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# Investigation on Canal Curvature and StressIntensity Patterns in Dental Canals

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**Purpose:** Dental anatomy is important in the human body because it aids survival. For dentists,

the after-treatment protocol in root canal treatment (RCT) for poor anatomical functioning is aserious difficulty. The success rate of treatment is based mostly on geometry and process factors, such as canal curvature coefficient and canal operating force. The objective of this work is to compare the stresses generated within the canal as a result of hypothesized compaction force in unprepared and biomechanically prepared canals.

**Design/Methodology/Approach:** Initially, Radio-Visio Graphs (RVG) of molar and premolarteeth were recorded for measuring of canal curvature and compared with biomechanically prepared standard endo training blocks examined under optical comparator. In later sage, modeling was done using traced canal geometry and analyzed using simulation software to compare stress generated within the canal with a known operating force of 3-15 N.

**Finding:** On the evaluation of RVG's of molar and premolar and compared with biomechanically prepared endo training blocks, the canal curvature lies within the moderate category i.e. ($20^0$-$40^0$). Also, the possibility of failures in the middle part of the canal on accountof vertical condensation mentioned in the literature was well governed in the middle region ofthe canal on account of vertical condensation and is well established by FE simulation results. **Keywords –** *Canal Curvature, RVG, Canal Operating Force, Stress Intensity*

## I. INTRODUCTION

Root canal treatment (RCT) is a medical technique that analyses, fixes, and saves a partly or completely decaying tooth. A root canal is a dental procedure in which the inner element/elementsof a tooth are treated. Endodontics is a sub-specialty of dentistry that is essential to the entire therapy. The current study is part of an endodontic (inside the tooth) treatment plan in which the focus is on obturation (a method used during RCT that involves filling and closing the three-dimensional root canal area to prevent bacterial development).The success index of root canal treatment [RCT] majorly depends on several mechanical factors such as kinematic viscosity of filling material (ν), canal operating force is commonly known as compaction force (F), specific heat (Cp), and pliability of filling material (P), geometry parameter (α), canal curvature coefficient(C), the adhesive bond strength between filling material and dentin (Fa) which can be considered as energy parameter, material parameter, process parameter and geometry parameter [1] as shownin figure 1.

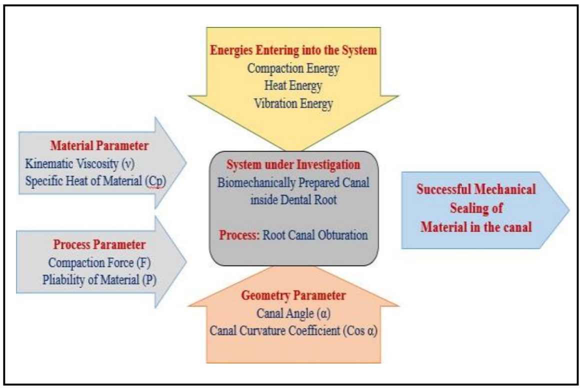



Fig.1: Mechanical parameters Considered in Root Canal Treatment

It has been discovered that researchers have not addressed the exact mathematical relationship between process parameter and geometry parameter over years; however, it has been stated that success index is proportional to process parameter and geometry parameter- higher the value of F,higher the success index, higher the value of P, which results in the dense filling [2] and to enhancekeep the success index towards the higher side, it is very essential to determine the exact geometry parameter. Several researchers suggested various experimental approaches and models measure canal operating force and its influence on the canal and the surrounding regionbetween 1960 and 2019, but no exact mathematical description of the force was provided or recommended. The researcher introduced the application of the Balanced Force Approach [BFT] to evaluate forces produced during root canal preparation in 1997 and came up with a range of components of forces that were recorded in the form of endograms regardless of the technique [12]. In the same year, the researcher looked at the forces again, this time using RCT techniques including Cold Lateral Compaction, Warm Vertical Compaction, and Continuous Wave Compaction [13] [14]. The goal of the study in 1998 was to examine the inter canal focus, also known as the wedging effect (forces generated by the application of hydrostatic pressure: plugger pushing gutta-percha (commonly used filling material) in the canal, and it was discovered that the most difficult aspect was determining the proper compaction force concerning gutta-percha being poor heat conductor due to its plasticity [15] [16]. Later, in the early 2000s, researchers researched the rheological characteristics of four commercially available gutta-percha for root canal filling. The relaxation modulus [Gr (0): instantaneous shear modulus], specific volume, and heat quantity of their materials were investigated. The Gr (0) values of each material were virtually equal at a smaller temperature range than the first-order transition temperature (melting point)

