Implant stability is an essential factor for achieving successful osseointegration and, therefore, the long-term success of dental implants. Accurate measurement and quantification of implant stability has become a fundamental procedure as it provides valuable diagnostic insight that helps dictate the time of functional loading and project a long-term prognosis to ensure successful treatment. Implant stability is usually divided into 2 stages: primary and secondary. Primary implant stability has proved to be a mechanical phenomenon as a result of mechanical engagement of an implant in the surrounding bone immediately after placement; secondary implant stability is attributed to the biological stability gained with bone regeneration and remodeling (osseointegration) around the implant. Several methods have been implemented to assess implant stability. Resonance frequency analysis (RFA) has gained popularity over the past years. It has proved to be straightforward, reliable, noninvasive, and more sensitive than other diagnostic methods, such as damping capacity assessment or the periotest.

The dental publications are rich with articles that have investigated the influence of host-site variables, some implant-related variables (implant length, diameter, taper, design, location, and surface topography), different loading protocols or surgical procedures, and measurement methodology on dental implant stability. However, the number of implants and its effect on implant stability remain unclear.

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Clinical Implications

The placement of 2 implants to support and retain a mandibular overdenture seems to provide a cost-efficient treatment approach that does not jeopardize implant stability over a 1-year follow-up period.

and augmentation procedures\(^ {40-45}\); and the effect of measurement methodology\(^ {3,18,46-48}\) on dental implant stability. However, the number of implants and its effect on implant stability remains unclear. The distribution of functional load on a greater number of implants may have a favorable influential effect on the biomechanical stability of each individual implant. Nevertheless, the validity of this assumption has not yet been tested. Therefore, the objectives of this randomized controlled trial were primarily to determine the influence of implant number on implant stability by using RFA to compare 2 versus 4 implants in mandibular implant overdentures and secondarily to monitor longitudinally the development of implant stability throughout a 1-year study period. The null hypothesis was that increasing the number of implants from 2 to 4 would have no significant influence on implant stability.

MATERIAL AND METHODS

The study was a randomized controlled trial with a parallel design, an equivalence frame, and a 1:1 allocation ratio in which the 20 included participants were randomly allocated to 1 of 2 equal groups, a 4-implant (experimental) group, in which 4 implants were placed, consisting of 2 anteriors (lateral incisor-canine region) and 2 posteriors (premolar region) on both sides of the arch; and a 2-implant (control) group, in which only 2 implants (the anteriors) were installed. The study protocol was approved by the Research Ethical Committee, Faculty of Oral and Dental Medicine, Cairo University (approval number 15/9/21).

The study was conducted in women and men (mean 52.5 years of age; median 54 years of age; range, 47 to 60 years of age) in whom 60 tapered screw vent implants (TSVB11; Zimmer Dental Inc) were placed. The baseline characteristics are shown in Table 1. Participants were randomly selected from 43 eligible individuals who visited the Prosthodontic Department, Faculty of Oral and Dental Medicine, Cairo University (June 2013 to June 2014). Eligibility of the participants was based on clinical and panoramic radiographic examinations. Eligible participants were those with edentulous mandibular ridges opposed by a complete maxillary dentition (natural maxillary teeth or restored with fixed restorations) assuming normal maxillomandibular relationship (class I Angle classification) and with adequate mandibular bone that allowed the placement of implants, 11.5 mm in length and 3.7 mm in diameter. Ridge mapping was done at the proposed implant sites. Diagnostic tooth arrangements for all participants were also prepared to ensure a crown height space of at least 12 mm to accommodate the ball attachments at the suggested areas. Participants with parafunctional habits or with systemic diseases that contraindicated implant placement and heavy smokers (>10 cigarettes/day) or who had received local radiotherapy were excluded. All participants signed an informed written consent.

Initially, all participants received a conventional mandibular complete denture fabricated with a bilaterally balanced occlusal concept against the adjusted occlusion of the existing or restored dentition. For proper planning of implant placement at the proposed sites, a cone beam computed tomography scan of the mandible of each participant was made while the participant was wearing a radio-opaque duplicate of the mandibular denture as a radiographic stent, which was then modified to act as a surgical guide.

