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Review

Current Status of Finite Element Analysis Based Studies on Optimal Dental Implant Length and Diameter in the Posterior Mandible Bone: A Review of the Literature

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ABSTRACT

The scope of this article is to review the current status of finite element analysis based studies on the matter of optimal dental implant length and diameter in the posterior mandible bone and discuss the findings in relation to 3D models used, materials used, type and magnitude of loading. The search of the literature was carried out using electronic databases PubMed, EbscoHost, as well as a manual search of finite element analysis based studies on dental implant diameter and length published between 2000 and 2018, using the terms: finite element analysis, dental implants, implant diameter an implant length. Current finite element analysis studies on the influence of diameter and length of implants present high variability due to the bone models used, material properties assigned, magnitude and type of loading, design of implants and dimensions investigated. However, a clear result is that the diameter of the implant has a great influence on crestal bone stress, an increase in the diameter leading to a decrease in stress. Increase in length leads to a decline in stress values in the bone tissue, but a clear consensus has not been reached yet concerning the extent of its influence on the cortical bone or cancellous bone.

Keywords: Implant dimensions; Periimplant bone; Stress; Finite element analysis.

INTRODUCTION

Even though dental implants have been successfully used in the oral rehabilitation of edentulous patients, implant failure remains still a critical issue [1]. The two main factors related to implant failure are bone resorption and poor Osseo integration [1-3]. Excessive implant loading causes stress concentration in the bone surrounding the implant which may lead to bone resorption. Osseo integration is dependent on biocompatibility parameters and micro-design of the implant but may also be influenced by an overload of bone tissue [4,5]. Masticatory loads are transferred through the implant to the surrounding bone tissue. The magnitude of the force applied can either promote bone remodelling or lead to resorption of the mandibular ridge [4-7]. However, both bone resorption and Osseo integration are reliant on the mechanical properties of the implant material and the implant diameter and length [7].

Many clinical in vivo and in vitro studies have investigated the complex matter of implant dimensions and their influence on stress values in the surrounding bone but no clear consensus has been reached yet, as many parameters are inaccessible due to the limitations of the clinical studies [7-10].

Finite element analysis allows the study of complex rehabilitation clinical cases in a virtual setting, through iterative assessments, with no ethical concerns. Such complex clinical scenarios would be ambitious or even impossible to examine through clinical investigations [10].

Studies have attempted to assess the influence of implant diameter and length on the stress magnitude and distribution in the surrounding bone through finite element analysis. However, there is a large variability among current studies in regards to both finite element parameters and results. Also, no clear consensus about the impact of implant dimensions on the periimplantar bone stress has yet been reached.

The scope of this article is to review the current status of finite element analysis based studies on the matter of optimal dental implant length and diameter in the posterior mandible bone and discuss the findings in relation to 3D models used, materials, type and magnitude of loading.

LITERATURE REVIEW

The search of the literature was carried out using electronic databases PubMed, EbscoHost, as well as a manual search of finite element analysis based studies on dental implant diameter and length published between 2000 and 2018, using the terms: finite element analysis, dental implants, implant diameter an implant length. Out of the search results, only articles that analyzed implant dimensions in the posterior mandible were analyzed. Also, only articles in English and 3D finite element type studies were selected for further analysis. Micro-implants were not selected for this literature assessment as their dimensions are far from common implants used in clinical cases and should be analyzed independently.

Diameter and length of dental implants

Diameter and length of dental implants are parameters that are dependent on the alveolar ridge dimensions and prosthetic requirements [10].

To gain maximum stability in the alveolar bone, the diameter of implants needs to be optimized to engage as much of the buccal and lingual plates as possible [9]. Implants currently accessible for use in the posterior mandibular bone are between 3 and 7 mm diameter [10].

Search results of finite element studies concerning implant dimensions are listed in **Table 1**, alongside a description of the variabilities of each study.

The increase of the diameter of implants has been reported by all of the studies to decrease the periimplant stress [5-8,11-33]. In particular, the diameter has a strong influence on the stress magnitude in the cortical bone. This effect of the diameter is in close relation to bone quality [7-10]. Consequently, bone quality is introduced as a varying parameter in finite element analyses. Kang reports in his study that in poor quality bone, a short implant with the smallest diameter is a favourable option [12].

