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Editorial Office
Dr. (Mrs) S. J. Nagda
Prof. & Head,
Dept. of Prosthodontics,
Nair Hospital Dental College,
Mumbai - 400 008, India.
E-mail: jipseditor@yahoo.co.in

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Royapettah, Chennai - 600014, India. E-mail: drvranga@gmail.com

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CONTENTS

Original Article

The curvature of the retentive arm in a circumferential clasp and its effect on the retention: 3D analysis using finite element method

Allahyar Geramy, Masoud Ejlali*
Department of Orthodontics, Tehran University of Medical Sciences (TUMS), Dental Research Center, Tehran University of Medical Sciences (DRC-TUMS), *Department of Prosthodontics, Shahid Beheshti University of Medical Sciences, Tehran, Iran

For Correspondence
Dr. Allahyar Geramy, Department of Orthodontics, Ghods Ave, Enghelab St., School of Dental Medicine, Tehran University of Medical Sciences, Tehran, Iran. E-mail: gueramya@yahoo.com

INTRODUCTION: Missed teeth are replaced to provide the patients with occlusal stability. Partial removable prosthodontics are still in use among the various applications in this field. Adequate retention is essential for its function. Circumferential clasps are used and the main goal of this study is to assess the importance of the geometry of the retentive arm and its effects on the quality of retention produced. **MATERIALS AND METHODS:** Three-dimensional finite element method of analysis was selected to find answer to the questions. Three models were designed with the retentive arms of same lengths and different angular coverages (α is explained in text). 0.01″ to 0.03″ of displacements were applied and the forces derived. **RESULTS:** Different amounts of retentive forces were produced, which were assessed in two directions. **CONCLUSION:** The greater the curve of a retentive arm, the greater the retention force produced, assuming that the length of retentive arm remains constant.

Key words: Circumferential clasp, finite element method, removable partial denture, retention, retentive arm

Prostheses are designed to provide esthetics, functions, phonetics and stability of the dental system by replacing the missed teeth. In spite of the progresses in fixed prosthodontics, partial removable ones are still in use. One of the most important considerations in partial removable prosthetic designs is retention. Direct retainers provide retention, which is the resistance of prosthesis against the moving away from the ridge. Circumferential clasps are the most widely used choices. These clasps provide retention by the resistance to deformation found in the retentive arms placed gingival to the height of contour.

In 1971, Clayton and Jaslow,[1] attempted to measure the forces produced by clasp arms on the abutment teeth by making use of resistance strain gauges and also compared the cast and wrought wire clasps on the basis of the forces produced. The application of a continuous force from all the clasp designs while in rest was found. Moris *et al.*,[2] measured different clasp patterns available in the market and their tapered forms. They found various width-to-thickness ratios ranging from 1.1 to 2.5. The largest deflection of a 10-mm-long clasp was reported to be between 0.175 to 0.250 mm. The importance of the geometric form in the retention produced by a clasp arm was not mentioned.[2] Snyder and Duncanson studied the effect of clasp thickness on its deformation after 1500 cycles of 0.01-in displacements. According to their findings, the permanent deformation of clasps is independent of their forms or their width-thickness ratios.[3]

In 1995, Sato *et al.*,[4] investigated the preferred design for a circumferential clasp by using 2D FEM models. They concluded that the use of the preformed clasp patterns with a taper of 0.8 is preferable for reducing fatigue and / or permanent deformation of the clasp arm. Two years later, Sato *et al.*,[5] discussed the importance of the friction coefficient on the circumferential clasp retention. They concluded that the retentive force increased linearly with the increasing friction coefficient between abutment material and clasp material and suggested that clasp designs should be changed based on the abutment materials.

Marei[6] compared the average measurements of forces required to dislodge circumferential clasps with round and half-round retentive arms in different amounts of undercut. The findings indicated the possible use of cast round clasps, where the advantages of clinical fit and reduction of transmitted forces to the abutments can be gained.

