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Effect of implant diameter and cantilever length on the marginal bone height changes and stability of implants supporting screw retained prostheses: A randomized double blinded control trial

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PURPOSE. This randomized controlled trial aimed to evaluate the effect of implants' two different diameters and cantilever lengths on the marginal bone loss and stability of mplants supporting maxillary prostheses. **MATERIALS AND METHODS.** Ninety-six implants were placed in sixteen completely edentulous maxillary ridges. Patients were randomly divided into two groups: Group A, implants were placed with a cantilever to anterior-posterior AP spread length (CL:AP) at a ratio of 1:3; Group B, implants were placed with a CL:AP at a ratio of 1:2. Patients were further divided into four sub-groups: Groups A1, A2, B1, and B2. Groups A1 and B1 received small diameter implants while Groups A2 and B2 received standard diameter implants. Bone height and stability measurements around each implant were performed at 0, 4, 8 and 24 months after definitive prostheses delivery. **RESULTS.** Statistical analysis of the mean implant stability and height values revealed an insignificant difference between Group A1 and Group A2 at all the different time intervals while significantly higher values in Group B1 in comparison with Group B2. Results also showed significantly higher values in Group A1 in comparison with Group B1 and an insignificant difference between Group A2 and Group B2 at all the different time intervals. **CONCLUSION.** It can be concluded that the use of small diameter implants placed with a CL:AP at a ratio of 1:3 provided predictable results and that the 1:2 CL:AP significantly induced more critical bone loss in the small diameter implants group, which can significantly reduce long term success and survival of implants [J Adv Prosthodont 2023;15:101-13]

KEYWORDS
Edentulous maxilla; Small diameter implant; Screw retained restoration

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INTRODUCTION

Small diameter or mini dental implants have been successfully used to support removable and fixed oral prostheses.[1,2] In comparison to standard sized implants, a small diameter implant offers less of a barrier to angiogenesis and results in less percutaneous exposure and bone displacement if proper prosthetic restorations are delivered and clinical recommendations are followed.[3,4] According to Schiegnitz *et al*.,[5] the use of narrow diameter implants has been demonstrated to increase therapy alternatives, prevent more invasive procedures, decrease patient morbidity, and minimize treatment time. In addition, González-Valls *et al*.[6] systematic review on small diameter implants (SDIs) concluded that narrow diameter implants (NDIs) is a predictable treatment choice due to their good survival, success, and tolerable bone loss rates, which are comparable to those of SDIs.

Narrow diameter implants may be more susceptible to overload, and therefore implants with greater tensile and stiffness are warranted. According to Al-Nawas *et al*.,[7] utilizing narrow diameter titanium alloy implants for two years, the survival and success rates were 97.8% and 97.6%, respectively. In a subsequent trial by Polack and Arzadon,[8] immediate loading of a titanium zirconium small diameter implant demonstrated high success rates. In contrast, 98.3 - 99.4% of small-diameter and mini dental implants in another study[9] survived for at least five years. Less surgical time, less postoperative pain, possible direct loading after surgery with no harm to the bone, and cost effectiveness are the advantages of these implants.[10]

Klein *et al*.[11] divided narrow dental implants into three categories: Category 1: 3.0 mm, Category 2: 3.0-3.25 mm, and Category 3: 3.30 - 3.50 mm. In their systematic analysis, Schiegnitz and Al-Nawas[12] found no significant difference in survival rates between narrow implants of category 2 and conventional diameter implants.

Cantilever length (CL)[13] is the segment of superstructure extending distal to the most posterior implant, while anteroposterior (AP) spread provides a rough estimate of the implant geometric distribution, which is measured from the distance between the line connecting the two most anterior implants and a line drawn between the two most posterior implants. AP spread of at least 10 mm was recommended for a cantilever of 20 mm for a mandibular implant supported prosthesis proposed by Maló *et al*.,[14] for managing occlusal loads on implants and prostheses.

In a highly rational rule of thumb, English[15] suggested that the posterior cantilever in a mandibular implant supported prosthesis should be 1.5 times the AP-spread (about 10 - 12 mm for the mandible), while the posterior cantilever in a maxilla should be lowered to 6 - 8 mm due to poor bone density. Another study recommended multiplying the AP spread by 1.5 - 2.5% to get a general idea of how long a distal cantilever could be appropriate.[16] When determining how long a cantilever is appropriate for a given patient circumstance, other aspects must be considered, including the patient's age, gender, and opposing dentition.[16]

Recording the changes in marginal bone height surrounding the implants serves as one of the long term clinical evaluations to assess effective osseointegration. Loss of bone height around the osseointegrated implant would occur if changes in marginal bone levels went beyond physiologic limits. Bone loss of about 1.5 mm after the first year of loading with an additional 0.2 mm amount of bone loss per year is determined to be within the physiologic limits.[17,18]

This randomized controlled trial aimed to evaluate the effect of implants' two different diameters (small versus standard diameter) and two different cantilever lengths to AP spread ratios on the marginal bone loss and stability of implants supporting maxillary prostheses.

MATERIALS AND METHODS

In this randomized control trial, sixteen male patients were recruited based on an inclusion criterion that required them to have fully edentulous ridges, a normal maxillomandibular relationship (Class I Angle classification), no para functional habits, and systematically free from any medical conditions. Patients who met the criteria signed the consent form according to the ethical principles stated in the Helsinki Declaration (https://www.wma.net) indicating their approval to

be involved in this study and undergoing surgical procedures of implant placement. Ethical approval was also obtained from the Ethical Approval Committee in the Faculty of Dentistry, Cairo University.

