# Impact of different access cavities and apical preparations on the biomechanical behavior of maxillary second premolar

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**Abstract:**

**Aim:** to evaluate which type of access cavities will not affect the tooth strength after preparation and canal preparation. **Methodology:** an extracted maxillary second premolar was scanned to make a finite model. Models were designed with two different canal preparations (30/.04 and 40/.04) and three different access cavity designs (conservative access cavity "CEC", caries driven access cavity and traditional access cavity "TEC") were generated. In order to simulate the normal masticatory force range, occlusal load of 50 N was applied. After applying the load to all models, finite element analysis was used to determine the maximum Von Mises stresses "vM" and life span of models. **Results**: The solid model had the least von mises stress value (7.12 MPa) and the highest life span (100%) while the traditional access cavity "TEC" prepared with 40/.04 had the highest von mises stress value (9.85 MPa) and the lowest fatigue life span (85.36%)**. Conclusion**: The wider isthmus preparation increased the stress concentration and decreased the life span of the tooth. No difference was noted between different canal preparations concerning fracture resistance.

**Keywords:** access cavity design, caries driven access, canal preparations, finite element analysis

## Introduction:

The stability of the teeth is mostly determined by the strength of the crown and root. During endodontic treatment, extensive tooth structure removal in the clinical crown may make the cusps unstable and eventually fracture. Minimally invasive preparation techniques, adhesive techniques, and restorative materials had all been developed in order to maintain and preserve tooth structure and strength. [1]

Access cavity preparation is one of the most crucial phases for a successful endodontic procedure. The traditional endodontic access cavity had been the most popular design for decades and can be applied to a variety of tooth types, but it has a significant drawback: in order to achieve complete deroofing of the pulp chamber, more tooth structure, including healthy and carious tissue, must be removed. This may make the tooth less resistant to fracture under functional loads. [2-6]

The conservative endodontic access cavity was created to preserve the peri cervical dentin, which increased the tooth's fracture strength, minimising the removal of tooth structure. This design was introduced to overcome the limitations of traditional access cavities. The caries-driven access cavity further reduces cuspal deflection and prevents the premolar wedging action by removing only the carious part of the tooth while leaving all healthy tooth structure intact. [7-10]

Finite Element Analysis (FEA) is a numerical simulation program used to calculate stress and strain on biological structures such as teeth. This method's importance comes from its ability to investigate a limitless number of variables (such as loads and cavity design) for a relatively low cost. [11-14]

This study was designed to evaluate the effect of different access cavity design (conservative access cavity, caries driven access cavity and traditional access cavity) and the effect of different apical preparations (30/0.4 and 40/0.4) on the biomechanical behavior of maxillary second premolar single-rooted single canaled.

The null hypothesis was proposed that the used cavity designs and apical preparations would have no effect on the biomechanical behavior of the tooth.

## Materials and Methods:

### Ethical committee approval:

This study has the ethical clearance from the research ethics committee Faculty of Dentistry the British University in Egypt (FD BUE REC 21-005).

### Sample selection:

This study used a human single-rooted -single canaled maxillary second premolar with mature apex and normal root morphology.

The selected sample was extracted for orthodontic, periodontal or prosthetic purposes.

Sample was cleared to be intact, non-carious, non-fractured or cracked, non-calcified canal or showing root resorption or previously endodontically treated.

### Finite Element Model Generation:

• The selected tooth was scanned using a high-resolution cone beam computed tomography machine (Planmeca ProMax 3d MID; Planmeca, Helsinki, Finland), operating at 90 KV, 12mA, and a voxel dimension of 75 m, producing a total of 668 images. Following the methods of [15].

• The identification of enamel and dentin in DICOM-format images was done using the Materialise interactive medical image control system (MIMICS 19.0; Materialise, Leuven, Belgium).

- To create three-dimensional structures, masks are created and threshold zones are grown automatically.

- Data were improved using 3-Matic Medical 11.0 software (Materialize NV).

• Enamel and dentin combination was done using SolidWorks (Dassault Systems SA, Concord, MA).

