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Dentistry Section

Single versus Two Implants-assisted Mandibular Overdentures: A Finite Element Analysis Study

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ABSTRACT

Introduction: Single-implant Overdentures (1IODs) have gained popularity as a more economical protocol than Two-implant Overdentures (2IODs). However, concerns have existed about the longevity of using a single implant compared to two implants.

Aim: To investigate the marginal bone loss and stress distribution around dental implants assisting 1IODs compared to 2IODs within five years of clinical service.

Materials and Methods: This randomised clinical trial was conducted at the Department of Prosthetic Dental Sciences, College of Dentistry of Qassim University in the Kingdom of Saudi Arabia from June 2018 to September 2023. Total 40 completely edentulous male patients, aged 50 to 60 years, were blindly allocated to two groups. Group I included 20 patients who received two implants at the canines' regions, and Group II included 20 patients who received one implant under their mandibular overdentures at the midline of the mandible. The implants in both groups were followed-up immediately after loading, at six and 12 months, three years, and five years for probing depth, mobility, and vertical bone loss. Finite Element Analysis (FEA) was used for stress analysis around the implants. One-way Analysis of Variance (ANOVA) and Mann-Whitney tests were used for statistical analysis at a significance level of p<0.05.

Results: Group II had significantly more fractures and required more new dentures than Group I. Specifically, 6 (37.5%) patients at three years and 8 (80%) patients at five years, compared to 2 (13%) patients at three years and 3 (20%) patients at five years in Group I. Additionally, Group II had more fractures at the metal housings in the denture base: 6 (37.5%) patients at the first year, followed by 11 (69%) patients at three years follow-up and 12 (75%) patients at five years, whereas in Group I, 2 (13%) patients in the first year, then at three years, 3 (20%) patients, and at five years, 5 (55%) patients. Regarding reattaching the O-ring to their metal housing, in Group II, 12 (75%) patients required this procedure at three years, and 15 (94%) patients at five years, whereas in Group I, 5 (33%) patients needed this procedure at three years, and 8 (53%) patients at five years. Comparison of the crestal bone loss showed that Group II had significantly more marginal bone loss than Group I. At three years, Group II had vertical bone loss of (3.97±0.16 mm) compared to (2.76±0.15 mm) of Group I, and at 5 years, Group II had (5.01±0.12 mm) compared to (3.41±0.14 mm) in Group I. FEA results revealed statistically significantly less stress concentration around implants in Group I (n=15, 100%) compared to implants in Group II (n=16, 100%), with maximum Von Mises values of 63.30 MPa and 129.94 MPa for vertical and inclined loading in Group I, respectively, and 89.32 MPa and 213.93 MPa for vertical and inclined loading in Group II, respectively.

Conclusion: Single implants exhibited more vertical bone loss than two implants, starting three years into service, and their dentures required more repairs and replacements than two-implant dentures, making their long-term use less economical.

Keywords: Implant overdenture, Stress analysis, Vertical bone loss

INTRODUCTION

Mandibular implant complete overdentures assisted with a minimum of two (2IODs) implants have been proven to be superior to conventional complete dentures in terms of efficiency, providing patients with better mastication, biting force, retention, satisfaction, and quality of life [1-3], especially when ball attachments are used, whether with immediate or delayed loading protocols, and with different occlusal schemes [4-6].

On the other hand, 1IODs, with a single implant placed centrally in the midline of the edentulous mandible, have gained popularity as an even more economical protocol than the two-implant overdenture [7-9]. They have been found to be easier to construct, requiring less home care, and providing better biting force and satisfactory quality of life compared to conventional complete dentures. This is true even when using different loading protocols and tooth forms, with the only disadvantage being repeated midline fracture, which can be overcome by reinforcing the denture bases [10-17].

When comparing 1IODs to 2IODs, it has been found that they have a similar rate of patient satisfaction after one to five years of clinical service and a similar amount of marginal bone loss after one year of loading [18-25]. However, after five years, 1IODs exhibit greater marginal bone loss than 2IODs [18], which is why some authorities consider 2IODs the minimum standard of care [21].