To simulate complex clinical situations where mandibular bone varies in quality, some FEA studies have introduced even more variables. Correlating the cortical thickness, quality of bone through variation of Young's modulus and implant diameter and length [11,19]. In an optimally dimensioned ridge that allows a large implant, bone quality needs to be taken into account to ensure appropriate stress values that preserve crestal bone [11,19]. Implants with a diameter above 4 mm and length above 12 mm are considered to be a relatively optimal choice for the posterior mandible however, other studies report an optimal choice to be length above 10 mm [13,19].

For implants of diameter between 3.3 and 5 mm, stress values in the periimplant bone were found to decrease with larger diameter implants, regardless of the loading direction [12,14]. Although studies suggest that larger diameter are preferred in terms of stress transferred to the periimplant bone, it is also reported that the benefits of over 5.5 mm diameter implants are negligible [12,15,16].

Concerning the influence of the implant diameter on the distribution of stress, it is suggested that stress concentration is independent of implant diameter but rather on implant geometry and forces applied [8-10]. As stress is concentrated in the crestal bone, implant diameter can only influence the magnitude of the stress concentration by increasing or decreasing stress in cortical bone [11,15,16]. Distribution of stress was found to be similar, in type I and II bone density and for type III and IV bone density as well. This suggests that improving bone quality may lead to a smaller stress concentration in conjuction with implant diameter [12,13].

FEA studies report smaller variations in the stress value due to change in length in comparison to the increase in diameter suggesting a less significant effect of the length to decrease stress concentration at crestal bone level [14-18]. However, in the cancellous bone, length has been reported to have a great effect on decreasing stress [11,13]. When considering poor quality bone, an increase of the implant length leads to a decrease in stress, because it allowed for a greater contact surface area between implant and bone [11].

Himmlova studies separately the effect of length and diameter on the stress values in the periimplant bone and also concludes that diameter has a greater influence than the length in reducing stress in the surrounding bone [16].

To ensure optimal range of stress induced by the implant to the per implant bone tissue by its dimensions, some studies have proposed a diameter-to-length ratio to assess a bone overload risk [15]. Narrow and longer implants, although may pertain to restrictive dimensional bone ridges, lead to a decrease in oclusal loading resistance [8]. Shorter and wider implants have been reported to be a good selection in the resorbed posterior mandible bone.

There is high variability in the magnitude and direction of applied loads in the finite element studies [11-20, 24,25,28-33]. However, the applied masticatory force was found in some studies to have a greater effect on stress values and distribution in the periimplant bone, than any other parameters. And since physiological loads are dependent on implant placement, an assessment of the magnitude of loads should be made before selecting implant dimensions [11,18].

Macro-design elements, such as thread type, apex design, micro threads or platform-switch, can influence the perimplant stress [20-23]. Platform switching had been shown to reduce stress in conjuction with implant dimensions at crestal bone level [18].

Alongside implant dimensions, shape of implants was introduced as a periimplantar stress influencing factor [24,25]. In tapered and parallel wall implants, increase in diameter resulted in lower stress values in the peri-implantar bone [24,25]. Because of the proven effects on bone tissue stress, diameter and length need to be assessed in conjunction with a taper of the implant. Increased diameter and length in untapered implants is favourable for reducing stress in peri-implant bone.

Table 1. Search results of finite element based studies on implant diameter and length with a description of variabilities.

