Selection of Dental Implants Based on Masticatory Load of the Patient: A Novel Approach

Abstract

Purpose: Masticatory load and efficiency vary from one individual to other. Maximum load of one person may be the least load of another. Hence, optimization of dental implants based on the load dissipation of an individual is essential for a better prognosis of implant-supported prosthesis. The aim of the study was to find the appropriate implant dimensions for the particular region based on the masticatory efficiency of the individual. Materials and Methods: A two-dimensional-threaded implant model was designed, which was duplicated in total 28 models with varying dimensions starting from 3 mm × 8 mm till 6 mm × 14 mm, with an incremental increase of 2 mm in length and 0.5 mm in diameter. All these implant models were surrounded in cancellous bone. Each implant model was loaded from 50 Newtons (N) to 700 N with an incremental increase of 50 N in load in vertical direction to the static model complex. Results: Von Mises stresses were calculated for all the models with different amount of load. The analysis showed that, with an increase in applied masticatory load the smaller dimensional implants showed more stress in the bone, with more stress concentration toward the crest of the implants, and in the apical bone, with respect to the ultimate stress capacity of bone. Conclusion: Thus, based on the numerical analysis results, a classification was designed, which will indicate that for a particular amount of masticatory load, a particular dimension of implant has to be selected, rather than just selecting the implant based on the available bone and its dimensions without knowing the load the implant is going to take once it is loaded.

Keywords: Classification, fatigue failure, implant dimension, masticatory force, pathological fracture

Introduction

The reported success of implant therapy has been ranging with a high favorable survival rate between 95% and 99%.[1] Failures do occur despite high success rate and stability of dental implants.[2] There can be early (before prosthetic treatment) or late (after prosthetic rehabilitation) implant failures.[3] The major etiologic factors for late failures seem to be excessive occlusal stress in conjunction with host characteristics and peri-implantitis (bacterial-induced marginal bone loss). The most common causes of implant failure at an early stage after implant placement could be operator experience, bacterial contamination, excessive surgical trauma, premature overloading with micromotion, and some local as well as systemic characteristics of the host.[4]

Cell destruction can be seen when the chewing forces are such that they exceed physiological tolerances. The generated excessive occlusal force presents an opportunity for fracture and/or loosening of the implant through bending overload. Frost’s theory of mechanostatics states that bone mass is a direct result of the use of the skeleton.[5] Frost established a mechanical adaptation chart relating trivial loading, physiological loading, overloading, and pathologic loading zones to ranges of microstrain [Figure 1]. Implant overload can be caused by a multitude of factors, including an insufficient number of implants to support the restoration, suboptimal implant design and size, improperly splinted abutments, violation of conventional prosthetic limitations for natural dentition, excessive cantilevered pontics; splinting to natural dentition (even with a stress breaking attachment), improperly positioned implants, the wrong type of restoration for the clinical condition, loss of supporting bone, excessive parafunctional forces, and nonmaintenance of the components.[6]

Dental implants are subjected to forces generated through muscles of mastication.

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Masticatory load of individuals varies from person to person. Parafunctional habits (clenching, bruxing, or engaging) can result in destructive lateral stresses and can transmit forces to the supporting bone that could result in overload.\[^7\] Such loads can vary dramatically in magnitude, duration and frequency, and depending on the degree of the patient’s parafunctional habits. During mastication, the maximum bite force attained in natural forces is much lesser than the parafunction bite force. In normal dentition without implants, mean maximal vertical (axial) bite force magnitudes in humans can be 469–485 Newtons (N) at the region of the canines, 583–599 N at the second premolar region, and 723–738 N at the second molar.\[^8\] Every change in the form and function of bone or of their function alone is followed by certain definite changes in their internal structure and equally definite alteration in their external confirmation, in accordance with mathematical laws.\[^9\] Thus, indicating that masticatory load plays an important role in stress dissipation and bone remodeling, and which varies in all the individuals. It becomes essential to formulate a classification, based on the individual’s masticatory load, wherein the implants can be selected to optimize the stress dissipation in the implant and bone.

The aim of the present study was to optimize an appropriate implant dimensions for the particular masticatory load of a particular individual using a numerical analysis.

Materials and Methods

A two-dimensional (2D)-threaded implant finite model was designed to evaluate stress generated in the alveolar bone and through the implant when loaded. The 2D implant bone model was assumed to be embedded in a homogenous cancellous bone and to be fixed at the lateral and apical borders of the bone making it a static model. This model was duplicated with varying dimensions of the implant length and width, starting from 3 mm in diameter and 8 mm in length (3 mm × 8 mm) till 6 mm × 14 mm, with an incremental increase of 2 mm in length and 0.5 mm in diameter. Thus, a total of 392 finite models altogether. Each implant model was individually loaded starting with 50–700 N with an incremental increase of 50 N in load in vertical direction, applied through the implant in the bone. To simulate the clinical situation, material properties were given to all the models [Table 1]. Stress and strain distributions along the bone-implant interface were calculated in Newtons.

