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Stability of edentulous, atrophic mandibles after insertion of different dental implants. A biomechanical study

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ABSTRACT

Objectives: Fractures of the atrophic edentulous mandible are a rare complication that can become severe after the insertion of dental implants. This *in vitro* study investigated the effects of different implant settings varying in number, diameter, and length. and the influence of a fixed bar.
Materials and methods: In biomechanical experiments on artificial mandibles, an unmodified reference group, four implant settings with two different implants, and the effect of adding a fixed bar to these settings were tested. All specimens were loaded with incisal biting forces until failure due to fracture.
Results: Implants weakened all specimens significantly compared with those in the reference group. Without a fixed bar, four short and thick implants showed the best results, with high significance. With a fixed bar, four long and thin implants withstood the highest loads. The addition of fixed bars reduced the differences between the implant settings. Fixed bars did not show increased stability for all groups; however, these groups showed a higher mean strength.
Conclusions: Four implants with a short and thick design should be the first choice when implants are placed without a fixed bar in an atrophic mandible. With a fixed bar, four long and thin implants should be used.

1. Introduction

Bone remodeling of the alveolar crest is a lifelong process. In edentulous jaws, the lack of physiological stress on the bone induces bone resorption. Pressure exerted on the bone by a conventional prosthesis and the duration of edentulism are factors that can accelerate this process. Implant-supported prostheses in edentulous mandibles have led to substantially reduced bone loss in comparison with those in conventional denture-wearing jaws (Carlsson, 2004). The remodeling is subject to high individual variations and is not sufficiently understood (Carlsson, 2004). Several studies have even detected bone apposition in patients treated with these prostheses (Davis et al., 1999; Reddy et al., 2002; von Wowern and Gotfredsen, 2001; Wright et al., 2002). In 1998, Fontijn et al. reported that patients with mandibular implant–retained overdentures had significantly higher maximum bite forces than conventional complete-denture wearers. In 2006, Fueki et al. reported, in their literature review covering more than 50 years, objective benefits in the masticatory performance of implant-supported overdentures compared with conventional dentures in edentulous patients with resorbed mandibles (Fueki et al., 2007). These overdentures appeared to yield higher patient satisfaction scores, even with patients who had undergone preprosthetic surgery (Sadowsky, 2001). In 2000, Awad et al. observed, in a randomized clinical trial, that treatment with implant-supported overdentures was associated with a significantly better quality of life.

The additional costs of implant insertion seem to be supported by the patients, because up to 77% of conventional denture wearers were willing to pay even three times more than the current cost of conventional dentures for implant-retained prostheses (Esfandiari et al., 2009).

Although the insertion of dental implants has become a standard treatment in recent years, the treatment of the severely atrophic mandible remains challenging. Due to the weakened mandibular bone lacking the alveolar crest, the insertion of

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implants decreases the stability of the bone and may lead to fractures either during or shortly after implant insertion. Numerous case reports have indicated the risk of mandibular fractures during cavity preparation or implant insertion (Almasri and El-Hakim, 2012; Fontijn-Tekampl et al., 1998; Karlis et al., 2003; Luhr et al., 1996; Oh et al., 2010; Raghoebar et al., 2000). A fracture of the mandible is the most feared of all complications related to endosseous implants in the extremely resorbed mandible. Mandibular fractures after implant placement are a rare complication in conjunction with severely resorbed mandibles (Goodacre et al., 1999; Raghoebar et al., 2000; Soehardi et al., 2011). However, several studies have pointed out that fractures of the atrophic mandible have severe consequences for the patient; therapy remains challenging and thus should be avoided by all means (Ellis and Price, 2008; Madsen et al., 2009, 2011; Melo et al., 2011; Soehardi et al., 2011; Wittwer et al., 2006). Atrophic mandibular fractures are often treated with an open reduction and internal fixation technique using a reconstruction plate via a submandibular transcutaneous approach (Soehardi et al., 2011; Toma et al., 2003). In the literature, complications such as non-union, osteomyelitis, and infection occur in up to 48% of patients with fractures after the seating of implants in atrophic mandibles (Soehardi et al., 2011).

The best treatment for implant-related fracture of the mandible is prevention. There are surgical precautions and guidelines to minimize the weakening of the bone and risk of fracture, such stepwise drilling, sufficient irrigation, and avoiding the inferior cortex, among others (Mason et al., 1990).