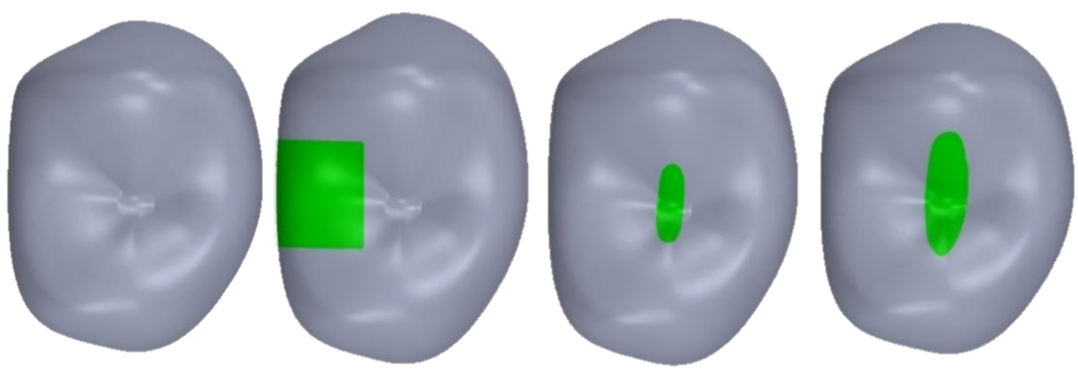
• SolidWorks (Dassault Systems SA, Concord, MA) was used to create the cortical and cancellous bone, as well as the periodontal ligaments.

**Intact Tooth Model Validation:**

• Model validation was done according to Nawar et al., (2022)[15]

**Access Cavity Design:**

- Three models were generated according to the cavity design: The intact control model, Caries driven access cavity model, CEC model and TEC model. (figure 1) ( table 1)
  - Caries Driven Access Cavity: the pulp chamber was reached by removing caries while preserving the entire intact tooth structure. [17]
  - Conservative Endodontic Access Cavity (CEC): The access outline was created by drawing a line from the center of the root canal orifice and extending it to the occlusal surface. This created two cross points that were then joined. [9]
  - Traditional Endodontic Access Cavity (TEC): This allowed a direct passage from the access cavity to the root canal orifice by removing the entire pulp chamber roof. [18]



(A) (B) (C) (D)

**Figure-1** A) Intact model B) Caries driven model C) CEC model D) TEC model

**TABLE 1-** showing volume of simulated composite used to fill the experimental models in $mm^3$.

| **Model** | **Volume of Simulated Composite** |
|---|---|
| Caries Driven Access Cavity | 29.73 $mm^3$ |
| CEC (occlusal defect) | 5.51 $mm^3$ |
| TEC (occlusal defect) | 10.08 $mm^3$ |

**Root Canal Preparation:**

- To replicate root canal preparation, the root canal's axis was marked with a line, and a conical form with the desired proportions was then made around it.
- The canals were prepared to 2 different sizes which are #30/.04 taper and #40/.04 taper.
- The prepared models were obturated with replicated gutta-percha 0.5mm short of the root apex and up to 2mm from the canal orifices.

- Six experimental models were simulated and restored with replicated composite resin above the gutta percha till the pulp horns level in order to restore the endodontic access cavities. [15]

**Meshing and Set Material Properties:**

- Models were introduced into the Cosmos software (Solidworks software; Dassault-Systems).
- Teeth, and materials used in the study, were assumed linear, homogeneous, and isotropic. [19]
- The enamel and dentin SN curve was chosen, and the elastic-modulus and Poisson's ratio of the structures were used to build the FEA model according to [22] and [21]. (table 2)
- Block of cancellous bone was joined mesially and distally while taking the boundary circumstances into account. The components were then replicated to have bonded connections.

**TABLE 2-** Mechanical Properties of the Materials for Finite Element Analysis. [15]

| **Material** | **Elastic modulus (MPa)** | **Poisson ratio** |
|---|---|---|
| Enamel | 84100 | 0.30 |
| Dentin | 18,600.0 | 0.31 |
| Periodontal-ligaments | 68.90 | 0.45 |
| Guttapercha | 140 | 0.45 |
| Alveolar-bone | 13,700.00 | 0.30 |
| Composite-resin | 7000.00 | 0.30 |

**Finite Element Analysis:**

- To accurately mimic clinical loading, models were subjected to 50 N of cyclic occlusal loading. [15][22]
- The load was applied on the slope of the tooth (which is located between the cusps and the centeral fossa). [23]
- The simulation of the intact model under loading and the number of cycles till failure (NCF) were completed first and the location of failure was recorded.
- After that, other models' life spans were simulated, and they were estimated as a proportion of each model's NCF relative to the IT model.
- Using the Solidworks Simulation Add-in, vM stresses following load application of all models were analyzed and mathematical analysis of the stress distribution patterns was performed.

