A finite element analysis of the effect of different margin designs and loading positions on stress concentration in porcelain veneers.

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ABSTRACT

Background: During mastication, stress may concentrate in points in the porcelain veneer which may lead to clinical failure. This study examined whether different finishing lines and different loading positions affect the bond of the porcelain veneers.

Materials and methods: A 2- dimensional finite element model was made. Location and magnitude of maximum Von Mises and shear stresses were calculated in porcelain veneer.

Results: Stress was concentrated in the butt finishing line more than the deep chamfer and chamfer finishing lines. Stress was concentrated in the incisal portion more than in the cervical portion of the porcelain veneer. The incisal loading exerted stress more than the bonding strength of the bonding agent, and more than the cervical and middle third loading.

Conclusion: The best stress distribution was formed around the deep chamfer finishing line. Clinical failure is inevitable in the butt finishing line and incisal loading. Incisal edge fracture of the porcelain veneer may be due to debonding of the bonding agent to the enamel and later fracture of the porcelain veneer

Keyword: Finite element, porcelain veneers **(J Coll Dentistry 2005; 17(2):8-12)**

INTRODUCTION

Porcelain veneers are used to treat discolored teeth, or teeth with minimal loss of the incisal edge. [1, 2]

The success rate of porcelain veneers was clinically evaluated to range from 75-100% [3-7]. Factors affecting long term success of porcelain veneers are age, gender of the patient and fabrication techniques [6]. The use of rubber dam isolation or number of years in service did not influence the rate of success. Therefore, failure in porcelain veneers seems to be associated with changes in bonding condition and / or the magnitude of incisal load [8].

The advanced bonding agents and techniques have given high bonding strength, hence improving bond of the porcelain veneer efficiently to the tooth structure.

The marginal design of the finishing line was studied to verify the stress concentration by the use of 2 dimensional finite element analysis [9, 10], but none emphasized clearly on the degree of stress concentration on different finishing lines and nearby points.

The purpose of this study was to examine the distribution of stresses in porcelain veneers in different tooth preparation finishing line designs (cervically and incisally) according to different positions of masticatory force loading.

MATERIALS AND METHODS

The finite analysis was conducted using the ANSYS 5.4 finite element package (Swanson Analysis System, Housten, Pennsylvania) with a pentium 4 processor (2.4 GHz).

Two dimensional finite element models of porcelain veneers on teeth with intermediate layers of bonding agent, and composite resin were designed according to the size of an average maxillary central incisor. The abutment was considered to be homogenous.

The dimensions of the preparation for the porcelain veneers were drawn according Rufenacht in1992, where 0.3 mm was prepared cervically, 0.5 mm in the middle and 0.7 mm incisally. The porcelain veneer preparation was all within enamel.

Three types of finishing lines incisally and cervically were drawn to create models and as follows:

Group I: Butt finishing line.

Group II: Deep chamfer finishing line.

Group III: Chamfer finishing line.

The composite resin was drawn to be 100 um thick [12] and the bonding agent was 1 um thick. [8]

The model was divided into 5 main areas representing porcelain laminate, composite cement layer, enamel bonding layer, enamel and dentine, while the pulp was assumed as a nul element (Fig. 1).

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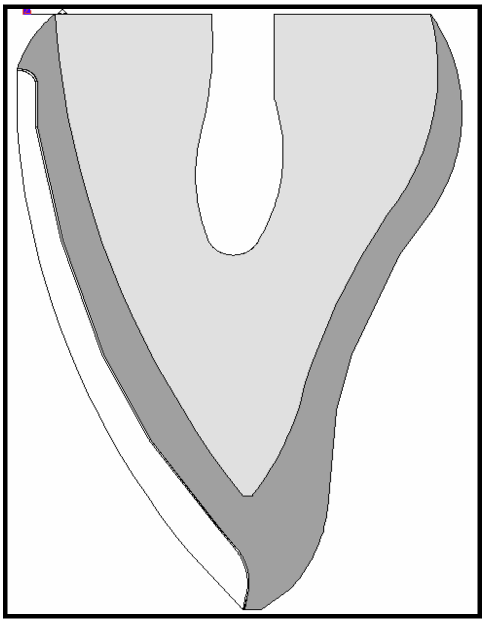

Figure 1: The model of tooth and porcelain veneer.

