

**RESEARCH AND EDUCATION**

# Evaluation of the biomechanics of Aramany class I obturators of different designs using numerical and experimental methods. Part I: Retention and associated stress



Mohammed A. Mousa, BDS<sup>c</sup>, MFDs, MDSc, PhD,<sup>a</sup> Adam Husein, BDS, GradDipClinDent, DCLinDent (Prosthodontics),<sup>b</sup>  
Mohamed I. El-Anwar, BSc, MSc, PhD,<sup>c</sup> Norwahida Yusoff, BSc, MSc, PhD,<sup>d</sup> and  
Johari Yap Abdullah, B.S. & I.T., GradDip ICT, MSc, PhD (Craniofacial Biology)<sup>e</sup>

## ABSTRACT

**Statement of problem.** Studies on the biomechanics of obturators in the currently used designs of Aramany class I defect are lacking. Also, modifications of the designs presently used in unilateral palatal defects are needed to produce a prosthesis with more retention and less stress on the abutments.

**Purpose.** The purpose of part I of this study was to differentiate among Aramany class I obturators of 4 designs regarding retention and associated stress using numerical and experimental methods.

**Material and methods.** Four finite element models and 36 different base obturators were fabricated and divided into 9 acrylic resin bases retained with Adams clasps and 9 linear, 9 tripodal, and 9 fully tripodal design obturators from casts obtained from a scanned skull. After modification, the prostheses were fabricated on the casts obtained from a 3-dimensionally printed cast. The retention was evaluated, and the data were collected and analyzed using a statistical software program ( $\alpha=.05$ ). The displacement and associated stress in the assorted casts were compared by using 5-N displacing force at 3 points using finite element analysis. The quantitative assessment was made by measuring the displacement and von Mises stress distribution on the prostheses and their supporting structures. The qualitative analysis was done by using a visual color mapping to depict stress location and intensity.

**Results.** No significant differences were found between fully tripodal ( $4.478 \pm 2.303$  MPa) and tripodal obturators ( $4.478 \pm 2.286$  MPa;  $P=.153$ ), although fully tripodal showed more resistance to anterior displacement ( $4.522 \pm 0.979$  and  $3.553 \pm 1.58$  MPa for fully tripodal and tripodal designs, respectively;  $P=.007$ ), and tripodal obturators produced more resistance to middle displacement ( $5.441 \pm 1.778$  and  $2.784 \pm 0.432$  MPa for tripodal and fully tripodal design respectively;  $P=.001$ ). The fully tripodal obturator showed more retention ( $3.736 \pm 1.182$  MPa) than the linear one ( $2.493 \pm 1.052$  MPa;  $P=.001$ ). The maxillary central incisor was the most stressed abutment, followed by the lateral incisor, while the second molar was the least.

**Conclusions.** Regarding retention, the fully tripodal obturator produces retention comparable with the tripodal and significantly more than the linear. Acrylic resin prostheses retained with Adams clasps may be similar to metal-based prostheses regarding retention and stress distribution on the supporting structures. (J Prosthet Dent 2024;132:1088.e1-e8)

Supported by a Short-Term Grant (project no. 304/PPSG/6315661) through Universiti Sains Malaysia, Malaysia.

No conflict of interest.

<sup>a</sup>Lecturer, Prosthetic Dental Sciences, College of Dentistry, Jouf University, Sakaka, Saudi Arabia; and Researcher, Prosthodontic Unit, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, Malaysia.

<sup>b</sup>Professor, Prosthodontics, Department of Preventive and Restorative Dentistry, College of Dental Medicine, University of Sharjah, Sharjah, United Arab Emirates; and Professor, Prosthodontic Unit, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, Malaysia.

<sup>c</sup>Professor, National Research Centre, Cairo, Egypt.

<sup>d</sup>Senior Lecturer, School of Mechanical Engineering, Universiti Sains Malaysia, Nibong Tebal, Malaysia.

<sup>e</sup>Senior Lecturer, Craniofacial Imaging Laboratory, School of Dental Sciences, Universiti Sains Malaysia, Kubang Kerian, Malaysia; and Adjunct Professor, Dental Research Unit, Center for Transdisciplinary Research (CFTR), Saveetha Dental College, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, India.

## Clinical Implications

A fully tripodal obturator can be considered a suitable option as it is comparable with tripodal and better than linear obturators regarding retention and associated stress distribution. The obturator retained with Adams clasps is still comparable with metal base obturators in the same regard. The maxillary central and lateral incisors are the most affected abutments, showing the highest von Mises stress during prosthesis displacement.

Surgical ablation of malignant tumors results in palatal defects, affecting patients in functional, esthetic, and psychological terms.<sup>1</sup> Choosing the appropriate rehabilitation depends on restoring the anatomic structures, esthetics, oral function, and psychological well-being of the patient and quality-of-life perception.<sup>2</sup> Although most patients with palatal defects can be rehabilitated surgically or with a combination of bone grafting and implant-supported fixed or removable prostheses, some may not be appropriate for such treatment. When surgical repair with fixed and implant-supported prostheses is not possible, removable obturators are the treatment of choice.<sup>3</sup>