Sample size calculation was performed according to a study[19] that compared the marginal bone height changes around implants supporting full arch maxillary prostheses placed with different cantilever length after a two year follow up period. A clinical important difference based on expert opinion of 0.4 was used. Independent *t*-test with a power of 80% and .05 alpha significance was used for sample size calculation, and 7 patients were reported in each group, with a total of 14 patients. 10% was added to compensate for drop outs with 8 patients per group with a total of 16 patients.

In sixteen patients, a total of 96 fixtures were implanted, over which screw-retained implant-supported maxillary prostheses were constructed. Using sealed envelopes, the patients were randomly divided into two groups:

Group A: implants (ScrewIndirect implants; Implant Direct Sybron International, Thousand Oaks, CA, USA) were placed with a cantilever length to AP spread (CL:AP) at a ratio of 1:3. Patients in Group A were further divided randomly into two sub-groups:

- Group A1 received small diameter (3.0 mm) implants and
- Group A2 received standard diameter (3.7 mm) implants.

Group B: implants (ScrewIndirect implants; Implant Direct Sybron International, Thousand Oaks, CA, USA) were placed with a cantilever length to AP spread (CL:AP) at a ratio of 1:2. Likewise, patients in Group B were further divided randomly into two sub-groups:

- Group B1 received small diameter (3.0 mm) implants
- Group B2 received standard diameter (3.7 mm) implants.

All patients included in this study received conventional maxillary full dentures after a six week adaption period. To create radio opaque scan appliances, the maxillary dentures were duplicated using a mixture of translucent self-cured acrylic resin powder (Pattern Resin; GC America Inc., Alsip, IL, USA) and amalgam powder. Cone-beam computed tomography (CBCT) scanning device (SCANORA® 3Dx; Soredex, Helsinki, Finland) was used to take 3D radiographic images of the patients' maxillae. Patients were asked to wear their stents while biting on an occlusal index specially fabricated for each patient to separate the mandibular teeth from the stent. The occlusal index also helps the patients bite in centric occluding relation in a reproducible and standardized position every time during imaging. The Mimics program (Mimics Software version 14.1; Materialise HQ, Leuven, Belgium) was utilized to obtain axial, coronal, and sagittal reformatting, as well as panoramic views after the DICOM files from the CBCT scan were loaded onto the program. The radiolucent channels that were previously prepared in the radiographic stent at the centres of the prosthetic teeth facilitated the localization of the desired implant sites.

According to the available bone height and width at the desired implant sites, six implants were planned in the lateral incisor/canine region, first premolar region, and first molar region (Fig. 1). The Mimics software was used to design the computer guided surgical stents where first importing of the virtual sterolithiographic (STL) files of the implants was performed followed by virtual planning of the implants at the suggested implant sites. The resultant STL files were exported as a 3D virtual stent (Fig. 1), which were in turn sent for 3D printing (Invision Si2; Valencia, CA, USA). The 3D printed computer guided stent was then tried in the patient's mouth to check stability and fit after which metallic sleeves were inserted into their corresponding designed holes.

Before beginning the surgical process, the patient's perioral area was cleaned with Betadine antiseptic solution (povidone-iodine, 10%) (Avrio Health L.P., New York, NY, USA), the surgical tools were autoclaved, and the computer-guided stent was cleaned with an appropriate disinfectant. At the time of the surgical operation, infiltration anaesthesia (Ubestesin; 3M ESPE, Seefeld, Germany) was injected at each implant location. Three fixation screws (Biomet M Fix, Zimmer Biomet, Warsaw, IN, USA) were used to secure the stent in place. Following that, osteotomies were prepared using a specific drill guide using the traditional drilling sequence (pilot, intermediate,