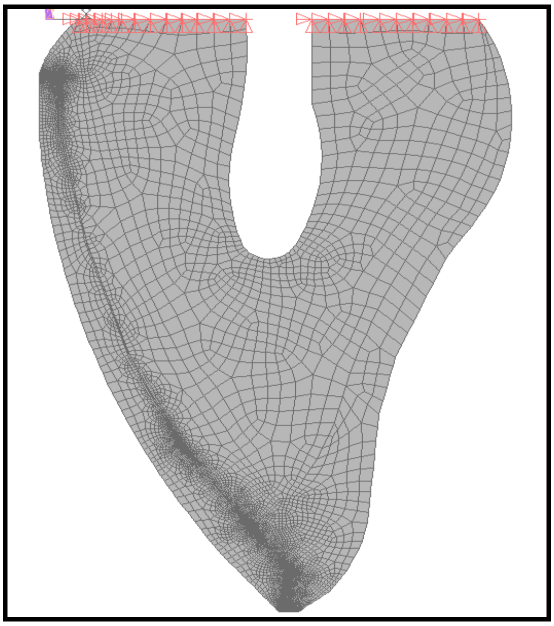

Figure 2: Meshing of the model into elements.

The properties for the material used in the study are listed in table 1. The models were meshed into elements ranging from (14622-18940) as is shown in figure 2.

Table 1: Materials' properties. [8]

Material	Esthetic Modulus (GPa)	Poisson's Ratio
Porcelain	**70**	**0.19**
Composite cement	**6**	**0.4**
Resin	**5**	**0.4**
Enamel	**84**	**0.33**
Dentin	**19**	**0.31**

The load of 50 N at 60^{o} labiocervically was applied at 3 different sites (lingual slope of incisal edge, the junction of the incisal and middle third, and at the beginning of the cingulum).

The stress distribution was measured in 9 different points from the incisal to the cervical finishing lines as is presented in figure 3. Stress concentration was studied by Von Mises and shear tests at three different layers:

A: Junction between the bonding agent and enamel.

B: Junction between the composite resin layer and bonding agent.

C: Junction between the porcelain veneer and composite resin.

RESULTS

Stress due to incisal third force

By the Von Mises stress analysis (table 2), all the types' of finishing lines gained stress above 30 MPa in most of the examined points (points 2 and 8)

DCH finishing line expressed a much less stress when compared to the butt finishing line which showed at point 2A stress of 325 MPa. This reading was more than at point 2B by 9 times but in the DCH finishing line the difference between the two points was comparable.

The incisal finishing lines gained stress much more than in the cervical finishing lines.

By the shear stress analysis (table 3), DCH and CH finishing line revealed a third of the stress gained in the butt finishing line that revealed stress at point 2A of 96.7 MPa.

At point 2B, stress at the DCH and CH finishing line increased with a decrease in points 2A and 2C, which is inversely proportional to that of the butt finishing line.

Stress at point 8 decreased at the DCH and CH finishing lines when compared with the butt finishing line and was placed under tension.

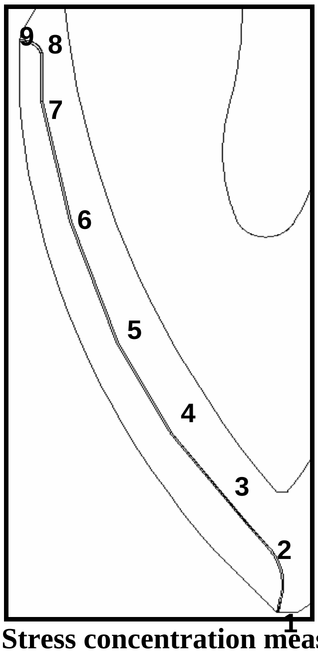

Figure 3: Stress concentration measured in 9 different points

Stress due to middle third force

In comparison with the incisal third force, stress dramatically decreased at the incisal region (points 1, 2, 3)

Von Mises test emphasized that the least stress was exerted upon the DCH finishing line when compared with the other finishing lines

At point 2A butt finishing line stress was found to be 6 times more than point 2B while in the DCH and CH finishing lines the difference was minimal.

The only points having stress exceeding 30 MPa were point 8A and 8C and 9C butt finishing line. At point 8 DCH and CH finishing lines, stress decreased at A and increased at B while butt finishing line showed stress at point 8A 7 times more than point 8B

The shear test revealed that DCH finishing line gained the least stress. Stress decreased dramatically especially in the incisal finishing line points and to a less degree in the cervical finishing line points where point 8 A butt finishing line gained stress of 25.9 MPa.

At point 2A butt finishing line the stress concentrating in this point was 11 times more than point 2B, while in DCH finishing line this difference was comparable.

Stress due to cervical third force

By the use of Von Mises stress analysis, DCH gained the least stress when compared with CH and butt finishing lines. The highest stress concentration was found to be in the cervical finishing lines points (points 7, 8, 9) while points 1, 2, 3 gained very much less stress.

