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Effect of implant number and height on the biomechanics of full arch prosthesis

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Aim: The goal of this study was to clarify the stress distribution in a full arch prosthesis according to the implant number and height in order to guide the clinical choice during planning. **Methods:** A computational analysis was performed to analyze the stress distribution in implants and bone tissue according to implant number (3, 4 or 5) and height (5, 8, 11 mm). A model of a jaw with polyurethane properties to simulate bone tissue was created through the Rhinoceros software (version 5.0 SR8, McNeel North America, Seattle, WA, USA). The titanium bar was fixed to the implant through a retention screw. The final geometry was exported in STEP format to ANSYS (ANSYS 15.0, ANSYS Inc., Houston, USA) and all materials were considered homogeneous, isotropic and linearly elastic. To assess distribution of stress forces, an axial load (200 N) was applied on the cantilever. Results in Von-Mises stress and strain criteria's were obtained for implants and bone, respectively. Qualitative and quantitative evaluations were performed. **Results:** The implant number and height influenced the prosthesis biomechanics, with more von-Mises stress and bone strain concentration for combination of 3 implants with 5 mm. **Conclusion:** It was concluded that higer length and more quantity of implant supporting a full arch prosthesis promoted less stress concentration during the simulated load. Decreasing the number of implants in rehabilitation is more harmful than decreasing their length for the stress and strain distribution.

Keywords: Dental implants. Finite element analysis. Bone implant interface. Prosthodontics.

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Introduction

Since the advent of osseointegration, several changes occurred in the scenario of implantology. Extreme conditions of rehabilitation became routine, and bone height and thickness were adapted to the surgeon's willingness to install the implants[1]. In this way, the number of implants to support the prosthesis became the number of implants possible according to the bone morphology of each patient[2]. Despite the success of osseointegration in cases of short implants or few implants in function[3,4], there is concern about treatment longevity. Success can be compromised when the distribution of forces occurs inappropriately[5,6] in an implant-supported prosthesis. For this reason, several studies seek to evaluate the stress in the peri-implant bone through studies that simulate a clinical condition[5-8].

Although there is no consensus regarding the number of implants[4] able to influence stress distribution and bone microstrain. A greater number is suggested as beneficial, corresponding to a safe approach and is more proper for the patient. The amount of available bone height directs the selection of short implants. Also, since it is pointed out that the reduction of the implants number can be an approach to reduce costs for many patients, the peri-implanted bone preservation is paramount and must prevail over clinical decisions in order for the treatment to have proper longevity[8].

It was reported that the number of implants may influence the bone strain and that a greater number may be beneficial for the prosthesis biomechanics[5]. But, it is possible to find success reports with three[2], four, five and even more implants number[4] to support the prosthesis. However, the available amount of bone height[4,9] is the limiting factor for the treatment, allowing only the surgeon the selection of short implants[10]. In these cases, the diameter of the implants is the main factor in achieving success. In cases of low bone height, the diameter of the implants is more relevant than its length, promoting a greater area of contact with the bone tissue, facilitating the stress distribution during chewing[11,12].

The association between implant number and height has not yet been clarified in the literature, unlike the number and position of them[13,14]. Therefore, studies are needed to situate the clinician regarding this relationship and the rehabilitation biomechanics. The greater the number of implants, the better the stress distribution in their structures[15], generating low values of bone strain.

One of the most used tools to study the biomechanics of dental implants is the finite element analysis[16]. This study evaluated the effect of implant number and height on stress distribution in a full arch prosthesis using finite element analysis; therefore, this methodology allows three-dimensional visualization of the structural mechanical behavior[6,17]. The hypotheses were that 1) the number of implants would be significant for biomechanics and 2) there would be no difference for the different implants heights.

Materials and Methods

A three-dimensional validated edentulous jaw[7] was used as the implants base installation. Nine (9) groups were modeled according to implant number and height, using a modeling software (Rhinoceros 4.0, USA). The implants were external hexagon connection type with 4.1 mm diameter (Conexão Sistemas de Prótese, Arujá, SP, Brazil) at three different heights (5, 8, 11 mm). The groups were arranged in different installation protocols according to the number of implants (3, 4 or 5) at each evaluated height. A flat bar simulating a full arch prosthesis was fixed on the implants with a 15 mm cantilever extension and the height of the 6 mm bar from the alveolar bone (Figure 1).