Sato and Hosokawa[7] attempted to discuss the importance of the guiding planes and proximal plates for conventional tooth-supported removable partial dentures with circumferential clasps. They geometrically analyzed the retention force of the clasps and concluded that short or oblique guiding planes resulted in reduced retention.

One of the latest studies on circumferential clasps considered the material used to fabricate it. In this study, Rodrigues *et al.*,[8] concluded that although titanium clasps produced less retention in comparison with Co-Cr ones, they preserve it in a 5-year period better than the other materials.

Finite element method (FEM) is a numeric means to find accurate answers to the clinical or basic questions with regard to the changing parameters; this method proven its efficiency in solving different problems in some 60 years of its introduction to the science. FEM has been used to easily demonstrate the principles for educational applications[9-11] to normal situations with respect to the nature of tooth movements under the orthodontic loads[12] and special situations such as alveolar bone resorption[13-16] and also from extraoral forces[17] to the optimization of treatment methods.[18, 19] It can also be applied to simply find an answer to a clinical question.[20]

According to McCracken,[21] flexibility of a clasp arm is affected by (1) the length of the clasp arm, (2) width of the clasp arm, (3) cross section of the clasp arm, (4) width-thickness ratio of the clasp arm and (5) the alloy used.

To explain the differences between the 3D models designed in this study, two parameters are defined. If we considered a tooth as a cylinder (in an occluso-gingival view), its radius is "R" and the angle between the radius connecting the start point of the retentive arm to the center of the cylinder and the radius connecting its end to the center is considered as "α." Three models were considered to rotate around different teeth (different values of R) with the same lengths. Apparently, when the value of R increases, the angle α decreases [Figure 1]. R = 5 mm and α = 180 degrees in model 1, R = 7.5 mm and α = 135 in model 2 and R = 10 mm and α = 90 degrees in model 3.

The main objective of this study was to investigate the importance of the curvature of retentive clasp arm of circumferential clasps in the retention produced with the same amount of undercut. If different clasps are fabricated with the same characteristics and lengths, except for the R and α, will the produced retention be affected? In other words, can the retention produced by two clasps with the same characteristics and placed at the same undercut depths be different?

MATERIALS AND METHODS

Three FEM models were designed for the analyses. A 3D approach was selected and the retentive arm of a circumferential clasp was considered for modeling. All the characteristics such as taper, width-thickness ratio and alloy used were the same. Each model consisted of 26496 nodes and 21375 elements [Figure 2 a-d]. A 3D brick, isoparametric, octahedral element was selected to construct the models. In the first model, α = 180 degree and R = 5 mm. For the second one, α increased to 135 degree and R decreased to 7.5 mm and for the last one, α = 90 degrees with R = 10 mm [Figure 3].

The boundary condition was defined so that all the nodes at the base of each model were fixed to simulate its connection to the clasp assembly. The buccal side of each clasp was assumed to be parallel to the tangent drawn at the most prominent part of the clasp under study, as shown in Figure 1. The displacements (0.01, 0.02 and 0.03″) in toward buccal direction were considered and evaluated. The analyses were performed in a Pentium IV personal computer by ANSYS Version 5.71 (ANSYS Inc., Soutpointe, 275 Technology Drive, Cononsburg PA 15317, USA). Output data for the forces produced in two directions (buccolingually and mesiodistally) were evaluated and presented.