At points 2A butt finishing line stress was 7 times more than point 2B while in CH and DCH finishing lines the difference was comparable.

The shear test revealed that stress was very minimal in the incisal and cervical points for all the types of finishing lines. At point 2A butt finishing lines stress was found to be 13 times more than 2B while in DCH and CH finishing lines, the difference was comparable.

DISCUSSION

This study examined the stress concentration in different preparations of finishing lines for porcelain veneers.

The DCH finishing line was found to be the best finishing line to disperse the stresses exerted by masticatory forces. The CH finishing line was comparable to the DCH in different points of the porcelain veneer, but the butt finishing lines concentrated stress around it to a degree that sometimes stress was beyond adhesive bonding strength values.

The incisal force exerted very high stress that was mostly concentrated in the incisal finishing lines and much less in the cervical finishing lines regardless of the type of finishing lines. This conclusion agrees with Troedson and Derandin in 1999 [(8)] and in 1995 [(13)], who found that small stress difference was found at the cervical finishing line.

Stress was found most in the bonding agent layer (A) and was more than toleration as many authors found that the maximal bonding and shear strength to enamel did not exceed 35 MPa [(14, 15)]. Therefore, it can be concluded that most of the failures start by a debonding of the adhesive layer at the incisal region, hence leaving the porcelain veneer debonded and the inner layer of the porcelain veneer at tension and as tensile strength of porcelain is about 25 MPa the high readings at the porcelain veneer layer (C) in all the types of finishing lines are higher. Therefore, the incisal edge region will be prone to fracture. This conclusion agrees with a study performed by Touati et al in 1999 [(16)], on the percentage of porcelain veneer failures. He found that 90% of the veneers' fractures affect the incisal edge or angles.

The middle third force distributed the stress evenly in the incisal and middle areas of the porcelain veneer, but stress still was concentrated in the cervical region in the butt finishing line. The DCH and CH cervical finishing lines decreased the stress to below 30 MPa.

The cervical third force exerted very minimal stress on the porcelain veneer least in the incisal region and slightly more in the cervical region.

It can e concluded that a patient with a moderate or deep overbite is compatible with porcelain veneer more than a patient with edge to edge incisal relation or minimal overbite.

Table 2: Von Mises stress analysis in Mpa of porcelain veneers with different finishing lines and force application sites.

	Incisal Third Force				Middle Third Force				Cervical Third Force			
Butt Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	138	71.1	9.3	**1**	1.7	0.9	0.1	**1**	0.5	0.2	0.003
	2	325.5	35.5	99.6	**2**	8.5	1.2	3.4	**2**	1.5	0.19	0.49
	3	35.8	11.1	36.6	**3**	6.4	6.1	5.5	**3**	1.4	1.3	1.1
	4	23.8	9.7	44	**4**	3.1	1.6	4.4	**4**	6	4.9	4.6
	5	30.1	9.7	34.8	**5**	1.9	0.7	3.0	**5**	6.8	4.4	7.2
	6	19.2	4.2	29.7	**6**	9.5	9.5	8.4	**6**	7.9	7.2	7.5
	7	26.3	5.8	47.2	**7**	14.1	8.2	20.2	**7**	5.9	5.2	5.9
	8	116.7	18.3	77.5	**8**	73.7	11.1	38.9	**8**	27.4	4.1	12.2
	9	23.3	14.9	63	**9**	12.8	8.2	32.2	**9**	4.7	3	11
Deep chamfer Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	149.6	71.8	9.3	**1**	0.5	0.3	0.2	**1**	0.07	0.3	0.005
	2	55.9	37.8	45.6	**2**	2	1.4	1.7	**2**	0.29	0.2	0.28
	3	34.9	9.8	36.2	**3**	6.4	6	5.5	**3**	1.4	1.2	1.1
	4	23.3	9.2	43.7	**4**	2.8	1.5	4.4	**4**	6.2	4.8	4.6
	5	29.9	9.4	35	**5**	1.8	0.6	3.0	**5**	6.6	4.3	7.1
	6	19.1	4.0	24.8	**6**	9.3	9.3	8.3	**6**	7.7	7.1	7.1
	7	21.9	5.0	45.9	**7**	12.1	7.7	19.7	**7**	5.6	4.9	5.8
	8	27.9	26.2	47.7	**8**	11.6	13.1	24.6	**8**	3.9	4.1	7.9
	9	25.6	12.9	59.5	**9**	13.9	7.1	30.4	**9**	5.1	2.6	10.3
Chamfer Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	149.6	71.6	9.2	**1**	0.4	0.1	0.2	**1**	0.9	0.44	0.006
	2	55.9	42.9	48.6	**2**	1.8	1.5	1.8	**2**	0.27	0.2	0.29
	3	35	9.3	30.4	**3**	6.4	6	5.5	**3**	1.4	1.2	1.1
	4	23.2	9.2	44.7	**4**	2.8	1.5	4.5	**4**	6.2	4.8	4.6
	5	30.1	9.3	34.6	**5**	1.8	0.6	3	**5**	6.6	4.2	7.1
	6	21.2	3.8	25.6	**6**	9.4	9.3	8.1	**6**	8	7.1	7.1
	7	20.9	5.4	56.7	**7**	13.2	7.1	23.8	**7**	6.8	4.5	6.3
	8	34.9	36.1	48.0	**8**	17.5	18.2	24.3	**8**	5.4	5.7	7.7
	9	44.1	20.9	47.8	**9**	23.1	11.8	24.3	**9**	8	4.1	8.4

