Statement of problem. Some patients may opt for a prosthetic rehabilitation without replacing all missing teeth, finishing treatment with a reduced dental arch. This choice may be due to biologic reasons or financial restrictions. It is unclear if a reduced dental arch functions as well as a complete dental arch.

Purpose. The purpose of this study was to analyze whether shortened dental arches could result in tooth displacement.

Material and methods. Four different 3-dimensional maxillary and mandibular arches with different levels of arch length reduction were created. In all models, anatomic structures that represent the temporomandibular joint, cortical and cancellous bone, enamel, dentin, and periodontal ligament were modeled. Mechanical properties were attributed to each anatomic component, and a total occlusal load of 100 N on masseter, temporal, and medial pterygoid muscles was simulated for each model. The MSC. Patran software was used for the preprocessing and postprocessing of the biomechanical analysis of the models. One complete dental arch was used as the control.

Results. The simulations showed that shortened dental arches presented greater tooth displacements than those found in a complete dental arch. The changes in mandibular tooth position were greater than those observed in the maxillary arches. In finite element models 1 and 2, the largest maxillary displacements were found for posterior teeth.

Conclusions. Decreasing numbers of occlusal units resulted in increasing amounts of displacements of the remaining teeth, which may compromise dental stability in patients with shortened dental arches. (J Prosthet Dent 2014;111:460-465)

Clinical Implications
There is a tendency for increased tooth displacement when the number of remaining teeth in the dental arch is reduced. Therefore, the more teeth present, the greater the area to support the occlusal load and the lower the chances of having undesired excessive forces overloading the remaining teeth. Finally, this study provided important information about the stress distribution on reduced dental arches that may assist the clinician who faces the decision whether or not to rehabilitate a patient who presents a reduced dental arch.
The maintenance of occlusion with complete dental arches is frequently a primary goal of prosthetic treatment planning. However, the prosthetic rehabilitation of decayed or missing teeth may not be possible in certain patients because of technical difficulties or financial restrictions.\(^1\)\(^-\)\(^3\) This situation is often seen in patients without health insurance coverage in some industrialized countries and in large numbers of the population of developing nations.\(^1\) The molars are the teeth most frequently affected by caries and periodontal disease, and also the most costly teeth to preserve.\(^4\)\(^,\)\(^5\) Unfortunately, tooth extractions, especially of molars, remain commonly performed when patients cannot afford more conservative treatment, which leads to a large number of individuals with shortened dental arches (SDA).\(^6\) SDA has been defined as a dentition with fewer occlusal units due to the loss of most posterior teeth.\(^7\)\(^-\)\(^10\) One occlusal unit is a pair of occluding premolars, and a pair of antagonist molars is equivalent to 2 occlusal units.\(^11\) This concept has been associated with periodontitis, tooth migration, impaired occlusal stability, and temporomandibular joint disorders.\(^6\)\(^,\)\(^11\)

For many years, the complete restoration of compromised dental arches was considered a requirement to achieve a successful prosthetic rehabilitation. However, since the early 1980s, several studies have been conducted to evaluate the oral function of patients with SDAs, and some researchers have suggested that some patients who exhibit SDAs might have adequate oral function.\(^11\)\(^-\)\(^14\) Conversely, because of the reduced bone support of SDAs, patients with this condition may be more susceptible to occlusal instability.\(^11\) In addition, in 1992, the World Health Organization suggested that a minimum of 20 teeth are necessary to maintain adequate oral health throughout an individual’s lifespan.\(^15\) Although accepted by most dentists, this concept is not widely applied.\(^16\)

Kanno and Carlsson\(^17\) reviewed the work developed by the Kayser/Nijmegen concluded that patients with SDAs generally fulfilled the overall requirements of functional dentition. The majority of the research reviewed was based on epidemiological studies, which accurately determine the consequences of oral function with SDAs in certain population groups. However, this research method does not allow a direct evaluation of the effects of specific occlusal forces on tooth positioning.\(^11\) The finite element method has been used as an alternative to study occlusal function and stability under different clinical conditions, and finite element models (FEM) have been successfully applied to analyze the effects of different occlusal forces on tooth positioning and occlusal stability with complete dental arches.\(^18\)\(^-\)\(^22\) Few studies have evaluated SDA function with the FE method FEM.\(^9\)\(^,\)\(^18\)\(^,\)\(^22\)

The application of this methodology for studying SDA would provide important information on possible tooth displacements and on the clinical behavior of the occlusal system submitted to forces of varying intensity, frequency, and duration. Therefore, the purpose of this study was to determine whether differences exist in tooth displacements in both the mandible and maxilla between complete and SDAs simulated in tridimensional FEMs.

