Original Article

Influence of the Angle of Cervical Convergence on Stresses to the PDL of Abutments: A 3D Analysis Using Finite Element Method

A. Geramy[1,2], Gh. Ommati-Shabestary [3], L. Eghlima[4]

[1]Associate Professor, Department of Orthodontics, Faculty of Dentistry, Medical Sciences/Tehran University, Tehran, Iran
[2]Associate Professor, Dental Research Center, Medical Sciences/Tehran University, Tehran, Iran
[3]Assisatant Professor, Department of Prosthodontics, Faculty of Dentistry, Medical Sciences/Tehran University, Tehran, Iran
[4]Dentist, Private Practice

Corresponding author:
A. Geramy, Department of Orthodontics, Faculty of Dentistry, Tehran University of Medical Sciences, Tehran, Iran.
gueramya@yahoo.com

Received: 8 April 2006
Accepted: 2 August 2006

Abstract:

Objective: This study was designed to compare the stress produced at the PDL of abutment teeth with two angles of cervical convergence, in otherwise similar settings.
Materials and Methods: Two finite element models were designed for a second premolar and a removable partial denture frame containing an I-bar clasp. Maximum Principal Stress (S1) and Von Mises Stress (SEQV) were assessed along a cervico-apical path of nodes in the PDL.
Results: Output data for S1 and SEQV were the same regarding the height of contour. A gradual decrease in both models was observed. A larger decrease was found in the model with the higher angle of cervical convergence.
Conclusion: I-bars placed on teeth with lower angles of cervical convergence produce a higher stress to the PDL of abutments.

Key Words: Removable prosthodontics; Circumferential clasp; Retention; Finite element method(FEM); I-Bar; Angle of cervical convergence

Journal of Dentistry, Tehran University of Medical Sciences, Tehran, Iran (2007; Vol: 4, No.1)

INTRODUCTION

A thorough knowledge of the quantity and quality of distributed forces in oral and dental tissues produced by a removable partial denture (its retentive parts), can deeply affect treatment plan [1]. The design should be so that the maximum stress is within physiologic limits for the tissues. I-bars produce retention in partial removable dentures. Accurate determination of their position in free-end dentures based on suitable stress distribution helps to maintain the tooth and ridge for a longer period of time [1].

An improper design of the retentive arms of partial dentures can accelerate tooth loss and finally lead to complete edentulism. Cohesion, adhesion, friction resistance, neuromuscular control, the length of the edentulous ridge, the quality of the supporting ridge, direct retainers, and surface characteristics of the tooth are some of the factors affecting stress distribution to the tooth.

The amount of retention produced by a clasp is related to clasp type, flexibility of the retentive arm and the angle of axial convergence of the abutment tooth which lies apical to the height of contour (H of C).

The end of the retentive arm in relation to the H of C is described in 2 dimensions [1]:

1- Horizontal position (in-out).

2- Vertical position (occluso-gingival).

The exact locus of the free end of the retentive arm seriously affects retention. This is determined and monitored by the analyzer rod of the surveyor. The depth of the undercut, the angle of cervical convergence, and the flexibility of the clasp arm are considered as factors that can influence retention [2].

According to Phoenix et al [1], in identical situations, the deeper the retentive arm is placed in an undercut, the more retention is produced. This retention is directly related to the depth of undercut. Furthermore, a larger angle of cervical convergence necessitates a larger force to remove a partial denture [2,3].

Avant [4] has clearly explained the important role that the angle of convergence plays in retention. The effort necessary to remove two clasps may be equal but the force needed for this removal is different and the vertical distance from the clasp tip to the H of C affects this force. Force and distance are indirectly related so that larger forces are produced in smaller distances. Schneider [5] has also discussed the importance of the angle of gingival convergence in the retention of a removable partial denture, and believes that all factors have been extensively investigated except for the angle of convergence.

There are few published articles on retention that have dealt with this angle. According to Schneider [5], if all given factors are considered to be equal, larger angles of convergence have higher potentials of producing retention.

Grabow [6] criticized Schneider a year later and added other concepts such as friction, lack of force while the prosthesis is seated completely, etc.

The finite element method (FEM) has shown its capabilities in providing accurate results in different fields of medicine and dentistry. FEM is a numerical technique that presents accurate answers to various questions and has proven its efficiency in different aspects. The wide range of performance of FEM includes confirmation of basic points [7]; evaluation of a theoretic situation [8], normal situations concerning tooth movement [9] and special situations like alveolar bone resorption in tooth movement [10-12]; extra-oral force application in orthodontics [13]; optimization of an orthodontic mechanotherapy [14] or treatment procedure [15]; and replying to clinical questions [16-18].