[17]. Other researchers have studied the method ofprotecting tooth samples from the vertical force generated during the RCT preparation process,that is, the empirical spreader penetration and the load of 1.5 kg to 7.2 kg have been shown toproduce cracks, and the method used in the process The material has no significant effect on the success rate of the teeth. Factors such as gender, age, preoperative vitality, and periapical pathology lead to changes in other parameters, which are closely related to significantly different success rates. [18]. At the end of 2000, researchers used geometric parameters, especially the coefficient of curvature (C), to estimate the relationship between technology and

geometric parameters, and found that the treatment effect of root canals is higher than that of root canals with smaller curvature. Compared with slightly and moderately curved root canals,severely curved root canals are more difficult to install and fill [19]. Some of the researchers proposed a new method of estimating canal operating force, that is, in UTM, the study was conducted with different operators and found that the force ranged from 1 to 8 N [20]. Considering the safety load to avoid breakage, the operating force value of 1 to 4.9 kg of the canal is considered safe relative to the widely used technology. [21]. Few researchers have alsopointed out that the ability to measure the entire root canal length and root filling level significantly affects the treatment results [22]. And after years of research, researchers have claimed that the reason many teeth do not respond to root canal treatment is that procedural errors impede the control and prevention of root canal infection, and procedural accidents often make root canals difficult or impossible. Complete appropriate endodontic surgery [23]. The force generated during the filling step can be captured and recorded in real-time using electronic monitoring equipment equipped with a mechanical testing machine. Thus, within the scope of the article, an attempt is made to find out the exact canal curvature of teeth using Radio-Visio Graphs (RVG) and examining biomechanically prepared canals with 25.04 and

25.06 K-files and analyzing those canals using simulation software to compare stress generatedwithin the canal with a known operating force of 3-15 N subjected to vertical condensation.

## II. GEOMETRY VERIFICATION

The success index largely depends on biomechanical preparation of the canal which governs the smoothness of the canal wall; part of the geometric parameters, proportional to the appliedload or operating force of the canal. Studies have shown that a root canal with a smaller curvature has a higher success rate than a root canal with a higher curvature [2]. According to Schneider’s method [14,15], the calculated root canal curvature can be divided into three categories: 0-10 degrees root canal curvature belongs to category I (also known as basically no curvature), 10-30 degrees root canal curvature roots The canal curvature is type II (moderate root canal curvature), and the root canal curvature exceeds 30 degrees as type III (severe root canal curvature). The combination of category II and category III represents a curved root canalas shown in figure 2.

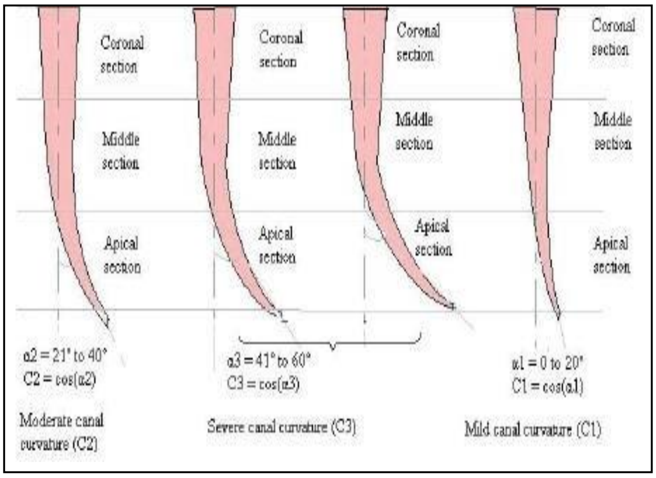



Fig No.2: Typical Canal Curvatures [1]