Stress analysis around different numbers of implants with ball attachments, assisting mandibular complete overdentures, and using different denture base materials has also revealed that the use of two implants leads to better stress distribution and less deformation compared to the use of a single implant [26,27]. However, when the biomechanical behavior of 1IODs was studied in several other studies [28-31], increasing the number of implants was not found to reduce the stresses in either the denture base or at the crestal bone neighboring the implants.

Based on the previously presented data, the current study was conducted to investigate the marginal bone loss and bone density profiles around dental implants assisting 1IODs compared to 2IODs after five years of clinical service.

MATERIALS AND METHODS

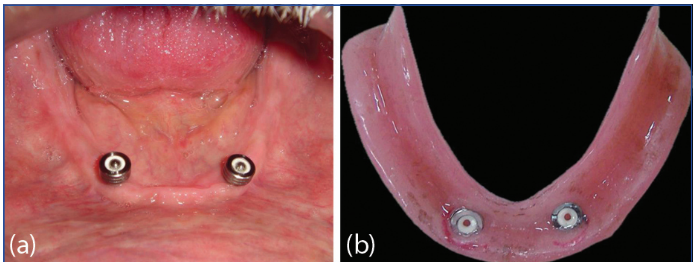
In this randomised clinical trial, 40 healthy completely edentulous male patients, aged between 50 and 60 years, attended the Department of Prosthetic Dental Sciences Outpatient clinic at the College of Dentistry of Qassim University in the Kingdom of Saudi Arabia. The study commenced in June 2018 and concluded in September 2023. The study was approved by the ethical committee of the college and the university's Institutional Review Board (IRB) under number Qu-A-2018-40. All patients provided informed consent after the study procedures were translated into their native language, Arabic, to ensure their understanding. Patients were informed that they would receive one or two implants under their mandibular overdentures and would be followed-up for five years. The trial was conducted in accordance with the Declaration of Helsinki (2008).

Inclusion and Exclusion criteria: The inclusion criteria utilised stipulated that patients participating in the study were non-smokers and free from a chronic diseases such as diabetes, cardiovascular diseases, or any bone-affecting diseases. Additionally, patients were required to have no temporomandibular joint disorder that could affect their movement or psychological disorders that could impact follow-up procedures. Patients were selected based on having sufficient bone in the inter-mental foramen region to accommodate implants of 15 mm length and a 3.5 mm diameter. Exclusion criteria included patients who used tobacco in any form, had chronic debilitating temporomandibular disorders, or had insufficient bone for the implant procedure.

Study Procedure

To prevent bias, patients were randomly allocated to two groups by an independent assessor. Group I comprised 20 patients who received two implants under their mandibular complete overdentures at the canine regions, as shown in [Table/Fig-1,2a,b], while Group II included 20 patients who received one implant under their mandibular complete overdentures at the midline of the mandible, as seen in [Table/Fig-3,4a,b].

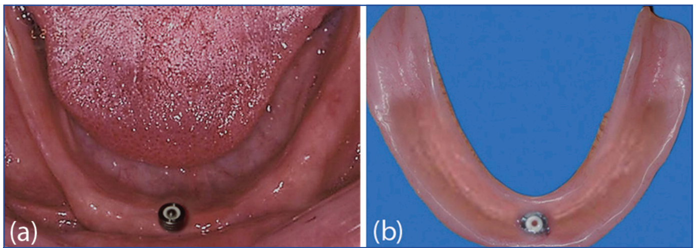
[Table/Fig-1]: Group I patient with two implants, with ball and socket abutments, at the canine regions of the edentulous mandible.



[Table/Fig-2a,b]: Group I showing the metal housings and O-rings of the ball and socket abutments.

New upper and lower complete dentures, conventionally fabricated with semi-anatomic teeth and a bilaterally balanced occlusal scheme, were provided to all patients. During the jaw relationships registration stage, the interarch distance was checked to ensure adequate space for the attachments used under the dentures. The two-piece Sterngold PUR® NP implants (3.2×14 mm) were placed by an Oral Surgeon using a radiographic stent fabricated from Cone Beam

[Table/Fig-3]: Group II patient with one implant, with ball and socket abutment, in the midline of the edentulous mandible.

