ORIGINAL RESEARCH

Comparison of Attachment Types in Maxillary Implant-assisted Obturators using Digital Image Correlation Analysis

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Abstract

Aim: The purpose of the study was to evaluate the stress on the implant and to assess the denture displacement for locator and bar and clip attachment types in implant-assisted obturators.

Materials and methods: A maxillary edentulous experimental model with a maxillectomy defect was made along with an opposing edentulous mandibular model with self-cure acrylic. Two endosseous implants were placed in the maxillary model. Corresponding obturator complete denture was fabricated for the maxillary model and a complete denture for the mandibular. The attachments were positioned on the implants in maxillary model, and their sleeve/clip was placed on intaglio surface of the dentures. The mounted articulator was placed on a loading apparatus, and force was incrementally applied to it. The strain and displacement for both the attachment types were measured and compared using Digital Image Correlation (DIC).

Results: Locator attachment showed the least stress and minimal displacement as compared to bar and clip attachment.

Conclusion: The stresses around the implants and displacement of the obturator are affected by the attachment type used. It was found that bar and clip (splinted) showed the maximum stresses around the implant and maximum denture displacement. Locator attachment is the better choice over bar and clip because of its additional retentive features.

Clinical significance: The advantage of using DIC over the conventional strain gauge analysis is that a full-field data of displacement and strain can be obtained instead of getting a mean value on the small surface where the strain gauge is positioned.

Keywords: Bar and clip attachment, Digital Image Correlation, Implant-assisted obturators, Locator attachment.

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Introduction

Maxillectomy is the surgical removal of all or part of the maxilla for a tumor, trauma, infections, or any congenital malformations in the maxillofacial region. This leads to an oronasal and oroantral communication causing fluid leakage, hypernasal speech, impaired masticatory function, and various degrees of cosmetic concerns.[1] Rehabilitation of the defect can be done by surgical reconstruction or by an obturator prosthesis alone. Prosthetic management of total or partial maxillectomy defects involves separation of the nasal and oral cavities for sufficient deglutition, mastication, and articulation, establishing a patent nasal airway, supporting the orbit and soft-tissue to restore the midfacial anatomy, and a dental rehabilitation to get a suitable aesthetic result. The size, location, severity, etiology of the defect, age, and the patient's wishes are the key factors for selecting either of the options.[1]

An obturator is a device fabricated to occlude the defect, usually in the hard or soft palate following maxillectomy. It is retained and supported by the patient's remaining hard and soft tissues and the existing dentition. For edentulous patients, the treatment with the obturator is even more challenging as it gets displaced with the mastication forces and drops down if there is no occlusal contact. The degree of movement depends on the height of the remaining alveolar ridge, volume and contour of the residual palatal bone, extent and conformation of the defect, and availability of undercuts.[2] Most common problems with the obturator prosthesis are the lack of retention, stability, and support.[3] Obturators supported with osseointegrated implants provide structural and functional rehabilitation of patients with maxillectomy defect.[4] Several attachment systems associated with the implants such as locator, ball systems, and bars and magnet are indicated for this kind of prosthesis.[5] In a maxillectomy defect, the implant site and number are restricted by the nature of the defect and the amount of available bone.[6]

Excess stress on the implant will transmit the stress to the underlying hard tissue and lead to loss of crestal bone.[7] There should be minimal stress on the implant for the longevity of the prosthesis. There should be maximum stability of the denture with an adequate peripheral seal during functional movements. Thus, the amount of stress on the implant and denture displacement are the two most significant factors for the success of the prosthesis. Implant stress cannot be measured directly in *in vitro* studies. So, strain, one of the indices of stress, has generally been employed. The most frequently used forms of anchorage for

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obturators are: locator attachments and bar and clip attachments.[8,9] It is crucial to determine whether implants that are splinted (bar and clip attachments) or the unsplinted implants (locator attachments) can endure the loads.

A lot of relevant data and studies have been done comparing splinted and unsplinted attachment types for maxillary and mandibular overdentures. There is very limited study on implant-assisted obturators and none comparing the effect of attachments (splinted and unsplinted) on implant strain and denture displacement. In this study, DIC has been used to analyze the strain and denture displacement, which has never been used for implant-retained dentures in the past.

