Dental Journal
Majalah Kedokteran Gigi
Vol. 42. No. 4 October–December 2009

Research Report

Evaluation of seat and non-seat post preparation design using conventional and computational methods

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ABSTRACT

Background: *Design of root canal preparation especially in cervical-third area of the root, is one of many factors involved in the success of post-core restoration. Seat design that is used in Prosthodontics Installation, Faculty of Dentistry, University of Padjadjaran, is in the contrary to minimal preparation design. The root fracture resistance of this design has not been proven yet.* ***Purpose:*** *The aim of this study was to evaluate the root fracture resistance of seat compare to non-seat design, with two different research methods: experimental laboratory and computer simulation with Finite Element Method (FEM).* ***Method:*** *The experimental laboratory investigation used 20 upper central incisors: 10 used seat design and 10 non-seats, with the cast posts cemented in the preparation. The specimens were tested by using Universal Testing Machine with compressive force until the root fracture. The FEM used 2D digital models: seat and non-seat design of maxillary central incisors using a finite element software. The distribution of internal stress caused by static loading 110N at 135° angle with longitudinal axis of the tooth was evaluated.* ***Result:*** *The results of the fracture strength test showed a significant difference (p = 0.05) between the non-seat group (852.27N ± 112.6N) and the seat group (495.78N ± 82.90N). The FEM showed a lower stress concentration in non-seat compare to seat group. This study proved that non-seat distributes stress better than seat design.* ***Conclusion:*** *It can be concluded that the FEM confirmed the result of the laboratory method. Stress concentration will cause fracture, therefore root fracture resistance in the non-seat design was higher than the seat design.*

Key words: *post preparation design, stress distribution, finite element method (FEM), root fracture resistance*

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INTRODUCTION

In vitro studies in dentistry which deal with designs and structures of prostheses or appliances used in oral environment are complicated procedures. Many obstacles are found e.g. identical samples collection, procedures of making the research specimen, making jigs for mechanical properties test, giving the identical treatments for every specimen, and evaluating the test results and especially if the intention is to study the mechanism of internal stress distribution in the hard tissue in oral cavity (i.e.: enamel, dentine, bone, and restorative materials) while in physiological function of mastication system.[1] All of these make the studies become more complicated, expensive, and time consuming.

Therefore nowadays a research method that are quick, accurate, and inexpensive is developed in form of computer simulation technique of a design or structure under various treatments, using finite element method (FEM) or also called finite element analysis (FEA). The method is very helpful in overcoming the difficulties caused by the conventional technique, at the same time lowering the cost of the study and still produce very accurate results.[2–4]

In Prosthodontics Department at Faculty of Dentistry, University of Padjadjaran, undergraduate students are required to make a post-core crown restoration with cast post. The post alloys that usually used are CuZn alloy. This alloy is beneficial for both patient and operator because it is inexpensive and easy to manipulate, but it is also considered as a weak alloy compared to gold alloys type III/IV according to ADAS for post metal.[5]

Martanto[6] offered a technique to solve a weak alloy problem in the clinic. In his experience he found that if a post is bent or fractured, the bending location is always at the cervical area of the tooth. According to him even though the post is weak, it can be prevented from bending by making a suitable preparation design at the cervical area which is called seat design. This design can enhance the fracture resistance of the post material. In seat design more tooth structure is prepared from the root, so this design in is the contrary with other authors who recommend to preserve as much intact dentine structure as possible to prevent the root of the tooth from fracture.[7–11] In fact the advantage that has been described about seat design has not been proven scientifically. Whereas in Evidence Based Medicine era, any guidelines which are suggested to be used, have to be supported with research findings, literature reviews, and retrospective clinical studies, before all those things can be used in the clinics.

