

Review

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Biomechanics and load resistance of small-diameter and mini dental implants: a review of literature

Abstract: In recent years, the application of small-diameter and mini dental implants to support removable and fixed prosthesis has dramatically increased. However, the success of these implants under functional biting forces and the reaction of the bone around them need to be analyzed. This review was aimed to present studies that deal with the fatigue life of small-diameter and mini dental implants under normal biting force, and their survival rate. The numerical and experimental studies concluded that an increase in the risk of bone damage or implant failure may be assumed in critical clinical situations and implants with <3 mm diameter have a risk of fracture in clinical practice. The survival rate of the small-diameter and mini dental implants over 5 years was 98.3–99.4%.

Keywords: force; mini implants; overdenture; small-diameter implants; stress; survival rate.

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Introduction

After tooth loss, severely atrophic residual alveolar ridges are fairly common, especially in patients who have been edentulous for a long period. The posterior areas of the maxilla and the mandible are areas where clinicians have greater anatomical limitations.

In addition to standard and short implants, there are implants of smaller diameters. Those are generally 2.75–3.30 mm in diameter and are frequently used in cases of limited bone volume. The mini dental implants (MDIs) exist with even smaller diameters, ranging from 1.8 to 2.4 mm [33, 34]. In the beginning, the main application of MDIs was to serve as the remedy and provisional instrument for insertion of provisional restorations during the osseointegration phase of conventional standard (larger-diameter) endosseous implants [1, 4, 20]. The assumption was that MDIs are unable to provide functional load of implant-supported prostheses [4, 20]. In the course of time, it was observed that those implants osseointegrated very well clinically [20]. It became clear that, in combination with a minimally invasive implant insertion protocol for the MDIs, they could provide a satisfactory prosthodontic rehabilitation effect [20, 34].

The advantage of using small-diameter and MDI implants is the minimally invasive, single-stage placement procedure [4, 19] in comparison to the procedure for conventional implants (diameter, 3.5 mm and wider). The philosophy of small-diameter implant insertion is a minimally invasive technique of inserting the implant into the bone through a small opening of the soft tissue, but not a prepared bone site [4, 19]. Therefore, the bone damage and bone wound during implantation is minimized. Bleeding and postoperative discomfort are reduced [20] and soft tissue healing time is shortened. It is recommended to load such implants immediately [4, 7, 8, 29].

The use of small-diameter implants has been suggested to reduce trauma for elderly patients when the use of standard-sized implants (>3.3 mm in diameter) would require bone reshaping or grafting [9, 15, 35]. Clinical reports have shown that the success rates of MDIs for retaining mandibular dentures are good [20, 34]. However, randomized clinical trials supporting (or even rejecting) the long-term use of extremely small-diameter (1.8 mm) implants is lacking in the literature [8].

This article was aimed to review the works regarding the stability and survival rate of the small-diameter and

mini implants under functional loads. Numerical and clinical studies were reviewed.

Implant fatigue under biting force

Prospective studies have shown the positive effect of conventional implant therapy on the maximum bite force [3, 14, 17, 27, 36]. However, bones carrying mechanical loads adapt their strength to the load applied by bone modeling/remodeling [18, 22, 23]. The response to increased mechanical stress beyond a certain threshold produces fatigue microdamage resulting in bone resorption [24]. The type of attachment system provides different degrees of horizontal and vertical resistance against dislodging forces that could lead to different magnitudes of loading transmission to the implant-bone interface. This does not seem to evoke bone resorption around conventional implants [26, 30]. However, the high levels of stress on the bone shown by single narrow implants [31] could lead to a mechanical overload, causing bone remodeling [24].

Mathematical finite element analyses of small-diameter implants have shown high levels of risk due to stress on the bone, suggesting that they cannot be used as definitive, under masticatory loads [31]. An implant can be considered to be definitive if the bone around it remains stable after receiving a physiological load. With conventional implants, the average bone loss in the first year is 1.0 mm [25].

Similar results were obtained in the finite element study of Hasan et al. [21] and Bourauel et al. [6]. In their studies, 13 commercially available MDI implants (Figure 1) were investigated in the anterior mandibular jaw region at a force of 150 N under immediate loading using finite element analysis. von Mises stresses (up to 1150 MPa) in mini implants partly exceeded the ultimate strength. Implant diameter and geometry had a pronounced effect on stresses in the cortical plate (up to 266 MPa). They concluded that an increased risk of bone damage or implant failure may be assumed in critical clinical situations.

In the study of Jofré et al. [25], the effect of maximum bite force on marginal bone loss around MDI implants was investigated in edentulous patients wearing mandibular overdentures with two retention systems: ball and bar. They obtained no relationship between the maximum bite force and marginal bone loss in patients wearing overdentures retained on MDI implants using bar or ball attachment systems during the 15-month follow-up period.