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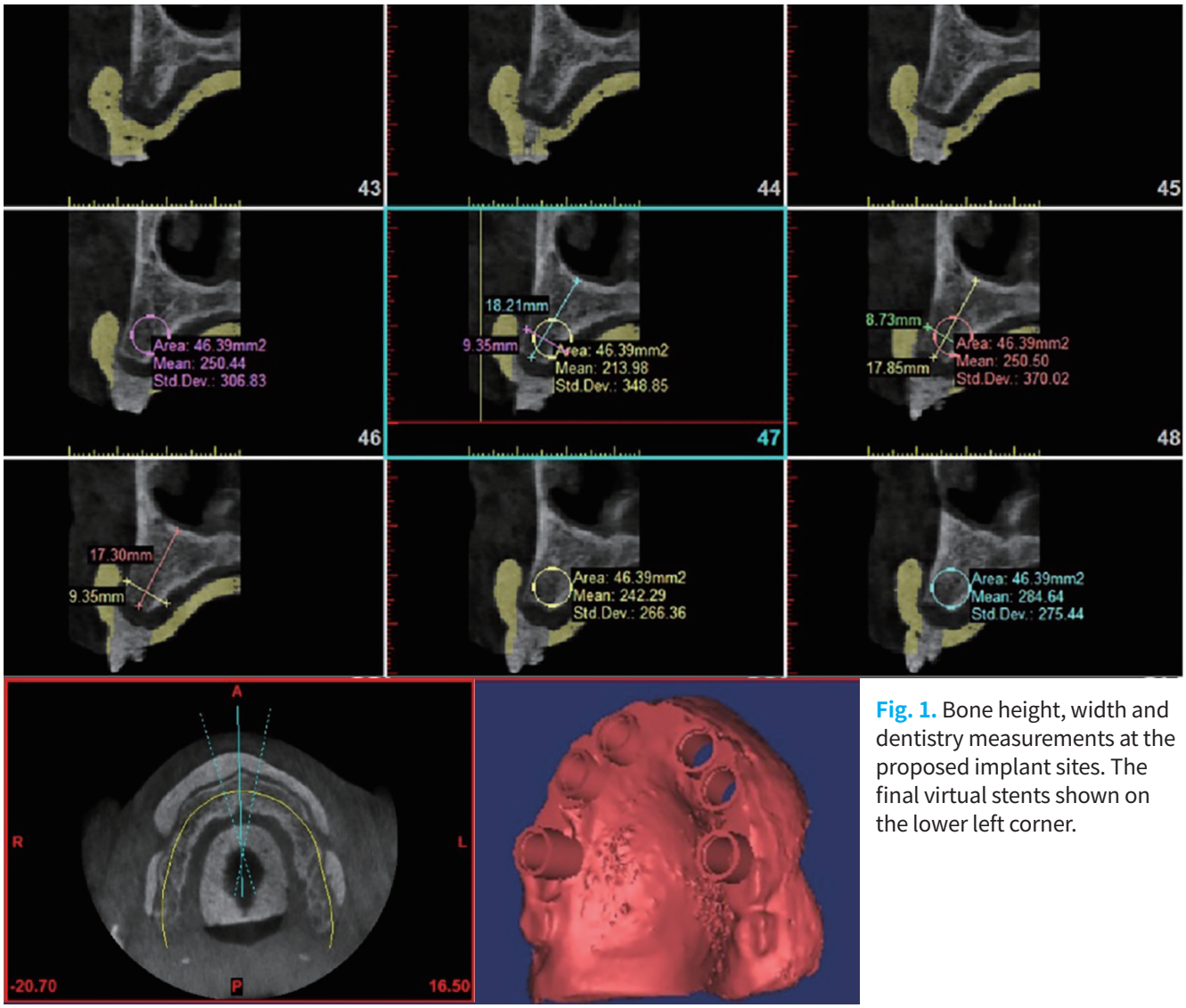

Fig. 1. Bone height, width and dentistry measurements at the proposed implant sites. The final virtual stents shown on the lower left corner.

and final drills) as shown in Figure 2A, while irrigating with sterile saline solution after each drill (Fig. 2A). The implants (ScrewIndirect implants; Implant Direct Sybron International, Thousand Oaks, CA, USA) were then opened and manually placed through the stent before being further tightened with a ratchet while utilizing a depth-controlling implant driver (Fig. 2B). Using the Osstell Implant Stability Quotient (ISQ) device (Osstell AB, Göteborg, Sweden), the primary stability of each implant was tested to be between 55-65

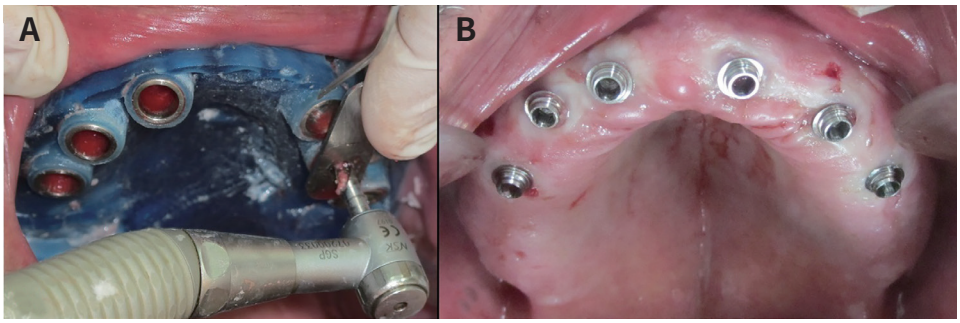

Fig. 2. (A) Osteotomy performed using the conventional drilling sequence (pilot, intermediate and final drills), (B) Implants after being surgically installed and stent retrieved.

ISQ.

Patients were recalled after 4-6 months, and the implants were examined again using the Osstell ISQ sensor to ensure acceptable implant stability and osseointegration. Preliminary impressions were then taken using a closed tray technique with a medium body monophase polyether impression material (Identium Medium; Kettenbach, Eschenburg, Germany). The implant analogues were then connected to the transfer copings within the impression, which was then poured with extra hard stone.

The implant analogues (ScrewIndirect implants; Implant Direct Sybron International, Thousand Oaks, CA, USA) within the primary cast were then attached with temporary titanium abutments and a verification jig was fabricated using DuraLay resin (DuraLay; Reliance Dental MFG Co., Worth, IL, USA). The verification jig was then screwed over the implants intraorally to check for passivity utilizing the single screw test. Sectioning of the verification jig was warranted if lack of passivity was detected at any implant site followed by reconnection with Duralay as shown in Figure 3A. After complete setting of the Duralay, passive fit was then rechecked finally using the single screw test.

Secondary impressions with a medium body monophase polyether impression material (Identium Medium; Kettenbach Co., Eschenburg, Germany) using an open tray impression technique was performed utilizing the modified radiographic stents as special trays. Temporary titanium abutments were screwed over the implants intraorally, connected together with dental floss and Duralay. Then, injection of medium consistency silicone elastomeric impression material was used to record the secondary impressions. Implant analogues were screwed over the temporary titanium abutments within the final impression, and then pouring of the master cast was done.