The success of the post-core restoration is when the tooth structure is preserved and not only the post. It is totally no point in preventing the post from fracturing and bending, while the root itself is vulnerable to fracture. When making a treatment plan for post-core crown, the construction and relation between post-core and dentine root structure have to be planned so that the stress can be distributed evenly in the post-core material and dentine, which can prevent root fracture when receiving normal chewing function. One of the factors influenced in stress distribution of post-core material and root is the root canal preparation design at cervical area of the root.[11,12]

In vitro study to examine whether there is a difference of root fracture resistance between seat and non-seat preparation design, in combination with the usage of a weaker alloy of CuZn has been performed recently.[13] Computer simulation using Finite Element Method to investigate whether there is a difference in stress distribution (which at the end will influence root fracture resistance) between seat and design in combination with the usage of CuZn alloy has also been done.[14]

This study will evaluate the effect of post preparation designs: seat and non-seat on the root fracture resistance of central maxillary incisors with CuZn post-core placement under simulated mastication force, using two different research methods: conventional fracture strength test and numeric method using 2D (2 dimensional) FEM. Evaluating the seat and non-seat design is crucial because the seat design is still used until now in our installation without knowing the disadvantages. Comparing these two techniques is also important, to introduce and to develop FEM for dental researches especially in Faculty of Dentistry, University of Padjadjaran. It will make the researches of material structures and designs can be done continuously, accurately, quickly, and inexpensively.

MATERIAL AND METHOD

Conventional laboratory fracture strength test[13] and numeric technique using finite element method were done in thus study.[14] Twenty extracted, intact single-rooted maxillary central incisors were selected for investigation and preserved in physiologic saline solution. Teeth were selected for similarity in size, shape, and root anatomy. The teeth were visually inspected to ensure the absence of caries, surface cracks, and fractures. The teeth were randomly divided into two groups of 10, and were decoronated until 2 mm above the cemento enamel junction, perpendicular to their long axis using a water spray-cooled diamond bur at high speed. The first group was given non-seat design (group 1) whereas the other was given seat design (group 2).

For non-seat design (group 1), the root canal of each tooth was prepared with a peeso reamer (Maillefer Ballaigues, Switzerland) followed by tapered fissure diamond 1.6 mm. Post space diameter was made round; the depth was 10 mm similar with the length of the tapered fissure diamond 1.6 mm (Figure 1).[11] The accuracy of post space preparation was examined with compound impression.

A B

Figure 1. Non-seat preparation design. (A) Root canal preparation: incisal view, (B) root canal preparation: labial view.

For seat design (group 2) initially the root canal of each tooth was prepared similar with the group 1. Then the preparation was continued by making a *seat* that was prepared at the cervical part of the root, with the depth of 1 mm and the width of 0.7 mm, similar with the width of fissure cylinder diamond bur diameter 0.7 mm encircling the tooth. (Figure 2).[6] The accuracy of the preparation was then examined with compound impression.

A B

Figure 2. Seat preparation design. (A) Root canal preparation: incisal view, (B) root canal preparation: labial view.

After that, the post-core wax pattern was made and casted. After trying in the cast post-core into the root canal, all dowels were luted with zinc phosphate cement (mixed according to the manuals) and the cement was also put in the channels then pressed with the thumb for one minute until the cement set. The teeth were stored in normal saline at 37° C before embedding it in a resin blocks jigs for testing procedures. Each tooth was embedded in a self curing acrylic resin in a cylinder mould, so that the long axis of the tooth was parallel to the cylinder walls and the acrylic resin covered the root, leaving 2 mm above the remaining dentin.

A B

Figure 3. Making the jigs. (A) Specimens, (B) Specimens in the test position.

The specimens were then mounted in Universal Testing Machine (Shimadzu Japan). A continuous increasing compressive force was applied at a point in the middle of the lingual part and 2mm below the incisal edge of the core. The load was applied at an angle of 135° to the long axis of the tooth at a crosshead speed of 0.5mm/min until failure occurred (Figure 3).[7,9,15] Failure loads (measured in Newton) from each tooth preparation designs were recorded and statistically analyzed for significant correlation between designs and failure loads using independent t test.