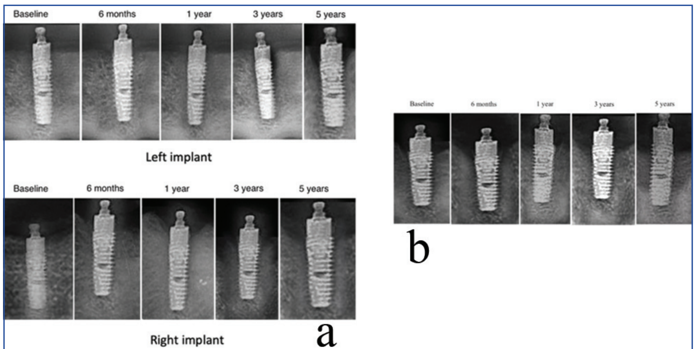


[Table/Fig-4a,b]: Group II showing the metal housing and O-ring of the ball and socket abutment.

Computed Tomography (CBCT) data (Sirona Galileos Comfort Plus) to ensure parallel placement of the implants. A three-month, two-stage delayed loading protocol was followed, even if all implants had sufficient initial stability. Subsequently, ball abutments (ORA implant abutment with a 5.0 mm cuff) were attached to the implants, and their metal housings were incorporated into the dentures using self-cured acrylic resin. Follow-up appointments were scheduled every six months to check for loosening of the O-rings of the abutments and to replace dentures in cases of fractures.

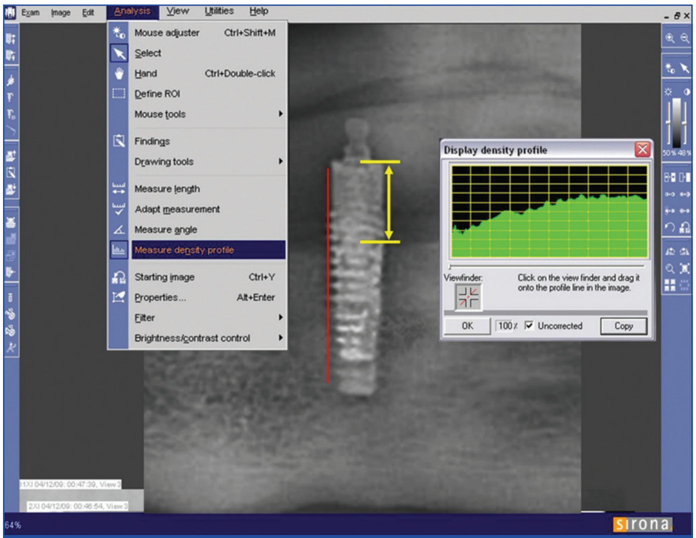
The implants in both groups were followed-up by the same periodontist immediately after loading, at six and 12 months, and then at three and five years. Probing depth was assessed using plastic probes with light pressure at six sites around the implants. Mobility was assessed using Periotest, with the tip of the Periotest retractable pin applied to the same position on the implant abutment.

Values between -8 and zero indicated good stability, while values above that range indicated mobility. Vertical bone loss was assessed using standardised digital periapical radiographs (Sirona) with the same exposure parameters, using a patient-specific index for accurate repositioning of the X-ray sensor [Table/Fig-5a,b].



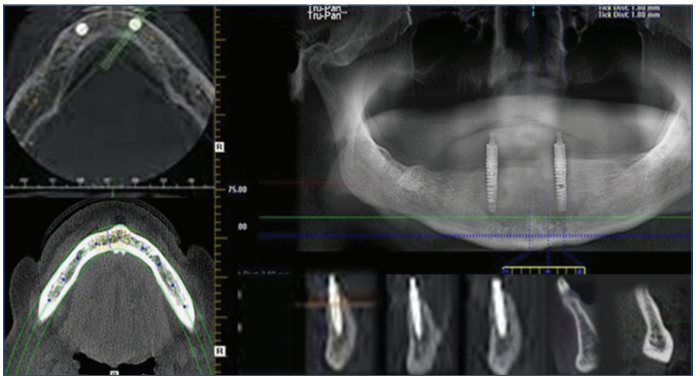
[Table/Fig-5]: Vertical bone loss assessment done using periapical radiographs for both the groups: a) Group I (two implant supported overdenture); b) Group II (single implant supported overdenture).