To measure the curvature and classify it under the mentioned category, various researchers have contributed in their peculiar way. One of the researchers measured canal angle on white

paper in the center of the file, at the level of the canal orifice, point a was marked with a 0.3- mm lead pencil, and a line was drawn with a straight edge aligned in parallel to the image of the file from point A to a point where the instrument was dived. As indicated in figure 3a, a third point (C) was conducted in the apical foramen and determined to be $28^0$ [3]. Another researcher also examined primary, secondary and tertiary curvatures of the canal using teeth were radiographed in mesiobuccal, mesiolingual (clinical), and mesiodistal (proximal) directions [8] and found to be in the range of $20^0$-$25^0$ (Class II) for primary curvature, $20^0$-$28^0$ for secondary curvature (Class II) and Class III tertiary curvatures [4] as shown in figure 3b.

Fig No.3a: Technique to Determine Canal Curvatures [3]

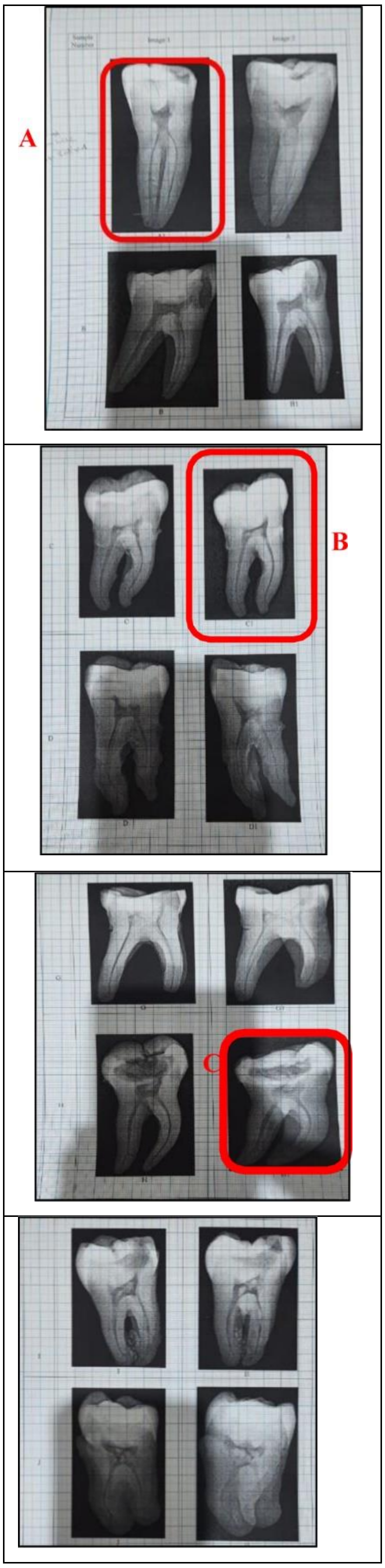
Fig No.3b: Technique to Determine Canal Curvatures [4]