The aim of this study was to evaluate strain on the implants and to assess the denture displacement in anteroposterior direction and along the line of retention in implant-assisted obturators with locator and bar and clip attachment types using digital image correlation.

Materials and Methodology

Model Preparation

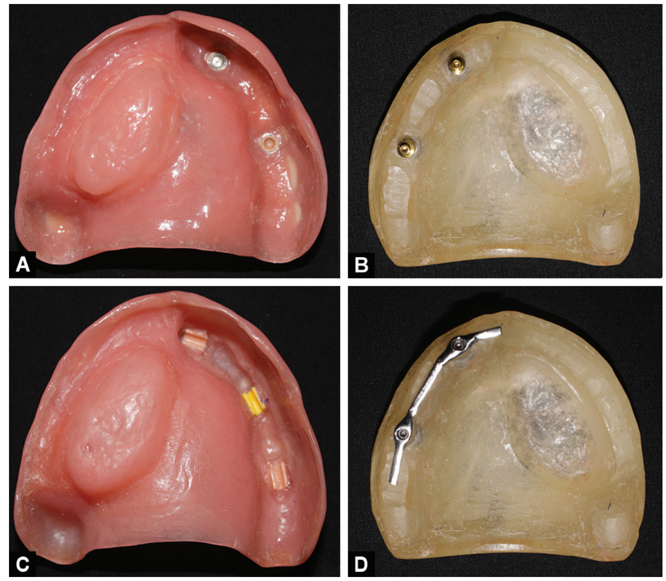
A maxillary experimental model was fabricated from a silicone edentulous mold (402-U) in clear self-cure acrylic resin dental product of India (DPI) (RR). Aramany Class 1 defect was created on the left side (dimensions: 3.5 × 2.5 × 1 cm). The surface (2 mm) of the acrylic model was scraped and covered by soft liner (GC TOKYO 1-1 PKG) to simulate soft tissue. A mandibular edentulous model was made with self-cure acrylic resin from a silicone mandibular mold (402-L) and used as the opposing model.

Obturator/Denture Fabrication

The maxillary closed bulb obturator with a complete denture was fabricated from the experimental model with heat-cure acrylic resin (DPI) in the conventional manner. The mandibular complete denture was fabricated using heat-cure acrylic resin. Acrylic artificial teeth were arranged in both the dentures in maximum intercuspation (centric occlusion). Another maxillary experimental obturator was duplicated from this maxillary denture obturator. The maxillary and the mandibular models with the corresponding dentures in occlusion were mounted on a semi-adjustable articulator (Jabbar and company, Disc Articulator). The incisal pin of the articulator was detached to prevent the load from being directly transferred to the pin.

Implants and Attachments

Two endosteal dental implants (ALPHA BIOCARE) were placed with dimensions 11.5 mm length and 4.2 mm diameter in the canine and molar region on the right ridge of the maxillary experimental model. Two types of attachments were used for this investigation: Locator and bar and clip. Locator abutments (ALPHALOC Rp height: 4 mm) were connected to the endosteal implants. The stainless-steel metal housing, with the male parts, nylon replacement discs, were placed on the intaglio surface of the experimental maxillary obturator (Figs 1A and B). A castable bar made from cobalt chromium of length of 20 mm and clip length of 2 mm connecting the two implants was used for the bar and clip attachment along with castable abutments. The nylon sleeves were placed on the intaglio surface of the other maxillary experimental obturator (Figs 1C and D).



Figs 1A to D: Maxillary obturator with model (A) Nylon retentive discs; (B) Locator abutment; (C) Nylon sleeve; (D) Bar and clip attachment

Digital Image Correlation

In this study, an optical, noncontact and full-field measurement technique called DIC was adopted to evaluate the displacement and strain values at multiple data points on the denture. DIC experiment consists of three major steps: (1) speckle pattern generation, (2) specimen loading and image capture, and (3) image analysis.

Nonrepetitive and isotropic speckle patterns are recommended for maintaining a homogeneous correlation. Therefore, in this study, uniform and fine speckle patterns were generated using spray painting method. Matte finish white spray paint was uniformly sprayed throughout the surface of interest on the maxillary obturator (overlying the implants) and mandibular denture. At a specific acute angle and from a distance, black matte finish paint was sprayed in order to obtain a very fine and homogeneous speckle pattern. The specimen was mounted on a standard loading frame, which is controlled hydraulically. Two monochromatic light sources were placed symmetrically with respect to the specimen. Using CANON EOS600D DSLR camera, image capturing was carried out. The lens model used is EFS 18-135 mm f/3.5-5.6. All the specimens, which will be discussed in the following sections, were loaded gradually up to 500 N, and images were captured at equal intervals of time (Fig. 2).