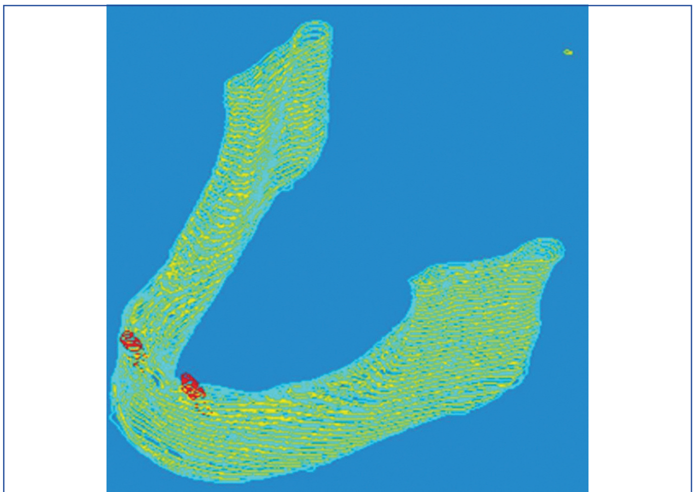
To measure vertical bone loss, the Sirona Sidexis software was used to measure the distance from the implant shoulder to the first surface of the crestal alveolar bone around the implant. Readings were collected from both the mesial and distal sides of the implants, and their mean values were considered [Table/Fig-6].

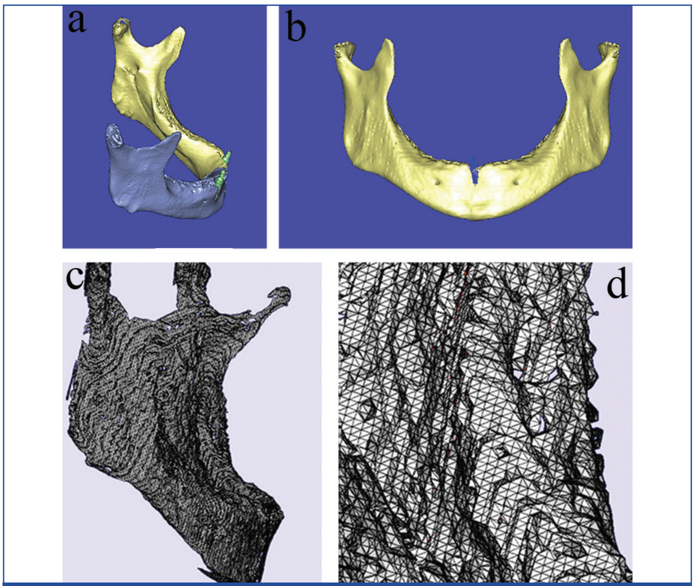


[Table/Fig-6]: Standardised digital periapical radiograph showing measurement of the vertical bone loss.

Finite Element Analysis (FEA) was used for stress analysis around the implants in present study. A 3-dimensional (D) FEA model was constructed for the dental implants and surrounding alveolar bone from CBCT scans of each patient. Para-axial cuts were made to show scans in a labio-lingual direction [Table/Fig-7]. The CBCT cuts were used by computer software (ANSYS 10) to develop patient-specific 3-D models [Table/Fig-8], followed by the meshing process [Table/Fig-9] in preparation for FEA. The elastic moduli of each structure in the three-dimensional digital model were determined [Table/Fig-9a-d] [Table/Fig-10], and the nature of the structures in the model was set to be anisotropic. The magnitude, direction, and mode of the applied occlusal forces were set to a vertical load of 100 N and an oblique load of 70 N. The resulting color map (von Mises) revealed the magnitude of stresses around each implant.


[Table/Fig-7]: Cone Beam Computed Tomography (CBCT) for one of Group I patients showing panoramic X-ray view and selected axial and para-axial CBCT cuts.


[Table/Fig-8]: Skeleton frame of the 3-D model generated from the CBCT for one of Group I patients.