To study the effect of 2 (control) versus 4 (experimental group) implants on implant stability in mandibular overdentures with an allocation ratio of 1:1, the sample size was calculated using software (G* Power v3.1.9.2; Universität Düsseldorf). This was based on a study conducted by Barewal et al\(^ {10}\) in which implant stability within each group was normally distributed with a standard error of 0.7. If the true mean difference between the experimental and control groups was 1.6, 14 participants were needed, 7 in each group, to be able to reject the null hypothesis that the population means of the experimental and control groups were equal with probability (power) of .85. The Type I error probability associated with this test was .05. In an attempt to overcome the attrition bias, a 30% increase was accounted for, dictating a sample of 20, 10 in each group. A computer-generated random sequence for the numbers 1 to 20 was developed in a 2-column table using http://random.org, a site for creating tables with random numbers. Each column contained 10 numbers and represented a treatment group. Allocation concealment was

Data presented as mean ±SD, unless stated otherwise. * Based on chi-square test for sex and age and t test for bone parameters.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>4-Implant Group</th>
<th>2-Implant Group</th>
<th>P*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Males/females</td>
<td>5/5</td>
<td>6/4</td>
<td>.861</td>
</tr>
<tr>
<td>Age (y)</td>
<td>53.7 ±6.3</td>
<td>51.4 ±5.7</td>
<td>.614</td>
</tr>
<tr>
<td>Bone density (HU)</td>
<td>760 ±150</td>
<td>779 ±170</td>
<td>.129</td>
</tr>
<tr>
<td>Anterior bone height (mm)</td>
<td>18.4 ±1.9</td>
<td>18.6 ±2.01</td>
<td>.743</td>
</tr>
<tr>
<td>Posterior bone height (mm)</td>
<td>14.5 ±2.4</td>
<td>15.2 ±1.7</td>
<td>.552</td>
</tr>
<tr>
<td>Anterior bone thickness (mm)</td>
<td>6.9 ±0.7</td>
<td>7.1 ±0.4</td>
<td>.431</td>
</tr>
<tr>
<td>Premolar bone thickness (mm)</td>
<td>10.6 ±1.2</td>
<td>10.9 ±1.0</td>
<td>.768</td>
</tr>
</tbody>
</table>
ensured by allowing each participant to draw a number that was enclosed within an opaque sealed envelope. This was done at the time of surgery, after the 2 anterior implants had been placed, to eliminate the possibility of performance bias and to overcome the problem of blinding by the operator.

All participants were given 2 g of antibiotic (amoxicillin capsules; Teva Canadal Ltd) 1 hour before surgery in addition to an analgesic and anti-inflammatory medication (ibuprofen, 400 mg tablets; Shasun Chemicals & Drugs Ltd) to be taken every 8 hours for 2 days after the surgery and 0.2% chlorhexidine (Chlorhexidine; Kahira Pharm & Chem Ind Co) mouth wash for 1 week after surgery. All implants were placed under local anesthesia by 2 experienced prosthodontists (W.R.A., I.A.R.). As dictated by the random numbers, either 2 or 4 implants were placed using the surgical guides. Before threading the covering screw, the baseline implant stability measurement was made. All participants were given similar written postoperative instructions and medications. Three months after insertion, the implants were exposed, and healing collars (HC333; Zimmer Dental Inc) were fastened to the implants for 2 weeks. They were then removed, and ball attachments (BAC4; Zimmer Dental Inc) were screwed in (Fig. 1). While the participants closed in centric occlusion, standard direct pickup procedures were done to incorporate nylon caps and metal housings within the previously fabricated dentures.

Implant stability was measured by using an external assessor for all implants of both groups immediately following implant installation (0 month) and then at 1, 3, 6, 9, and 12 months postoperatively. It was measured using the Osstell (Oststell ISQ; Oststell AB Gamlestadsvägen) implant stability quotient (ISQ) measurer by inserting a standardized transducer (a magnetic peg; Smartpeg; Integration Diagnostics AB, Gamlestadsvägen 3B) of fixed length into each implant (Fig. 2). The device’s probe was held perpendicularly to the implant’s long axis at a distance of 2 to 3 mm from the transducer to avoid measurement inconsistencies. This was carried out at the buccal, lingual, mesial, and distal aspects to measure respective implant stability from all implant sides. To simplify the data, the average of the readings of the 4 sites was then recorded to represent the stability of each implant. The records of all average readings for both groups at the different follow-up periods were tabulated. The participants, operators, and assessor were not blinded because of the obvious difference between the numbers of installed implants in the groups.