The site of an implant that has not yet been osseointegrated is characterized by tensile stress concentration and weakness. Repeated submaximal functional forces in such an area of bony weakness may lead to a spontaneous fracture without associated trauma (Mason et al., 1990). The use of immediately loaded implants in the anterior mandible for overdenture design is a promising treatment concept and has shown success rates of 95.6–100% (Chiapasco and Gatti, 2003; Payne et al., 2002). However, atrophic mandibles require special attention. The above mentioned negative consequences indicate that the weakening of the bone should be minimized. Different implant settings are proposed for the treatment of the atrophic mandible. In the moderately resorbed edentulous mandible, fabrication of an overdenture for two or four interforaminal implants is currently an accepted, widespread treatment modality for improving the function of a mandibular prosthesis (Batenburg et al., 1998; Thomason et al., 2012).

Although there are many studies that have focused on the topic of implant-supported overdentures in the edentulous mandible, statements relating to the impacts of implant design, number, diameter, and length on the weakening of the atrophic bone are rare and not based on biomechanical evidence. No large prospective studies have been performed; most publications are retrospective single-case studies. To address the open clinical question regarding which implants place the least strain on the atrophic mandible, we performed biomechanical experiments on a self-developed test bench. This allowed for the simulation of physiological loading of artificial, atrophic mandibular models in the laboratory. Prior to these experiments, no commercially available atrophic mandibular model was on the market. Therefore, our working group developed artificial mandibles derived from computed tomographic data. To our knowledge, no biomechanical data have been published on the stability of edentulous, atrophic mandibles.

Previous studies have examined the effect of implant cavity preparation on the stability of the jaw. The results have shown that the number and dimensions of dental implant cavities have a significant impact on mechanical stability (Steiner et al., 2015). We hypothesized that different implant settings could have a significant influence on the weakening of the jaw.

The aim of this *in vitro* study was to investigate the effects of implant settings, differing in number, diameter, and length, on the stability of the jaw. Furthermore, we investigated whether the use of a fixed bar would deliver a favorable outcome.

2. Material and methods

2.1. Experimental setting

The experimental testing device used was the same as that introduced by Steiner et al. (2015) for experiments on atrophic mandibular models weakened by implant cavities but without inserted implants. The incisal biting forces were modeled with a rope, pulled by a controlled testing device (Zwick i-line 5 kN, Zwick Messtechnik, Ulm, Germany). Accordingly, the masticatory muscle forces were modeled by ropes acting at the mandibular angles to represent the physiological actions of the pterygomasseteric sling (Fig. 1). A specially developed platform was used to perform the tests with repeatable accuracy. The temporomandibular joints were modeled through bearings made of concavely lathed spherical boxes to represent the anatomical shape of the temporomandibular fossae (Steiner et al., 2015). This load setting has proved its applicability in various biomechanical studies for investigations on the stability of mandibular reconstructions with autologous bone grafts (Grohmann et al., 2013; Steiner et al., 2012; Trainotti et al., 2014). In our tests, force was applied continuously until the test bodies failed due to fracture. Incisal load and incisal movement were recorded by the Zwick device at a sampling rate of 4 Hz.

2.2. Artificial mandibular specimens

Standardized conditions are a crucial requirement for *in vitro* biomechanical experiments. High interindividual differences in atrophy, bone quality, and morphology in human mandibles would make the use of cadaver specimens nearly impossible for testing, because the statistical power is reduced by these overlaid scattering factors. However, prior to these experiments, no commercially available atrophic mandibular model was on the market. Therefore, our working group developed artificial mandibles. These artificial, biomimetic mandibular specimens (Synbone #8570, Synbone, Malans, Switzerland) were fabricated with two individualized polyurethane foam materials. The density of the foam was adjusted to mimic the biomechanical behavior of the cortical and spongiose part of the mandibular bone, respectively. The geometry of these specimens was designed according to a mean shape based on 27 atrophic mandibles, derived with an algorithm that has previously been published (Steiner et al., 2015).

2.3. Specimen preparation and implantation procedure

All implants, abutments, fixed bars, and tools were used as recommended by the manufacturer. The implant cavities were prepared under standardized conditions in a box column drill with a tapping machine (Steiner et al., 2015). This was executed stepwise with steel drills of different diameters (800–200 rpm), and tabs were cut (15 rpm) by one experienced implantologist, according to the standardized procedure described by Steiner et al. (2015). Straumann (Straumann AG, Basel, Switzerland) tools were used for all steps of preparation. To ensure a very high level of standardization, all specimens were drilled in parallel by means of the same drilling rig and templates in each group (Fig. 2). The implants were placed with Straumann tools in all test bodies. All implants were placed interforaminally equidistant from each other, with equal bone remaining to the labial and lingual borders. The distance