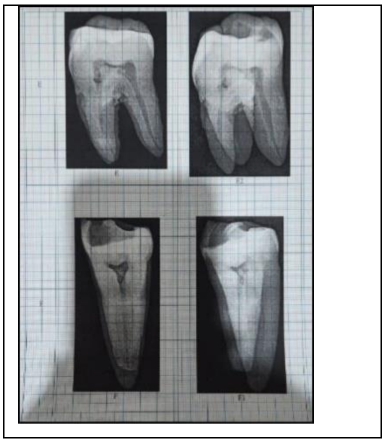
In continuation with the classification of canal curvatures in various classes according to its severity, one researcher worked on more than 100 extracted molar teeth to worked on developing a correlation between root canal patterns w.r.t distance in mandibular first molars and classified curvature in several categories shown in figure 4 and found to classified under Class II [5] i.e. within $18^0$ to $25^0$. After analyzing mesiobuccal and mesiolingual canals with Micro CT for a group of molars the average angles of primary curvatures were $24.34^0$ for the mesiobuccal, $22.39^0$ for the mesiolingual [6]. In recent years, root canal morphology was studied for 274 maxillary posterior teeth are analyzed analytically for primary curvature as shown in figure 5 after X-ray film measurement and found to be $25.16{\pm}6.6^0$and $28.05{\pm}8.65^0$ infirst and second molars, respectively [7].

Fig No.4: Classification of Canal Curvatures [5]

Fig No.5: Canal Curvature Measurement [7]

After reviewing all the methods, RVG for molar and premolar teeth was recorded and canal curvatures were measured as given in figure 6 and most of the curvatures were found to be resembling with class II as shown in table I as mentioned in literature.





Total No. of Samples: 20 A= Class I canal curvatures B= Class II canal curvatures

C= Class III canal curvatures

Fig No.6: RVG Images of Premolar and Molar to Measure Canal CurvatureTable: I Sample RVG for Estimation of Canal Curvature

| Sr. No. | Samples | RVG Plot (Unprepared) | Curvature type |
|---|---|---|---|
| 1 |  |  | Class-II |
| 2 |  |  | Class-II |
| 3 |  |  | Class-III |
| 4 |  |  | Class-II |
| 5 |  |  | Class-III |
| 6 |  | - | Class-II |

The canal morphology, if analyzed mechanically found to be an amalgamation of analytical and synthetic curves [1]; following an examination of the canal's 3D complexity, To adhere tothe RCT's ethical and medical criteria, the author limited the scope of the numerical trial to

acrylic blocks shown in figure 7 as the measurand (canal curvature) falls into the moderate group [1]. To carry out numeric study trail using simulation tool; standard endo training blocks on optical comparator which were biomechanically prepared using 25.04 and 25.06 K-type hand files with 4%,6% taper and with Motopex-M Endomotor.

*Endo Training Block Specification Diadent Endo Training Blocks MD-127Size: 3.5cm x 1.6cm (Height x Width) Material: Acrylic*

Fig No.7: Endo Training Block

The used optical comparator was having projection accuracy of ± 0.1%, measuring accuracy of (3+L/100) Microns and 10x magnification was used to examine canal curvature shown in figure 8. Total 10 unit samples were prepared each with mentioned files and canal curvature profiles was traced as shown in figure 9 to determine the average canal curvature mentionedin table III for the apical region and found to be in Class II.