This study is a numerical technique using finite element method (FEM) to analyze stress distribution of Cu-Zn cast post metal toward tooth structure, under mastication force simulation, on non-seat and seat root canal preparation design in cervical area using two dimensional (2-D) models. A personal computers and commercial finite element software were used.[4,16,17] Picture of 2-D sagital sectioned model of maxillary central incisor that were prepared with non-seat and seat designs were restored with CuZn cast post metal, respectively.

The research procedures consisted of several phases: pre-processing, solution/solving, and post-processing (post-solution), convergence test, and data analyzes. In pre-processing phase, a structure geometry of tooth model (Creating Geometry) was constructed.[3,16,17,18] The normal geometry data's of an intact maxillary central incisor were quoted from the reference.[19]

The type of element used in this study was triangular. The model was then divided into small symmetrical elements (meshing) and the material was created.[17] The model consisted of 3 types of materials: dentin, gutta-percha, and alloys CuZn. The modulus of elasticity (E) and Poisson Ratio (μ) were quoted from literatures[20–22] except for alloys CuZn the elastic modulus data of alloy CuZn were found by bending test, done in Institute Technology Bandung.[5] The tooth was restrainted by all of the nodes on the outer surface of the root toward translation, compression, and rotation force to all direction.[17] The static load of 110 N, which resembled biting force on incisor region, was applied. The direction of force to the axial long axis was 135° on the palatal surface of the core, to simulate the normal chewing condition.[7,9,15]

The solution in structural problem was to figure out the displacement of nodes and stress value on each element which had been loaded. At post-processing phase, the location of the deformation and the value of maximal stress on the structure were interpreted and analyzed, so the result could be used in analyzing the stress distribution and to choose the proper preparation design. On 2-D model, the structure was assumed as a surface or a plane structure, so that the stress in thickness direction was not taken into account. The data was then analyzed by qualitative analysis to determine the stress distribution through the color change on 2-D digital model of maxillary central incisor after treatment and quantitative analysis to identify the comparison of the maximal stress value in the critical area between non-seat and seat design.

RESULTS

From the conventional fracture strength test it was found that the mean compressive load for non-seat and seat designs was as follow:

Table 1. t-test data for maxillary central incisors with non-seat and seat design

Preparation Designs	N	$\overline{X}$	p
Non- Seat	10	852.27	8.062
Seat	10	495.78	

The statistical analysis showed a significant result ($p < 0.05$); the mean fracture load in non-seat design was significantly higher than seat design. In group with seat design, root fractured happened in all teeth and none of the post was bent. Whereas in non-seat design, all teeth underwent the root fracture and 8 posts were bent and came off from the root canal, at the mean fracture load of 852.27N. The bending location of the post was at the 1/3 apical of the post and not on the border between post and core in cervical area. It was clear that the root fracture locations were always located at the cervical area of the root in both designs.

From qualitative analysis result of the Finite Element Method it was found that the color change pattern which related to the stress distribution pattern scattered through out the 2-D model of maxillary central incisor in both non-seat and seat design. The higher stress could be detected from the range color of blue until red, when other location which shows white color has the lowest stress. Compare to the laboratory test, on the Finite Element Method of 2D maxillary central incisor simulated the seat and non-seat design using the normal biting force 110 N showed the change in color code pattern that support the laboratory test work. The change in color was initiated on the location of loading and spread to the cervical area (Figure 4).

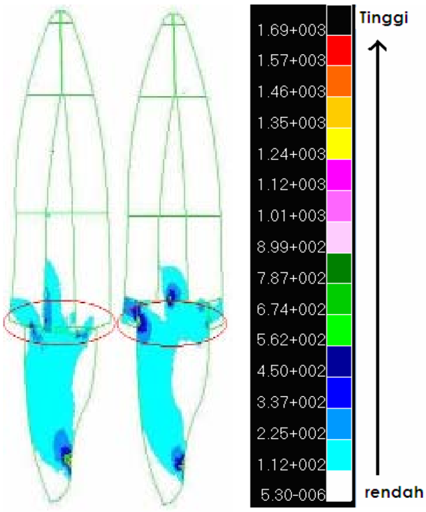

Figure 4. Stress distribution pattern on non-seat and seat design.