Many classifications have been introduced to classify palatal defects, with few options for prosthesis designs.<sup>4–8</sup> The primary advantage of Aramany classification is that it helps the clinician design the framework of the obturators using the same principles used for designing removable partial dentures. In addition, it is regarded as a valuable tool in communication among prosthodontists.<sup>1</sup> Brown et al<sup>5</sup> provided 4 new classes expressing the vertical and horizontal extension of the maxillary defect by incorporating 4 numbers (1–4) associated with 3 gradings (a–c).<sup>5,9</sup> For unilateral palatal defect, Aramany and Parr<sup>10,11</sup> recommended 2 designs: linear and tripodal. The linear design uses the posterior teeth, including premolars and molars, for support and retention if the remaining anterior teeth are not strong enough. In contrast, the tripodal design is suggested when anterior teeth are strong enough to provide retention and support.<sup>10,11</sup>

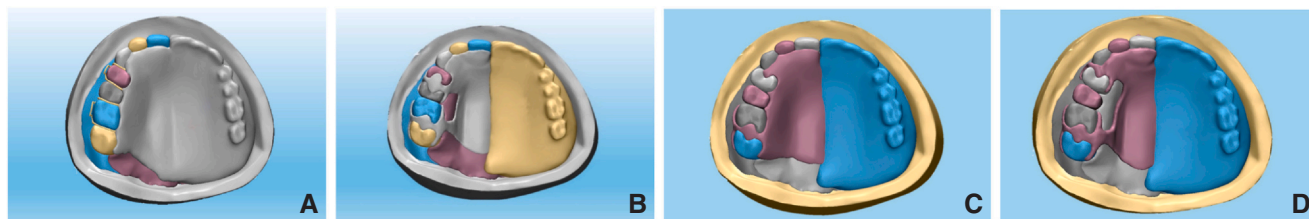
One of the essential factors for success in maxillofacial prostheses is retention and stability. However, the remaining dentition may not provide adequate retentive features because of mutilation. Furthermore, because of orofacial communication, the size of the prosthesis may put more weight on the major connectors, resulting in massive lateral forces on the abutments, leading to their loss and subsequent prosthesis failure. Preserving the abutments and minimizing the deformation of the prosthesis could be the key to success.<sup>12–16</sup>

Finite element analysis (FEA) has been used in different prosthodontic studies, providing valid and clear information about stress distribution, deflection, and displacement in complex structures that can be difficult to model.<sup>12,17–19</sup> However, the authors are unaware of evidence regarding the study of the biomechanics of prostheses in the currently used designs of Aramany class I defect, compared with the conventional acrylic resin obturators. This means the estimation of the obturators' retention and associated stress distribution depends only on a theoretical view with no scientific validation. Also, the authors are unaware of attempts to modify the current designs in Aramany class I to produce a prosthesis with more retention and support while keeping oral hygiene optimal.<sup>12</sup> Understanding the influences of the currently used designs and determining whether a newly modified one has better retention and favorable stress distribution is essential before designing prostheses. The current study aimed to evaluate the retention and associated stress distribution of the existing designs and a new design. The null hypothesis was that no difference would be found in the retention, displacement, or associated stress distribution of the different obturator designs.

## MATERIAL AND METHODS

This mathematical and in vitro study was conducted in the School of Dental Sciences, Universiti Sains Malaysia after approval from the Ethics and Research Committee, USM (USM/JEPeM/21030222). The retention and associated structures of Aramany class I obturators of 4 designs, including acrylic, tripodal, linear, and fully tripodal, were evaluated using FEA and a universal testing machine.

The inclusion criteria were adult patients with Brown class IIb defect (Aramany class I), with the contralateral side having no missing teeth, frameworks that met the criteria of the assorted designs, and prostheses with no defect or fault during fabrication. Other Aramany or Brown classifications and inappropriate frameworks or prostheses were excluded. Four finite element models and 36 maxillofacial metal frameworks were fabricated and divided into 9 acrylic resin-based obturators retained with Adams clasps and 9 linear, 9 tripodal, and 9 fully tripodal obturators from casts obtained from a scanned human skull. The sample size was calculated using a *t* test in Power and Sample size calculation software (PS 3.1.2; Dupont and Plummer)<sup>20</sup> based on a pilot study which involved the fabrication of 3 frameworks of tripodal and linear obturators and evaluating the retention for each. The response within each subject group was normally distributed with a standard deviation of the tripodal ( $\sigma$ ) of 2.633, while the actual difference in the linear and tripodal means ( $\delta$ ) was 1.543.



**Figure 1.** Obturator models. A, Acrylic resin-based obturator retained with Adams clasps on first premolar and molar. B, Linear design obturator. C, Tripodal design obturator. D, Fully tripodal design obturator.

Therefore, 9 frameworks per group were sufficient to reject the null hypothesis with a power of 0.81 and  $\alpha=.05$ .

The data were obtained from the archived data of a CT scanner (Somatom Definition AS; Siemens) with 128-slice at the Radiology Department, Hospital USM, for a 35-year-old man who had undergone undefined major surgery that required a CT scan of his head. The patient had a dentate and symmetric maxilla without massive destruction or missing teeth on the maxillary right side. The CT data were imported into a software program (Mimics 17.0; Materialise Innovation Suite) for segmentation, and the palate, teeth, and associated structures of the left side were removed to produce an Aramany class I defect; the teeth on the contralateral side were segmented separately. The model produced was then exported to a software program (Meshmixer 5.3.4; Autodesk Inc) to form a solid cast for printing. The printed cast was then modified, and the holes were obliterated with modeling clay (Plasticine; Craft E.) to facilitate impression making with silicone (PVS Flexceed Kit; GC Dental). The impressions were boxed and poured using high-strength acrylic resin (Extra-hard self-cure; Vertex dental) to produce 36 casts upon which the 4 different designs were prepared.