In this randomized controlled trial, AP spread for each of the 16 cases recruited in this study was measured utilizing two straight rulers where one ruler was laid across the center of the right and left anterior implants screw access holes and the second ruler was laid across the center of the right and left posterior implants screw access holes (Fig. 3B). Then, using a Boley gauge, the distance between the two straight anterior and posterior lines were measured in millimeters to obtain the exact AP spread of each of the 16 cases recruited in this study (Fig. 3B). At this point, patients in Groups 1 (with small diameter implants) and patients in Group 2 (with standard diameter implants) who were already blinded from the primary investigator were further randomized into two sub-groups; Group A received cantilever to AP spread ratio of 1:3 and Group B received cantilever to AP spread ratio of 1:2. The laboratory technician involved in this study was given the task of concealing the subjects' name, randomizing them into each group and giving them codes in sealed envelopes. The length of the cantilever segments were fabricated for each case according to the group that they were sorted in from the beginning, i.e. Group A or B and according to the AP spread measurement recorded for each patient (Fig. 4A, B). This procedure was performed during the next step, which is the waxing up of the frameworks.

Six plastic castable abutments (ScrewIndirect implants; Implant Direct Sybron International, Thousand Oaks, CA, USA) were fastened over the six implant analogues within each master cast, and then waxed up according to guidelines explained above for each patient randomized into each group (Fig. 4C, D). This is followed by investment, wax elimination, and then cast into chrome-cobalt alloy using the tradition-

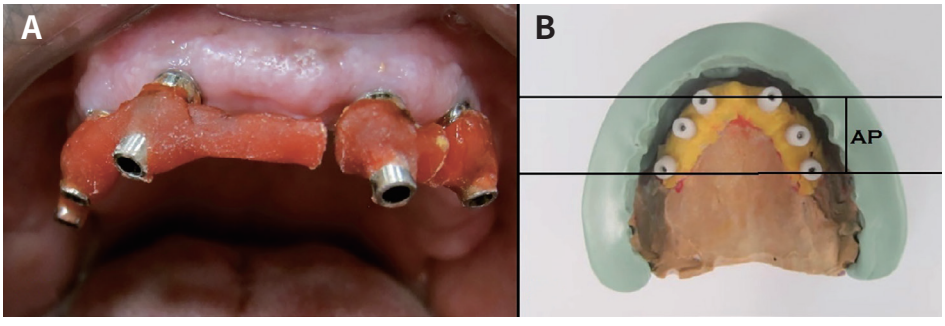

Fig. 3. (A) Verification jig checked for passivity intraorally and sectioned in areas of nonpassivity. (B) Plastic abutments fixed firmly to the implant analogs in the master cast and AP spread for each case being measured.

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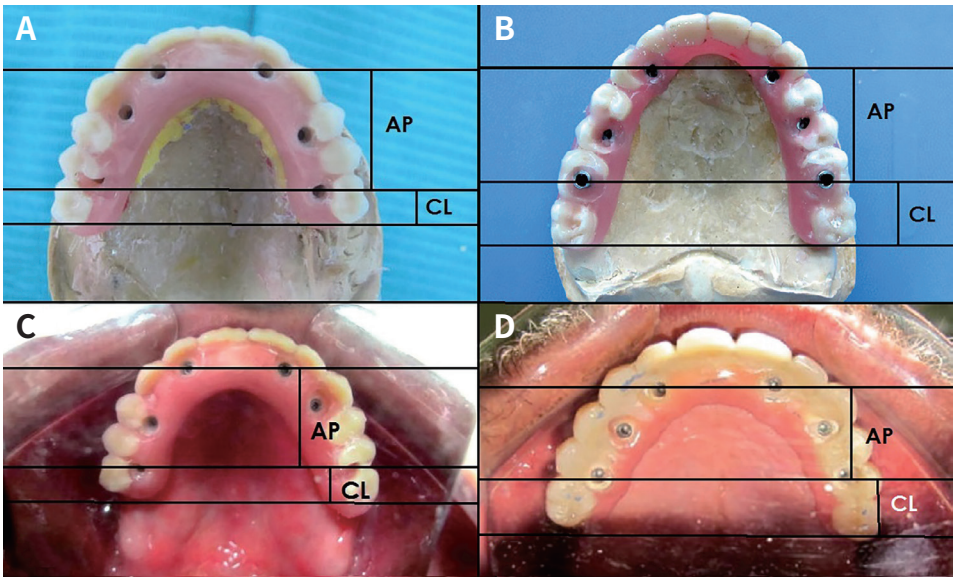

Fig. 4. (A) Restoration fabricated on the cast with CL (cantilever length) to AP (Antero-posterior) Spread CL:AP ratio of 1:3. (B) Restoration fabricated on the cast with CL:AP ratio of 1:2. (C) The screw retained implant supported prostheses delivered in the patient's mouth for Group A. (D) The screw retained implant supported prostheses delivered in the patient's mouth for Group B.

al casting procedure. Metal try-in of the superstructure frameworks for all patients involved in this study were checked intraorally for fit and passivity using the single screw test. If lack of passivity was detected during the try-in stage, sectioning of the framework, followed by secure fastening the sectioned frameworks to the implants, and reconnecting with Duralay resin and soldering was performed.

Centric occluding relation was then registered utilizing sheets of baseplate wax, followed by mounting of maxillary and mandibular master casts on an articulator. Setting of acrylic teeth over the frameworks was done following the IPO guidelines suggested by Misch's (Fig. 4A, B).[13] The gingiva was created using Visio-lign Veneering (Visio-lign; Bredent GmbH & KG, WeissenhornerSenden, Germany) light cured system utilizing a free-hand technique (Fig. 4A, B).

