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A Comparative Assessment of Stress Distribution and Fracture Resistance of Porcelain Laminates Depending on Their Design Characteristics – An *In Vitro* study with *3-D Finite Element Analysis*

KEYWORDS: Aesthetic Dentistry, Ceramic Laminates & Finite Element Analysis

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ABSTRACT *There is a growing demand of the patients for good esthetic and the use of ceramic laminates has become a reliable and successful technique for restoring discolored, worn, malformed or fractured teeth. Preparation design is one of the most important variables affecting the final success of ceramic laminates. Two designs most commonly used are: the so-called 'Window-preparation' (limited to buccal tooth surface) and 'incisal-overlap preparation' (preparation extending to the lingual surface). These preparations may influence the pattern of stress distribution within the laminate and the tooth itself. To study this stress analysis of dental structures, the latest approach is the 'Finite Element Analysis (FEA). A study was undertaken to evaluate fracture resistance of the two designs by an in-vitro test and further validating the results of stress distribution in porcelain laminates using a 3-D FEA with the results from the in-vitro test.*

Introduction-

In today's world looking good is a prime concern. The dental profession, conscious of this growing demand, began a search for cosmetic restoration. Newer technologies are being harnessed for this purpose and advanced research is being undertaken. According to the principles of so called *'minimal intervention dentistry'* and due to the growing demand of the patients for good esthetic, the use of ceramic laminates has become a reliable and successful technique for restoring discolored, worn, malformed or fractured teeth and the range of clinical indications of such restorations is continuously increasing[1].

The important failure factors associated with porcelain laminates are fracture, microleakage and debonding[4]. Fracture represents approximately 67% of total failures after an observational period of 15 years of clinical performance of such restorations Preparation design is one of the most important variables affecting the final success of porcelain laminates[2].Two designs most commonly used are: the so-called *'Window-preparation'* (limited to buccal tooth surface) and '*incisal-overlap preparation*' (preparation extending to the lingual surface).A study was undertaken to evaluate fracture resistance of the two designs of the laminates by an in-vitro test and further validating the results of stress distribution in porcelain laminates using a 3-D FEA with the results from the in-vitro test.

Material and Method-

The study consisted of two parts:

- The in-vitro fracture strength test
- The 3-dimensional finite element analysis.

A) The in-vitro fracture strength test:

Human permanent maxillary central incisors that were free of caries, abrasion, fractures and resorption, extracted purely due to loss of periodontal support were collected. Sixty such sound maxillary central incisors were randomly assigned into 3 groups:

Group A : Control group without any tooth preparation.

Group B : Teeth with laminate preparation limited to facial surface (Window preparation).

Group C : Teeth with laminate preparation extending 2 mm palatally (Incisal overlap preparation).

After the preparations were over, ceramic laminates ('*Finesse*' All Ceramic DENTSPLY Ceramco) were prepared and luted. Then these samples were mounted and subjected to stress analysis using universal testing machine (Instron Corp, No. 4487, Canton, Mass USA).The fractured samples were removed from the machine and evaluated for pattern and region of fracture.

B) THE 3-DIMENSIONAL FINITE ELEMENT ANALYSIS:

This study was carried out in the Department of Mechanical Engineering at the Visvesvaraya National Institute of Technology (VNIT), Nagpur.

The computer facilities used in the study were:

Hardware: Pentium IV, 2.4 GHz, 1GB RAM. Operating system – M/s Windows XP, Professional Version 2002, Service Pack 2.

Software: Solid Edge V-15 (Modeling software). ANSYS Workbench 10.0 (Finite Element Analysis Software).

A 3-dimensional tooth model was created using solid edge V-15 using data from a standard dental anatomy book. On the similar lines, a 3-dimensional model was prepared(fig.01) in which facial surface of the tooth was restored using a 3-dimensional model of ceramic laminate with the two different designs. A static load of 200 N was then applied along the long axis of the tooth and was distributed over the incisal edge. The desired results after the analysis was picked up in the form of contour plots of von Mises stress and plots of total deformation.

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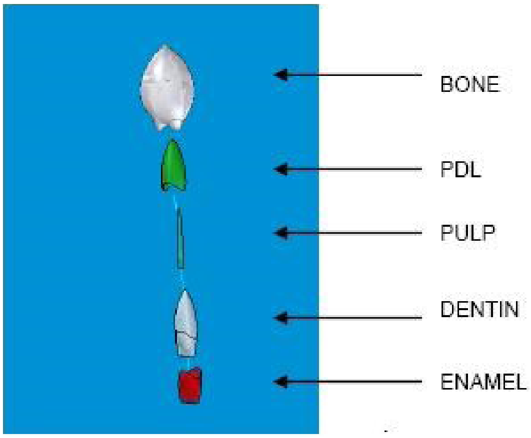
Fig. 1: Exploded view of the tooth with different layers



Observations & Results-

In Group A the lowest and the highest values of fracture resistance were 618.5 N and 867.8 N respectively with a mean of 728.62 N and a standard deviation of 64.198 N. In Group B, the lowest and the highest values of fracture resistance were 622.7 N and 823.1 N respectively with a mean of 701.42 N and a standard deviation of 49.557 N. In Group C, the lowest and the highest values of fracture resistance were 458.4 N and 687.4 N respectively with a mean of 572.68 N and a standard deviation of 57.375

Table I: Comparative Evaluation between Control and Experimental Groups Using Scheffe's Analysis

Group	Group	Mean Difference	P value	Std Error	Results
A	B	27.20	0.3319	18.1378	NS
A	C	155.94	0.0000	18.1378	S
B	C	128.74	0.0000	18.1378	S

NS- Nonsignificant.