Image analysis was carried out using an open-source MATLAB code capable of performing 2D DIC analysis. DIC parameters such as region of interest (ROI), subset radius, and subset spacing were set according to the obtained speckle pattern. Based on the calculated pixel per mm, displacement values were evaluated. Followed by the displacement calculations, strain data are then evaluated based on the ROI.

The aforementioned workflow discussed the generic DIC method adopted by the authors in this study for all the experiments. In this study, two mechanical aspects (displacements and strains) of the dentures' motion subjected to a compressive loading were assessed. The following section discusses the measurement of displacement and strain of certain denture specimens under specific compressive loading conditions of 200 N (L1) and 500 N (L2). Jörnéus et al. observed that masticatory force acting on every dental implant is approximately 140–390 N.[10] So, these two load values were taken.

Measurement of Denture Displacement

Locator abutments were positioned in place on the endosteal implants on the model, and the corresponding maxillary experimental obturator was attached to it with the opposing mandibular denture in occlusion. The articulator was mounted on the loading apparatus and the force was applied directly along the central axis of the articulator. The articulator was then unloaded gradually and removed from the loading apparatus. The experiment was repeated in the same manner for bar and clip attachment after replacing the locator abutments and obturator from the experimental model with bar and clip attachment and obturator. Displacement values for loads 200 N (L1) and 500 N (L2) in both X and Y directions were obtained from NCORR at three distinct positions of the central axis along both the implants: crestal, middle, and apical.

Measurement of Strain

The maxillary experimental obturator was removed, and the maxillary model was demounted from the articulator. The locator abutments were placed on the implants. The maxillary experimental model with the locator attachment was placed on the loading apparatus. A loading bar was placed on both implant attachments. The camera was adjusted in position to focus the speckled pattern on the buccal region. The force was directly applied on both the locator attachments via the metal bar. The specimen was then oriented in a way such that the palatal side was the area of interest, and the camera was focused on that particular area. The loading process was again repeated, and images were taken at each increment. Followed by unloading, the locator attachments are replaced with bar and clip attachment, and the same experiment is repeated (Fig. 3). Strain measurement at nine points was carried out: three points on the central axis (crestal, middle, and apical), three points mesial to the implant, and three points distal to the implant.

Statistical analysis was done for these points using SPSS version 20 by an independent statistician. Variables were represented by mean, standard deviation, median, and inter quartile range (IQR). Mann–Whitney test was performed to compare the study variables between groups. A p-value of less than 0.05 was taken to be statistically significant.

Results

Denture Displacement

Bar and Clip and Locator in X-axis

The range of displacement at load L1 for locator was from −0.04 to −0.01 (low to high, blue to red) and, for load L2, it was from −0.05 to −0.005. The range of displacement on the colored bar for bar and clip at load L1 was from −0.085 to −0.04 and, at L2, it was from −0.22 to −0.13 (Fig. 4). From the images and the values obtained, bar and clip attachment showed more displacement along the anteroposterior direction, i.e., *X*-axis. The displacement in three points (crestal, middle, and apical) on the anterior and posterior implants was measured from the images. Then, Mann–Whitney test was performed. Denture displacement in anteroposterior (*X*-axis) direction was lesser in locator attachments than in bar and clip for both anterior and posterior implants under L1 and L2 loading conditions. The difference was statistically significant (p-value >0.05, Table 1a).