FEA studies	Diameter (mm)	Length (mm)	Type of loading	Type of FE analysis	Type of material properties assigned to bone tissue
Guan et al. 2009 [11]	3.5, 4, 4.5, 5.5	7, 9, 11, 13, 15	250 N horizontal loads, 500 N vertical, 162.5 N along z axis.	Linear Elastic	Isotropic
Kang et al. 2014 [12]	3.3, 4.1, 5, 5.5, 6.5, 7.1	8	200 N vertical load, 100 N 45 oblique load	Linear Elastic	Isotropic
Li et al. 2011 [13]	3-5	6, 11, 16	100 N and 30 N axially and 45 buccolingually	Linear Elastic	Isotropic
Kong et al. 2009 [14]	3-5	6-16		Linear Elastic	Isotropic
Demenko et al. 2014 [15]	2.5-7	3-17	114.6 N, 17.1 N and 23.4 N in axial, lingual and disto-mesial direction,	Linear Elastic	Isotropic
Himmlová et al. 2004 [16]	2.9, 3.6, 4.2, 5, 5.5, 6, 6.5	12	200 N vertical force, 40 N horizontal force	Linear	Isotropic
	3.6	8, 10, 12, 14, 16, 17, 18		Elastic	
Ding et al. 2008 [17]	3.3, 4.1, 4.8	6, 8, 10, 12, 14	vertical and oblique loads of 150 N	Linear Elastic	Isotropic
Baggi et al. 2008 [18]	3.3-4.5	7.5-12	static load lateral 100 N; vertical load 250 N	Linear Elastic	Isotropic
Ueda et al. 2017 [19]	3.5-6	41487	60N divided in vertical load, and a 15° oblique load lingually	Linear Elastic	Isotropic
Mohammed Ibrahim et al. 2011 [24]	3.7, 4.1, 4.7	13	114.6 N axial load, 17.1 N lingual direction, 23.4 N disto-mesial direction	Linear Elastic	Isotropic
Petrie et al. 2005 [25]	3.5 - 6	5.75- 23.5	200 N axial load, 40 N horizontal load	Linear Elastic	Isotropic
Raaj et al. 2019 [28]	3.5, 4.3	10, 11.5	100 N axial load, 50 N buccolingual load, 50 N mesiodistal load	Linear Elastic	Isotropic
Anitua et al. 2010 [29]	2.5, 3.3, 3.75, 4, 4.5, 5	8.5, 1, 11.5, 13, 15	150 N at 30°	Linear Elastic	Isotropic
Kong et al. [30]	43588	42522	100 N axial load, 30 N oblique load	Nonlinear	Isotropic
Yu et al. 2009	3.3, 4.1, 4.8	10	100 N at 30°	Linear Elastic	Isotropic
Pellizzer et al. 2013	3.75, 5	10	200 N axial load	Linear Elastic	Isotropic
Moraes et al. 2018	3.75, 5	8.5	Axial 200 N axial load, 100 N oblique load	Linear Elastic	Isotropic

The variability of the FEA studies extends to the 3D bone models used, which is oversimplified and do not sufficiently enough describe the anatomical aspects of the investigated mandible bone [26,27]. Simple mandible like structures may not accurately describe the complex geometry of the alveolar ridge, thus leading to unreliable results.

Also, mechanical properties of materials assigned play a crucial role in the accuracy of the finite element analysis results. The bone tissue, considered to be isotropic alongside a completely osseo-integrated bone-implant interface is a great simplification of the actual clinical conditions. In reality, the biomechanical behaviour of bone is complex and anisotropic mathematical models have been proposed to describe it [34,35]. Also, the bone-implant interface presents various degrees of osseointegration [34,35]. Also, the bone-implant interface presents various degrees of osseointegration, thus the FEA results may be underestimated, leading to a change in stress patterns and magnitude [34-38].

CONLUSION

Current finite element analysis studies on the influence of diameter and length of implants present high variability due to the bone models used, material properties assigned, magnitude and type of loading, design of implants and dimensions investigated. However, a clear result is that the diameter of the implant has a great influence on crestal bone stress. An increase in the diameter leads to a decrease in stress in the mandibular bone. Diameter cannot be assessed independently but in conjunction with the length of the implant. Increase in length leads to a decline in stress values in the bone tissue, but a clear consensus has not been reached yet concerning the extent of its influence on the cortical bone or cancellous bone. Future finite element studied should focus on patient data derived mandible models and accuracy of mechanical properties of materials assigned as well as an appropriate physiological load.

Materials currently available do not meet our needs. There are certain advantages and disadvantages in every material. Future research should concentrate on two major goals.

1) Improving the properties of materials, so that it will behave more like human tissue.

2) Color-stable coloring agents for coloring facial prosthesis.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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