The designs included acrylic-based obturators retained by Adams clasps on the first premolar and molar on the edentulous side, and the linear, and tripodal obturators were prepared as specified by Aramany and Parr<sup>10,11</sup> (Fig. 1 A-C). The fourth design was nominated as a fully tripodal obturator and used the same occlusal rest location as the tripodal obturators to provide the same tripodal support configuration. However, the fully tripodal design included 1 gingivally approaching clasp on the central incisor, 1 reverse Akers clasp on the mesial side of the first premolar, and an embrasure clasp between the first and second molars. Palatally, the margin of the prosthesis was 6 mm away from the gingival margin in the area between the mesial side of the first premolar and the mesial side of the second molar area and covered the remaining part of the palate mesial to the first premolar (Fig. 1D). The casts were then duplicated, the frameworks were designed, fabricated, finished, and seated on their corresponding casts. Randomization was achieved by drawing lots on each cast.

Retention was evaluated experimentally by using a hook engaged to 3 rings (anterior, middle, and posterior) in the frameworks. The casts were adjusted to the testing machine and removed with a crosshead speed of 0.1 mm/minute. Nine removals were made for each cast: 3 at the anterior, 3 at the middle, and 3 at the posterior rings. The average for each ring and the overall prosthesis was obtained to compare the different designs (Fig. 2).

The data were collected and analyzed statistically by using a statistical software program (IBM SPSS Statistics, v22; IBM Corp). The data were assessed for normality by using the Shapiro-Wilk test. The Kruskal-Wallis test, 1-way ANOVA, and chi-squared test, followed by Mann-Whitney tests, were used to compare the retention among prostheses of different designs ( $\alpha=.05$ ).

For retention evaluation using FEA, 1 cast for each design was scanned using a laboratory scanner (3D scanner; Next Engine) and imported into a software program (Meshmixer 5.3.4; Autodesk Inc), and the different designs were then drawn, separated, and extruded to increase the thickness of the framework according to the material base—0.7 mm for metal and 2 mm for acrylic resin, using the software tools.<sup>21–23</sup> The teeth segmented from the skull during manipulation using the Mimics software program were imported to the Meshmixer software program to be replaced in their corresponding location. The roots of the teeth to the cement-enamel junction were selected and extruded to 0.2 mm to simulate the periodontal ligament. The cast



**Figure 2.** Framework in universal testing machine device.

**Table 1.** Number of nodes, elements, modulus of elasticity, and Poisson ratio of model components

| Materials                           | Young Modulus (MPa) | Poisson Ratio      |
|-------------------------------------|---------------------|--------------------|
| Enamel <sup>28</sup>                | 80 000              | 0.30               |
| Periodontal ligament <sup>28</sup>  | 175                 | 0.45               |
| Mucosa <sup>29</sup>                | 3.45                | 0.4                |
| Cancellous bone <sup>29</sup>       | 1370                | 0.30               |
| Cortical bone <sup>29</sup>         | 13 700              | 0.3                |
| Cobalt chromium alloy <sup>30</sup> | 220 000             | 0.33               |
| Titanium alloy <sup>30</sup>        | 110 000             | 0.35               |
| Acrylic resin <sup>29</sup>         | 2200                | 0.35               |
| Design                              | Number of nodes     | Number of elements |
| Acrylic resin                       | 2 133 577           | 1 365 410          |
| Linear                              | 1 935 433           | 1 090 905          |
| Tripodal                            | 1 697 520           | 839 327            |
| Fully tripodal                      | 1 784 732           | 954 282            |

was then adjusted to fit around the root of the teeth.<sup>24</sup> The mucosa, cortical bone, and cancellous bone were simulated by separating 2 mm of mucosa and 1 mm of cortical bone from the cast, while the rest was considered cancellous bone.<sup>25–27</sup> To simulate the part of the prosthesis that restored the defective part, 1 of the finished prostheses was scanned using the same laboratory scanner, and the defect part of the obturator was imported to the Meshmixer software program and adjusted to fit within the corresponding models. The components of all the models were then imported into a software program (3-Matic Innovation Suite; Materialise) to adapt and smooth the surface errors. The components of the models were then exported to the Workbench software program (ANSYS 2023R2; ANSYS Inc) for processing. The Young modulus (E) and Poisson ratio ( $\nu$ ) were added, as shown in Table 1.<sup>28–30</sup> The properties of the models were considered linearly elastic, homogeneous, and isotropic. The meshing of the models was performed using 4-node 3D tetrahedral full integration with a total number of elements and nodes constituting the models, as specified in Table 1. The base of the models was constrained, and 3 points were chosen to identify a 5-N displacing force: 1 at the central incisor, 1 at the premolar area, and 1 at the molar region.