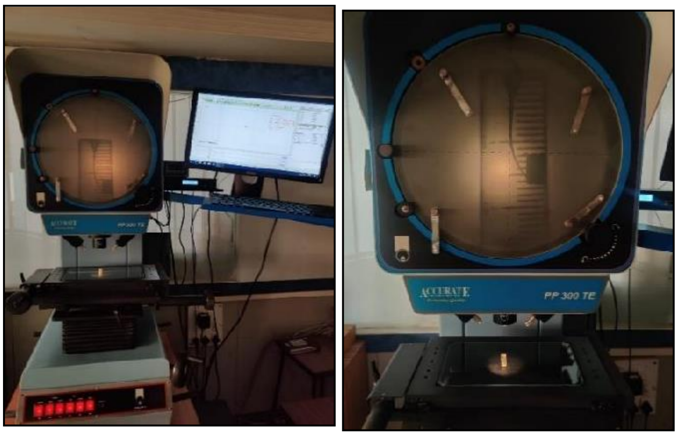



Fig No.8: Optical Camparator Used for Canal Curvature Examination

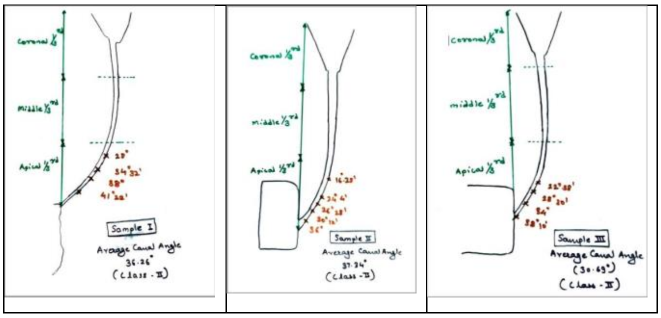


Fig No.9a: Canal Curvature Traces for Unprepared Canal

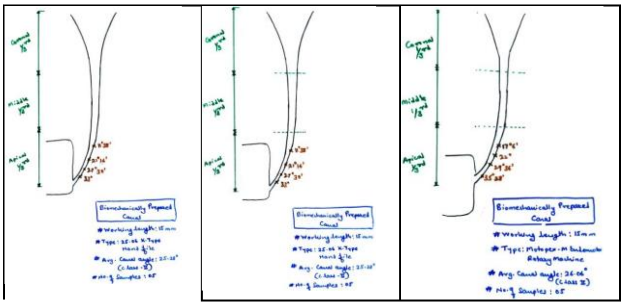


Fig No.9b: Canal Curvature Traces for Prepared Canals

## III. NUMERICAL STUDY

As part of the 2D canal analysis, a 2D model was created for all the canals in the central area in ANSYS (used as a tool for FE simulation), consisting of the base canal, the ½mm outer dentin layer, and the alveolar bone with a 2D structural element of the body (plane182) and isotropic properties were taken into account shown in table II.

Table.II: Material Propoerties for FE Simulation [9-11]

| Sr.No. | Dental Tooth Element | E (Modulus of Elasticity) | μ (Poisson's ratio) |
|---|---|---|---|
| 1 | Gutta Percha (GP) | $3*10^2$ MPa | 0.485 |
| 2 | Dentine | $2*10^4$ MPa | 0.310 |
| 3 | Bone | $1.4*10^4$ MPa | 0.15 |

The initial canal model in ANSYS APDL contains different levels of material, i. H. Gutta- percha, dentin, and alveolar bone, with areas A1 and A2 as alveolar bone, A3 and A4 as dentin,and A5 as gutta-percha, as shown in figure 10.

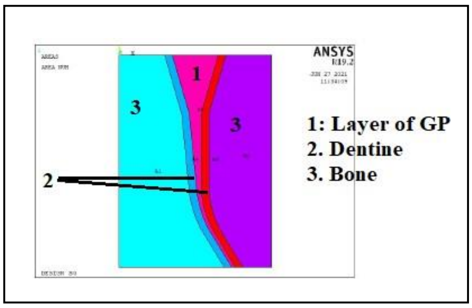



Fig No.10: Geometry Preparped in Simulation Tool (ANSYS)

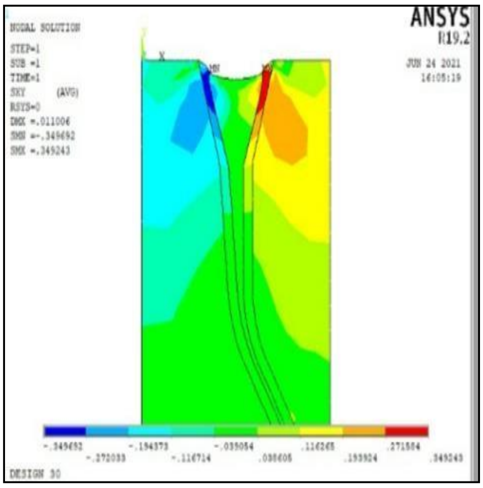
Vertical condensation treatment was considered for the analysis, and a variable vertical force within the range of 3-15 N was applied progressively with unit increment on A5 and for A1- A3, A2-A4 layers were provided with bonded contact and outer boundary displacement was constrained.