The statistical analysis was conducted by blinded researcher (A.A.S.) using statistical software (SPSS for Windows, v16.0; SPSS Inc). Descriptive statistics (arithmetic mean, standard deviation) were used to summarize the data. The ISQ values of the right and left anterior and then posterior implants were compared using a paired t test. Because no statistical significance was found between the right and left implants, the ISQ values of both sides were averaged for further analysis. The data were tested using the Shapiro-Wilk test and found to be normally distributed. Accordingly, the t test was used to compare the ISQ values of anterior implants in the 4-implant group with those of the implants in the 2-implant group. A paired t test was used to compare the anterior and posterior implants in the 4-implant group. Two-way ANOVA was performed to investigate group-time interaction. Because no interaction was found (F=2.207; P=.070), 1-way ANOVA followed by the post hoc Bonferroni test was performed to investigate the effect of time on the ISQ values among the different follow-up periods within each group (α=.05).

RESULTS
All participants attended all follow-up visits, and their results were analyzed (Fig. 3). No implant was lost, giving
a 100% survival rate for both groups. At any given observation period, the mean ISQ values of all implants ranged between 66.5 and 72.0.

The mean ISQ values recorded for anterior implants in the 4-implant group were slightly higher than those recorded for implants in the 2-implant group at all follow-up periods. However, these differences were not statistically significant \((P>.05)\) (Table 2). Statistical analysis revealed nonsignificant differences between mean ISQ values recorded for anterior and posterior implants in the 4-implant group \((P>.05)\).

Table 3 shows the within-group changes in implant stability of all implants in both groups. For all implants, regardless of their site, initial (0 month) implant stability values were higher than those of the 1-month ISQ values. This apparent decrease in implant stability was statistically significant for the 2-implant group \((P<.001)\) and for the posterior implants in the 4-implant group \((P<.001)\). This decrease was then followed by a gradual increase in implant stability values for implants of both groups. At the end of the follow-up period (12 months), ISQ values in the 4-implant group reached 71.8 ±2.1 for anterior implants, 72.0 ±5.3 for posterior implants, and 68.6 ±5.8 for the 2-implant group. This increase was statistically significant for implants in the 4-implant group, whether anterior \((P<.001)\) or posterior \((P<.001)\), at the 9 month follow-up period, after which the increase became nonsignificant \((P>.05)\). Nevertheless, at the 12th month, it maintained a significant difference compared with baseline for both anterior \((P<.024)\) and posterior \((P<.001)\) implants. For the 2-implant group, the closest mean ISQ value to baseline was reached at 3 months after insertion; it then gradually increased but not significantly \((P>.05)\) until the end of the follow-up period.

**DISCUSSION**

Results of the current study revealed no statistically significant differences between the 2 groups for both primary stability (represented by ISQ values at 0 month) and secondary stability (represented by ISQ values from 1 to 12 months). Hence, the results support the null hypothesis and suggest that the number of implants may not be as influential on implant stability as other factors.

ISQ values above 54 represent clinically acceptable stability.14,25,26,50 Therefore, all implants in the present study were and remained clinically stable at placement and throughout the 1-year study period with a mean ISQ range of 66.5 to 72.0, indicating that good primary and secondary stability and, hence, successful

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**Table 2.** ISQ implant stability values of anterior implants in 4-implant group compared with those in 2-implant group at different follow-up periods (mean ±SD)

<table>
<thead>
<tr>
<th>Time of Measurement</th>
<th>4-Implant Group</th>
<th>2-Implant Group</th>
<th>95% CI of Mean Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>At insertion (0)</td>
<td>68.2 ±4.2a 66.5 ±3.2</td>
<td>.354 -1.94 to 5.16</td>
<td></td>
</tr>
<tr>
<td>Post Insertion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>65.6 ±2.6b 64.3 ±2.9</td>
<td>.294 -1.26 to 3.94</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>67.0 ±3.4c 66.6 ±3.6</td>
<td>.787 -2.86 to 3.72</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>68.9 ±3.7d 67.5 ±4.0</td>
<td>.419 -2.19 to 5.03</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>71.6 ±3.7e 68.8 ±5.4</td>
<td>.203 -1.62 to 7.10</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>71.8 ±2.1f 68.6 ±5.8</td>
<td>.116 -0.88 to 7.30</td>
<td></td>
</tr>
</tbody>
</table>

CI, confidence interval; ISQ, implant stability quotient; m, month; SD, standard deviation. Not significant at \(P<.05\).

