

Fig. 1. Models of the groups. (a) Group A: implants were splinted with a metallic framework and submitted to conventional loading; (b) group B: implants were splinted with a metallic framework and submitted to immediate loading; (c) group C: implants were splinted with acrylic resin and submitted to immediate loading; (d) group D: implants were splinted with acrylic resin and a prefabricated distal bar and submitted to immediate loading.