Table.III: Canal Curvatures (Mean)

| Sr. No | Unprepared Canal (Supplier A) | Unprepared Canal (Supplier B) | Unprepared Canal (Supplier C) | Prepared Canal With 25.04 K-TypeHand Files | | | Prepared Canal With 25.06 K-Type Hand Files | | | Prepared Canal With 25.04 and 24.06 Rotary Files operated withMotopex-M Endomotor | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Doc 1 | Doc 2 | Doc 3 | Doc 1 | Doc 2 | Doc 3 | Doc 1 | Doc 2 | Doc 3 |
| 1 | 32.24 | 35.35 | 41.75 | 26.06 | 25.29 | 25.32 | 25.03 | 24.64 | 24.89 | 26.29 | 25.72 | 25.91 |
| 2 | 32.54 | 37.31 | 36.54 | 25.15 | 26.96 | 24.52 | 25.62 | 25.18 | 25.06 | 26.11 | 25.80 | 25.77 |
| 3 | 29.32 | 34.42 | 39.87 | 25.43 | 24.73 | 25.94 | 24.93 | 26.29 | 25.25 | 26.17 | 26.00 | 25.55 |
| 4 | 33.70 | 36.40 | 39.45 | 25.99 | 26.44 | 24.69 | 25.76 | 24.95 | 26.10 | 26.24 | 26.25 | 25.74 |
| 5 | 29.06 | 35.84 | 36.46 | 24.74 | 26.30 | 25.89 | 25.97 | 25.80 | 24.83 | 26.06 | 25.72 | 26.16 |
| 6 | 29.75 | 38.85 | 38.20 | 24.53 | 26.02 | 26.55 | 25.63 | 26.07 | 25.04 | 26.21 | 25.63 | 26.15 |
| 7 | 30.69 | 34.45 | 35.81 | 24.79 | 25.91 | 24.73 | 25.13 | 26.01 | 25.22 | 25.90 | 25.52 | 25.90 |
| 8 | 31.06 | 39.37 | 36.71 | 26.78 | 24.68 | 25.96 | 25.97 | 24.86 | 25.40 | 26.03 | 26.09 | 25.92 |
| 9 | 30.17 | 36.52 | 35.46 | 24.91 | 26.75 | 26.27 | 25.74 | 24.92 | 25.21 | 25.72 | 25.95 | 26.14 |
| 10 | 28.58 | 34.57 | 34.50 | 25.83 | 25.91 | 26.31 | 25.19 | 24.97 | 25.87 | 25.90 | 25.51 | 26.12 |
| Average: | **30.67** | **30.27** | **37.34** | **25.42** | **25.90** | **25.62** | **25.50** | **25.37** | **25.29** | **26.06** | **25.82** | **25.94** |

Researchers [1] offered canal curvature values and shape as guidelines for doing quantitative analysis using simulation with changing loads and preset boundary conditions. A statistical tool like MINITAB was utilized to determine connectivity using the acquired coordinates and a supervised machine learning technique.

As shown in figure 11, the canal was observed and evaluated for plane shear stress operating in the XY plane before and after biomechanical preparation using 4%, 6% hand tapered files, and rotary taper files under natural and imposed boundary conditions with a progressive increase in load.