Bar and Clip and Locator in Y-axis

The range of displacement at load L1 for locator was from 0.295 to 0.335 (blue to red, low to high) and, at L2, it was from 0.5 to 0.56. The range of displacement on the colored bar for bar and clip at

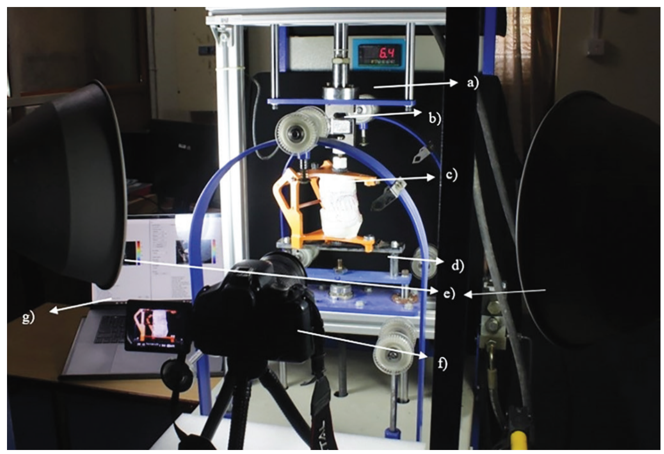
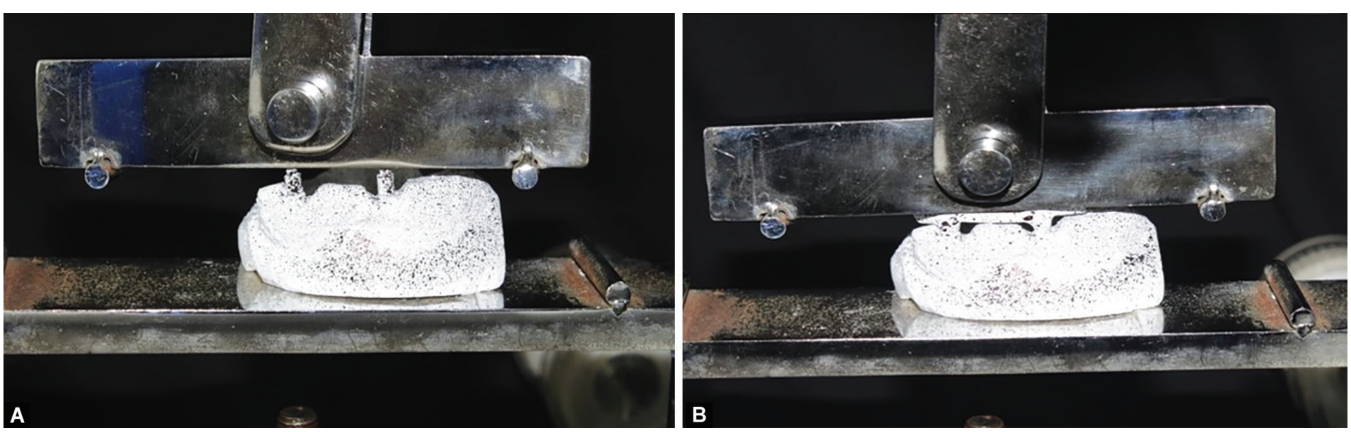
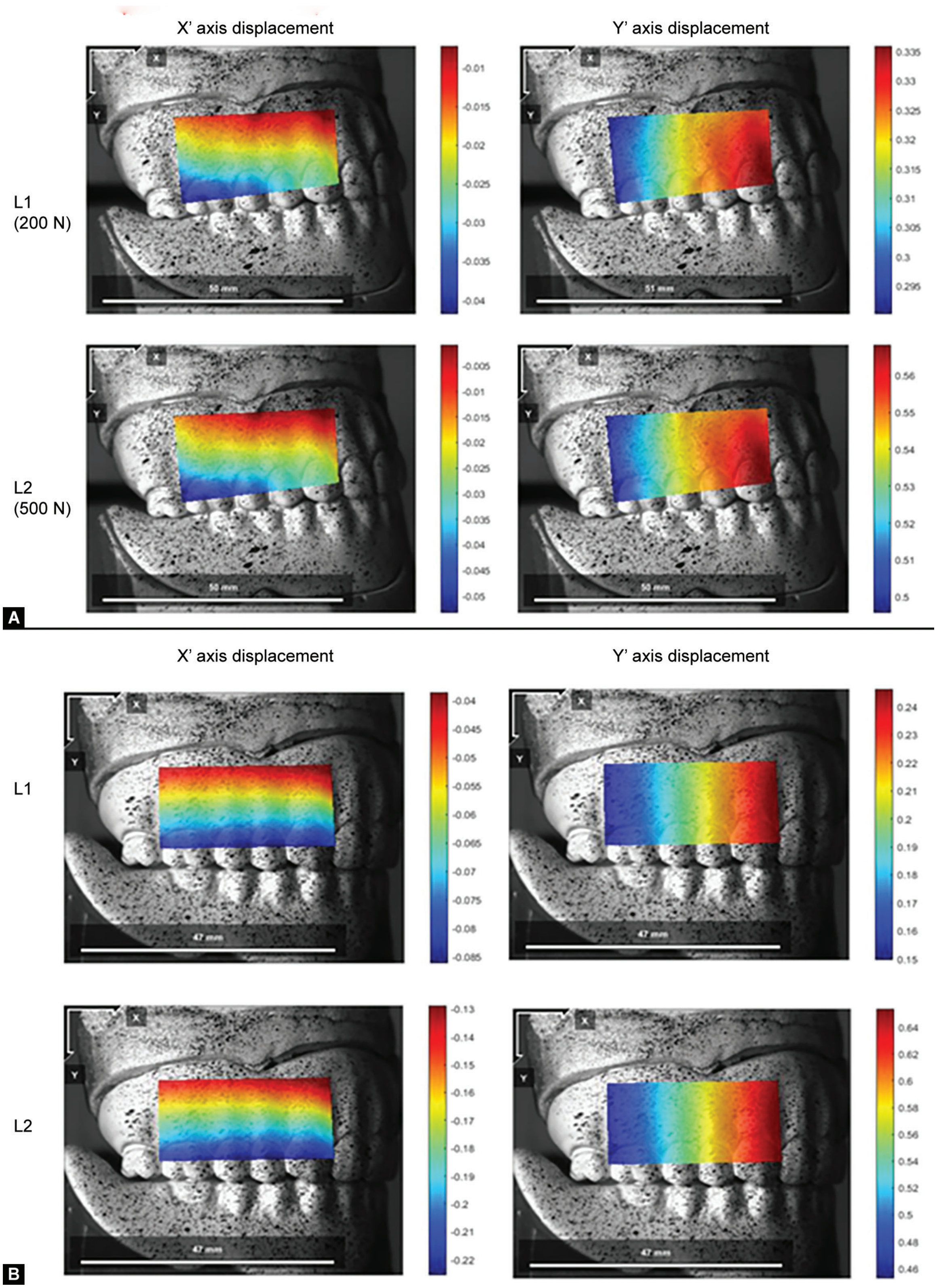