Descriptive statistics of displacement and von Mises stress value were assessed with ANSYS workbench to predict the failure of prosthetic components and supporting structures appropriately.<sup>31</sup> Higher von Mises value represents a higher risk of failure in prosthetic components or resorption in the supporting bone. Also,

the outcomes enabled the evaluation of stress distribution in all directions using colored diagrams.<sup>32,33</sup>

## RESULTS

Table 2 shows the comparison of the retention of the different designs and the entire prostheses. Regarding the anterior loop, the fully tripodal showed the highest retention ( $5.522 \pm 0.979$  MPa;  $P < .001$ ), followed by the acrylic resin-based obturator. The linear expressed the lowest retention ( $2.116 \pm 1.118$  MPa;  $P < .001$ ), followed significantly by the tripodal design ( $3.553 \pm 1.58$  MPa;  $P < .001$ ). Regarding the middle loop, the tripodal demonstrated the highest retention ( $5.441 \pm 1.778$  MPa;  $P < .001$ ), while no significance existed among the other designs ( $P = .07$ ). As for the posterior loop, no significance existed among all designs ( $P = .071$ ). Regarding the obturators entirely, the linear ( $2.493 \pm 1.052$  MPa) showed the lowest retention compared with the other obturators ( $P < .001$ ). There was no significance between tripodal ( $4.478 \pm 2.286$  MPa) and fully tripodal obturators ( $4.478 \pm 2.303$  MPa;  $P = .153$ ). The tripodal obturator showed significantly higher retention than the acrylic resin-based obturator ( $3.22 \pm 0.972$  MPa;  $P = .01$ ), while the fully tripodal obturator showed no significance compared with the same prosthesis ( $P > .999$ ).

Table 3 shows the displacement and von Mises values from 5-N displacing forces in the different designs using FEA. The abutments had the lowest displacement with the linear design and the highest with the acrylic resin-based obturator ( $66.5$  and  $132.75 \times 10^{-5}$  mm for linear and acrylic resin base, respectively). They showed the lowest von Mises value with the tripodal obturator and the highest with the fully tripodal obturator. The stress was concentrated on the mesial side of the central incisor. Regarding the bone, the lowest von Mises value was related to the tripodal and fully tripodal obturators, but the lowest value was related to the linear obturators. The stress was concentrated at the alveolar bone of the central incisor (Fig. 3). Regarding the prostheses, the linear obturator expressed the highest displacement and von Mises value compared with the others, while the acrylic resin-based obturator showed the lowest. The stress was concentrated on the anterior part of the framework and the clasp of the first premolar.

**Table 2.** Comparison of different rings and prostheses with different designs as unit

| Rings             | Assorted Designs (1-way ANOVA followed by Mann-Whitney Test) |                                      |                                        |                                              | P     |
|-------------------|--------------------------------------------------------------|--------------------------------------|----------------------------------------|----------------------------------------------|-------|
|                   | Acrylic Mean $\pm$ SD <sup>1</sup> MP                        | Linear Mean $\pm$ SD <sup>1</sup> MP | Tripodal Mean $\pm$ SD <sup>1</sup> MP | Fully Tripodal Mean $\pm$ SD <sup>1</sup> MP |       |
| Anterior ring     | 3.279 $\pm$ 0.779 <sup>ab</sup>                              | 2.116 $\pm$ 1.118 <sup>d</sup>       | 3.553 $\pm$ 1.58 <sup>bc</sup>         | 4.522 $\pm$ 0.979 <sup>a</sup>               | .001* |
| Middle ring       | 2.688 $\pm$ 0.795 <sup>b</sup>                               | 2.445 $\pm$ 0.936 <sup>b</sup>       | 5.441 $\pm$ 1.778 <sup>a</sup>         | 2.784 $\pm$ 0.432 <sup>b</sup>               | .001* |
| Posterior ring    | 3.706 $\pm$ 1.061 <sup>a</sup>                               | 2.918 $\pm$ 0.97 <sup>a</sup>        | 4.49 $\pm$ 2.285 <sup>a</sup>          | 3.9 $\pm$ 1.242 <sup>a</sup>                 | .071  |
| Entire prosthesis | 3.225 $\pm$ 0.972 <sup>b</sup>                               | 2.493 $\pm$ 1.052 <sup>c</sup>       | 4.478 $\pm$ 2.304 <sup>a</sup>         | 3.736 $\pm$ 1.182 <sup>ab</sup>              | .001* |

a-d: shows Mann-Whitney and Asymp. Significant (2-tailed), while "a" highest and "d" lowest, and similar letters show no significant differences with asymptotic significance\*, adjusted to  $P \leq .05$ .

SD, standard deviation.



**Table 3.** Displacement and von Mises stress value subjected to 5-N anterior displacing forces using finite element analysis

| Supporting Structure | Total Displacement ( $\times 10^{-5}$ mm) |        |          |                | von Mises Values (MPa) |        |          |                |
|----------------------|-------------------------------------------|--------|----------|----------------|------------------------|--------|----------|----------------|
|                      | Acrylic                                   | Linear | Tripodal | Fully Tripodal | Acrylic                | Linear | Tripodal | Fully Tripodal |
| Abutments            | 132.75                                    | 66.5   | 95.894   | 104.46         | 11.208                 | 12.029 | 10.865   | 13.657         |
| Periodontal ligament | 81.66                                     | 61.75  | 66.447   | 71.138         | 0.023                  | 0.032  | 0.012    | 0.037          |
| Mucosa               | 135.41                                    | 271.78 | 106.91   | 102.3          | 0.005                  | 0.012  | 0.003    | 0.003          |
| Bone                 | 77.537                                    | 78.095 | 67.778   | 71.1           | 0.908                  | 3.232  | 1.489    | 1.832          |
| Framework            | 46.936                                    | 138.05 | 92.783   | 93.619         | 3.086                  | 9.821  | 5.704    | 4.446          |
| Acrylic resin        | 368.57                                    | 788.02 | 415.87   | 450.54         | 1.669                  | 7.27   | 2.779    | 6.301          |