The purpose of this study was to assess the behavior of the PDL of two abutments with I-bars and various angles of cervical convergence placed at the same depth of undercut during removal of the prosthesis. The other characteristics of the crown were similar.

MATERIALS AND METHODS

Two 3D models of a second premolar and an edentulous ridge were designed with a partial

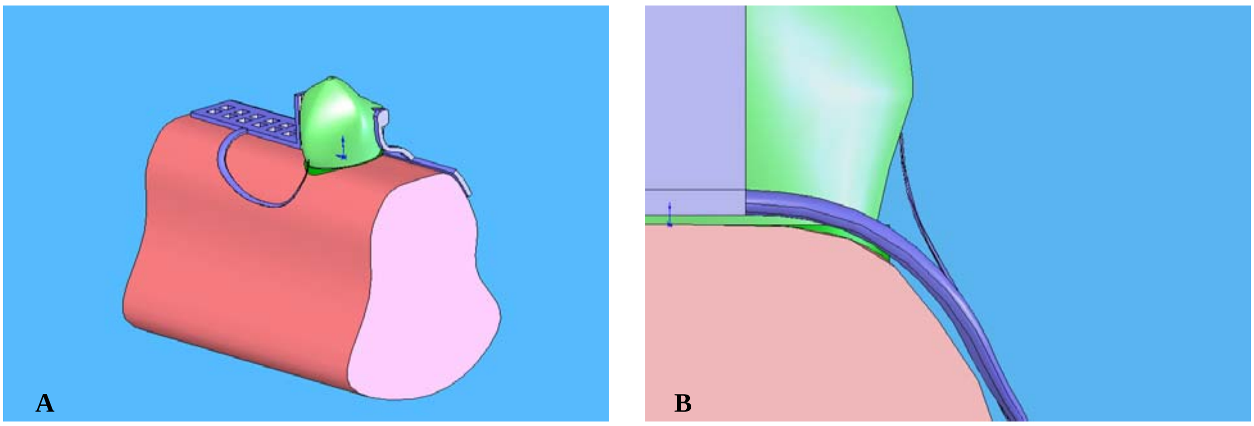

Fig. 1: Three dimensional model designed and used for the present study.

removable framework including an I-bar clasp (Fig. 1). Each 3D model contained a premolar tooth with average dimensions, 0.25mm PDL surrounding the root, bone designed as an edentolous ridge, and a partial framework including an I-bar clasp. The only difference between the two models was the angle of convergence of the tooth. The I-bar clasp arm was placed in a 0.254 mm undercut. The distance between the H of C and this undercut depended on the angle of convergence which was 1.83 mm in the first model and 1.07 mm in the second one. The models were designed in Solidworks 2006 (Structural and research analysis corporation SRAC, LA. California, USA) and transferred to ANSYS Workbench 10.0. (Ansys Inc. Southpointe, PA, USA).

Material properties which were defined according to recent studies [18-24] are summarized in Table I. Contacts were depicted between the bone surface and PDL, and between the PDL and root surface as bonded. The definition of a frictional contact between the I-bar clasp and crown surface was especially important. Meshing was performed (tetrahedral and hexahedral elements) and the mesh size was adjusted at the contact area (I-bar-tooth). A total of 10295 elements and 17828 nodes were used in the models. Boundary condition was defined so that the bone was restrained at the mesial and distal ends. There was also a restraint in the mesial part of the framework, preventing it from medio-lateral and mesio-distal movements. Small amounts of framework displacement were defined in a vertical direction. S_1 (Maxi-mum Principal Stress) and SEQV (Von Mises Stress) [$S_e=(0.5[(S_1-S_2)^2+(S_2-S_3)^2+(S_3-S_1)^2])^{0.5}$ data were assessed in nodes along a path on the lingual side of the PDL according to Geramy et al [8,15,16].

Table I: Mechanical properties of the materials that modeled in the present study.

	Young's modulus (MPa)	Poisson's Ratio
Tooth	20300	0.3
Cr-Co	218000	0.3
PDL	0.667	0.49
Bone	3170	0.38

RESULTS

S_1 and SEQV data are presented in Tables II and III. These two criteria seem adequate for

Table II: Output data for the model with low angle of cervical convergence.

