Original Article

Finite Element Analysis

Follow Up of Short and Standard-Length Dental Implants Retaining Mandibular Kennedy Class I Removable Partial Dentures

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ABSTRACT

Objective: Short dental implants (6 mm or less) can present a replacement to standard length dental implants (more than 6 mm) in atrophic edentulous ridges with no augmentation procedures. The aim of the current work was to evaluate the clinical performance of short dental implants assisting mandibular free end partial dentures and study the stresses generated around them after 3 years of loading.

Study Design: Controlled clinical trial study

Place and Duration of Study: This study was conducted at the Department of Prosthetic Dental Sciences in the College of Dentistry, Qassim University, KSA, for a period of more than 3 years, starting August 2020 to November 2023.

Methods: The current work represented a prospective observational study which implemented clinical evaluation and stress analysis using finite element analysis of the short implants assisting mandibular free end partial dentures, placed once at the location of the missing first molar, and once at the location in the missing second molar, on the right side of the edentulous ridges with long implants placed on the left sides

Results: The short implants placed at the locations of second molars had more vertical bone loss, less bone density profile, and more stress concentrations than those placed at the locations of the first molars. Similarly, the long implants had the same results, however, their values were better than those of related short implants

Conclusion: After three years of loading, short dental implants were still clinically successful in supporting class I Kennedy mandibular free end partial dentures, with implants placed at the locations of the first molars having better vertical bone loss and stress distribution than those placed at the locations of second molars.

Key Words: Short Dental Implants, Free End RPD, Follow-Up, Finite Element Analysis

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INTRODUCTION

Short dental implants provided a successful replacement of standard-length dental implants in situations that otherwise needed bone augmentation,[1-3] and have shown clinical success for up to 10 years.[4-6] Finite element stress analysis have also shown success of short implants, whether splinted or not, as compared to standard length implants, inserted with the same insertion torque, and used for support of full arch restorations.[7-14]

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However, claims about the location of the implants, marginal bone loss, rate of failure, stress concentration related to decreased length, and response to axial and oblique loading,[15-24] were the motives to conduct the current study.

METHODS

The current work represented a prospective observational study, where standard length and short dental implants assisting distal extension mandibular class I Kennedy removable partial dentures (Fig. 1A) were evaluated after 3 years of function for plaque index, pocket or probing depth, implant stability using the periotest, and radiographic examination which included determination of the peri-implant vertical bone loss, and bone density profile using standardized digital peri-apical x-rays and stress analysis using finite element analysis.

Originally, before beginning of the study, ethical approval was obtained, which approved the use of one short implant on one side of the arch and a standard-length implant on the contralateral side, and patients signed an informed consent that explained the use of one short implant under their removable partial dentures. The number of the patients participated in this study was determined using convenience sampling, where the patients were blindly divided into two groups, in group I, ten patients had one short implant (6 mm long and 4 mm width, Astra tech) placed at the approximate site of the missing first molar (Fig. 1B), and one long implant (10 mm long and 4 mm width, Astra tech) placed at the approximate site of the missing first molar, whereas in group II the same number of patients had the same implants distribution, but placed at the approximate site of the missing second molar. (Fig. 1C).

For assessment of the vertical bone loss, the x-ray images were made using a film holding device (SIRONA) for extension cone paralleling technique, and the vertical bone loss was assessed by the linear measurement tool of the SIDEXIS software, attached to the Sirona digital X-ray machine, which measured the span from the surface of the alveolar bone next to the implant up to the implant shoulder. The recorded vertical bone loss readings were statistically analyzed using the paired *t* test. For assessment of the bone density profile, the SIDEXIS software utilized a gray scale of 0-255, where a vertical line was drawn almost contacting the implant mesial and distal sides (Fig. 1D), giving readings of the bone gray scale. The average readings from the mesial and distal sides were recorded and statistically analyzed also using the paired *t* test.

Finite element analysis (FEA) was used for stress analysis around the implants used in this study, where a 3-D FEA model was constructed for the dental implants and investing alveolar bone from cone beam computed tomography (CBCT) scans of every patient, where the para-axial cuts were made to show scans in a buccolingual direction as seen in Figure 2. Then computer software (ANSYS 10) used the CBCT cuts to develop the patient specific 3-D model.