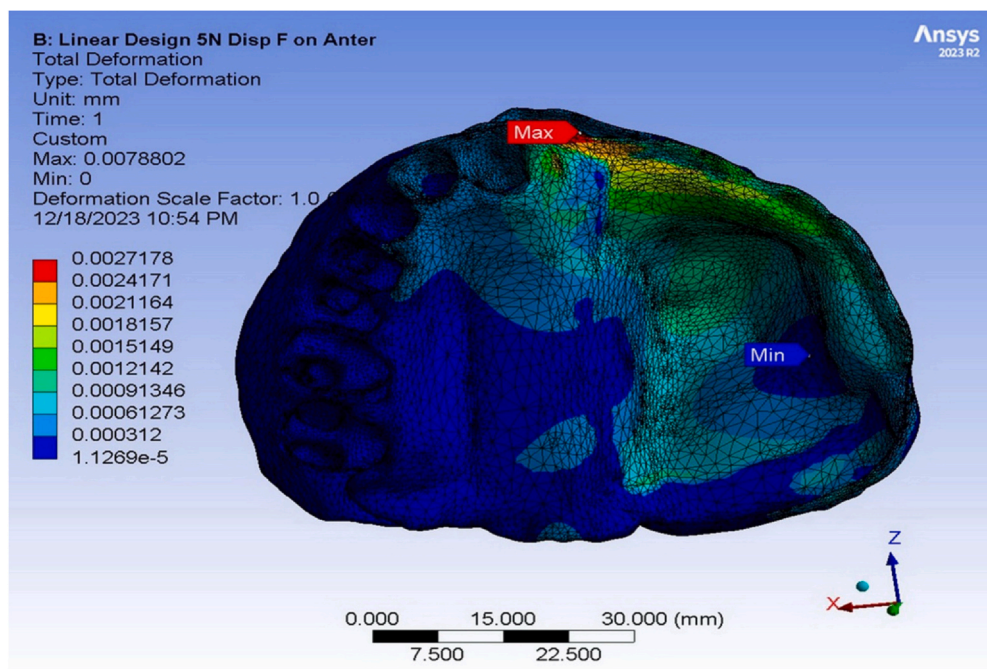
**Figure 3.** Displacement of mucosa and underlying bone in linear obturator from 5-N anterior displacing forces.

Table 4 shows the displacement and von Mises stress value from 5-N displacing forces at the premolar area. The abutments of the linear obturator showed the lowest displacement and von Mises value, while those of the acrylic resin-based obturator showed the highest. The stress was concentrated in the mesial side of the central incisor, followed by the lateral incisor. As for prosthetic components, the linear obturator showed the highest displacement, while the tripodal obturator showed the lowest. The acrylic resin base obturator showed the lowest von Mises values, while the tripodal

showed the highest. The stress was concentrated in the clasp of the central incisor.

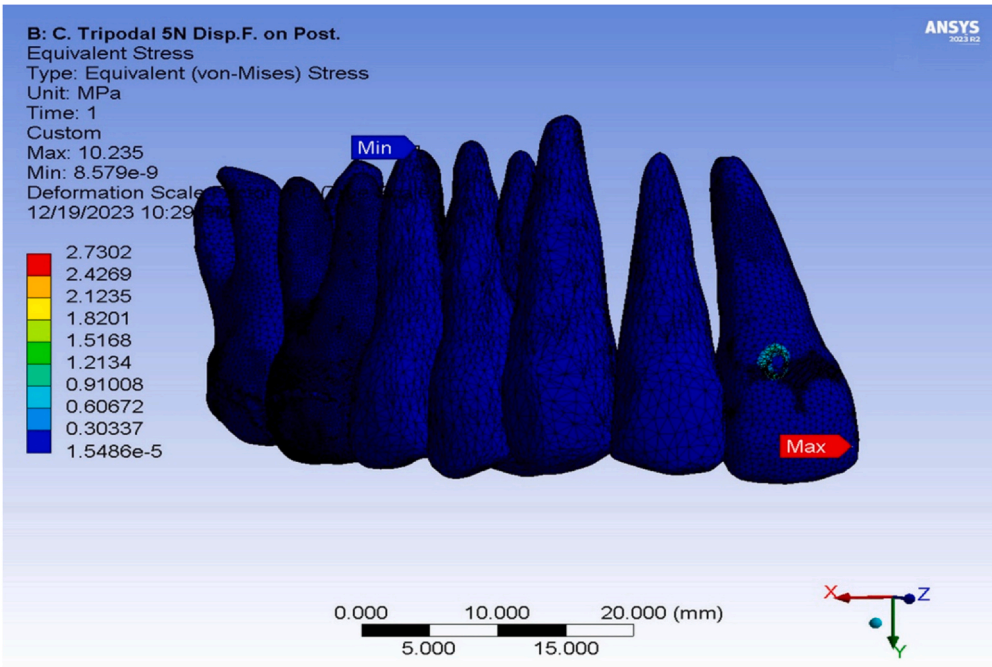
Table 5 shows the displacement and von Mises values in the different designs subjected to 5-N posterior displacing forces. The abutments of the acrylic resin-based obturator showed the highest displacement, while those of the linear obturator showed the lowest. The abutments of the fully tripodal obturator showed the highest von Mises value, while those of the linear obturator showed the lowest. The stress was concentrated on the palatal side of the posterior abutments and the