### MATERIAL AND METHODS

The 3-dimensional FEM used in this experiment was developed from serial images of a multiplane computerized tomography of a young adult who presented complete permanent dentition, except for the third molars. This study was approved by the research ethics committee of the Pontifical Catholic University of Minas Gerais, Belo Horizonte, Brazil, protocol no. 122/2011. The construction of this FEM has previously been described in detail.\(^18\) However, some modifications were made as follows: enamel, dentin, and pulp were differently characterized. Enamel width was constructed thinner at the cervical surface and limited to 2.5 mm in all teeth. Cortical bone was differentiated from cancellous bone, and its thickness varied from 1 to 3 mm in both the mandible and maxilla. The periodontal ligament was modeled with an interface between the root surface and alveolar bone. The mechanical properties of each anatomic structure were attributed to the models (Table I) and were considered homogeneous with isotropic elastic characteristics.

Five 3-dimensional FEMs were created, and each model presented different levels of dental arch reduction, as described in Figure 1. Each model was created with different numbers of nodes and elements (Table II). The software (MSC.Patran; MSC Software Corp) generated a finite element mesh of the anatomic structures with tetrahedral elements, with the exception of the pulp, which was characterized as an empty space as previously reported.\(^23\)

Restrictive elements were inserted in the upper section of the model to inhibit its displacement when mandibular closure was simulated, which provided rigidity to the region (Fig. 2). Elastic restrictions were inserted in the condyles along the 3 planes of space represented by the x, y, and z axes. The rigidity coefficient (k) used was 1 × 10\(^{-7}\) N/m to allow small mandibular movements.\(^18\) In the region

<table>
<thead>
<tr>
<th>Anatomic Structure</th>
<th>Elastic Modulus (MPa)</th>
<th>Poisson Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>13.7</td>
<td>0.30</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>1.37</td>
<td>0.30</td>
</tr>
<tr>
<td>Enamel</td>
<td>84.1</td>
<td>0.20</td>
</tr>
<tr>
<td>Dentin</td>
<td>18.6</td>
<td>0.31</td>
</tr>
</tbody>
</table>
of interproximal and interocclusal contacts, elements of transition (multipoint constraint) were used, which permitted transference of displacements from 1 tooth to the teeth adjacent to it. The interocclusal pattern evaluated was canine-crest, and, in FEM 3, 4, and 5, contacts between maxillary and mandibular anterior teeth were generated.

Multiple force vectors were used in the regions that correspond to the temporal, masseter, and medial pterygoid muscles to characterize muscular force (Fig. 3). The simulation of various force vectors instead of having a single point of force application for each muscle avoided overloading in specific regions of the mesh. During preprocessing, a time independent static load of 100 N was attributed to the muscular force vectors with the MSC.Patran program. Tooth displacement data were collected with the software (MSC.Nastran; MSC Software) by evaluating a point at the incisal edge of the anterior teeth and at the occlusal surface of the posterior teeth.

RESULTS

The results demonstrated that increasing amounts of tooth displacements were directly related to higher degrees of dental arch reduction. The highest values of displacements were registered with FEM 5, the most unstable model tested (Figs. 4, 5). Values of changes in the mandibular tooth position were higher than in those observed in the maxillary arches tested, and differences were noted between right and left side displacements in all FEMs studied (Fig. 6).

In FEMs 1 and 2, the largest maxillary displacements were found for the posterior teeth. Conversely, in FEMs 4 and 5, the highest values of changes in tooth positioning were recorded in the anterior teeth, especially the central incisors. The results of mandibular tooth positioning revealed small alterations in FEMs 1 and 2, which gradually increased in FEMs 3 and 4, and achieved the highest values in FEM 5.