[Table/Fig-9]: Meshing and nodes of the 3-D model generated from the CBCT of one of Group I patients. Three-dimensional models generated from the CBCT and their meshing: (a) 3-D model of Group I patient with two implants (green); (b) 3-D model of Group II patient with one implant (blue); (c) meshing of the 3-D models; (d) magnification of the 3-D model meshing showing the nodes.

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/Fig-10]: Material properties inputs for Finite Element Analysis (FEA).

STATISTICAL ANALYSIS

For statistical analysis of the results, the Shapiro-Wilk test was used to test normality. One-way ANOVA and Tukey's post-hoc test were used for normally distributed data on vertical bone loss. For non-parametric data, the Friedman test, Nemenyi post-hoc test, and Mann-Whitney test were used at a significance level of $p<0.05$.

RESULTS

The characteristics of the study participants are shown in [Table/Fig-11]. Initially, both studied groups had the same number of patients with an average age of 55.3 years in Group I and 56 years in Group II. They used implants of the same length and diameter, with an insertion torque of 35 Ncm and an initial stability of more than 70 ISQ when measured by resonance frequency analysis at the time of loading. The patients were followed-up for five years, with five dropouts in Group I and four in Group II. The survival rate of the implants in both groups was 100%. The reason for dropouts in both groups was the departure of the patients as their work contracts in the Kingdom of Saudi Arabia ended.

Groups	Mean age (years)	Number of patients	Mean bone height in intermetal foraminal area (mm)
Group I (2IODs)	55.3	15	17.4 (2.8)
Group II (1IODs)	56	16	16.2 (3.8)

[Table/Fig-11]: Characteristics of participating patients.

The follow-up maintenance procedures carried out for the patients are shown in [Table/Fig-12]. Group II had significantly more fractures and required more new dentures than Group I. Specifically, at three years, 6 (37.5%) patients in Group II and 2 (13%) patients in Group I encountered fractures, and at five years, this number increased to 8 (80%) patients in Group II and 3 (20%) patients in Group I. During the first follow-up year, 2 (13%) patients in Group I had their

Groups	Time interval	Reattached O-ring metal housing	Fractured denture base at metal housing	New dentures due to repeated fractures
Group I (2IODs) (n=15)	6 months	0	0	0
	1 year	0	2 (13%)**	0
	3 years	5 (33%)*	3 (20%)**	2 (13%)**
	5 years	8 (53%)*	5 (33%)*	3 (20%)**
Group II (1IODs) (n=16)	6 months	0	0	0
	1 year	0	6 (37.5%)*	0
	3 years	12 (75%)*	11 (69%)**	6 (37.5%)**
	5 years	15 (94%)*	12 (75%)*	8 (50%)**

[Table/Fig-12]: Number of patients requiring different maintenance procedures in the two studied groups along the follow-up periods.
*Borderline difference between groups with Z^2 test (p<0.1); Z^2 used Yates correction if expected cell counts <5
**Borderline difference between groups with Wilcoxon Mann-Whitney U test (p<0.1)

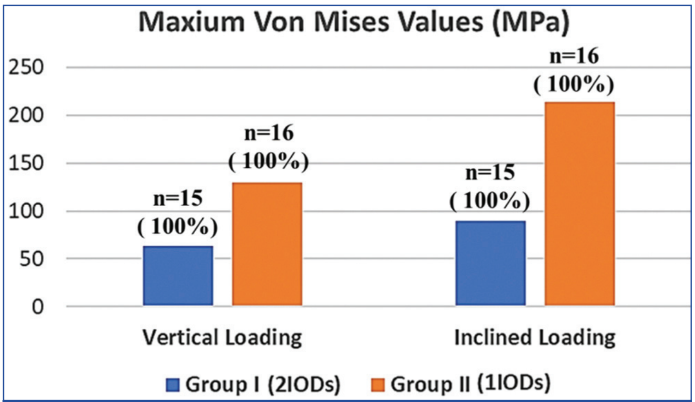
dentures fractured at the metal housings of the ball abutments. Subsequently, at three years, 3 (20%) patients in Group I and 6 (37.5%) patients in Group II faced similar problems with fractures in the denture base at the metal housing of the ball abutments. This was followed by 11 (69%) patients in Group II and 5 (55%) patients in Group I at the three-year follow-up, and 12 (75%) patients in Group II and 3 (20%) patients in Group I at the five-year follow-up. Repairs were conducted for these cases, followed by relining procedures, after which no further fractures were encountered. Statistically significant differences were also observed regarding the maintenance procedures of reattaching the O-ring to their metal housing. In Group I, 5 (33%) patients required present procedure at three years, and 8 (53%) patients at five years. In contrast, in Group II, 12 (75%) patients needed present procedure at three years, and 15 (94%) patients at five years required the same procedure.