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Table 3: Shear stress analysis in Mpa of porcelain veneers with different finishing lines and force application sites.

	Incisal Third Force				Middle Third Force				Cervical Third Force			
Butt Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	20.7	-2.09	-3.2	**1**	0.02	-0.003	0.004	**1**	0.008	0.0008	-0.001
	2	96.7	13.3	53.04	**2**	2.35	0.2	-1.1	**2**	-0.4	-0.03	0.2
	3	17.3	2.3	17.6	**3**	-1.1	-0.89	-1.6	**3**	0.2	0.5	-0.022
	4	7.9	-0.36	19.6	**4**	-1.7	-0.89	-2.42	**4**	-2.3	-1.6	-2.4
	5	8.2	-1.5	10.7	**5**	-0.9	-0.4	-1.4	**5**	-3.9	-2.2	-3.9
	6	4.1	-0.13	7.25	**6**	4.8	4.7	4.5	**6**	2.7	3.4	1.9
	7	2.1	-0.24	4.4	**7**	5.5	4.68	5	**7**	3.1	3	2.4
	8	33.6	2.3	-26.4	**8**	25.9	2.7	-12.24	**8**	10.5	1.27	-3.5
	9	-0.17	-0.4	-6.76	**9**	-0.1	-0.23	-3.46	**9**	-0.04	-0.09	-1.1
Deep chamfer Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	33.6	-7.1	-3.2	**1**	0.01	-0.004	0.018	**1**	0.018	-0.0035	-0.002
	2	29.8	19.2	24.6	**2**	-0.4	-0.37	0.04	**2**	0.04	0.07	0.06
	3	17.1	2.2	17.6	**3**	-0.9	-1.2	0.15	**3**	0.1	0.02	-0.02
	4	7.5	-0.24	19.4	**4**	-1.6	-0.8	-2.4	**4**	-2.3	-1.5	-2.4
	5	7.8	-1.6	10.4	**5**	-0.9	-0.4	-1.4	**5**	-3.8	-2.1	-3.8
	6	4.2	-0.17	5.9	**6**	4.7	4.6	4.4	**6**	2.7	3.4	2.1
	7	1.6	-0.26	4.4	**7**	4.4	5.02	3.14	**7**	3.1	2.8	2.4
	8	-9.6	-7.4	-9.7	**8**	-3.1	-4.3	0.48	**8**	0.4	-0.8	-1.2
	9	2	-1.95	-6.3	**9**	1.8	-3.2	0.39	**9**	0.3	-0.3	-1.1
Chamfer Finishing Line		**A**	**B**	**C**		**A**	**B**	**C**		**A**	**B**	**C**
	1	33.4	-6.9	-3.15	**1**	-0.09	0.0005	0.009	**1**	0.022	-0.004	-0.002
	2	30.1	18.6	24.6	**2**	-0.17	-0.46	-0.4	**2**	0.06	0.084	0.07
	3	17.4	2.36	30.7	**3**	-1.15	-0.904	-1.14	**3**	0.15	0.02	-0.02
	4	7.5	-0.23	20	**4**	-1.6	-0.81	-2.45	**4**	-2.3	-1.5	-2.4
	5	8	-1.6	10.7	**5**	-0.9	-0.36	-1.36	**5**	-3.8	-2.1	-3.9
	6	4.8	-0.2	6.14	**6**	4.8	4.7	4.3	**6**	2.6	3.4	2.02
	7	0.8	-0.5	5.4	**7**	6.3	4.05	4.935	**7**	3.86	2.6	2.2
	8	-8.1	-8.95	-10.1	**8**	-6.1	-3.32	-3.7	**8**	-0.96	-0.9	-1.2
	9	3	-3.1	-5.2	**9**	1.6	-1.61	-2.63	**9**	0.55	-0.5	-0.9