S - Significant.

For Experimental group B Vs Control group A, Scheffe's analysis shows nonsignificant difference (p value = 0.3319). The teeth restored with incisal overlap preparation (group C) shows mean fracture strength significantly lower than those restored with window preparation (group B) (where p= 0.0000) and those without any preparation (group A) where p==0.000). Standard error was calculated as 18.1378.

THE FINITE ELEMENT ANALYSIS:

Computations of the Von Mises stress contours and displacement plots were obtained after post processing. The von- Mises stress contours in the various models were as follows:

- The highest stresses were localized at the node on the tooth at which the load was applied. Stresses did progressively decrease towards the apex. Apart from this there were some differences in the pattern of stress distribution among the various models.
- Model I – Stresses were distributed uniformly in the crown with concentration on the incisal edge of the tooth. A maximum stress value of 62 MPa was obtained.
- Model II – Stresses were distributed uniformly in the crown with concentration on the incisal edge of the tooth. A maximum stress value of 84.3 MPa was obtained. A slight difference in stress produced along the palatal surface of the incisor and the laminate was found where the palatal surface showed creation of higher amount of stresses.
- Model III – Stress distribution was uniform along the facial and the palatal surface of the tooth with slightly higher amount of stresses developed in the cervical margin of the tooth and the palatal margin of the laminate. Also, the maximum stress value was found to be 95.3 MPa along the incisal edge and palatal finish line.

The total deformation shown by the three models also revealed small but significant difference –

- Model I – Showed a maximum deformation of1.58 x 10^{-9} m.
- Model II –Showed a maximum deformation of 1.96 x 10^{-9} m.
- Model III – Showed a maximum deformation of 6.54 x 10^{-9} m.

Discussion-

The results of this study are consistent with the study of **Hui et al (1991)**[7] where they recommended the use of 'window' preparation as the design of choice where strength is an important prerequisite. **Hahn et al (2000)**[6] study results also are consistent with the present study. They observed lowest fracture resistance (466±99N) for incisal overlap preparation. When prepared only facially, the teeth restored with Empress veneers (693±187 N) even exceeded the strength of natural, unprepared teeth (653±201 N) but the difference between these two groups did not differ significantly. What fracture loads are required for a successful porcelain laminates restoration is a question of high clinical relevance? Because of dynamic nature of masticatory forces and stresses, the actual biting stresses during functional and parafunctional movements are in a range of 50 to 300 N respectively for anterior dentition[6]. If strength and conservation of tooth structure is required 'window' preparation is the design of choice but for aesthetic or functional reasons the incisal edge of the tooth can also be included in the preparation.

The result from FEM study is in confirmation with the result obtained 2-D FEM study by **Troedson** and **Derand**[8]. The conclusions from the 3-D finite element analysis by **Fernando Zarone, Davide Apicella, Roberto Sorrention, Valeria Ferro, Raffaclla Aversa** and **Antonio Apicella**[4] showed contrast from this study. They observed that the chamfer with palatal overlap preparation better restores the natural stress distribution under load than the window preparation. This variation might be because of the different load (10 N) and different angle (125^0 and 60^0) of loading. As the stress and direction of load on maxillary anterior cannot be standardized because of the complex dynamic acting in that region, such variations in results have to be expected. The results from this study show that finite element model can closely simulate the natural stress distribution in a tooth. Models used in this study should give the best possible three-dimensional representation of the 'real' situation.

Conclusion-

Within the limitations of this study we can conclude:

1. The 'window' and 'incisor overlap' preparation design

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for porcelain laminates resists the normal masticatory load but however, when the choice is between the two preparation designs, the 'window' preparation can give more longevity to the restoration as compared to the 'incisal overlap' preparation Ceramic laminates do not significantly alter the pattern of stress distribution in the tooth, but the 'window' preparation design restores the original pattern of stress distribution of a natural tooth.

2. A 3 – dimensional finite element model can be used effectively to simulate natural teeth and study effects of different porcelain laminate preparation designs.

The results of this study suggest that the use of both mechanical testing and FEA for ceramic laminates can provide more accurate and reliable results than either test alone. State-of-the-art mechanical testing devices and perhaps long-term clinical studies can provide us with evidence – based data that may influence the restorative choice for welfare of our patients.

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