The screw retained implant supported prostheses were screwed intraorally once the build-up was accomplished, and occlusal modifications were done in both groups (Fig. 4C, D). Using a torque wrench, the implant prosthetic screws were tightened to 30 Ncm. Rubber pieces were used to partially seal the access holes, and light-cured composite resin was used to restore normal occlusion with the opposing mandibular teeth for final delivery of the implant supported screw retained maxillary prostheses in all groups (Fig. 5A, B).

In this trial, four follow-ups were performed using the RFA Osstell device and CBCT (SCANORA 3Dx; Soredex, Helsinki, Finland) at 0 (time of prosthesis delivery), 4, 8, and 24 months after final prostheses delivery. The raw DICOM data from the CBCT scans was imported into a specialized third-party software (On-Demand 3D version 1.0.9; Cybermed, Seoul, South Korea) in order to assess the marginal bone height. A virtual line drawn parallel to the mesial, distal, buccal, and lingual aspect of each implant was used to measure the distance between the most crestal point of contact between the bone and the implant and the most apical point of contact between the bone and the implant (Fig. 6). Additionally, implant stability

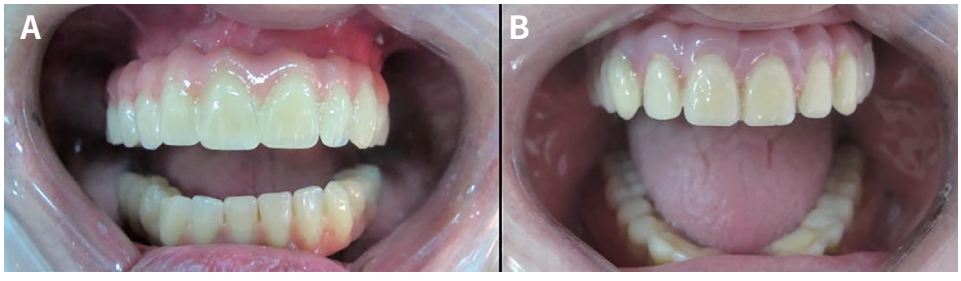

Fig. 5. Frontal view of the screw retained implant supported prostheses being delivered in the patient's mouth. (A) Group 1, (B) Group 2.

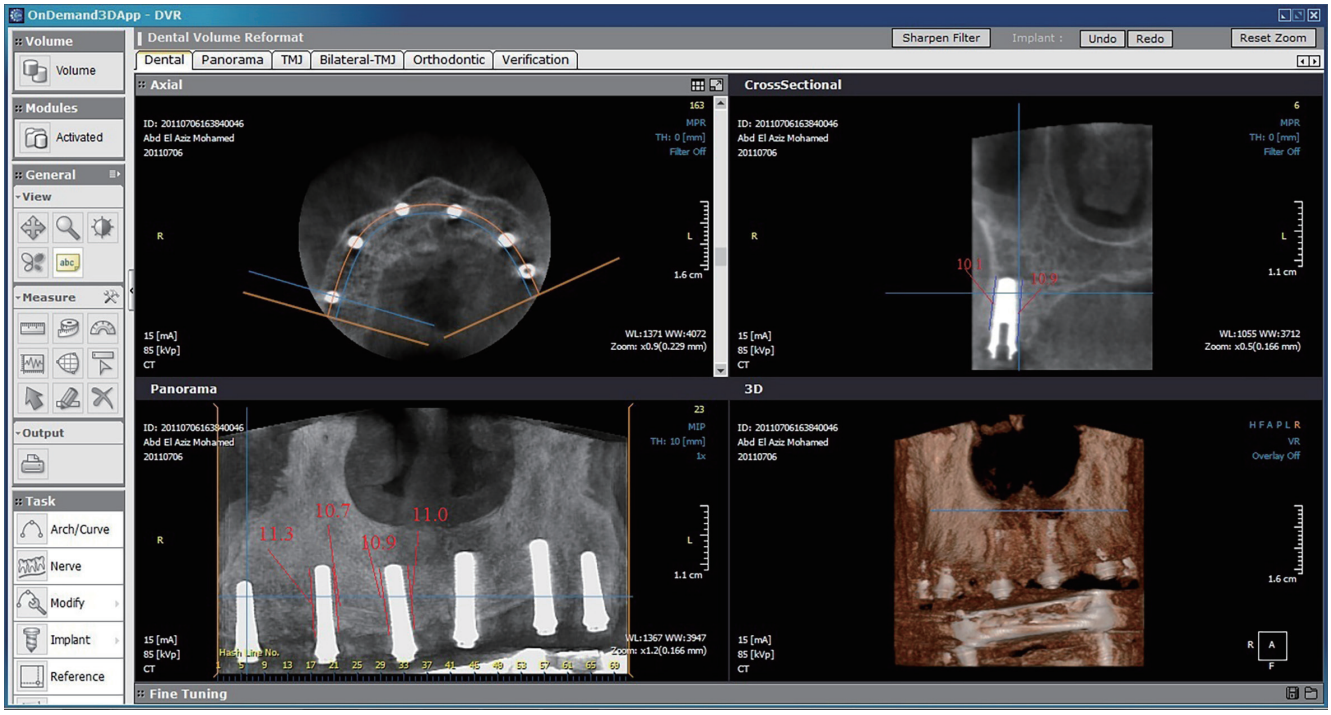

Fig. 6. Buccal, lingual, mesial and distal bone height measurements at the axial and panoramic reformatted images.

values were obtained at the mid-mesial, mid-distal, mid-buccal, and mid-lingual aspect of each implant in all groups using the resonance frequency analysis the Osstell ISQ device (Osstell AB, Göteborg, Sweden). Results obtained from the data sets were tabulated, compared to each other, and then statistically analyzed.