Statistical analysis

Von Mises stresses were calculated for all the models with different amount of load.

| Table1: Mechanical properties to simulate Finite model |
|------------------------------------------------------|
| **Youngs Module** | **Yield Strength** | **Poisson’s Ratio** |
| (MPa) | (MPa) | |
| Titanium | 96000 | 930 | 0.34 |
| Cortical bone | 12000 | 100 | 0.3 |

Results

Maximum Von Mises stresses generated on an implant model of 3 mm × 8 mm diameter when subjected to 200 N of force was 125.092 N at the crest of the implant, and 57.443 N at the apex when compared to 4 mm × 14 mm diameter implants which was 86.498 N at the crest of the implant and 30.9 N at the apex, and when 3 mm × 8 mm diameter implant was subjected to 600 N, the stress generated in the bone region was 378.368 N at the crest of the implant and 204.099 N at the apex of the bone. Similarly, the maximum stress generated in bone, when 4 mm × 14 mm diameter implant was subjected to 600 N of force was 262.862 N at the crest of the implant and 111.778 N at the apex of bone, respectively. When 6 mm × 8 mm implant was subjected to 200 N of force was 68.58 N at the crest of implants and 68.58 N at the apex of bone, maximum stress when 6 mm × 8 mm implant was subjected to 600 N of force was 247.216 N at the crest of implant, and 135.638 N at the apex of the bone and likewise for all the implants with varying dimensions from 3 mm × 8 mm to 6 mm × 14 mm with incremental increase of 5 mm in diameter and 2 mm increase in length of the implants when each implant was subjected to forces from 50 N to 600 N with incremental increase of 50 N maximum stress in the implant and the bone was tabulated.

When this was represented graphically with the various force applied ranging from 50 N to 700 N with incremental increase of 50 N on the X-axis and various size of dental implants of diameter from 3 mm to 6 mm with incremental increase of 0.5 mm in diameter on Y-axis with blue bars representing implant length of 8 mm, red bar representing implant length of 10 mm, green bar representing implant length of 12 mm, lavender bar representing implant length of 14 mm, the length of each bars indicates the maximum stress the surrounding bone can withstand before going to pathological fracture under that load [Graph 1].

When dental implants are overloaded, they may undergo fatigue failure. In this study, each dental implant with varying sizes was loaded vertically with different amount of forces each time, and the maximum stress each dental implant could bear was noted. The forces, the dental
implants were subjected varied from 50 N to 700 N with an incremental increase of 50 N each time. The sizes of the dental implants which were considered in this study were with varying diameter ranging from 3 mm to 6 mm with an incremental increase of 0.5 mm and length ranging from 8 mm to 14 mm with an incremental increase of 2 mm.

The maximum stresses generated around these implants in the bone were graphically represented, with the various forces on the X-axis and various diameters of the dental implant on Y-axis. The various colored bars represent the length of dental implants (blue bar - 8 mm, red bar - 10 mm, green bar - 12 mm, and lavender bar - 14 mm), and the length of each bars indicates the optimal stress of that dental implant beyond which that size of dental implant may undergo fatigue failure [Graph 2].

Stress and strain levels of the analysis calculated using Von Mises stress analysis showed that, with increase in applied masticatory load the smaller dimensional implants showed more stress in the bone, with more stress concentration at the crest of the implants [Figure 2] and the bony apex, with respect to the ultimate stress capacity of bone.

**Discussion**

The greatest natural forces exerted on dental implants, and natural teeth are during masticatory process. Overloading of dental implants leads to bone loss and sometimes lead to failure of the dental implant. Reliability of single-molar crown supported with a narrow diameter implant is lower than that of standard diameter implants.[10] Goodacre, in a series of 13 studies, reported that the failure rate of the shorter implant group was 10% compared to 3% in the longer implant group on a total of 2754 implants with a length of 10 mm or less and compared their success rates with 3015 implants of >10 mm in length, which is well supported by a study of Naert.[11,12] Shiffler et al. recently concluded that length of the implant may have a clinically relevant effect on implant stability.[13] Sohrabi et al. reported that the failure rate appeared to be higher in shorter small diameter implants than in longer ones.[14] Thus, these studies indicate that the short and narrow implants have little less stress bearing capacity and little more higher failure rates than standard length implants.

Similarly, heavy masticatory loads are generated in individuals with bruxism as documented in the literature.[15,16] The mean maximum bite force documented by Braun et al. was 738 N with a standard deviation of 209 N. The mean maximum bite force as related to gender was found to be statistically significant, whereas the correlation coefficients for age, weight, stature, and body type were found to be low.[8] Similar results were also reported by Raadsheer et al., who showed average values of the maximal voluntary bite forces as 545.7 N in men and 383.6 N in women.[17] These studies indicate that masticatory forces are not constant in all the individuals but vary from individual to individual. Similarly, even the masticatory varies from region to region in one individual.[17,18] Hence, the authors feel that implants cannot be selected based on the available bone of an individual.