When comparing probing depths and implant mobility, no statistically significant differences were found between the two groups. On the other hand, the comparison of crestal bone loss showed a statistically significant increase in marginal bone loss within the groups at the studied time intervals when compared to the baseline measurements. Additionally, between the groups at the third and fifth follow-up years, Group II exhibited significantly more marginal bone loss than Group I. At three years, Group II had vertical bone loss of (3.97±0.16 mm) compared to (2.76±0.15 mm) in Group I, and at five years, Group II had (5.01±0.12 mm) compared to (3.41±0.14 mm) in Group I. The results also indicated significance in the post-hoc pairwise comparisons as shown in [Table/Fig-13].

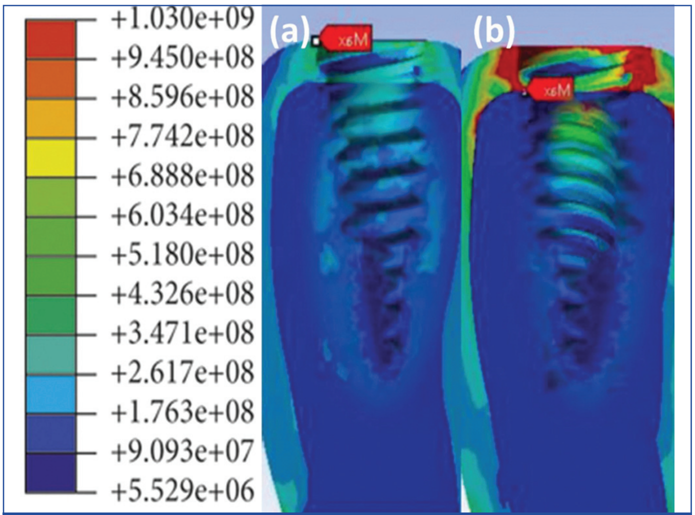
Time interval	Vertical bone loss (mm) (Mean±SD)		p-value
	Group I (2IODs)	Group I (1IODs)	
Baseline	0.21±0.11	0.22±0.15	0.320
6 months	0.53±0.13	0.59±0.12	0.430
1 year	1.52±0.14	1.66±0.21	0.122
3 years	2.76±0.15	3.97±0.16	0.016*
5 years	3.41±0.14	5.01±0.12	0.021*
p-value	<0.05*	<0.05*	
Baseline- 5 years	1.7±0.13	2.25±0.15	0.035*

[Table/Fig-13]: Vertical bone loss within and between groups.
*indicates statistically significant difference

The FEA results revealed a statistically significant lower stress concentration at the marginal bone around implants used in Group I (n=15, 100%) compared to implants in Group II (n=16, 100%). The maximum Von Mises values [Table/Fig-14] were 63.30 MPa and 129.94 MPa for vertical and inclined loading in Group I, respectively, and 89.32 MPa and 213.93 MPa for vertical and inclined loading in Group II, respectively. The von Mises stress distribution indicated that Group I had less stress concentration in the cortical bone surrounding the implants' neck and subjacent cancellous bone [Table/Fig-15a] compared to Group II [Table/Fig-15b], which exhibited more stresses in the cortical bone around the implants' necks and along the cancellous bone almost to the middle of the implant shaft.



[Table/Fig-14]: Maximum Von Mises values registered for Group I and II under vertical and oblique loading.