Fig. 2: DIC setup: (a) hydraulic loading; (b) load cell; (c) mounted articulator; (d) supports; (e) white light source; (f) camera; and (g) data acquisition setup



Figs 3A and B: Load applied on maxillary model. (A) Locator; and (B) Bar and clip



Figs 4A and B: Denture displacement. (A) Locator; and (B) Bar and clip

load L1 was from 0.15 to 0.24 and, at L2, it was from 0.46 to 0.64 (Fig. 4). Denture displacement under load L1 was lower for bar and clip along the line of retention (*Y*-axis) for both anterior and posterior implants. However, the denture displacements calculated at L2 were higher for bar and clip attachment when compared to locator attachment. This can be explained on basis of the fact that due to settling of dentures, there might occur a sudden locking that eventually causes a high displacement. In addition, one important

Table 1a: Displacement in (a) *X*-axis and (b) *Y*-axis

Type	*Mean*	*Standard deviation*	*Median*	*IQR*	*p-value*
Bar and clip	–0.125	0.064	–0.120	–0.19 to –0.06	0.000^{S}
Locator	–0.026	0.008	–0.024	–0.03 to –0.02	

S, significant

Table 1b

Type	*Mean*	*Standard deviation*	*Median*	*IQR*	*p-value*
Bar and clip	0.377	0.192	0.363	0.19–0.58	0.299^{NS}
Locator	0.428	0.117	0.424	0.31–0.55	

NS, not significant

takeaway point is that the load transfer is observed to be more in the anterior implant of the bar and clip attachment. The same points were evaluated and the statistical test was repeated. The difference was not statistically significant (p-value < 0.299, not significant; Table 1b).