	HC	**HC**	**HC-0.3**	**HC-0.3**	**HC-0.6**	**HC-0.6**	**HC-0.9**	**HC-0.9**	**HC-1.2**	**HC-1.2**
	S1	**SEQV**	**S1**	**SEQV**	**S1**	**SEQV**	**S1**	**SEQV**	**S1**	**SEQV**
Cervical	0.0044	0.0026	0.0030	0.0018	0.0023	0.0014	0.0016	0.0009	0.0005	0.0003
2	-0.0227	0.0100	-0.0154	0.0067	-0.0119	0.0052	-0.0083	0.0036	-0.0024	0.0010
3	-0.0441	0.0033	-0.0299	0.0022	-0.0230	0.0017	-0.0161	0.0012	-0.0046	0.0003
4	-0.0415	0.0023	-0.0281	0.0015	-0.0216	0.0012	-0.0151	0.0008	-0.0043	0.0002
5	-0.0395	0.0022	-0.0263	0.0014	-0.0203	0.0011	-0.0142	0.0008	-0.0041	0.0002
6	-0.0276	0.0013	-0.0183	0.0009	-0.0141	0.0007	-0.0099	0.0005	-0.0028	0.0001
7	-0.0047	0.0010	-0.0037	0.0006	-0.0029	0.0005	-0.0020	0.0003	-0.0006	0.0001
8	0.0094	0.0006	0.0057	0.0003	0.0044	0.0003	0.0031	0.0002	0.0009	0.0001
9	0.0164	0.0008	0.0108	0.0006	0.0083	0.0004	0.0058	0.0003	0.0017	0.0001
10	0.0252	0.0009	0.0176	0.0006	0.0135	0.0005	0.0095	0.0003	0.0027	0.0001
11	0.0480	0.0026	0.0320	0.0016	0.0246	0.0013	0.0172	0.0009	0.0049	0.0003
12	0.0721	0.0032	0.0482	0.0021	0.0371	0.0016	0.0260	0.0011	0.0074	0.0003
13	0.0735	0.0037	0.0493	0.0024	0.0379	0.0019	0.0266	0.0013	0.0076	0.0004
14	0.0736	0.0036	0.0500	0.0024	0.0385	0.0019	0.0269	0.0013	0.0077	0.0004
15	0.0889	0.0039	0.0601	0.0026	0.0462	0.0020	0.0323	0.0014	0.0092	0.0004
16	0.0913	0.0058	0.0178	0.0020	0.0474	0.0030	0.0332	0.0021	0.0095	0.0006
Apical	0.0930	0.0109	0.0627	0.0073	0.0482	0.0057	0.0338	0.0040	0.0096	0.0011

the explanation of the situation [15-16].

Tooth displacement occurred lingually in both models as expected. The highest values of S1 and SEQV were in the H of C which was almost the same for both models as anticipated. S1 and SEQV decreased from the H of C to the rest position with different inclinations. S1 and SEQV of the model with the larger angle of cervical convergence was less than the other model.

The center of rotation of the tooth in different stages of the sliding clasp arm is shown as curves in Figure 2.

DISCUSSION

This study tried to evaluate the stress that was produced along the path of nodes in the PDL while removing the partial denture with two different angles of cervical convergence, while other parameters were considered the same.

All parameters were identically designed except for the location of the retentive arm which was in direct relation to the angle of cervical convergence.

According to the output data, the stress produced by the I-bar in the PDL of the abutment with the smaller angle of convergence was higher than the one with the larger angle. FEM models, if designed properly, show signs of acceptable function. The easiest way to test them is to apply a single force on the buccal surface in a lingual direction and evaluate their displacement. In order to prove the efficiency of this model, according to orthodontic tooth movement principles, the center of rotation should be a few millimeters apical to the center of resistance [25]. The same pattern of stress in the H of C of two models showed that clasp arms with the same amount of deformation and the same distances from the center of resistance can produce similar moments and consequently harmonious stresses. Moving cervically from the height of contour, retentive arms experience different amounts of deformation until a passive state is reached. In any given distance of cervical from the H of C, the retentive arm sliding on the tooth with a larger angle of cervical convergence is nearer to its passive state than when it moves on a tooth with a smaller angle. Sliding on an inclined plane with a larger angle of cervical convergence produces more deformation compared to

Table III: Output data for the model with high angle of cervical convergence.