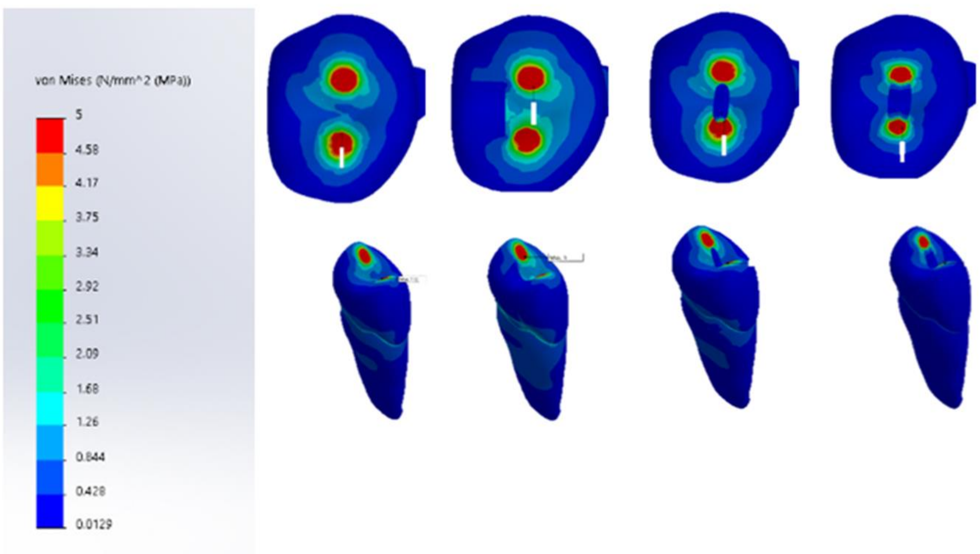
**RESULTS:**

Maximum vM stress was found in TEC prepared with 40/.04 model with a value of (9.85 MPa) while the lowest were also found in solid model with a value of (7.12 MPa).

Highest NCF was found in solid model with a value of 3.46E+09 total life (cycle), while the lowest NCF was found in TEC prepared with 40/.04 model with a value of 1.39E+08 total life (cycle).

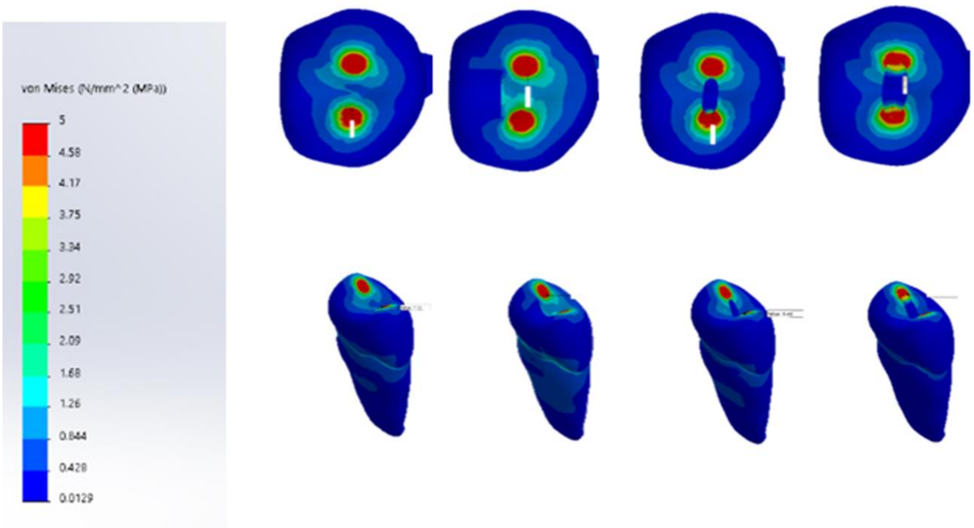
The stress distribution patterns were analyzed in two different views; occlusal view and isometric view. [15] (figure 2) (figure 3)

The stress distribution patterns, the highest vM stresses were found at point of loading in solid and caries driven models and decreased gradually as it goes toward the buccal and palatal cusp tips. While the rest of the models the highest vM stresses were concentrated at the interface between the tooth structure and the simulated composite




(A) (B) (C) (D)