Implant Strain

Bar and Clip and Locator in X-axis

The strain values on the buccal side at loads L1 and L2 for the locator was observed to lie in the range of -5×10^{-4} to 15×10^{-4} (blue to red, low to high) and -5×10^{-4} to 15×10^{-4}, respectively. The range of strain for bar and clip at load L1 was from 2×10^{-4} to 14×10^{-4} and, for L2, it was from 0 to 20×10^{-4} (Fig. 5). Strain along the *X*-axis direction was higher in bar and clip at both the loading conditions. At L1 and L2, strain around the crest of the anterior and posterior implant was high for bar and clip, whereas for locator at L2, high strain values were concentrated around the posterior implant crestally and apically. Measurement at nine points was taken: three points on the central axis (crestal, middle, and apical), three mesial to the implant, and three points distal to it. Mann–Whitney test was performed. Along the *X*-axis, the strain was much higher in bar and clip, and the difference was statistically significant at 0.05 level (p-value < 0.05, Table 2a).

Bar and Clip and Locator in Y-axis

For the locator, the strain values in the buccal side at loads L1 and L2 were found in the range of -1×10^{-3} to 3×10^{-3} and 1×10^{-3} to 7×10^{-3}, respectively. The range of strain for bar and clip at load L1 was -5×10^{-3} to 5×10^{-3} and, at L2, it was -4×10^{-3} to 8×10^{-3} (Fig. 5). Toward the *Y*-axis strain, values were higher for bar and clip attachments when compared with locator attachments for both the implants. However, there were sudden variations (red–orange flecks) in the values, which cause local high strains in locator attachments. The same nine points were evaluated, and the statistical test was repeated. Along the *Y*-axis, the strain was slightly higher in bar and clip, but there is no statistical difference (p-value > 0.577, not significant, Table 2b).

Inference of the study

- Denture displacement is more with bar and clip along *X*-axis as compared to the locator
- Implant strain was more with bar and clip along the *X*-axis as compared to the locator

Discussion

Maxillectomy defect plays a big toll on the patients' quality of life and psychological status. The complex 3D anatomy of the maxillofacial region makes the restoration of the maxillectomy defects very difficult. A multidisciplinary approach involving the surgeon and the maxillofacial prosthodontist has to be followed for any treatment plan to be a success. If surgical reconstruction is not done, then prosthodontic management of a maxillectomy defect includes giving an obturator prosthesis.