Fatalla et al. [13] analyzed numerically the optimum design and attachment combination to support an

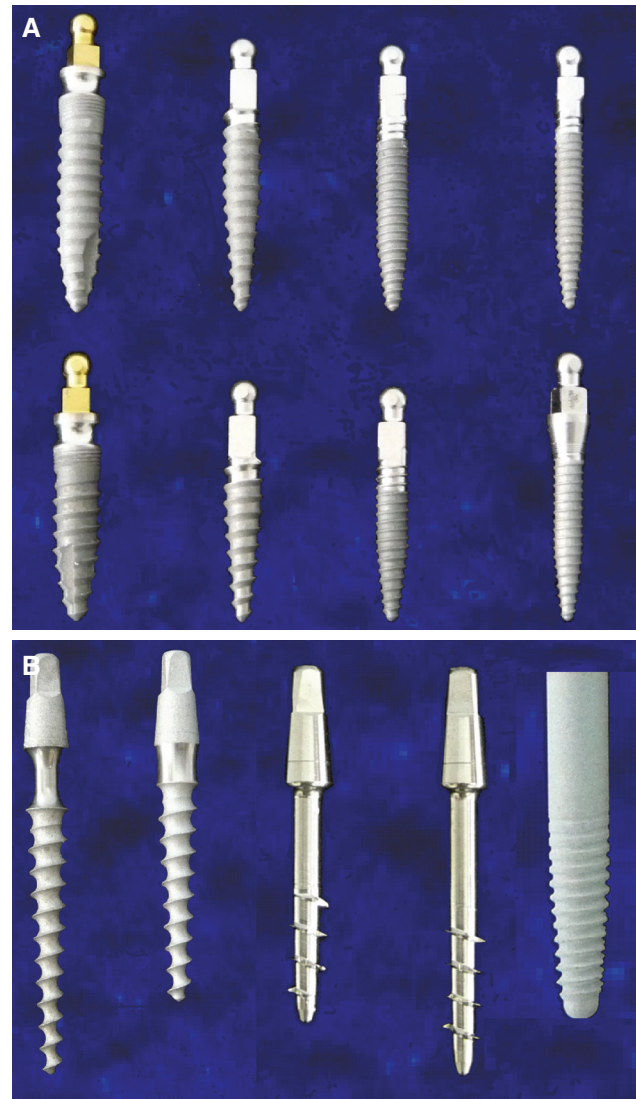


Figure 1 Commercial implants used in the numerical analysis of Bourauel et al. [6].

(A) MDI implants. (B) From right to left: K.S.I.-Bauer Schraube, Bicortical, and Komet MicroPlant implants.

overdenture with minimal stress and flexing in the alveolar bone surrounding MDI dental implants. They tested six support designs of the overdenture and two attachment combinations: Dalbo elliptic and/or O-ring attachments under vertical (35 N) and lateral (17.5 N) loads. They concluded that three freestanding MDI dental implants with flexible acrylic attachment systems supporting an overdenture were better choices than four MDI dental implants with O-ring attachment systems, which showed the maximum flexing and stress values in this qualitative comparison.

Knowledge of the fatigue life of an implant may prove to be an important therapeutic parameter. To accurately and confidently predict how long one of these very

small-diameter implants will function properly, fatigue tests are needed to find the fatigue life of the implant. With the information on how many cycles the implant functions until failure, the life expectancy of the implant can be predicted more accurately, which is important for prosthetic longevity. The fatigue life of an implant depends on both the implant itself as well as on the physical properties of the bone. However, the capability to predict the fatigue life of a newly placed implant does not currently exist. In the study of Fnagan et al. [16], one-piece MDI dental implants with 2.0 mm diameter were tested under 200 N unidirectional cyclic loads while embedded in a rigid base. A finite element-based computer model was developed capable of predicting the corresponding fatigue life. The results, as predicted by the model, were fairly well correlated with experimental results [16].

It was reported that implant fractures constitute between 5% and 20% of all implants lost during function [5]. Various workers have previously highlighted the risk of fatigue fracture of smaller-diameter implants, especially in areas of high loading [12, 37]. Furthermore, finite element analysis has shown small-diameter implants to adversely affect loading conditions on crestal bone [31]. This is of particular importance as loss of crestal bone could be detrimental to loading conditions by increasing the lever arm effect and bending moments on the implant [12].

Allum et al. [2] investigated the mechanical performance of a number of small-diameter commercially marketed implants under a standardized test setup similar to that recommended for standardized ISO laboratory testing. The maximum loads for Straumann (control) implants were 989 N (± 107 N) for the 4.1 mm RN design, and 619 N (± 50 N) for the 3.3 mm RN implant (an implant known to have a risk of fracture in clinical use). Values for MDI implants were recorded as 261 N (± 31 N) for the HiTec 2.4 mm implant, 237 N (± 37 N) for the Osteocare 2.8 mm mini, and 147 N (± 25 N) for the Osteocare mini design (Figure 2). They concluded that the diameters of the commercially available implants tested demonstrated a major impact on their ability to withstand load, with those < 3 mm diameter yielding results significantly below a value representing a risk of fracture in clinical practice. The results therefore advocate caution when considering the applicability of implants ≤ 3.0 mm diameter.