**Table 3.** ISQ implant stability values of implants at different follow-up periods within each group (mean ±SD)

<table>
<thead>
<tr>
<th>Follow-up Period (mo)</th>
<th>4-Implant Group</th>
<th>2-Implant Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Anterior (n=10)</td>
<td>Posterior (n=10)</td>
</tr>
<tr>
<td>0</td>
<td>68.2 ±4.2a 66.5 ±3.2</td>
<td>66.5 ±3.2 65.5 ±3.9</td>
</tr>
<tr>
<td>1</td>
<td>65.6 ±2.6b 64.3 ±2.9</td>
<td>64.3 ±2.9 63.7 ±2.9</td>
</tr>
<tr>
<td>3</td>
<td>67.0 ±3.4c 65.4 ±4.7</td>
<td>64.3 ±4.0 63.7 ±4.0</td>
</tr>
<tr>
<td>6</td>
<td>68.9 ±3.7d 69.6 ±5.4</td>
<td>67.5 ±3.4 66.6 ±3.6</td>
</tr>
<tr>
<td>9</td>
<td>71.6 ±3.7e 71.9 ±5.2</td>
<td>68.8 ±5.4 67.5 ±5.4</td>
</tr>
<tr>
<td>12</td>
<td>71.8 ±2.1f 72.0 ±5.3</td>
<td>68.6 ±5.8 67.5 ±5.8</td>
</tr>
</tbody>
</table>

ISQ, implant stability quotient; SD, standard deviation. Different superscript letters are statistically significant; those with similar letters are insignificant \((P>.05)\), based on Bonferroni pairwise comparison test.
osseointegration had been achieved. This explains the 100% survival rate.

The nonsignificant differences found between the 2 groups can be attributed to different factors. Primary stability is a mechanical phenomenon and is mainly influenced by the bone density of the osteotomy site. It could also be influenced by the surgical technique and implant-related factors especially implant length. During healing, this primary stability is replaced by a biological bonding of newly formed bone to the implant surface and is then termed secondary stability. The degree of which is determined by the dynamic changes taking place during the tissue-integration process, such as bone modeling and remodeling at the bone-implant interface.

During healing, this primary stability is replaced by a biological bonding of newly formed bone to the implant surface and is then termed secondary stability. The degree of which is determined by the dynamic changes taking place during the tissue-integration process, such as bone modeling and remodeling at the bone-implant interface. Evidently, this healing process will also be influenced by the bone morphology and the total surface area of the implant. In the current study, bone density values of both groups were not found to be significantly different. Other potentially influential factors, namely: implant design, implant size, opposing dentition, loading protocol and surgical technique, were all standardized in the present study. All implants were installed in the mandible. Consequently, all these aspects may have attributed to the nonsignificant differences between stability readings of the groups. Considering the elimination of the effect of such confounding variables, the results imply that the addition of 2 posterior implants did not play a significant role in favor of the stability of the anterior implants. Even though mean ISQ values of anterior implants in the 4-implant group were slightly higher than those of the 2-implant group throughout the study, yet this cannot be safely attributed to the presence of the posterior implants. Simply because the mean ISQ values of the anterior implants were initially higher at baseline in the 4-implant group (68.2 ±4.2) than in the 2-implant group (66.5 ±3.2).