**Table 4.** Displacement and von Mises stress values subjected to 5-N middle displacing forces using finite element analysis

| Supporting Structure | Total Displacement ( $\times 10^{-5}$ mm) |        |          |                | von Mises Value (MPa) |        |          |                |
|----------------------|-------------------------------------------|--------|----------|----------------|-----------------------|--------|----------|----------------|
|                      | Acrylic                                   | Linear | Tripodal | Fully Tripodal | Acrylic               | Linear | Tripodal | Fully Tripodal |
| Teeth                | 76.289                                    | 46.431 | 62.452   | 67.377         | 5.312                 | 4.755  | 4.707    | 6.793          |
| Periodontal ligament | 46.712                                    | 39.344 | 45.005   | 51.265         | 0.019                 | 0.016  | 0.01     | 0.072          |
| Mucosa               | 351.02                                    | 348.36 | 279.49   | 297.54         | 0.011                 | 0.013  | 0.008    | 0.008          |
| Bone                 | 42.321                                    | 82.637 | 60.862   | 66.887         | 0.467                 | 4.147  | 2.476    | 2.646          |
| Framework            | 41.812                                    | 149.13 | 122.67   | 129.52         | 1.885                 | 3.905  | 15.416   | 6.789          |
| Acrylic resin        | 571.61                                    | 576.6  | 406.47   | 465.89         | 0.944                 | 2.634  | 2.263    | 5.09           |

**Table 5.** Displacement and von Mises stress values subjected to 5-N posterior displacing forces, using finite element analysis

| Supporting Structures | Total Displacement (×10 <sup>-5</sup> mm) |         |          |                | Von Mises Value (MPa) |        |          |                |
|-----------------------|-------------------------------------------|---------|----------|----------------|-----------------------|--------|----------|----------------|
|                       | Acrylic                                   | Linear  | Tripodal | Fully Tripodal | Acrylic               | Linear | Tripodal | Fully Tripodal |
| Teeth                 | 60.551                                    | 33. 886 | 44.677   | 43.625         | 2.269                 | 1.457  | 2.73     | 3.16           |
| Periodontal ligament  | 37.716                                    | 25.199  | 29.532   | 27.955         | 0.019                 | 0.008  | 0.008    | 0.017          |
| Mucosa                | 348.03                                    | 276.61  | 249.19   | 226.554        | 0.013                 | 0.01   | 0.008    | 0.009          |
| Bone                  | 35.386                                    | 131.67  | 92.615   | 129.53         | 3.668                 | 7.022  | 4.043    | 5.464          |
| Framework             | 56.535                                    | 76.652  | 91.595   | 76.125         | 1.552                 | 1.743  | 10.235   | 2.873          |
| Acrylic resin         | 422.8                                     | 370.39  | 324.43   | 407.49         | 0.515                 | 2.475  | 2.953    | 2.326          |



**Figure 4.** Stress distribution in abutment for a tripodal obturator subjected to 5-N posterior displacing forces.

mesial side of the central incisor (Fig. 4). Regarding the bones, the linear obturator was associated with the highest displacement and von Mises value, the acrylic resin- based obturator showed the lowest. As for the prosthetic components, the acrylic resin-based obturator showed the highest displacement, while the tripodal obturators showed the lowest. The components of the tripodal showed the highest stress, while the acrylic resin-based obturator showed the lowest. The stress was concentrated at the anterior palatal part of the prosthesis.

DISCUSSION

The current study was conducted to introduce a novel design that can provide optimum support and retention from a maximum number of abutments to improve the biomechanics of the obturators and simultaneously cover less tissue. An experimental and mathematical evaluation was performed to explore the retention and associated von Mises stress value during dislodgement.

The retention (displacement) of obturators with the different designs showed significant differences, leading to rejecting the null hypothesis that no difference would be found in the retention, displacement, or associated stress distribution in the different obturator designs.

The 2 available designs for treating Aramany class I maxillary defect depend mainly on the abutments used for support and retention, including linear and tripodal.<sup>10,11</sup> The fully tripodal design could provide tripodal support through the occlusal rests on the central incisor, canine, first premolar, and molars, and tripodal retention through the clasps on the central incisor, first premolar, and molars. In addition, a biological advantage can be provided by less tissue coverage.

During the experimental evaluation of the retention, at 5-N displacing force, all the prostheses were displaced entirely from their model, so this force was chosen to be the force of dislodgement in FEA. Experimentally, each prosthesis framework was displaced from the corresponding models 9 times (3 from the anterior, 3 from the middle, and 3 from the posterior rings). The removal

from the anterior ring could express the resistance of the framework to the anterior dislodgment during mastication, while the middle ring expressed the resistance to the dislodgment because of the weight of the prosthesis. The removal from the posterior ring could express resistance of the prosthesis to the posterior displacement during incising or contact with the anterior teeth. The objective of the current study was not to evaluate the retention of specific clasps but rather to assess the retention of the framework of the designs as a whole.