	HC	HC	HC-0.3	HC-0.3	HC-0.6	HC-0.6	HC-0.9	HC-0.9
	S1	**SEQV**	**S1**	**SEQV**	**S1**	**SEQV**	**S1**	**SEQV**
Cervical	0.0041	0.0024	0.0033	0.0017	0.0026	0.0015	0.0018	0.0011
2	-0.0212	0.0092	-0.0172	0.0075	-0.0133	0.0058	-0.0093	0.0040
3	-0.0411	0.0030	-0.0334	0.0024	-0.0257	0.0019	-0.0180	0.0013
4	-0.0387	0.0021	-0.0314	0.0017	-0.0242	0.0013	-0.0169	0.0009
5	-0.0363	0.0019	-0.0294	0.0016	-0.0227	0.0012	-0.0158	0.0009
6	-0.0252	0.0012	-0.0205	0.0010	-0.0158	0.0008	-0.0110	0.0005
7	-0.0051	0.0008	-0.0042	0.0007	-0.0032	0.0005	-0.0022	0.0004
8	0.0079	0.0005	0.0064	0.0004	0.0049	0.0003	0.0034	0.0002
9	0.0149	0.0008	0.0121	0.0006	0.0093	0.0005	0.0065	0.0003
10	0.0242	0.0009	0.0196	0.0007	0.0151	0.0005	0.0106	0.0004
11	0.0441	0.0023	0.0358	0.0018	0.0276	0.0014	0.0193	0.0010
12	0.0664	0.0029	0.0539	0.0024	0.0416	0.0018	0.0290	0.0013
13	0.0679	0.0033	0.0551	0.0027	0.0425	0.0021	0.0297	0.0015
14	0.0688	0.0034	0.0558	0.0027	0.0431	0.0021	0.0301	0.0015
15	0.0727	0.0036	0.0672	0.0029	0.0517	0.0023	0.0361	0.0016
16	0.0849	0.0053	0.0689	0.0043	0.0531	0.0033	0.0371	0.0023
Apical	0.0863	0.0101	0.0700	0.0082	0.0540	0.0063	0.0377	0.0044

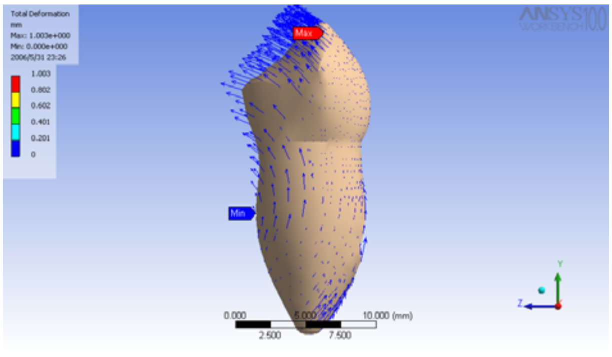

Fig. 2: Vector diagram of the movement produced in abutment tooth when removing the prosthesis.

the one with a lower angle. As demonstrated in Table II, when a retentive arm moves from the H of C towards its passive state, it has a greater amount of deformation when sliding on lower angles of cervical convergence. This information cannot be derived from previous data on partial removable prosthodontics, since they have only stated that in similar situations, higher angles of cervical convergence cause higher forces on abutment teeth.

Avant [4] and Schneider [5] used a "work" approach for explaining the impact of force on teeth. They stated that the "work" (w) done in two situations are the same ($w_1=w_2$) and W= Fd, therefore $F_1.d_1 = F_2.d_2$. Considering $d_1 > d_2$, they concluded that $F_2 > F_1$ (F and d represent the required force and distance respectively).

The current study did not apply the "work" approach for analysis, but tried to assess the stresses in the PDL. This can be considered an easy method for the evaluation of abutment teeth.

According to the findings of the present study, in both models S1 and SEQV data were identical when the clasp arm was in the H of C. Therefore, it was not possible to establish statistical superiority of one model over the other.

Lighter forces with longer durations are produced in teeth with lower angles of convergence. On the other hand, heavier forces with shorter durations are generated in models with higher angles of convergence. Clinical follow-up is needed to evaluate the challenge between these two forces. Cell reaction to different types of force application ultimately determines which method is better. The influence of these two methods of force application on PDL cells remains open to future studies.

CONCLUSIONS

In similar settings comparing teeth with different angles of cervical convergence, I-bars on teeth with lower angles produce higher amounts of stress to the PDL of their abutment teeth. A statistically significant difference was not found between the two groups.

Further investigations with an in–vivo approach are suggested to compare the effects of longer-lighter forces and shorter–heavier ones on tissues.