Within-group comparisons revealed a common stability pattern for all studied implants, regardless of the group or site, represented by a considerable initial decrease in implant stability during the first month followed by a gradual increase during the subsequent follow-up periods. This pattern seemed consistent with previous studies. The initial decrease was statistically significant for the 2-implant group and for posterior implants in the 4-implant group. However, the decrease in implant stability of anterior implants in the 4-implant group during this period was not significant, which could reflect the relative importance of the posterior implants in the initial periods of bone healing. The phenomenon of this transient decrease in implant stability during the initial healing period has been termed as a “dip” or “drop” in stability and is thought to correspond to the transition from primary to secondary stability. Studies have demonstrated that this stability dip is commonly observed between the second and eighth weeks after insertion with a peak drop detected during the third or fourth week and ranged from 2 to 12 ISQ values. The findings of the current study coincide with these 2 observations. The significant decrease in implant stability was indeed recorded during the first month, and it was within the reported range, where it decreased by 2.6 ISQ values (3.8%) for anterior implants in the 4-implant group, 3.5 ISQ values (5.1%) for posterior implants in the 4-implant group, and 2.2 ISQ values (3.3%) for the 2-implant group. This dip phenomenon has been broadly discussed and has been proposed as a consequence of the dynamic early modeling-remodeling phase which involves resorption of the necrotic bone adjacent to the implant after surgery and its replacement by a biological attachment of woven bone. This in turn results in minimal bone-implant contact, and consequent reduction in the mechanical anchorage. Results of the present study confirm this phenomenon.

This stability dip has been correlated to primary implant stability values. Several investigators came to the conclusion that only implants with high primary stability exhibited that decrease in stability during the initial healing phase, whereas implants with low primary stability showed a significant increase. Nedir et al reported that implants with ISQ values <60 at baseline exhibited a stability increase, whereas implants with ISQ values between 60 and 69 exhibited the stability dip. The implants then approached their initial stability values at the end of their 12-week study period. This was typically demonstrated in the current study as the mean primary ISQ values were 68.2 for anterior implants in the 4-implant group, 68.0 for posterior implants in the 4-implant group, and 66.5 for the 2-implant group, and the 3-month mean ISQ values were 67.0, 67.0, and 66.6, respectively. However, an increase in stability readings in the initial 2 weeks has been reported. It seems that parameters of the dip can be influenced by other factors, such as implant surface properties and timing of functional loading, indicating that stability changes during the initial healing phase is a multifactorial phenomenon that cannot be generalized for all implants and clinical scenarios.

The presumed interval between mechanical stability originally achieved by macro-retentions of the implants (threads) and direct bonding of newly formed woven bone onto the implant surface possibly takes place from 2 to 4 weeks. Subsequently, the osseointegration process and maturation of woven bone into lamellar bone takes place and progresses, thereby establishing biological bonding and increasing secondary stability by time. This could have contributed to the gradual increase that was observed in the ISQ values at the subsequent follow-up periods of the present study. Compared with values from the 1-month follow-up, 12-month values reflected a mean ISQ increase of 6.2 (9.5%) for anterior implants in the 4-implant group, 7.5 (11.6%) for posterior implants in...
the 4-implant group, and 4.3 (6.7%) for the 2-implant group. Compared with baseline values, this increase was statistically significant (P<.001) for implants in the 4-implant group after 9 months of healing, with an insconsiderable increase thereafter. However, this increase was not statistically significant (P>.05) in the 2-implant group throughout the distribution of functional loading among 4 implants instead of only 2 implants, could have been in favor of the remodeling process and might have speeded up the biological response around implants in the 4-implant group. However, this within-group significance was not profound enough to create a significant difference between the two groups as previously discussed. This observation has been confirmed by the nonsignificant group-time interaction reported earlier.

Comparison between anterior and posterior implants in the 4-implant group revealed no significant differences (P>.05) between their mean ISQ values at all time points. Balshi et al.24 reported the same conclusion for mandibular implants but not for maxillary implants. Whereas, Bischof et al.24 found that implant location had no influence effect on implant stability for either mandibular or maxillary implants.

The number of participants did not allow for a post hoc subgroup analysis to explore the effect of sex or bone density on implant stability. Therefore the results of the current study should be interpreted with caution and cannot be generalized. Including more mandibular implants (> 4) or conducting a similar study with maxillary implants (where bone density is typically lower) may reveal significant differences, considering that overall stability levels have been found to be higher in the mandible than in the maxilla.5, 10, 21, 22, 24 Hence, further work with an increased sample size and subgroup analysis, different clinical scenarios, and longer follow-ups are recommended to provide generalizable conclusions.

CONCLUSIONS

Within the limitations and time frame of this randomized controlled trial, the following conclusions were drawn:

1. Increasing the number of implants from 2 to 4 in mandibular implant overdentures did not have a significant influence on implant stability.

2. Longitudinal measurement of implant stability using RFA demonstrated a decrease in implant stability during the initial healing period (1 month) followed by a gradual increase in the subsequent healing periods.

REFERENCES


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