Survival rate of mini implants

Degidi et al. [10] studied the survival rate based on the marginal bone loss of 510 small-diameter implants. Implant

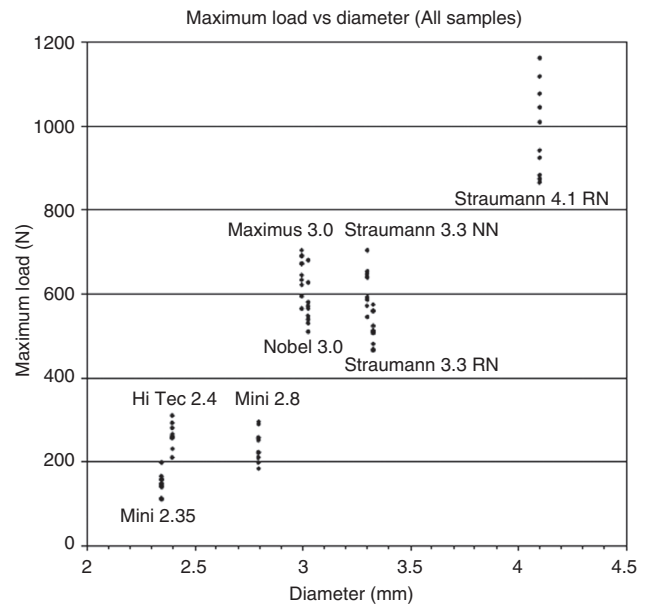


Figure 2 Summary of the results obtained by Allum et al. [2].

diameter ranged from 3.0 to 3.5 mm, multiple implant systems were used, and 255 implants were restored immediately without loading. The survival rate was 99.4%.

Krennmair et al. [28] evaluated retrospectively the long-term survival and success rates of 541 screw-type (Camlog) implants of various diameters (3.8, 4.3, and 5/6 mm) and their implant-prosthetic reconstructions for > 5 years of clinical use. The overall cumulative 5-year survival and success rates were 98.3% and 97.3%, respectively.

Degidi et al. [11] compared the bone loss pattern and soft tissue healing of immediately versus one-stage-loaded small-diameter implants of 3.0 mm diameter in cases involving a single missing lateral maxillary incisor in 60 patients. No statistically significant differences were observed for bleeding or plaque index. No implant fractures occurred. At the 36-month follow-up, the accumulated mean marginal bone loss and probing depth were 0.85 ± 0.71 and 1.91 ± 0.59 mm, respectively, for the immediate-loading group and 0.75 ± 0.63 and 2.27 ± 0.81 mm, respectively, for the one-stage group. There was no statistically significant difference ($p > 0.05$) for the tested outcome measures between the two procedures.

Romeo et al. [32] compared in a longitudinal study the prognosis of 122 small-diameter implants (3.3 mm diameter) to 208 standard implants (4.1 mm diameter) over a 7-year period. The small-diameter implants were inserted in 68 patients to support 45 partial fixed prostheses and 23 single-tooth prostheses. Furthermore, standard implants were used to support 70 partial fixed prostheses and 50

single-tooth prostheses. For small-diameter implants, the cumulative survival rate was 98.1% in the maxilla and 96.9% in the mandible. The cumulative success rate was 96.1% in the maxilla and 92% in the mandible. Conversely, standard-diameter implants showed a cumulative survival rate of 96.8% in the maxilla and 97.9% in the mandible. The cumulative success rate was 97.6% in the maxilla and 93.8% in the mandible. The cumulative survival and success rates of small-diameter implants and standard diameter implants were not statistically different ($p > 0.05$).

Conclusions

The choice of longer and/or wider implants in relation to the available bone quality and biting force decides the survival rates of these implants and the overall success of the prosthesis. Small-diameter and MDI implants offer the

possibility to reduce the surgical complications and total treatment duration for patients with extremely narrow alveolar ridge, where the insertion of dental implants is often problematic.

In this review, we aimed to understand the biomechanical aspects of small-diameter and MDI implants and the relation of biting force and marginal bone resorption to the selection of implant diameter/length. The small-diameter and MDI implants of the presented studies showed a high survival rate with different treatment approaches for a period of up to 5 years. There is, however, a lack of long-term clinical studies. Such studies are essential as the experimental and numerical investigations showed a relative shorter fatigue life for the small-diameter and MDI implants in comparison with the conventional implants, and high fracture risk under function.

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