The muscle strength, masticatory dynamics, and maximum bite force exhibited by adults could all be influenced by sex, muscle mass, exercise, diet, bite location, parafunction, state of the dentition, physical status, and age.[19-24] Many theories have been proposed linking the bone adaptation to strain rate. Frost proposed that bone responds to a complex interaction of strain magnitude.[25]

In the present numerical study, when the various dimension implant finite models were subjected to sequence of forces,
stresses were generated around the implants. The maximum von mises stress generated around the implant were noted and tabulated based on Frost’s mechanostat theory.

According to Frost’s mechanostat theory, to prevent net loss in bone mass (disuse atrophy), a 50–250 μ-strain of minimal effective strain (MES) is necessary, whereas normal remodeling exists from 50 to 250 and 2500–3500 μ-strain as a steady-state level. Strains above 2500–3500 μ-strain MES lead to new bone formation (modeling) until strain values decrease below modeling MES by increase in bone mass. Rapid catastrophic fracture is caused by peak load levels >25,000 μ-strain. Twenty-five thousand microns-strain corresponds to a stress of 130 megapascals (130 N/mm²) or 16,000 Lbs/square inch.[9]

When mechanostat theory, adopted to tabulate the stress generated around the implants in this numerical study, the red zone depicts the range of force, around and above which the pathological fracture may occur in the bone. Moreover, the yellow and green zone depicts the modeling and remodeling zone, and finally, the orange zone depicts the zone of disuse atrophy.[26] The stresses generated were tabulated accordingly [Figure 3].

Thus, this classification is designed which states the minimum required size of an implant that is the minimum length and diameter of the implant required to bear a particular masticatory load of that particular individual. According to the classification, for an individual with 700 N of masticatory force, the minimum implant dimensions required may be 4.5 mm × 12 mm, 5.0 mm × 12 mm, 5.5 mm × 10 mm, 6.0 mm × 10 mm, for an individual with 600 N of masticatory force the minimum implant dimensions required may be 4.0 mm × 12 mm, 4.5 mm × 8 mm, 5.0 mm × 10 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm, for an individual with 550 N of masticatory force the minimum implant dimensions required may be 3.0 mm × 14 mm, 3.5 mm × 12 mm, 4.0 mm × 12 mm, 4.5 mm × 8 mm, 5.0 mm × 8 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm, for an individual with 500 N of masticatory force the minimum implant dimensions required may be 3.0 mm × 12 mm, 3.5 mm × 10 mm, 4.0 mm × 8 mm, 4.5 mm × 8 mm, 5.0 mm × 8 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm, for an individual with 450 N of masticatory force the minimum implant dimensions required may be 3.0 mm × 10 mm, 3.5 mm × 8 mm, 4.0 mm × 8 mm, 4.5 mm × 8 mm, 5.0 mm × 8 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm, for an individual with 400 N of masticatory force the minimum implant dimensions required may be 3.0 mm × 8 mm, 3.5 mm × 8 mm, 4.0 mm × 8 mm, 4.5 mm × 8 mm, 5.0 mm × 8 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm, and for an individual with 350–500 N of masticatory force the minimum implant dimensions required may be 3.0 mm × 8 mm, 3.5 mm × 8 mm, 4.0 mm × 8 mm, 4.5 mm × 8 mm, 5.0 mm × 8 mm, 5.5 mm × 8 mm, 6.0 mm × 8 mm [Figure 4].

Classification can be read as, for a patient with masticatory force of 700 N, minimum size of dental implant choice could be 4.5 mm × 14 mm, 5.5 mm × 12 mm, 6.0 mm × 10 mm. If a 4.5 mm diameter implant is planned, then the minimum length of choice should be 14 mm or above or for 5 mm diameter implant, minimum length of the implant should be 12 mm or above or if 5.5 mm diameter implant used length should be 10 mm or above. This selection of dental implant dimension will be purely based on is masticatory load. The masticatory bite of the individual patients needs to record with the strain gauges such as T-scan.[27]

Figure 3: The correlation of stress on bone by various sizes of dental implants with various zones of mechanostat theory where red depicts the zone of catastrophic fracture, green and yellow depicts the zone of modeling and remodeling, and orange zone depicts the zone of disuse atrophy

Figure 4: Classification chart showing the implant selection based on the masticatory load
Limitation of the classification

1. The present classification is limited for unilateral single and multiple teeth replacements, as the counter-lateral side masticatory load with the complete set of existing teeth will be taken into consideration.
2. For recording the masticatory bite, a full arch bite gauge is required.
3. Further research is required in this regard to assess the masticatory load in complete edentulous patients, which could be based on the tonicity of the muscle of mastication.

Conclusion

Within the limitations of this numerical analysis, the following conclusions can be made:
1. The stress generated in the bone, on application of different amount of the load through same implant dimension is different.
2. By increasing the dimension of the implants, the amount of stress generated in the bone can be reduced.
3. Selections of implant dimensions based on the masticatory load of an individual can reduce the over stress in the bone minimizing stress-induced complications.

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Conflicts of interest

There are no conflicts of interest.

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