The elastic moduli of each structure composing the three-dimensional digital model were determined (table 1), and the nature of the structures composing the three-dimensional digital model was set to be anisotropic. Finally, the magnitude, direction and the mode of the applied occlusal forces were set to a vertical load of 100 N and an oblique load of 70 N and the resulting color map (von Mises) revealed the magnitude of stresses around each implant.

RESULTS

Comparison of the means of plaque index, probing depth, and mobility revealed no statistically significant differences between the implants within each group and between group I and II as seen in table 2, however, the radiographic evaluation revealed that the mean vertical bone loss (mm) was significantly greater for short implants than that for long implants within each group, and significantly greater for both short and long implants in group II as compared to those in group I. (table 2)

Statistical analysis of the bone density measurement three years after loading revealed that it was significantly lower for short implants than long implants within each group, and significantly lower for long and short implants of group II as compared to those of group I on individual basis and as a whole when all implants of group II were compared to all implants of group I as seen in table 3.

Comparison of the finite element analysis stress distribution revealed no differences between group I and II in the peri-implant bone response under axial loading, however, under oblique loading the von Mises stress distribution results conformed to the radiographic findings, where long implants of group I had the least stress concentration in the surrounding bone with stresses concentrated more on the lingual than the buccal side of the implants (Fig. 3A), followed by long implants of group II (Fig. 3B) which had more stresses on both the lingual and buccal sides on the implants, then, short implants of group I, which had an increasing pattern of surrounding stresses on the lingual and buccal sides of the implants(Fig. 3C), and finally short implants of group II which had the highest stress concentration in its surrounding bone (Fig. 3D), and highest bending in a buccolingual direction of the implant abutment as seen in figure 3E.

Table No.1: Material properties inputs for finite element analysis.

Material	Young's modulus E (MPa)	Poission's ratio
Cortical bone	15000	0.3
Cancellous bone	1500	0.3
Titanium implant	110000	0.35

Table No.2: Descriptive (mean and standard deviation SD) and statistical analysis (p value) of the three years follow-up of the short and long implants

		Group I			Group II			Group I versus Group II (p)		
		Long implants	Short implants		Long implants	Short implants		Long implants	Short implants	All implants
Plaque index	Mean	1.2	1.5	0.07	0.813	1.167	0.08	0.06	0.08	1
	SD	0.404	0.753		0.239	0.408				
Probing depth	Mean	1.7	1.8	0.08	2	2.3	0.06	1	0.07	0.08
	SD	0.522	0.546		0.498	0.425				
Mobility	Mean	-4.3	-3.2	0.06	-4.1	-2.9	0.09	0.07	0.08	0.08

	SD	1.11	1.37		1.45	1.56				
Vertical bone loss	Mean	1.7	1.8	0.07	1.9	2.1	0.06	0.04	0.02	0.03
	SD	0.654	0.524		0.521	0.389				

Table No.3: Descriptive and statistical analysis (p value) of bone density profile within each group and between groups after 3 years of loading

	Group I			Group II			Group I versus group II		
	Long implants	Short implants	p	Long implants	Short implants	p	Long implants	Short implants	All implants
Range	237-238	190-234	0.03	198-235	155-199	0.01	0.04	0.01	0.02
Mean	235.2	210.5		215.2	172				
Standard deviation	232.1	227.5		228.4	189.3				
Median	235	220		228	172				