Statistical analysis was performed with SPSS version 20 (IBM, Cary, NC, USA), GraphPad Prism® version 8.0.2 (Dotmatics Insightful Science, Boston, MA, USA) and Microsoft Excel 2016 (Redmond, WA, USA). All data were analyzed for normality by using Shapiro Wilk and Kolmogorov Normality test and presented as mean difference and standard deviation (SD) values.

RESULTS

In this work, the effect of combining two different implant diameters with two different cantilever lengths on the hard tissue supporting structures of implants inserted in the maxilla was statistically evaluated. A total of 96 implants were placed in 16 patients over which screw retained implant supported maxillary prosthesis were fabricated. Each patient received six implants, which were nominated from 1 to 6 starting from the right hand side to the left hand side of each patient.

Bone height and implant stability measurements surrounding each implant were used to evaluate the hard tissue reactions in both groups at 0, 4, 8, and 24 months after definitive prostheses delivery. A total of 95 implants were considered osseointegrated with a total success rate of 98.96% (one implant failed in Group B1) according to the standards of osseointegration declared in the ICOI.[18]

Osstell Implant Stability Values: Osstell implant stability mean values and standard deviation of all groups at different time intervals were presented in Table 1. Statistical analysis between Groups 1 and 2 was performed using the independent *t*-test regarding Groups A and B at the different time intervals, which revealed insignificant difference between Group A1 & Group A2 at all the different time intervals as $P > .05$. However, statistical analysis revealed significant difference between Group B1 and Group B2 at all time intervals as $P < .05$ where the mean Osstell implant stability values in Group B2 were significantly higher than Group B1.

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Table 1. Mean and standard deviation of the marginal bone height values and Osstell implant stability values in all groups at different time intervals

			Subgroup 1		Subgroup 2		*P* value
			M	SD	M	SD	
Osstell implant stability values	Baseline	Group A	67.06	0.39	63.53	3.56	.09
		Group B	62.21	2.78	66.99	0.16	.01*
		P value	.01*		.1		
	After 4 months	Group A	64.22	2.25	60.71	1.79	.06
		Group B	55.86	1.58	60.70	3.67	.04*
		P value	.0009*		.99		
	After 8 months	Group A	57.75	3.36	62.38	3.32	.09
		Group B	53.65	0.89	57.26	2.81	.04*
		P value	< .0001*		.058		
	After 24 months	Group A	57.68	3.21	62.68	4.20	.1
		Group B	52.36	0.93	56.44	3.10	.04*
		P value	< .0001*		.54		
Bone height values	Baseline	Group A	11.40	0.00	11.28	0.27	.4
		Group B	11.57	0.06	11.40	0.00	.001*
		P value	.001*		.41		
	After 4 months	Group A	10.32	0.00	10.51	0.43	.41
		Group B	11.13	0.06	10.32	0.00	< .0001*
		P value	< .001*		.4		
	After 8 months	Group A	10.05	0.07	10.49	0.45	.1
		Group B	8.55	0.16	9.97	0.01	< .0001*
		P value	< .001*		.06		
	After 24 months	Group A	9.05	0.17	10.08	0.90	.06
		Group B	7.68	0.14	9.08	0.12	< .0001*
		P value	< .0001*		.06		

M: mean, SD: standard deviation
*Significant difference at $P < .05$

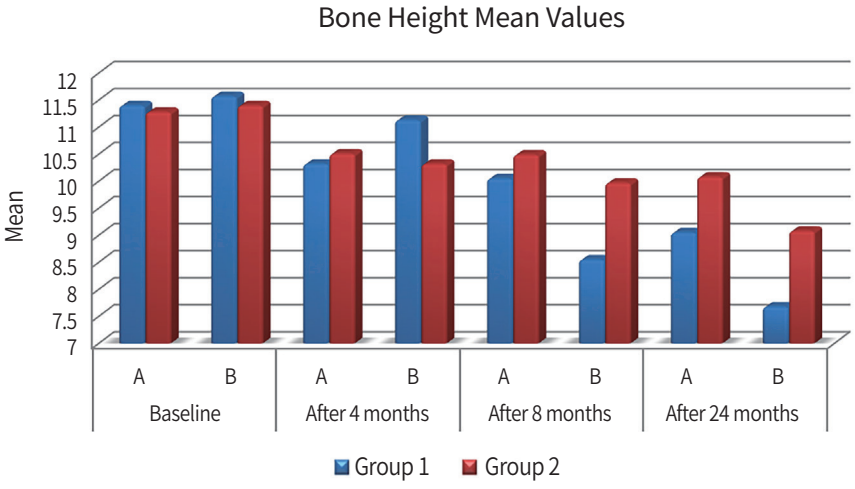

Fig. 7. Bar chart showing bone height results in all groups at different intervals.

Statistical analysis between subgroups A and B was performed using independent *t*-test regarding Groups 1 and 2 at all the different intervals, which revealed statistically significant difference between Group A1 and Group B1 at all intervals as $P < .05$ where the mean Osstell Implant stability values in Group A1 was significantly higher than Group B1. Additionally, statistical analysis showed insignificant difference between Group 2 and Group 2 at all the different time intervals as $P > .05$.