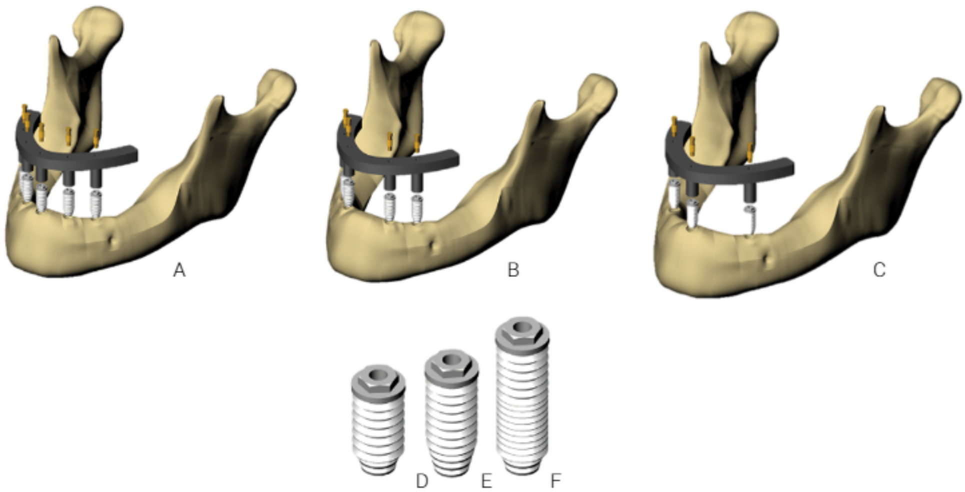

Figure 1(a–f). A schematic illustration of the sequentially performed procedures. Nine groups were modeled according to implant number [5 (a), 4 (b) or 3 (c)] and height [5 (d), 8 (e) and 11 mm (f)].

The elastic modulus for titanium and bone simulator (polyurethane, an isotropic material scientifically validated) were 110 GPa[18] and 3.6 GPa[19], respectively; and Poisson ratio was 0.3 for both (Tribst, indian)[7]. All reported properties of the materials were based on literature data considering them as homogeneous, linear and isotropic. All contacts were considered ideals and, the jaw was fixed on its base, preventing the assembly from shifting on the z-axis.

The mesh convergence test was performed with 10% of significance to prevent that the subdivision of the complex geometry into a finite number of elements interferes in the results[7,17]. Table 1 summarizes the total number of element and nodes for each group mesh (Table 1). Then, a load (200 N) was applied on the cantilever most distal portion. The mesh generation and load application are exposed in Figure 2. Von-Mises stress results for implants and microstrain for peri-implant bone were then analyzed, reproduced numerically, color-coded, and compared among the groups[3,7,17].

Results

It is possible to perform a quantitative analysis for Von-Mises stress in implants and strain in bone tissue using Figure 3 and Table 1. The implants were numbered from

Table 1. Groups distribution, number of nodes and elements for each group mesh and stress (Sp) and strain (Stp) peak values for implants and bone structures.

Implants number	Implants height	Nodes	Elements	Implants	Jaw
				Sp (in MPa)	Stp (in μ/μ)
3	5	506,279	297,086	114	1067
	8	534,782	305,118	111	1010
	11	560,722	325,791	103	977
4	5	636,462	356,545	111	998
	8	668,348	376,767	110	905
	11	691,923	396,652	103	847
5	5	745,298	447,257	98	835
	8	767,867	462,834	92	790
	11	788,228	483,475	87	675