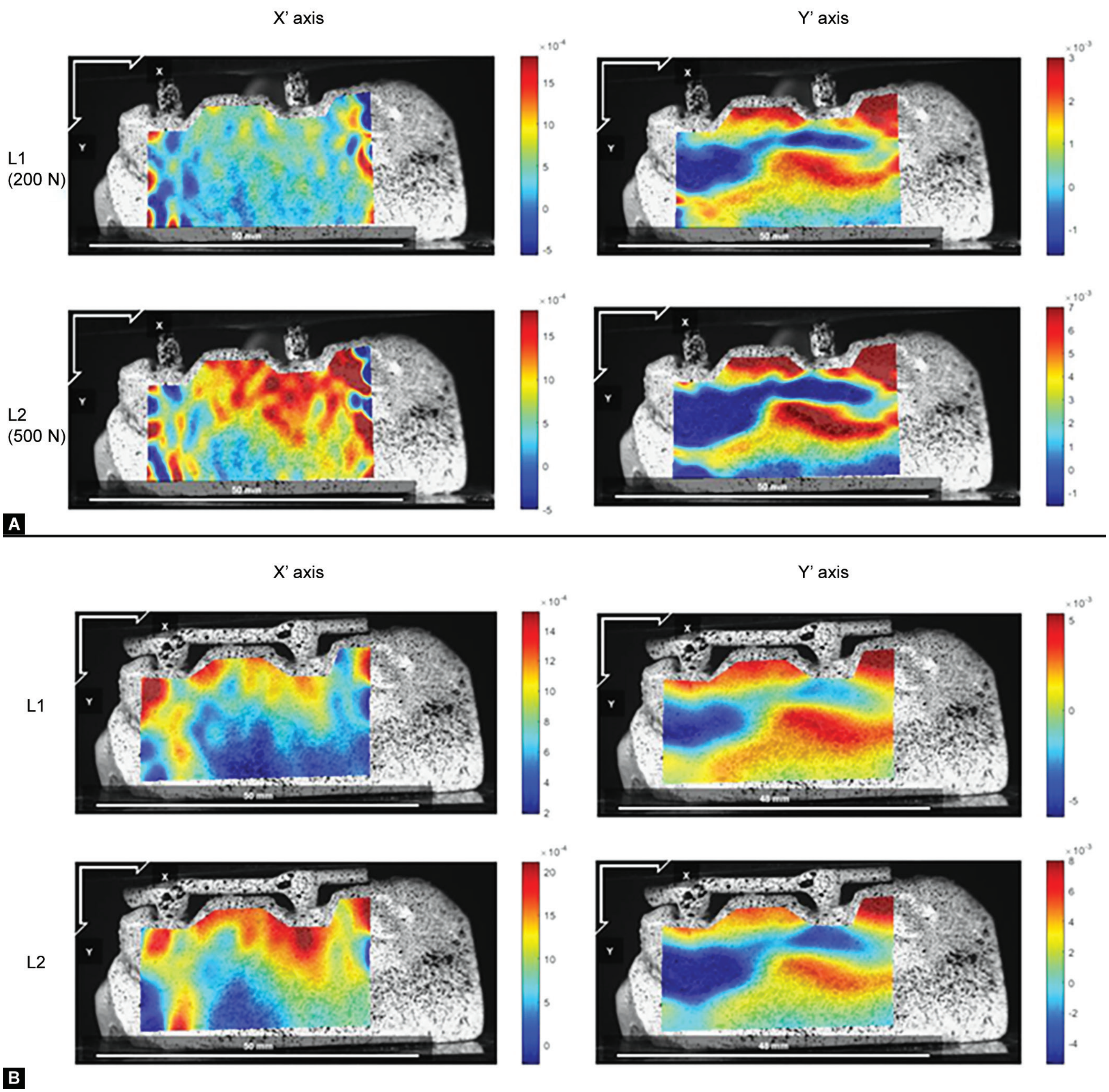
In this study, Class I Aramany defect has been created as majority of the patients fall under this category.[11] In edentulous patients, the masticatory load is mostly absorbed by the residual tissues. This affects the remaining bone and the tissues near the defect. Overtime conventional obturator prosthesis may cause progressive bone resorption around the defect region leading to increase in defect size.[12] Obturators supported with osseointegrated implants are a good treatment alternative for maxillectomy patients.[4] Implants also decrease the load on the remaining bone surrounding the defect and hence reduce its resorption.[13] There is no clear or recommended protocol on number, length, diameter, and distribution of implants for an implant-assisted obturator. It usually depends on patient-specific conditions with regard to the size of the defect and available bone sites. Implant placement for maxillectomy cases will be compromised by the resection site, insufficient remaining bone, and irradiated tissues.[14] Zygomatic implants offer remote anchorage and can be employed for the restoration of maxillectomy defects, but this cannot be used for all cases because of the lack of available bone.[15]

In this study, two endosteal implants have been inserted in the canine and molar region on the ridge opposite to the defect along the alveolar ridge spread equally from anterior and posterior side for a more favorable load.

There are several attachment systems associated with the implants such as locator, ball systems, bars, and magnet for retention.[5] Broadly, they can be divided into splinted and freestanding implants (unsplinted).

In the present study, we have compared locator (unsplinted) and bar and clip attachments (splinted) on denture displacement and implant stress. There should be maximum stability and retention of the prosthesis with a tight peripheral seal between the denture and the defect during functional movements. Excessive stress on the implant will transmit the stress to the underlying bone and lead to crestal bone loss and result in failure of osseointegration and bone resorption; so, we need to select the attachment type that transfers minimum stress to the implant.[7] Implant stresses cannot be measured directly in *in vitro* studies. So, we have used strain, one of the indices of stress to measure the stress in this study.[16]

Various techniques have been used in the past to study the stress distribution on implants such as photoelasticity,[17–23] finite element analysis, and strain gauges measurements.[24] In the present study, using DIC, denture displacements and implant strains are evaluated for dentures with both locator and bar and



Figs 5A and B: Strain measurement. (A) Locator; and (B) Bar and clip

Table 2a: Strain in (a) *X*-axis and (b) *Y*-axis

Type	*Mean*	*Standard deviation*	*Median*	*IQR*	*p-value*
Bar and clip	0.0013	0.0004	0.0013	0.001–0.002	0.000^{S}
Locator	0.0007	0.0006	0.0005	0.000–0.001	