**Figure-2** Stress distribution patterns A) Solid model B) caries driven model 30/.04 C) CEC 30/.04 D) TEC 30/.04.

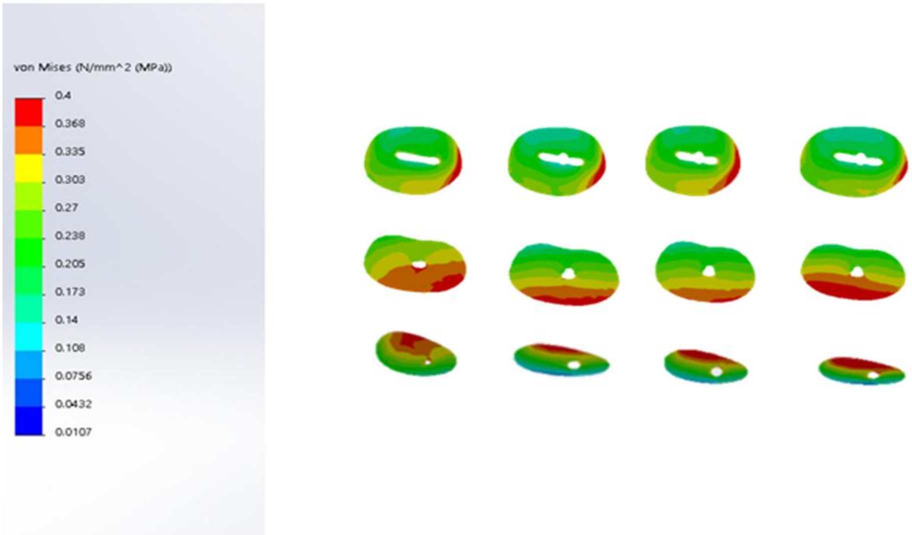



(A) (B) (C) (D)

**Figure-3** Stress distribution patterns A) Solid model B) caries driven model 40/.04 C) CEC 40/.04 D) TEC 40/.04.

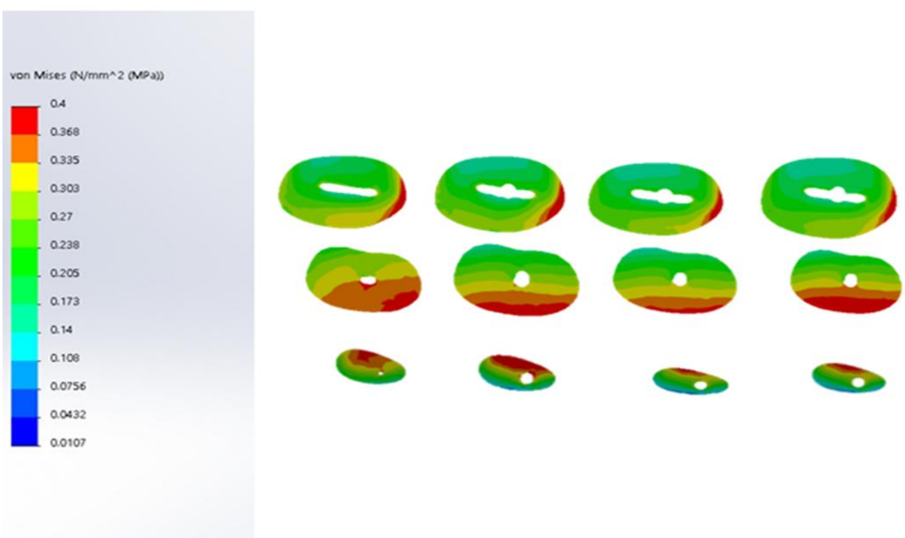
The radicular stresses distribution patterns were analyzed in 3 different root cuts; apical cut was taken 2 mm from the apex, middle was taken 7.5 mm from the apex and coronal was taken 13 mm from the apex. [15] (figure 4) (figure 5)

The radicular cuts stress distribution patterns; in the apical cuts the highest vM stresses were found at the distal aspect of the root surface externally. In the middle cuts the highest vM stresses were found at the mesial aspect of the root surface externally. In the coronal cuts the highest vM stresses were found at the palatal aspect of the root surface externally and the palatal aspect of the root canal internally.




(A) (B) (C) (D)

**Figure-4** stress distribution patterns in the radicular cuts, A) Solid model B) caries driven model 30/.04 C) CEC 30/.04 D) TEC 30/.04.




(A) (B) (C) (D)

**Figure-5** stress distribution patterns in the radicular cuts, A) Solid model B) caries driven model 40/.04 C) CEC 40/.04 D) TEC 40/.04.

**TABLE 3-** Maximum vM stress values (MPa) and fatigue values total life (cycle) in the models under the vertical loading.

| Model | Taper | Stress (MPa) | Percentage | NCF | NCF percentage |
|---|---|---|---|---|---|
| Solid | | 7.12 | 100.00% | 3.46E+09 | 100% |
| Caries driven | 30/.04 | 8.2 | 115.1% | 8.54E+08 | 93.64% |
| | 40/.04 | 8.34 | 117.1% | 7.23E+08 | 92.88% |
| Conservative | 30/.04 | 8.35 | 117.2% | 7.11E+08 | 92.80% |
| | 40/.04 | 8.46 | 118.8% | 6.53E+08 | 92.41% |
| Traditional | 30/.04 | 9.73 | 136.6% | 1.72E+08 | 86.34% |
| | 40/.04 | 9.85 | 138.3% | 1.39E+08 | 85.36% |