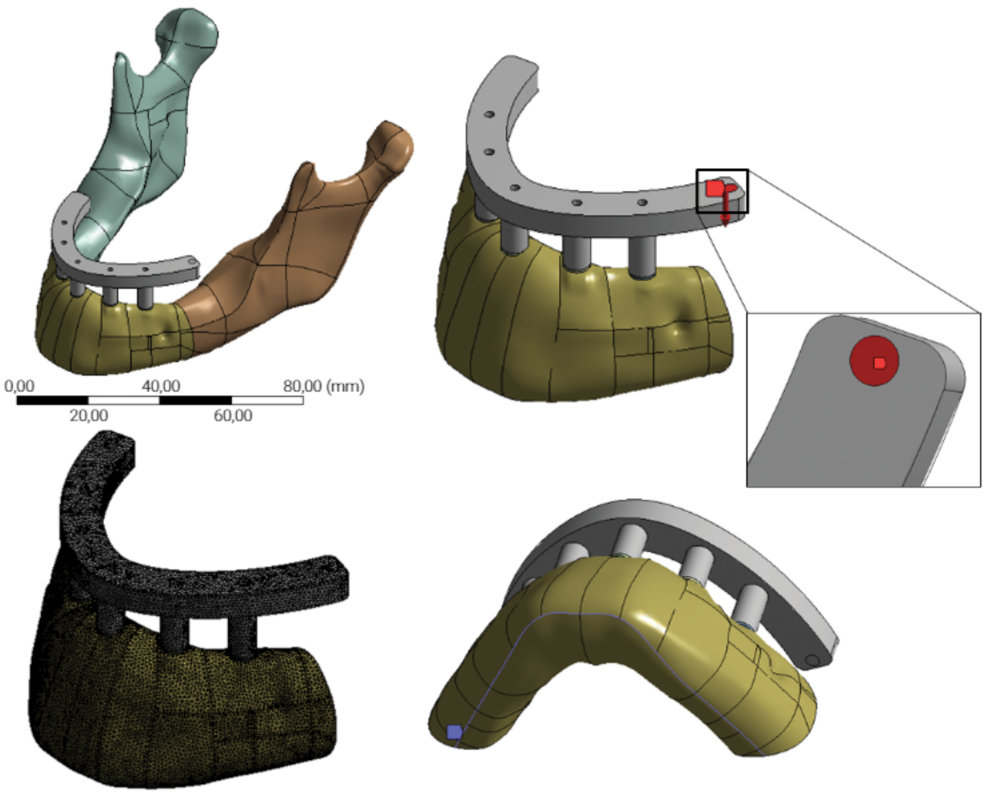

Figure 2. Mesh generation and load application.

the cantilever of the working side (implant 1 is the closest to the loading area, followed by implant 2 and 3 successively). It is also possible to notice that the stress peak had greater magnitude for the three-implant drilling protocol, followed by the groups with four and five implants. The effect of implant height was the same for all groups:

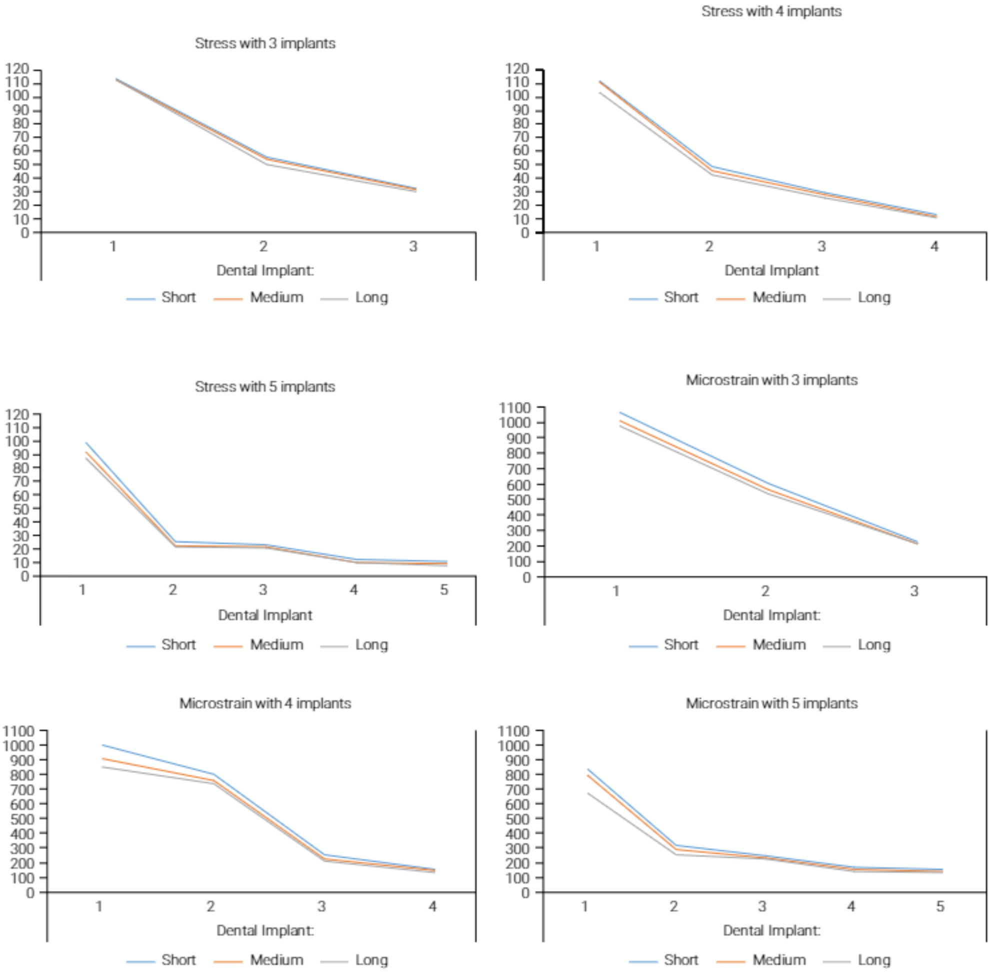

Figure 3. Stress (MPa) and microstrain(μ/μ) values according to implant number and height factors.

the higher the implants, lower is the stress concentration through the structures. For all groups, the implant that concentrated more stress was the implant closest to the loaded cantilever (Implant 1), presenting the peak values (Figure 3 and Table 1). Groups with 3 implants had a greater stress peak values (Table 1), followed by the groups with four and five implants. Bone microstrain was directly proportional to the stress generated in implants (Table 1).

In Figure 4, for the implants, it is possible to observe that the implant platform is the most compromised region, independent of the implant height. When the implant number was decreased, other areas of high stress were observed. The results show that implant number is more influential than implant height for the implant platform closest to the cantilever.

For bone tissue, the implant closest to the cantilever concentrated more strain in all groups (Figures 2 and 5). For groups with 4 and 3 implants, the second implant (counting from the load application point) also shows high strain (> 500). This is not