REFERENCES

1- Phoenix RD, Cagha DR, Defreest CF. Stewart's Clinical Removable Partial Prostho-dontics. 3rd ed. China: Quintessence Publishing; 2003; Chapter 4, 8. P: 63-9, 217-20, 261-71.

2- Johnson DL, Stratton RJ. Fundamentals of Removable Prosthodontics. 1st ed. Chicago: Quintessence Publishing:1980; Chapter7: 81-8.

3- McGivney CP, Carr AB. McCraken's Removable Partial Prosthodontics. 10th ed. Ohio: Mosby; 2000.

4- Avant WE. Factors that influence retention of removable partial dentures.J Prosthet Dent 1971 Mar;25(3):265-70.

5- Schneider RL. Significance of abutment tooth angle of gingival convergence on removable partial denture retention. J Prosthet Dent 1987 Aug;58(2): 194-6.

6- Grabow W. Significance of abutment tooth angle of gingival convergence on removable partial denture retention. J Prosthet Dent 1988 May; 59(5):640.

7- Geramy A. Harmonious translation of CRes in different tooth movements while the force in remained constant: 3D analysis using finite element

method. Journal of Dentistry, Shiraz University of Medical Sciences 2002;3:59-65.
8- Geramy A, Faghihi S. Secondary trauma from occlusion: three-dimensional analysis using the finite element method. Quintessence Int 2004 Nov-Dec;35(10):835-43.
9- Geramy A. Moment/Force ratio and the center of rotation alteration: 3D analysis by means of the FEM. J Dent, Shiraz University of Medical Sciences 2000; 1:26-34.
10- Geramy A. Alveolar bone resorption and the center of resistance modification (3-D analysis by means of the finite element method). Am J Orthod Dentofacial Orthop 2000 Apr;117(4):399-405.
11- Geramy A. Initial stress produced in the periodontal membrane by orthodontic loads in the presence of varying loss of alveolar bone: a three-dimensional finite element analysis. Eur J Orthod 2002 Feb;24(1):21-33.
12- Geramy A. Stress tensor modification in alveolar bone resorption: 3D analysis using FEM. Journal of Dentistry, Shiraz University of Medical Sciences 2002; 3:39-49.
13- Geramy A. Cervical headgear force system: 3D analysis by means of the finite element method. Journal of Dentistry, Shiraz University of Medical Sciences 2001; 2:21-30.
14- Geramy A. Optimization of unilateral overjet management: three-dimensional analysis by the finite element method. Angle Orthod 2002 Dec; 72(6):585-92.
15- Geramy A, Morgano SM. Finite element analysis of three designs of an implant-supported molar crown. J Prosthet Dent 2004 Nov;92(5): 434-40.
16- Geramy A, Sharafoddin F. Abfraction: 3D analysis by means of the finite element method. Quintessence Int 2003 Jul-Aug;34(7):526-33.
17- Geramy A. V-bend force system: 3D analysis using finite element method. Iranian journal of orthodontics 2006;1:12-17.
18- Mackerle J. Finite element modelling and simulations in dentistry: a bibliography 1990-2003. Comput Methods Biomech Biomed Engin 2004 Oct;7(5):277-303.
19- Muraki H, Wakabayashi N, Park I, Ohyama T. Finite element contact stress analysis of the RPD abutment tooth and periodontal ligament. J Dent 2004 Nov;32(8):659-65.
20- Naik PR, Duncanson MG Jr, Mitchell DL, Wiebelt FJ, Johnson DL, Ghosh J. Evaluation of stresses and forces in selected I-bars using the finite element method. J Prosthodont 1997 Mar;6(1):43-54.
21- Morris HF, Asgar K. Physical properties and microstructure of four new commercial partial denture alloys. J Prosthet Dent 1975;33(1):36-46.
22- Bates JF. The mechanical properties of the cobalt-chromium alloys and their relation to partial denture design. Br Dent J 1965 Nov 2;119(9):389-96.
23- International Organization of Standard. ISO 6871-1. 1st ed. Printed in Switzerland; 1994 P:1-6.
24- Kim D, Park C, Yi Y, Cho L. Comparison of cast Ti-Ni alloy clasp retention with conventional removable partial denture clasps. J Prosthet Dent 2004 Apr;91(4):374-82.
25- Nanda R. Biomechanics and esthetic strategies in clinical orthodontics. St.Louis: Saunders,2005, Chapter 1.