Bone height mean values and standard deviation of all groups at the different time intervals were presented in Table 1 and Figure 7. Statistical analysis between Groups 1 and 2 was performed using the independent *t*-test regarding Groups A and B at the different time intervals, which revealed insignificant difference between Group A1 & Group A2 at all the different time intervals as $P > .05$. However, statistical analysis revealed significant difference between Group B1 and Group B2 at all time intervals as $P < .05$ where the mean bone height values in Group B2 were significantly higher than Group B1.

Statistical analysis between subgroups A and B was performed by using independent *t*-test regarding Groups 1 and 2 at all the different intervals, which revealed statistically significant difference between Group A1 and Group B1 at all intervals as $P < .05$ where the mean bone height values in Group A1 was

Table 2. Comparison of the mean and standard deviation of Osstell implant stability values and marginal bone height values in the molar, premolar and anterior regions in all groups 24 months after prosthesis delivery

			Molar		Premolar		Anterior		*P* value
			M	SD	M	SD	M	SD	
Implant stability values	Subgroup 1	Group A	57.167 ^{Aa}	0.938	57.375 ^{Aa}	0.433	58.5 ^{Aa}	0.65	.06
		Group B	51.625 ^{Ba}	0.573	51.833 ^{Ba}	0.591	53.625 ^{Bb}	1.625	.001*
	Subgroup 2	Group A	61.417 ^{Aa}	2.779	63.875 ^{Ca}	3.439	62.75 ^{Aa}	4.272	.63
		Group B	54.208 ^{Aa}	3.073	56.083 ^{Aa}	0.564	59.04 ^{Aa}	3.545	.08
	P value		.0002*		< .0001*		.006*		
Bone height values	Subgroup 1	Group A	8.629 ^{Aa}	0.289	9.196 ^{Ab}	0.094	9.329 ^{Ab}	0.137	.001*
		Group B	7.588 ^{Ba}	0.23	7.7 ^{Ba}	0.173	7.763 ^{Ba}	0.022	.36
	Subgroup 2	Group A	9.979 ^{Ca}	0.144	10.188 ^{Cb}	0.02	10.063 ^{Cb}	0.01	.01*
		Group B	8.842 ^{Aa}	0.137	9.063 ^{Ab}	0.065	9.321 ^{Ab}	0.144	.001*
	P value		< .0001*		< .0001*		< .0001*		

M: mean, SD: standard deviation
*Significant difference at $P < .05$
Means with the same superscript letters were insignificantly different at $P > .05$ (capital letters per column, small letters per row).
Means with different superscript letters were significantly different at $P < .05$ (capital letters per column, small letters per row).

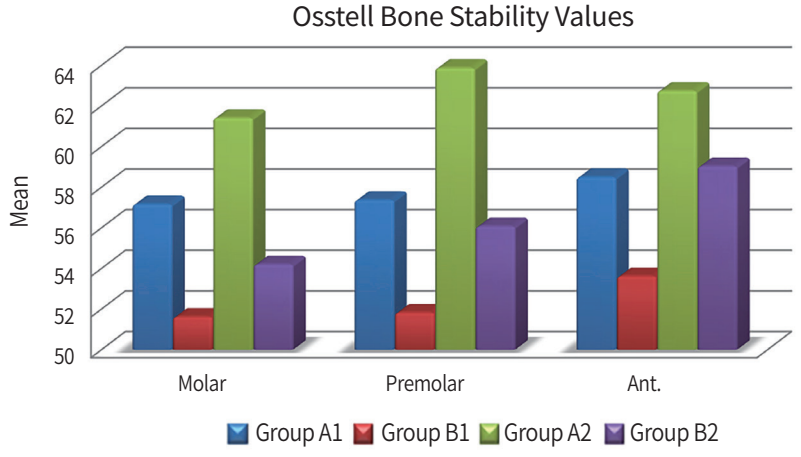

Fig. 8. Bar chart showing Osstell mean bone stability results at the molar, premolar and anterior areas in all groups at different intervals.

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significantly higher than Group B1. Additionally, statistical analysis showed insignificant difference between Group A2 and Group B2 at all the different time intervals as $P > .05$.

Comparison between different implant position in all groups regarding the Osstell implant stability and bone height mean values: Bone height and implant stability mean values and standard deviation of the different implant positions, namely anterior, premolar, and molar implants of all groups at the final time interval, are presented in Table 2 and Figure 8.

- Regarding the Osstell implant stability mean values, statistical analysis between different implant positions were performed by using One Way ANOVA test, which revealed significant difference in Group B1 as $P < .05$. Additionally, statistical analysis was further performed using Tukey's post hoc test, which showed that the anterior implant had the highest statistically significant Osstell implant stability values and that there was an insignificant difference between the premolar and molar implants in all groups.
- Regarding the bone height mean values, statistical analysis between different implant positions was performed by using One Way ANOVA test, which revealed significant difference in all Groups as $P < .05$ except for Group B1 as $P > .05$ Additionally, statistical analysis was further performed using Tukey's post hoc test, which revealed that the anterior and premolar implants had the highest statistically significant bone height values with statistically insignificant difference between them, while the molar implants showed the lowest statistically significant bone height values.
- Regarding the Osstell implant stability mean values, statistical analysis of the molar and anterior implants in Group B1 revealed the lowest statistically significant implant stability values while analysis of the molar and anterior implants revealed statistically insignificant difference among all other groups (all have letter A). Regarding statistical analysis of the premolar implants, Group B1 statistically showed the lowest implant stability mean values, followed by Group A1 and Group B2 with insignificant difference among them, and Group A2 showed the statistically significantly highest implant stability values.
- Regarding the bone height mean values, statistical analysis of the all implant positions revealed that implants in Group B1 statistically showed the lowest bone height mean values followed by Group A1 and Group B2 with insignificant difference among them, and Group A2 showed that statistically significantly highest bone height values.