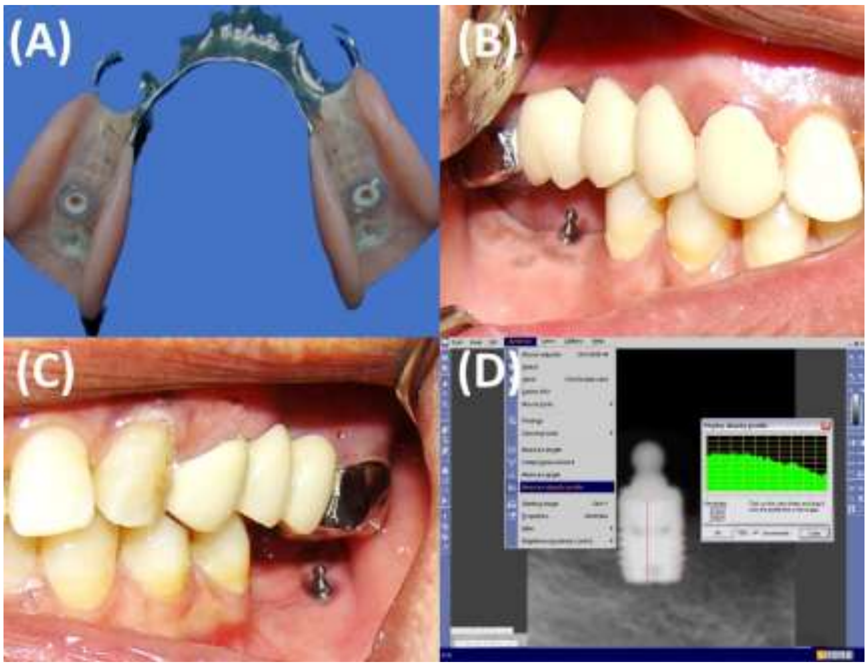

Figure No.1: A, intaglio surface of the RPD. B, Short dental implant placed at the location of the first molar in one of group I cases. C, long dental implant placed at the location of the second molar in one of group II cases. D, Measuring the bone density profile.

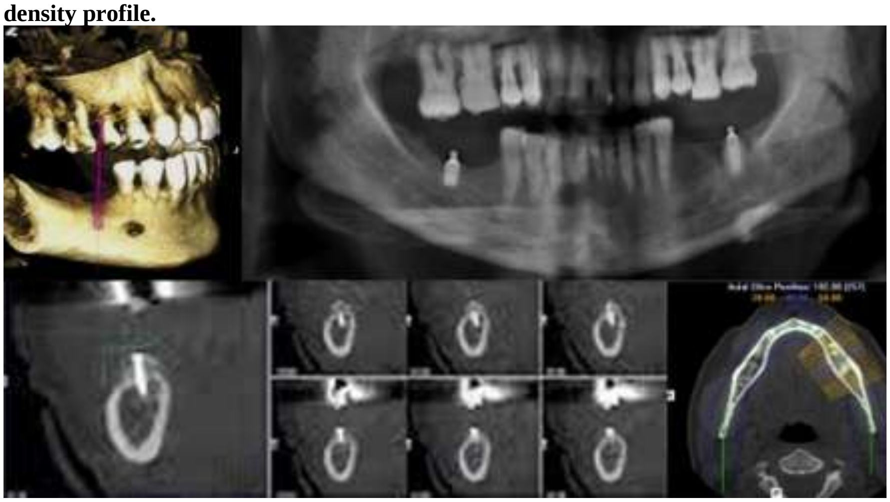

Figure No.2: Cone beam computed tomography (CBCT) showing the reconstructed three-dimensional model of one of the patients, the panoramic view, and the para-axial cuts.