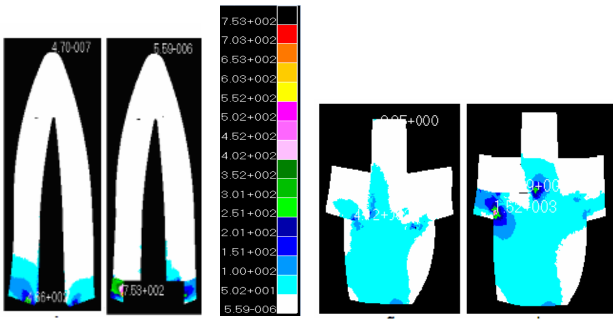

Figure 5. Comparison of stress distribution on the root. (A_1) non-seat design; (A_2) seat design. Comparison of stress distribution at the cervical region (B_1) non-seat design; (B_2) seat design.

This color spectrum on both the loading area and cervical area showed that the stress were concentrated on that location. Around the cervical area the concentrated stress was mostly located on the labial part. The color spectrum on seat design (red) was higher than non-seat area (blue). Focusing the stress distribution on the cervical or critical area, the color spectrum on seat design (red) was higher compare to non-seat design (blue) (Figure 5).

As from the FEM quantitative analysis: the internal stress value can easily be seen through Finite Element Method, where the loading on the model will produce stress detected by clinical or laboratory test. From this result, a comparison between the maximal stress value in both design can be calculate as a ratio of maximum stress value between seat and non-seat design.

$$\text{Maximum Stress Ratio} = \frac{\sigma \text{ seat design}}{\sigma \text{ non seat design}} = \frac{1520}{412} = 3{,}69$$

From this comparison of the maximum stress value between seat and non-seat design, can be seen that the maximum stress value of seat design was 3.69 higher than non-seat design. The higher the stress concentration in certain location, the higher the possibility of tooth fracture.

DISCUSSION

The laboratory test results showed that the average compressive forces which can be resisted by the seat design of maxillary central incisor root canal preparation was 495.78N, while for non-seat design was 852.27N ($p = 0.05$). The statistic calculation of the data showed a significant difference. This result indicated that the thickness of remaining dentin root structure influence the root fracture resistance. The thicker the remaining dentin root structure, the higher the root fracture resistance. Those findings were in accordance to the studies which have been done by other investigators. They proposed that a large root structure lost can weaken the strength of the tooth itself and increase the facture risk.[7,9,23]

Within the seat design group, which was tested using Universal Testing Machine at laboratory, the whole specimens, in other words 10 teeth were fractured on the cervical area of the root but no posts were bent. The location of fractures were found around the cervical area, mostly on the labial site (6 teeth), while the rest of the specimens fractured on the linguo-cervical and proximo-cervical. On the other hand, at the non-seat design which can resist higher force, showed not only they fracture around the cervical area but also most of the posts were bent on one third of the apical area as well. The bending was not on post-core border around the cervical area, this condition maybe caused by some reasons, possibly because the compressive strength of the cast post alloys were higher than 495.78 N and lower than 852.27 N. All the specimens were imbedded in self curing acrylic and did simulate the supporting tissue of natural tooth, so that the roots were defended from fracture. On the other hand, the supporting tissue could act as a shock absorber, which could reduce the actual stress applied on the surrounding root.

Actually the normal biting force is not as big as the force found in this study and it does not mean that for the tooth to fracture needs those big forces above. The dentin preparation work for creating the post space and cervical design, especially in this non-vital root structure may produce small crack around the preparation and can propagate further through the root structure.

The stress distribution on the cervical area which has been identified as critical area showed that at the seat area the maximum stress value was 3.69 times higher than non-seat area (see maximum stress ratio above). This was due to that in seat design there were more tooth structure removed, so it had the tendency to transfer stress differently. The stress distribution process to the dentine is more complex when the dentine structure is thin.[24,25] The higher stress on seat design means that the stress was not distributed evenly, therefore a high stress is concentrated on one location.