In both approaches, the fully tripodal obturator had the highest retention during the anterior displacement, while the linear obturator was the lowest. The tripodal distribution of clasps could explain this difference. However, the presence of the premolar clasp did not influence the retentive force of the fully tripodal compared with the tripodal during the middle (premolar) displacement. The similarity could have been because of the palatal coverage of the tripodal obturators compared with those of the fully tripodal obturators. No incongruity was found between the experimental and FEA results regarding the anterior and middle displacement. However, in the FEA, using the posterior displacing force, the tripodal obturator showed higher retention than the fully tripodal obturator, contrary to the experimental approach, which showed no significance difference between both designs. The linear obturator was the least retentive compared with all designs using both approaches, possibly because of the linear distribution of the clasps over abutments, facilitating prosthesis rotation. The acrylic resin-based obturators were comparable with the metal in both approaches, explained by the effectiveness of the Adams clasp in retention, as it can use both mesial and distal undercuts because of the flexibility of the wrought wire.<sup>34</sup> Besides, the complete palatal coverage of the acrylic resin-based obturator may provide physical and mechanical retention that the metal connectors may not provide.

The current study examined the stress distribution in the abutments using FEA. The fully tripodal and acrylic resin base obturators produced the highest von Mises value on the abutments compared with the other, while the linear produced the lowest. The stress was concentrated at the alveolar bone of the central incisor and adjacent teeth. Similarly, the displacement of the central incisor was the highest with the fully tripodal and the tripodal obturators, while the linear demonstrated the lowest. The differences could be explained by the absence of a clasp from the linear obturator on this abutment. The authors are unaware of previous studies assessing the displacement and associated stress of tissue-away displacing force, making comparisons impossible.<sup>12</sup>

Regarding the stress developed in the prosthetic components, the tripodal obturators showed the highest stress, especially during the displacement from the

premolar and molar areas. The stress was concentrated at the clasp of the central incisor. From a biomechanical point of view, if the tip of the gingival approaching clasp were placed more gingivally, that would result in more stress on the abutment and the clasp during the vertical dislodgment of the prosthesis. Compensation between the ideal location of the clasp tip, and form and esthetics should be followed to avoid increasing the stress on the central incisor and clasp.

Limitations of the study included its in vitro design and the biological comparison, and patient influences on the different designs were not modeled. That may be an area of interest for further investigations.

## CONCLUSIONS

Based on the findings of this numerical and experimental study, the following conclusions were drawn:

1. In terms of retention and stress distribution, this study determined that the fully tripodal obturator was appropriate for use in addition to the existing designs and conventional acrylic resin-based obturator.
2. The fully tripodal obturator design provided results comparable with those of the tripodal obturators and was better than the linear design.
3. The acrylic resin-based obturator retained with Adams clasps still provides an appropriate prosthodontic option from the biomechanical view.

## REFERENCES

1. Ali R, Altaie A, Nattress B. Rehabilitation of oncology patients with hard palate defects. Part 1: The surgical planning phase. *Dent Update*. 2015;42:326–328.
2. Cawood JL, Stoelinga PJ. International Academy for oral and facial rehabilitation—Consensus Report. *Int J Oral Maxillofac Surg*. 2006;35:195–198.
3. Freitas JA, Garib DG, Trindade-Suedam IK, et al. Rehabilitative treatment of cleft lip and palate: experience of the Hospital for Rehabilitation of Craniofacial Anomalies-USP (HRAC-USP)—Part 3: Oral and maxillofacial surgery. *J Appl Oral Sci*. 2012;20:673–679.
4. Aramany MA. Basic principles of obturator design for partially edentulous patients. Part I: classification. *J Prosthet Dent*. 1978;40:554–557.
5. Brown JS, Rogers SN, McNally DN, Boyle M. A modified classification for the maxillectomy defect. *Head Neck*. 2000;22:17–26.
6. Brown JS, Shaw RJ. Reconstruction of the maxilla and midface: Introducing a new classification. *Lancet Oncol*. 2010;11:1001–1008.
7. Futran ND, Mendez E. Developments in reconstruction of midface and maxilla. *Lancet Oncol*. 2006;7:249–258.
8. Okay DJ, Genden E, Buchbinder D, Urken M. Prosthodontic guidelines for surgical reconstruction of the maxilla: A classification system of defects. *J Prosthet Dent*. 2001;86:352–363.
9. Iyer S, Thankappan K. Maxillary reconstruction: Current concepts and controversies. *Indian J Plast Surg*. 2014;47:8–19.
10. Aramany MA. Basic principles of obturator design for partially edentulous patients. Part II: Design principles. *J Prosthet Dent*. 1978;40:656–662.
11. Parr GR, Tharp GE, Rahn AO. Prosthodontic principles in the framework design of maxillary obturator prostheses. 1989. *J Prosthet Dent*. 2005;93:405–411.
12. Mousa MA, Abdullah JY, Jamayet NB, et al. Biomechanical stress in obturator prostheses: A systematic review of finite element studies. *Biomed Res Int*. 2021;6419774:1–12.
13. Ali MM, Khalifa N, Alhajj MN. Quality of life and problems associated with obturators of patients with maxillectomies. *Head Face Med*. 2018;14:1–9.