DISCUSSION

The results of this study demonstrated differences in maxillary and mandibular tooth displacements between complete and SDAs simulated in
FEM. Although it has been reported that patients with certain levels of SDAs may have adequate function, the biomechanics and the consequences of these occlusal conditions for tooth position stability remain unclear. The 5 different FEMs were submitted to a load on the muscular force vectors that corresponded to 100 N according to Hart et al. This value was divided by the 3 multiple muscle force vectors bilaterally. This value was defined during preprocessing by the software program and was static. In the 5 models (MEF 1, 2, 3, 4, and 5) developed, the same load of 100 N was applied, which Hart et al considered the value of a physiologic load. When considering that the behavior of these models is linear, that is to say, the higher the load, the greater the displacement, with the inverse being true, this value could be more convenient in the case of alterations in the data inserted and the results obtained.

The results of this investigation represent a step forward in understanding the characteristics of SDA. Graphic evaluations of different FEMs have revealed that, as the dental arch is reduced, tooth displacement increases. Similar results have previously been reported. The most significant results were recorded with FEM 5, which was the shortest dental arch tested. For example, in FEM 5, the maxillary central incisor presented a higher displacement value than the same tooth in FEM 1, which coincides with

---

**Figure 3** Multiple force vectors simulating temporal, masseter, and medial pterygoid muscles function.

**Figure 4** Maxillary tooth displacement values in mm (M2, second molar; M1, first molar; P2, second premolar; P1, first premolar; C, canine; LI, lateral incisor; CI, central incisor).

**Figure 5** Mandibular tooth displacement values in mm (M2, second molar; M1, first molar; P2, second premolar; P1, first premolar; C, canine; LI, lateral incisor; CI, central incisor.)
the findings of other studies. These authors have suggested that this condition could represent a risk factor for dental stability.

In the mandibular arch, all teeth evaluated in FEMs 1, 2, 3, and 4 presented a more regular displacement pattern than that observed in the maxillary arch. However, the maxillary incisors showed greater displacements than the other maxillary teeth studied in FEMs 3, 4, and 5. This could have occurred because of the limitation imposed by the contact between the maxillary and mandibular anterior teeth. In addition, the loading direction of the maxillary incisors was less favorable to maintaining tooth position stability than that of the mandibular incisors.

When an individual loses posterior teeth and develops an SDA, migration of the remaining teeth may occur. This condition is named individual adaptive capacity. In FEMs 3, 4, and 5, the results showed greater displacement values than those registered in FEMs 1 and 2. Therefore, smaller numbers of occlusal units may result in increased instability. Although some investigators have suggested that patients with SDAs might have acceptable oral function, the results of the present study showed that tooth displacement increased when shorter dental arches were simulated. The clinical significance of these findings are that patients who present with SDAs could face higher chances of developing or increasing the mobility of the remaining teeth and that the dentist should consider replacing the missing posterior teeth to prevent further occlusal problems. Other factors such as the direction, frequency, and magnitude of the occlusal forces must be considered to achieve a precise prognosis of the remaining teeth in each patient, especially in those who...
present with parafunctional habits, severe periodontal diseases, and/or severe malocclusions.\textsuperscript{21,25}

A difference was noted in the dental displacement in the left side in comparison with the right. This occurred because, in this study, the anatomy of both sides was identical. It would practically be impossible to place occlusal contacts in the same nodes as those contained in the matrix because each one of them has a distinct number. Thus, the distribution of these contacts was not mirrored on both sides. The same fact occurred for the muscle force vectors.

Finally, FEM technology is not capable of reproducing 100% of all particularities present in humans, such as the neuromuscular regulatory system in the periodontal ligament. However, this model presents some advantages in comparison with other in vivo studies because it is virtual; that is, apt for computer simulation and totally controllable. For example, the researcher can change a variable of the test parameters for the model, geometry, and perform a simulation. Evidently, all of these items would be practically impossible to place occlusal contacts in the same nodes as those contained in the matrix because each one of them has a distinct number. Thus, the distribution of these contacts was not mirrored on both sides. The same fact occurred for the muscle force vectors.

REFERENCES


CONCLUSION

The results of this study contribute to a better understanding of SDA biomechanics. Decreasing numbers of occlusal units resulted in increasing amounts of displacements of the remaining teeth, which may compromise dental stability in some patients with SDAs.

Corresponding author:
Dr. Bruno Franco De Oliveira
Av. Dom José Gaspar, 500-Prédio 46, Sala 106
Belo Horizonte, MG 30535-610
BRAZIL
E-mail: brunofo@gmail.com

Copyright © 2014 by the Editorial Council for The Journal of Prosthetic Dentistry.