Table 2b

Type	*Mean*	*Standard deviation*	*Median*	*IQR*	*p-value*
Bar and clip	–0.0010	0.0042	–0.0016	–0.004 to 0.003	0.577^{NS}
Locator	–0.0003	0.0043	0.0008	–0.003 to 0.002	

clip attachments. Traditionally, strain gauges have been used to measure implant stress, but the limitation behind a strain gauge is that one strain gauge can detect strain at a single material point only. Moreover, the strain gauge gives a mean of the strains measured only over the length of the gauge, generating lower readings than the actual.[24] A characteristic aspect of the DIC method is that a full-field data of denture displacement and strain in the ROI can be obtained, instead of getting a mean strain value of the small surface where the strain gauge is positioned.[25]

In the present study, there were two loads 200 N (L1) and 500 N (L2) applied on the experimental model. In a study by Fontijn-Tekampl et al., they found that the mean maximum unilateral bite force for men in implant retained mandibular overdentures to be 233.8 N.[26] Flanagan said there are implant patients who have reported more than 900 N masticatory force. The range of biting force can be said is approximately 50–800 N.[27] So, implant-supported maxillary obturator has to be carefully planned keeping the occlusal load in mind.

The results of this study presented that bar and clip attachments (splinted) exhibit maximal implant stresses and show the highest denture displacement compared with locator attachments (unsplinted). This might be because of the "splinting effect," more stresses are being transferred down to the bone in case of bar and clip.

This result is in accordance with some studies that compare attachment types for implant supported obturators and overdentures. Jiang et al. used finite elemental analysis and found that for long-term stability of implants, the load transfer in overdenture using locator attachment is more well distributed under the same loading condition as compared to bar and clip type.[28] Zou et al. found that locator attachments produced better clinical results compared to bar attachments and telescopic crown when it comes to peri-implant hygiene factors, the frequency of prosthodontic maintenance measures, ease, and cost of denture preparation.[29] Amer et al. using finite element analysis concluded that magnet attachment showed the lowest stresses, and bar and clip models showed the maximum stress values.[7] Manju and Sreelal comparing bar and clip, magnet and ball-ring using strain gauge analysis found that bar and clip had the maximum stress.[30] Naert found ball attachment (unsplinted) to have better retention of the overdenture as compared to bar and clip and magnet.[31]

On the contrary, there are studies showing better results with splinted attachments for denture displacement and strain. Goiato et al. found that bar and clip displayed the least strain values around the dental implants.[32] Savabi et al. evaluated the retention offered by an implant-supported overdenture using different attachment systems and found that the ITI Dolder bar (splinted) recorded the highest average value retention.[33] Manju and Sreelal presented that bar and clip showed minimal denture displacement.[30] There are studies that show no difference between the splinted and non-splinted attachment types.[34–38]

In the present study, locator attachments are a better choice as it showed lower strain values and lesser displacement of the obturator. The reason could be that locator attachments have a dual retention feature, i.e., mechanical and frictional. The nylon male head is marginally bigger than its female counterpart, which provides a frictional fit. The mechanical attachment is provided by the outer margin of attachment, which engages the shallow undercut area on abutment. The one drawback with locator attachments is that regular replacement is required of the male nylon part due to constant wear and tear.[39]

There are certain limitations to the study. A 2D DIC has been used in this study, which gives measurements only in two planes, i.e., *X*-axis and *Y*-axis. A 3D DIC would give a wider field of view by giving values in three planes. There are several studies comparing splinted and unsplinted attachment types for conventional implant retained maxillary and mandibular overdentures, but there is a need for additional research for implant-assisted obturators using 3D DIC.

Conclusion

Implant-assisted obturator should provide the patient a long-term solution with good retention, support, and stability. Within the limitations of this study, it can be concluded that the stresses around the implants and displacement of the obturator are affected by the attachment type used. We found that bar and clip (splinted) showed the maximum stresses around the implant and maximum denture displacement. Locator attachment is the better choice over bar and clip because of its additional retentive features.

Clinical Significance

For this study, we have used 2D DIC for the first time in literature for implant-assisted obturators. So, the strain analysis and displacement values obtained gave a full-field view and were more accurate as compared to those from a traditional strain gauge.

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