14. Devi EM, Gupta C, Kochhar KP, et al. A long-term nutritional assessment of maxillary cancer patients undergoing prosthodontic rehabilitation after surgery: A longitudinal study. *J Oral Biol Craniofac Res.* 2022;12:702–708.
15. Chigurupati R, Aloor N, Salas R, Schmidt BL. Quality of life after maxillectomy and prosthetic obturator rehabilitation. *J Oral Maxillofac Surg.* 2013;71:1471–1478.
16. Balkaya MC, Sultan H, Erdem S, Mutlu D. Prosthetic rehabilitation of a patient with a unilateral cleft palate: A clinical report. *J Prosthet Dent.* 2014;111:269–272.
17. Farook TH, Mousa MA, Jamayet NB. Method to control tongue position and open source image segmentation for cone-beam computed tomography of patients with large palatal defect to facilitate digital obturator design. *J Oral Maxillofac Surg Med Pathol.* 2020;32:61–64.
18. Mousa MA, Abdullah JY, Jamayet NB, et al. Biomechanics in removable partial dentures: A literature review of FEA-based studies. *Biomed Res Int.* 2021;5699962:1–16.
19. Mousa MA, Jamayet N, Lynch E, Husein A. Biomechanical stress in removable complete dental prostheses: A narrative review of finite element studies. *J Int Oral Health.* 2020;12:413.
20. Dupont WD, Plummer WD. Power and sample size calculations for studies involving linear regression. *Control Clin Trials.* 1998;19:589–601.
21. Richert R, Alsheghri AA, Alageel O, et al. Analytical model of I-bar clasps for removable partial dentures. *Dent Mater.* 2021;37:1066–1072.
22. Sekinishi T, Inukai S, Murakami N, Wakabayashi N. Influence of denture tooth thickness on fracture mode of thin acrylic resin bases: An experimental and finite element analysis. *J Prosthet Dent.* 2015;114:122–129.
23. de Souza Batista VE, Silva LS, Catelan A, et al. Effect of the acrylic occlusal device on the stress distribution in the external hexagon implant in situations of dental tightening. A 3D finite element analysis. *Res Soc Dev.* 2021;10. e33610615601–e.
24. Vilela ABF, Soares PBF, Versluis A, Soares CJ. Dental trauma splints for the mixed dentition – A finite element analysis of splint material, splint extension, missing teeth, and PDL representation. *Dent Traumatol.* 2022;38:495–504.
25. Hussein LA. 3D finite element analysis of the influence of different soft lining materials with variable thicknesses on stress transmitted to underlying mucosa. *Int J Adv Res (Indore).* 2014;2:896–905.
26. Moldoveanu SAB, Munteanu F, Forna NC. Impact of implant-retained mandibular overdenture on oral mucosa-a finite element analysis. *Romanian Journal of Oral Rehabilitation.* 2020;12:6.
27. Yépez JE, Marangon RM, Saga AY, et al. Miniscrew composition, transmucosal profile, and cortical bone thickness: A Three-dimensional Finite-element Analysis of Stress Fields. *J Contemp Dent Pract.* 2018;19:881–887.
28. Archangelo CM, Rocha EP, Anchieta RB, et al. Influence of buccal cusp reduction when using porcelain laminate veneers in premolars. A comparative study using 3-D finite element analysis. *J Prosthodont Res.* 2011;55:221–227.
29. Chen X, Mao B, Zhu Z, et al. A three-dimensional finite element analysis of mechanical function for 4 removable partial denture designs with 3 framework materials: CoCr, Ti-6Al-4V alloy and PEEK. *Sci Rep.* 2019;9:13975.
30. Tribst JPM, Dal Piva AMO, Borges ALS, et al. Effect of different materials and undercut on the removal force and stress distribution in circumferential clasps during direct retainer action in removable partial dentures. *Dent Mater.* 2020;36:179–186.
31. Rungsiyakull C, Rungsiyakull P, Suttat K, Duangrattanapraphip N. Stress distribution pattern in mini dental implant-assisted RPD with different clasp designs: 3D finite element analysis. *Int J Dent.* 2022;2022:2416888.
32. Eom JW, Lim YJ, Kim MJ, Kwon HB. Three-dimensional finite element analysis of implant-assisted removable partial dentures. *J Prosthet Dent.* 2017;117:735–742.
33. Shahmiri R, Das R. Finite element analysis of implant-assisted removable partial dentures: Framework design considerations. *J Prosthet Dent.* 2017;118:177–186.
34. Mansuri M, Singh VP. Clasps in removable orthodontics. *J Nobel Med Coll.* 2014;3:1–9.

#### Corresponding author:

Dr Johari Yap Abdullah  
Craniofacial Imaging Laboratory  
School of Dental Sciences  
Universiti Sains Malaysia  
Kubang Kerian, Kota Bharu, Kelantan 16150  
MALAYSIA  
Email: johariyap@usm.my

#### Acknowledgments

The authors thank Assoc Prof Dr Yanti Johari (yjohari@usm.my), Dr Azirrawani Ariffin (wani@usm.my), Dr Nafij Jamayet (dr.nafij@gmail.com), Dr Ahmed Abbas (nawrozah@gmail.com) and the Prosthodontic Unit staff from the School of Dental Sciences at Universiti Sains Malaysia for their tremendous efforts in the accomplishment of this work.

#### CRediT authorship contribution statement

**Mohammed A. Mousa:** Conceptualization, Methodology, Software, and Writing, **Adam Husein:** Conceptualization, Methodology, original draft preparation, **Mohammed I. El-Anwar:** Visualization, Methodology, and Software. **Norwahida Yusoff:** Visualization, Methodology, **Johari Yap Abdullah:** Supervision, Validation, Reviewing, and Editing.

Copyright © 2024 by the Editorial Council of *The Journal of Prosthetic Dentistry*. All rights are reserved, including those for text and data mining, AI training, and similar technologies.  
<https://doi.org/10.1016/j.prosdent.2024.07.011>