**Discussion:**

One of the most important steps for a successful endodontic procedure is access cavity preparation. TEC had been the most widely used design for decades, but it had significant drawbacks that made the tooth more liable to to fracture under functional loads. To overcome the limitations of TEC, CEC was introduced. It is documented that it improved the tooth fracture resistance by preserving the peri-cervical dentin and the soffits. [9]

Maxillary premolars are more prone to fracture due to their smaller occlusal table compared with the maxillary molars, it is subjected to high forces as it is beside the molars, any removal of intercuspal tooth structure could increase wedging action. Despite all these liabilities still the maxillary premolars were not researched as often as molars.

This study evaluated the effect of different access cavity designs (caries driven access, CEC and TEC) and the effect of different apical preparation (30/.04 and 40/.04) on the biomechanical behavior of single-rooted single-canaled maxillary second premolar.

After producing the solid model, three access cavity models were generated, caries driven access cavity, CEC and TEC.

Cavities were filled with simulated composite [15][24], In order to give rigidity to the tooth as composite is a bonded material making adhesive filling.

In all models #30/.04 taper and #40/.04 taper were chosen to examine if the increase of apical preparation size would increase the stress level at the root canal. Also, to examine if the increase in the size of apical preparations would cause more stress distribution that extended to the cervical parts of the tooth but a little influence on crown stress distribution. [25][26][18]

All models were subjected to cyclic loading of 50N [15][23]. Cyclic loading was selected as the crack development and propagation increased with mastication over time. Load of 50N was chosen as the normal masticatory forces fall on maxillary premolar teeth ranging from 8N to 880N. [27]

There was no difference between models prepared with #30/.04 taper and #40/.04 taper. As the change of canal preparation size did not appear to make a significant mechanical difference with all access designs. So, the access cavities had more impact than the size of canal preparation. [24]

The radicular cuts had negligible values as the load wasn't applied on the root cuts directly but it was applied on the occlusal surface of the tooth. [15][24].

Concerning the results of von mises stresses; the traditional endodontic access cavity had composite volume (10.08 $mm^3$) and the highest von mises stresses value in this comparison (increase by 38.3% from the solid as the wider the isthmus preparation result in increased the stress concentration and the cuspal deflection of the tooth. The conservative endodontic access cavity provided true mechanical advantage when compared to the traditional access cavity, more tooth structure preservation, less composite volume (5.51 $mm^3$) that minimized the tooth-composite interface that would hinder smooth stress transition, percervical dentin preservation so less cuspal deflection of the tooth. Its von mises stress value increased by 18.8% from the solid model. The caries driven access cavity von mises stress value increased by 17.1% from the solid model. Although the caries driven access had a large composite volume (29.73 $mm^3$) it had less stress concentration compared to the traditional endodontic access cavity and the conservative endodontic access cavity as this type of access provided a preservation of the intercuspal tooth structure which decreased the cuspal deflection. Also, it preserved the distal marginal ridge. [15][9][19].

NCF was inversely proportional to vM stress, so as the vM stress value increased the NCF percentage decreased.

The TEC was compared to the CEC, caries driven access. The TEC had the lowest NCF in this comparison as its value decreased by 14.64% from the solid, The NCF of CEC decreased by 7.59% from the solid model The caries driven access the highest NCF decreased by 7.12% from the solid model. This was attributed to the preservation of the inercuspal tooth structure in the caries driven access cavity model that made the load fall on intact tooth structure while in case of traditional and conservative access cavities the load fall on the interface between the simulated composite material and the tooth structure. [19][28].

One of FEA's shortcomings is that it uses a computerized simulated technique; therefore the clinical circumstances could not be exactly duplicated. Although it is not true in reality, stress analysis is often carried out under static loads, and the mechanical characteristics of materials are assumed as uniform, isotropic, and linearly elastic. The Poisson's ratio and Young's modulus are often not similar in the dentin because the hardness of the dentin diminishes from the outside surface to the tooth pulp cavity. Additionally, it is said that dentin possesses unique anatomical structures and forms.

The null hypothesis was partially rejected as access cavity designs had an impact on the stresses and life span of teeth but canal preparations did not.

**Conclusion:**

Within the limitation of this study:

- The preservation of the intercuspal distance increased the tooth life span and minimized the stresses concentration.
- Canal preparation size does not affect the fracture resistance.

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**Conflict of interest:** The authors deny any conflict of interest.

**Authorship statement:** we confirm that all listed authors meet the authorship criteria and that all authors agree with the manuscript's content.

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