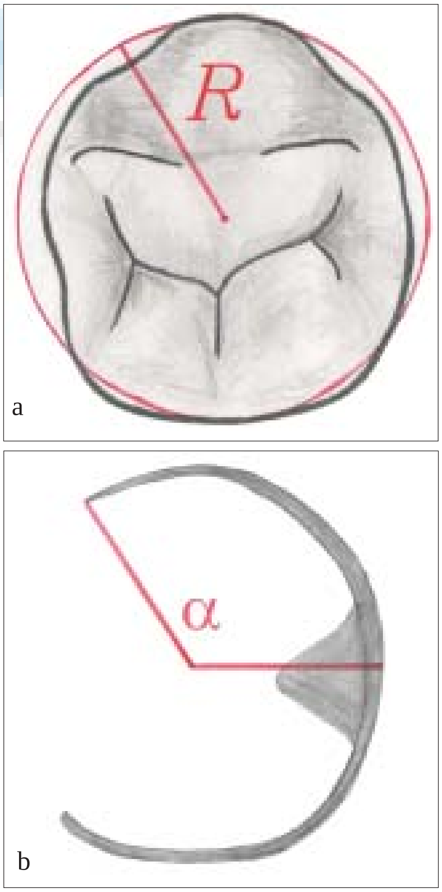

Figure 1: a) R; b) α

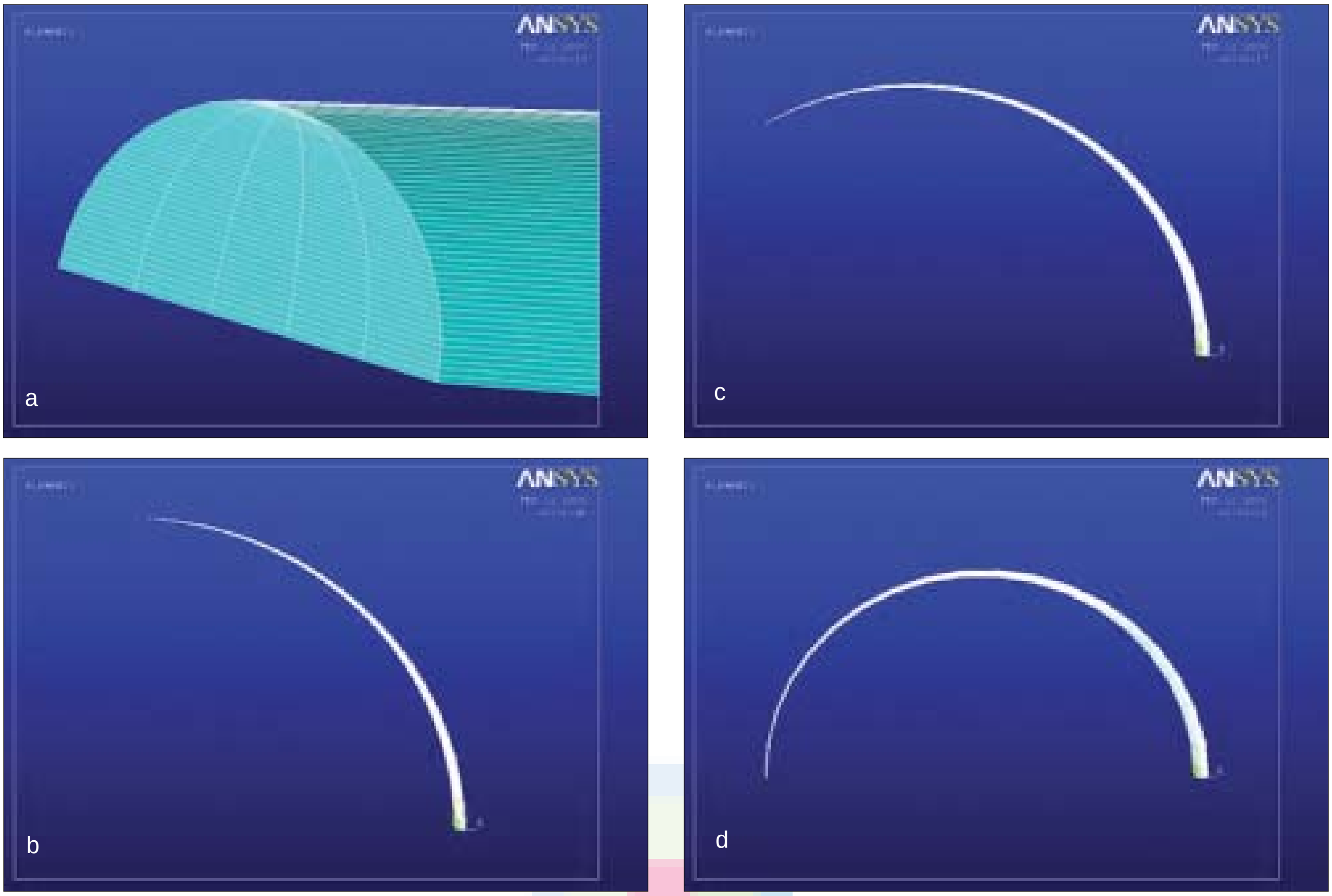

Figure 2: (a) Close-up of the meshed model in which the element size and the cross section of the retentive arm are shown, (b) 3D model of the 90-degree retentive arm, (c) 3D model of the120-degree retentive arm and (d) 3D model of the180-degree retentive arm

RESULTS

The output data for the forces produced in two directions (mesiodistal and buccolingual) were derived and divided according to α [Table 1].

α = 90 degrees

The mesiodistal force shows an increase between 60.76 gr for a 10-gauge undercut and 161 gr for a 30-gauge undercut.

The buccolingual force ranged between 9.39 and 23.37 gr in the three undercuts considered.

α = 120 degrees

Mesiodistal force: Increase of this result from 27.96 gr in a 10-gauge undercut to 77.69 in a 30-gauge undercut is recorded.

Buccolingual force: Although more slowly, these findings show an increase from 11.89 to 34.84 gr.

α = 180 degrees

Mesiodistal force: These findings are the lowest among all the mesiodistal findings - from 2.35 gr for a 10-gauge undercut to 6.82 gr for the 30-gauge one.

Buccolingual force: The highest findings among all the forces in this direction belonged to this group, which were between 17.65 and 52.48 gr.

DISCUSSION

The effect of *R* and α on the retention produced by three retentive arms were evaluated. Retention is essential for the proper functioning of a removable