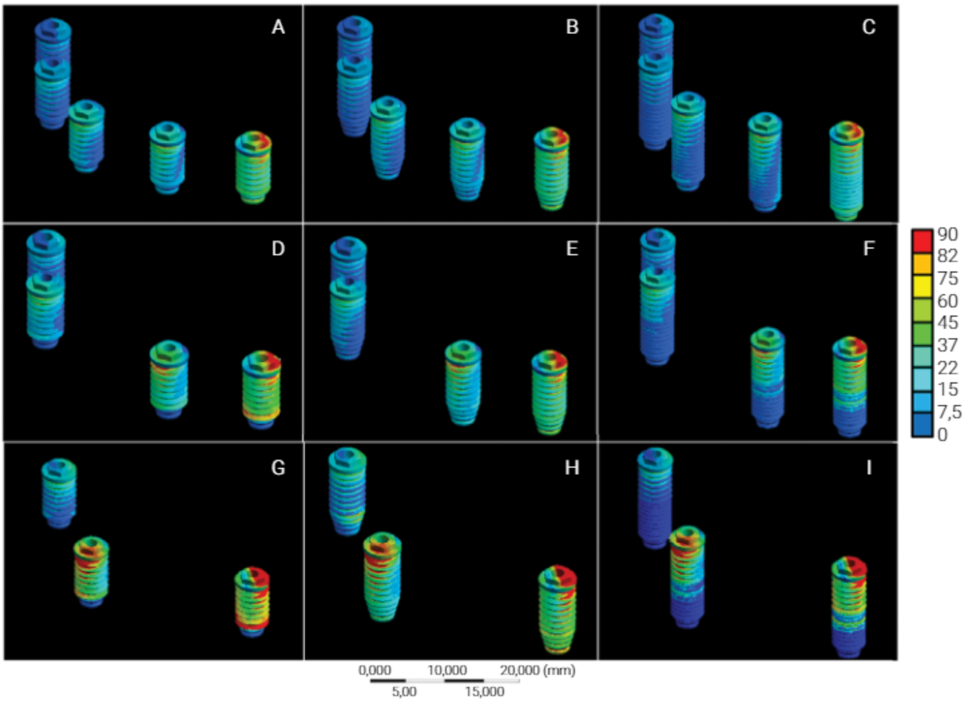

Figure 4. Von-Mises stress (MPa) in implants according to implant number (5, 4 and 3, up to down, respectively) and height (5, 8 and 11, left to right, respectively) factors.

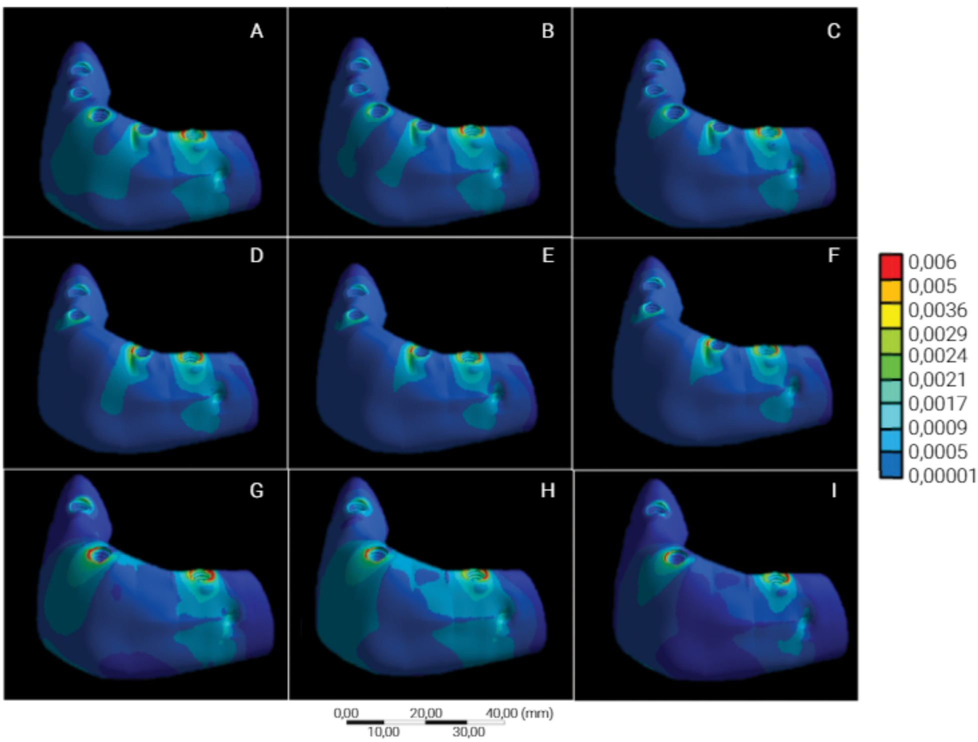

Figure 5. Microstrain (μ/μ) in bone tissue according to implant number (5, 4 and 3, up to down, respectively) and height (5, 8 and 11, left to right, respectively) factors.

observed in the group with 5 implants. The effect of implant length is less influential for bone tissue than implant number, but significant (> 10%); demonstrating worse mechanical behavior for smaller implants.

Discussion

Within the limitations of this study, it was observed that stress was increased in the bone and in the central and distal implants by decreasing the implant number. The most damaged implants were those closest to the load application (Figure 4)[7], however this effect was influenced by the implant number. Stress distribution was more homogeneous when more implants participated in the prosthesis support. Although high stress concentrations can lead to long-term fatigue failure, this sequel can be minimized with higher implant length and consequently greater bone contact area by dissipating loads. Nevertheless, increasing the length does not minimize the effect of decreasing the implant number (Figure 3). Therefore, "number" and "length" factors influenced the biomechanics of the evaluated prosthesis, and decreasing the implant number is more harmful than decreasing the implant length.