In contrary, at non seat design, the external forces were distributed through the large remaining root volume on cervical area, which was wider and thicker, so that the localized stress becomes smaller. Besides, it is also proven that too much preparation of tooth structure will have influence to the increase of stress concentration in root and root fracture can easily happens in tooth with minimal coronal structure.[25] Fracture is due to the inability of the material to resist the concentration of stress located in certain location. Therefore an evenly stress distribution is expected and has to be arranged in planning a treatment to prevent the tooth from fracture.

All the findings from the conventional fracture strength test and Finite Element Method confirm the recommendations that preserving more dentine around the post will give strength and resistance to tooth fracture.[13,14] These findings confirmed other author findings which recommended that the operator have to preserve as much tooth structure as possible to increase the fracture resistance of the tooth.[9,15,23,24,26,27]

Nevertheless, as in all other in vitro studies, the result of this study can not be directly applied in the clinic, because many of clinical parameters are not simulated here i.e. periodontal ligament, supporting bone, the condition of tooth structure, differences in mastication system etc. Long term clinical study has to be done to evaluate the influence of the post preparation design at the cervical area to the fracture resistance of the remaining tooth.

Oral rehabilitation is a difficult procedure since the functional forces in oral cavity will results in complicated response in oral tissue.[24,26] A difference in preparation design will result in different stress distribution patterns. The stress distribution is related to the restorative materials, in this case Cu-Zn alloy and tooth structure. In biomechanical function, the important thing is to detect stress that will cause tooth fracture. The results of numeric simulation using computational method[14] also confirm the results of conventional laboratory test that has been done in advance[13] and both concluded that preserving more dentine structure will minimalize the risk of tooth fracture. Considering all the findings it is recommended to use a non-seat than a seat design.

About the method comparison between conventional and computational method, the internal stress value can easily be observed through Finite Element Method where the given loading will result in calculation of stress value which distributed in every nodes and difficult to be detected by conventional or clinical studies.[28] FEM is a good method to test and predict the mechnical properties of a prosthesis or devices. FEM develops to overcome the laboratory and clinical research about material structures and designs which are relatively high in cost, difficult in procedures, and many other technical obstacles. This research used 2D model of tooth structure and static load. Forces in oral cavity is very complex which constantly change in direction, quantity, and location, therefore this study used only one clinical parameter which was static load with constant direction, which have been used in several investigation.[7,9,11,23,28,29] Three dimensional 3D model is more valid, but it needs more time and cost compared to 2D model.[30] Although the usage of 2D model is not fully representing the real condition, but the result was representatif enough for certain clinical conditions.[31] Therefore, further investigation about the usage of this method, in more complex situation imitating the condition in the oral cavity, has to be done. Other clinical parameters like periodontal tissue, bone support, and dynamic loading forces have to be involved.

Within the limitation of these studies, it can be concluded that non-seat design group showed a higher fracture resistance compare to the seat group. No post are bent in seat design, did not prove that the design was good. Possibly it was due to the fracture of the root in advance, even before the post bent and came out. Non-seat design can distribute the stress more evenly than seat design. The more tooth structure remains in the cervical area, the better the fracture resistance of the tooth restored with cast post. This Finite Element Method study confirm the result of the conventional study, therefore it can be used as an alternative method in studying the structures and designs of material used in dentistry.

ACKNOWLEDGEMENT

We wish to express our sincerest thanks to the chiefs of Laboratories Metallurgy PT Pindad and Laboratorium Struktur Ringan Institut Teknologi Bandung who are permitting us to use their research facilities. Our thanks are also due to Rikfi Kania and Aldilla Miranda, our intelligent students, for their technical assistance in preparing the work. Special thanks are extended to Program Hibah Kompetisi A2 FKG UNPAD for funding part of this work.

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