Table 1: Output data of retention forces decomposed to mesiodistal and buccolingual forces

	10 gauge		20 gauge		30 gauge	
	*MD force	**BL force	MD force	BL force	MD force	BL force
90	60.76	9.39	114.43	16.604	161	23.37
120	27.96	11.89	53.87	23.61	77.69	34.84
180	2.35	17.65	4.56	35.24	6.82	52.48

*Mesiodistal, **Buccolingual

Table 2: The ratio of retention modification in comparison to the 90-degree retentive arm at the same undercut

	10 gauge		20 gauge		30 gauge	
	*MD force	**BL force	MD force	BL force	MD force	BL force
90	1	1	1	1	1	1
120	0.46	1.266	0.47	1.42	0.482	1.49
180	0.038	1.879	0.0398	2.122	0.042	2.245

*Mesiodistal, **Buccolingual

partial prosthesis.

The basic literature with regard to partial removable prosthodontics state that the retention is affected by (1) length of the clasp arm, (2) width of the clasp arm (3) width-thickness ratio of the clasp arm, (4) cross section and (5) the alloy used. In this manner, the effect of the 3D form of the retentive arm on the retention produced by it is ignored in a circumferential clasp.

There are several articles studying the clasp arms from various viewpoints. To the best of our knowledge, this is the first time the curvature of the retentive arm in a circumferential clasp and its effects on the retention is numerically evaluated. In this manner, a factor that has been ignored in the retention produced by the retentive arms is explained.