DISCUSSION

Most participants in this trial were able to adapt and were generally satisfied with the implant-supported restorations being transformed from a removable complete denture to a fixed screw retained implant supported restoration. This enhanced masticatory efficiency, improved comfort, and eliminated the need for flanges, as reported by Misch.[20]

In this study, two groups with different CL:AP ratios were selected in accordance with the study performed by Purcell *et al*.,[21] who favored dividing them into two groups; Group I (high): AP spread ratio ≤ 2.1, and Group II (low): AP spread ratio > 2.1. In order to have enough implants to anchor maxillary prostheses with longer cantilever lengths, six implants were inserted in each maxilla where the most posterior implant was in the molar region. This was in agreement with a study performed by McAlarney and Stavropoulos,[16] who also found that the position of the most distal implant is a crucial clinical component and that placing distal implants in first molar sites is typically more clinically advantageous than placing them in a more anterior position. Additionally, the anterior posterior spread and cantilever lengths were measured using a millimeter ruler and a boley gauge in accordance with the methodology proposed by Drago's study.[22] However, this method of measurement is considered one of the limitations of this study as the accuracy of the millimeter ruler and the boley gauge was reported to be 0.5 mm and 0.1 mm, respectively. Walters *et al*.[23] added that when deciding the maximal distal cantilever length for a fixed full-arch implant-bearing prosthesis, AP spread evaluation is one of the factors that must be taken into account. For this reason, the CL:AP spread ratio was reported in the current study rather

than the CL solely to provide a better biomechanical perspective of load distribution on the implant supported superstructures.

Generally, the results of this study showed consistent and comparable results between the mean Osstell implant stability values and mean bone height values. This was in accordance with two studies performed by Lachmann *et al*.[24] and Turkyilmaz *et al*.,[25] who reported that the Osstell device can successfully detect crestal bone reduction. Merheb *et al*.[26] and Su *et al*.[27] agreed that resonance frequency analysis devices are capable of determining any alterations in the bone configuration and bone resorption around implants. The resonance frequency analysis ISQ value reflects the bone height levels of a given implant and the stiffness of the implant in the adjacent bone,[28,29] and is considered a relevant tool to predict osseointegration.[29-31]

In the current study, statistical analysis of the mean implant stability and bone height values revealed insignificant difference between Group A1 and Group A2 at all the different time intervals, while significantly higher values in Group B1 in comparison with Group B2 at all intervals. This means that there was no difference in the bone height and Osstell values in the 1:3 CL:AP ratio in both the standard and small diameter implants but statistically significant decrease in the 1:2 CL:AP group with the small diameter implants. This means that compromising both the diameter and cantilever lengths might have a negative impact on outcome of the implant stability, crestal bone height and hence success of osseointegration. This fact is supported by a study[31] which showed that axial and bending forces are the two main types of forces directed on the cantilevered prosthesis and that the greater the cantilever length, the greater the Class I lever arm and bending moment on the implants supporting the prosthesis and hence the greater the risk of implant and prosthetic complications and failures. Combining these findings with what Misch[32] previously stated, every 0.25 mm increase in implant width results in an increase of 20 - 30% total bone-to-implant contact surface area, hence providing better load distribution and reducing stress at the crestal bone-implant contact.

Additionally, the statistical analysis of the mean implant stability and bone height values in this study also revealed that the longer cantilever caused more significant reduction in crestal bone heights in the small diameter implants group than in the standard diameter implants group. As a result, the incorporation of longer cantilevers, especially on prosthesis supported by smaller diameter implants, tend to increase the magnitude of forces on the crestal bone around the implants as agreed upon and explained by Rodriguez *et al*.[33] and Aglietta *et al*..[34] This overload is proportional to the length of the cantilever and diameter of the implants,[35] which will eventually overload the system beyond its physiologic limit and enter the pathologic overload window zone[36] and in turn lead to more crestal bone loss[35] and compromised implant success.

Regarding the statistical analysis of the different implant positions, this study revealed that the molar and anterior implants in Group B1 had the lowest statistically significant implant stability values than all other groups. This can be explained by the fact that the presence of a horizontal cantilever as described by Misch[37] in the posterior implant region in Group B1 had additional overload than the implants in the rest of the groups in this study. Logically, the implants adjacent to the cantilever will receive the greatest bending moments during masticatory function, as explained by a study performed by Purcell *et al*..[21] Furthermore, the posterior implant placed in the most compromised prosthetic design in this study, which is Group B1 (the smallest diameter and the longest cantilever), will show the greatest amount of bone loss as revealed in the statistical analysis of the present study.

Small diameter implant supported screw retained restorations have success rates comparable to those of standard diameter implants and provide a reliable and a minimally invasive alternative to bone augmentation procedures. However, they just meet the condition of providing an acceptable prosthetic design, proper implant distribution, number, position and utilizing a maximum of 1:3 (CL:AP) ratio as recommended by the findings of this study.

CONCLUSION

Within the limited observation period and the num-

ber of patients, it can be concluded that the use of small diameter implants placed with an AP implant spread to the cantilevers lengths (CL:AP) at a ratio of 1:3 provides predictable results if clinical guidelines are followed and appropriate prosthetic restorations are provided. It can also be concluded that the 1:2 (CL:AP) significantly induced more critical bone loss in the small diameter implants group, which can significantly reduce long term success and survival of implants.

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