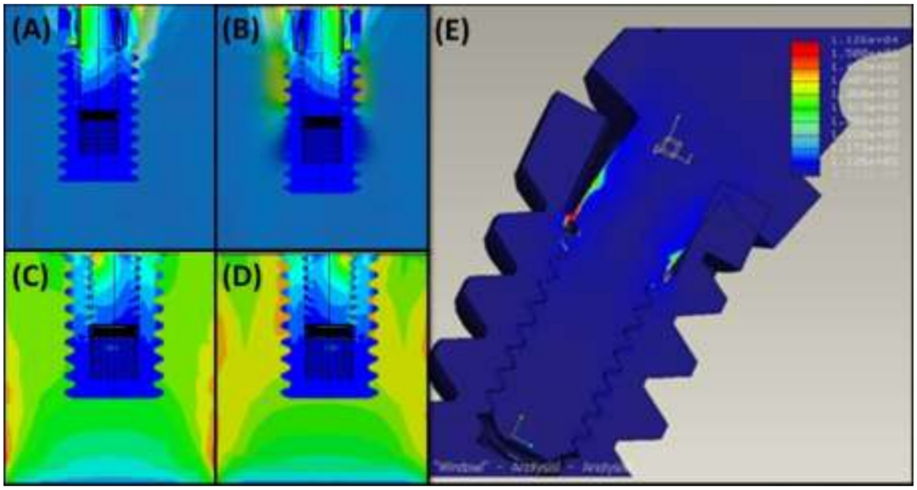

Figure No.3: Stress distribution around implants in group I and II: A. long implants of group I, B. long implants of group II, C. short implants of group I, D. short implants of group II, E. buccolingual flection of group II short implants abutments.

DISCUSSION

When the implants used in this study were followed-up after one year of loading, there was no statistically significant differences between short and long implants in both groups in regards to the plaque index, pocket or probing depth, implant stability, and vertical bone loss. However, the only significant difference was the higher bone density profile for long implants in group I as compared to short implants in the same group, and the higher bone density profile for implants in group I as compared to group II implants.[5] After three years of loading, there was no statistically significant differences between short and long implants in both groups in regards to the plaque index, pocket or probing depth, implant stability, however, both vertical bone loss and bone density profile had better values for group I implants. This came in contrast to the findings of Sun et al[17] and Lemos et al[18] who reported that short implants had marginal bone loss similar to standard length implants, and in accordance with Li et al[10] who concluded that short implants do not present superior performance as compared to conventional long implants.

In contrast to Hegazy et al[21] who suggested distal rather than mesial placement of the implants, the findings of this study suggested more favorable stress distribution around short and long implants placed in the first molar region compared to those placed in the second molar region, which could be subjected to the more buccolingual movement of the removable partial denture free end. Also as concluded by Qin S, Gao[7] that non-splinted short implants placed more distal regions can be subjected to more stresses as the implant length decreased.

In regards to splinting, Zupancic et al[23] suggested splinted over non-splinted short implants. Also, Talreja et al[11] suggested splinting of short implants provided better resistance to oblique loading conditions. However, this could be true for short implants supporting fixed prostheses, but for short implants under removable prostheses, it is possible that bilateral occlusal loading could minimize the oblique forces, that were also shared by the composite support obtained from the occlusal rests and the free end residual ridges as explained by Shahmiri et al.[20]

The finite element stress analysis in this study found more stress concentration around short implants, specifically in group II at the end of the edentulous ridges, a finding that came in agreement with Araki et al,[22] and Yang et al[24] who emphasized the effect of oblique loading on the generation of such stresses. These findings could give the impression that short implants have higher rates of failure in clinical service in 1 to 5 years as suggested by Papaspyridakos et al,[19] however, the short implants in this study did not show any signs of failure, and are to be followed up for further periods, a situation similar to the findings of Anitua and Alkhraisat[9] who followed up forty-one short implants for 3, 6, and 15 years.

In conclusion, the current work reported less vertical bone loss and better stress distribution around short implants placed at the sites of first molars rather than second molars under free end removable partial dentures, however, the limitations of this study might have effects on the results in case of duplication of the same clinical trial, these limitations might include the use of one of the followings: 1) a larger sample size, 2) implants with different diameter sizes or thread designs, 3) a different super-structure attachment other than ball abutments, such as locators or magnets, 4) a different occlusal scheme for the prostheses such as lingualized cusp occlusion to minimize lateral stresses, and finally, 5) a longer follow-up durations.

CONCLUSION

After three years of loading, short dental implants were still clinically successful in supporting class I Kennedy mandibular free end partial dentures, with implants placed at the locations of the first molars having better vertical bone loss and stress distribution than those placed at the locations of second molars.

Author's Contribution:

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Data Analysis:	Mohamed Ahmed Alkhodary
Revisiting Critically:	Mohamed Ahmed Alkhodary
Final Approval of version:	Mohamed Ahmed Alkhodary

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