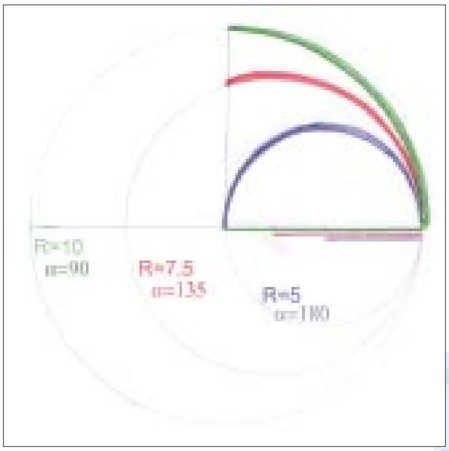

Figure 3: Different values of R and α considered in this study

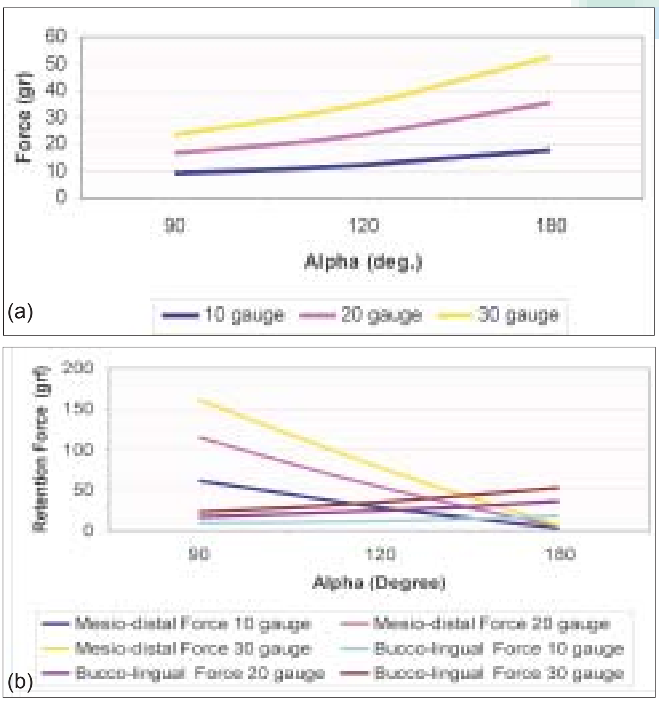

Figure 4: (a) Increase in the buccolingual force with the change in α and (b) superimposition of the changes in retention force with different values of α

The thorough assessment of the output data and the tables reveal that in considering an undercut to produce retention, extending the retentive arm at any instant increases the retention produced under the same conditions. This increase in retention is directly proportional to the amount of undercut gauge. In this study, the variations in the numeric data suggest that this factor should be taken into consideration because it affects the retention quality produced by an undercut. An increase of 1.879 times for a 10-gauge undercut between R = 90 and 180 to 2.245 times for the same condition in a 30-gauge undercut confirms that, at any instant, we can shift from the big molars towards the smaller premolars without damaging the retention produced [Table 2].

The only factor that must be considered for such a suggestion is the root surface of the premolars.

According to the results presented, the exact shape of the retentive arm in a circumferential clasp can be considered as a determining factor in the quality of its retention, which is apart from other factors considered for the retention produced by a clasp arm.

The retention produced by a retentive arm, keeping all the features the same, may be changed by the amount of curvature (α and R). This has not been considered in partial removable denture texts. It shows that the different teeth in two quadrants can be considered to produce comparable retentions according to their R and α values.

[Figure 4a] shows the increase in retention between α = 90 degrees and α = 180 degrees. The comparison of these data with the findings of the decreased mesiodistal retention shows the interrelationship that is present [Figure 4b]. This figure opens a new area of research for the researchers and also to the clinicians to consider the shifting toward lower gauges of undercut and maintaining the same retention. In this manner, the clasp life is increased while the stress produced in the PDL in the path of removal and seating of the prosthesis is maintained at a low level (in the absence of an ideal reciprocation).

Due to the size of the structure, FEM seems to be the sole method with accurate findings and low cost, while this can also be considered as quite conservative.

CONCLUSION

The given length of the retentive arm placed at the same depth of undercut in different teeth (different mesiodistal dimensions) produces various retention forces based on to the values of R and α.

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