[Table/Fig-15]: Von Mises stress distribution color map: (a) for Group I; (b) for Group II.

DISCUSSION

According to Mahoorkar S et al., IODs were proven to be more successful compared to conventional complete dentures, with increased biting force and better chewing ability as reported by Vo TL et al., [7,11]. Additionally, these dentures were found to have greater mastication improvement when used with anatomic tooth form, as concluded by Emam AN et al., [16]. The success of IODs, whether with ball and socket or with magnet attachments, was also reported by Ismail HA et al., who further added that these dentures required less home care to maintain gingival health, along with increased patient satisfaction as reported by de Souza RF et al., and Singh S et al., [10,13,17].

When 1IODs were compared to 2IODs, after one year of clinical service, Tavakolizadeh S et al., found no statistically significant difference in the amount of vertical bone loss around the implants in the two groups. Additionally, when the patients' quality of life was compared [19].

Dewan H et al., found that both 2IODs and 1IODs improved the quality of life equally after one year of use [25]. Bryant SR et al., found no statistically significant difference between the two groups in patient satisfaction and implant survival up to a 5-year follow-up period [20]. However, Patil PG and Seow LL found that after one year, the 2IODs significantly improved the quality of life in elderly patients compared to the 1IODs, within a one-year observation period [23]. Al-Fahd et al., [21] discovered that the 2IODs exhibited better biting force and patient satisfaction than the 1IODs, as the 2IODs provided significantly more retention, as reported by AlSourori AA et al., who further mentioned that the only reason for using 1IODs would be the low economic status of the patients [21,22].

AlSourori AA et al., followed-up on the 1IODs for three years and reported results similar to those of the current study, where they found no statistically significant differences in the gingival and plaque indices of the 1IODs and 2IODs groups [18]. However, they observed more vertical bone loss around the single implants and concluded that 1IODs could replace 2IODs for patients with poor economic status.

Considering the finite element stress analysis studies, and in agreement with the results of the current work, El-Zawahry MM et al., reported that using two implants under overdentures led to better stress distribution than using one or even four implants [26]. These findings were further corroborated by Anca BM et al., who mentioned that increasing the number of implants reduces stress [29]. However, El-Anwar MI et al., and Abdelhamid AM et al., reported that the use of locator attachment resulted in less stress concentration than ball and socket attachment, which in the long term would minimise maintenance procedures, but El-Anwar MI et al., still recommended the use of two implants under the overdentures [30,31].

In conclusion, the results of the current study indicated that single implants placed in the midline under complete overdentures experienced more vertical bone loss and stress concentration compared to two implants positioned in the canine regions under the complete overdentures. Despite the fact that 1IODs might offer a more economical solution than 2IODs, the maintenance procedures required over five years might undermine the economic advantage of 1IODs. Nonetheless, improvements to 1IODs such as the use of glass fiber-reinforced acrylic denture bases, as recommended by Shaaban AA et al., or reinforcementof these denture bases with Poly Ether Ether Ketone (PEEK) or metal frameworks [27], as recommended by Abozaed HW and El-Waseef FA; Youssef H and Shawky Y, may improve their clinical performance and minimise the maintenance and repairs needed. However, they still do not decrease the vertical bone loss compared to 2IODs [14,15].

Limitation(s)

The limitations of the current study must be considered before any generalisation can be made. For example, a larger sample size, different attachments such as locators or magnets, different denture base materials, or different denture construction techniques such as Computer-aided Design (CAD)/Computer-aided Design (CAM) milled denture bases. These variables might have effects on the reported results.

CONCLUSION(S)

From the results of the current study, it can be concluded that the use of one implant, compared to the use of two implants under mandibular complete overdentures, is associated with significantly more stress concentration and vertical bone loss. The use of conventionally fabricated denture bases, with no reinforcement, over one implant results in more fractures and repairs than when used over two implants. Over a 5-year period, patients with single implants under their mandibular complete overdentures required significantly more newly constructed dentures than patients with two implants. Therefore, the use of a single implant under mandibular complete overdentures might provide a more economical solution initially compared to using two implants. However, the required repair procedures or the fabrication of new dentures might not be economical in the long term.

Acknowledgement

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