The first hypothesis that the number of implants will be significant for biomechanics was accepted. Since, reducing the number of implants from 5 to 4 or 3 increased stresses on the bone and implants (Figures 3-5). Thus, although high clinical success rates have been obtained for rehabilitation with 3 implants in the jaw[2], the use of regular implants in this configuration can overload the system and lead to mechanical failure of the prosthesis. This suggests that this type of drilling protocol needs more monitoring and better adaptation of the prosthesis after its installation. The philosophy of reducing the number of implants is based on the load distribution between them, so that Duyck et al.[20] (2000) reported that regardless of the number of implants, the load dissipation will be restricted to the distal and central implants. Herein, the most injured implants were the ones closest to the load application (Figure 3 and 4), but this effect was influenced by the number of implants, and the distribution was more homogeneous when more implants participated in the prosthesis support (Figure 5). These results are supported by other studies that verified a greater microstrain in the region of the distal implant near to the load application[3,21-23].

The second hypothesis that there would be no difference between different implant heights was rejected. Qualitatively, stress maps are very similar. However, according to the quantitative analysis, there was a difference of more than 10% between 5 and 11 mm implants in the group with 5 implants. Regarding bone strain, the difference was also observed between implants of 5 and 11 mm in the groups with 4 and 5 implants.

Considering studies that evaluated the implants diameter, it was reported that larger surface areas in contact with the bone provide greater stress dissipation when a prosthesis is loaded[24]. Likewise, the length of the implants seems to present proportional increase ratio of the titanium surface area and masticatory load dissipation[25]. However, the height effect appears to be less prominent than the diameter effect of the intraosseous screws. However, herein, the increase in implant height was not sufficient to minimize the effect of decreasing the amount of implants (Figure 2), different from authors who reported that only by increasing the implant diameter it would be possible to equalize the stresses with a prosthesis containing more implants[3].

Other studies have reported that decreasing implant length may increase the stress concentration in the peri-implant bone and in the implant itself[25]. In addition to the benefit of better stress distribution, the use of higher implants is favorable for primary bone stability[26]. Herein, in the three-dimensional models, for standardization to be possible, the mandibular bone height was kept identical for all groups; so that, the prosthesis bar height was the same and only the desired effects could be studied. However, often when a short implant is used, the ratio between crown and root is negatively altered so that the lever over the implants may turn out to be a future problem[27], even though short implants are a viable option. Several authors have pointed out that the increase in the implants number to support the prosthesis is beneficial[3,5,21,22]; thus, corroborating with the results of the present study. Therefore, the best mechanical behavior in the group with 5 implants was observed. Thus, an ideal situation based on our results would be the use of 5 long implants to support the prosthesis (Figure 5).

The concern with the generated strain around the peri-implantar tissue is directly related to the capacity of the bone tissue to adapt and remodel as a function of mechanical stimuli[17,23,28-31]. As occlusal overload is reported as one of the main reasons for failures in already osseointegrated dental implants[32], several previous studies associate the value of bone strain generated around the implants with the values of physiological limit of bone resorption[30] stablished by Frost et al.[33] (1998)[7,10,17,23,29,30].

Thus, several clinical approaches may alter the dissipation of the masticatory load and cause the values of bone strain to increase 8x with the same applied load[31]. Herein, no strain value approximates to 3000 stipulated as borderline[33]. But, as the applied load was 200 N, the results can vary with values greater or smaller than the bite force. With the same applied load and lever arm, the situation with 5 implants presented about 22% less bone strain around the last implant compared to the use of 3 implants of the same diameter, and that difference increased to 35% with the use of 5 long implants (table 1).

Although the finite element analysis is a computational simulation and that several variables of the oral medium cannot be simulated[34], the results of this method must be used as a complement to the future studies, to understand and justify the mechanical complications that can happen in this system of implant supported prosthesis. Although high concentrations of stress can lead to long-term fatigue failure[35].

In conclusion: (i) higer length and more quantity of implant supporting a full arch prosthesis promoted less stress concentration during the simulated load. (ii) decreasing the number of implants in a rehabilitation is more harmful than decreasing their length for the stress and strain distribution.

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