*XY shear stress distribution in 20° unprepared canal of force*

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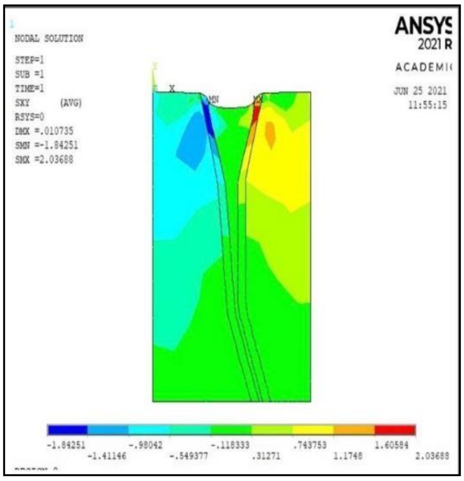
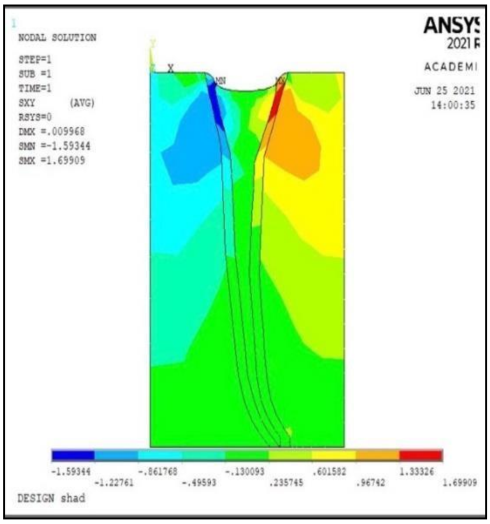
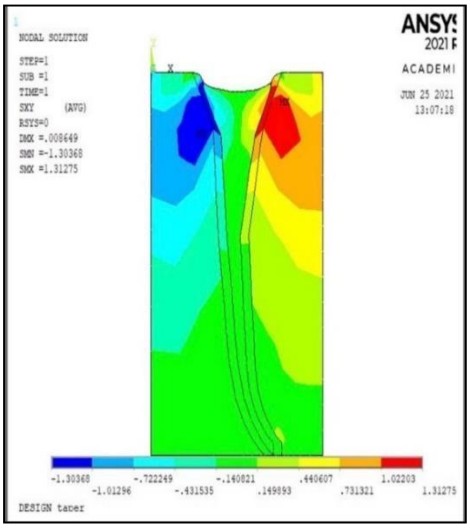
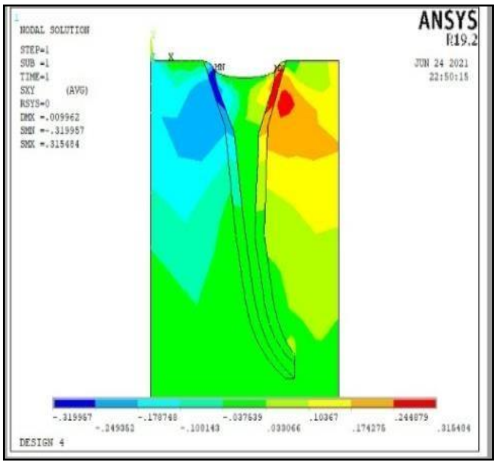


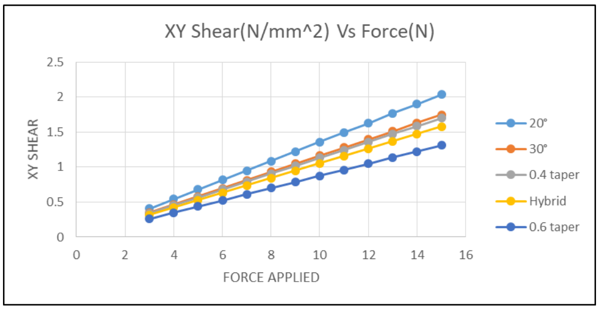






*XY shear stress distribution prepared Canal with 4% Tapered Hand Files*

*XY shear stress distribution prepared Canal with 6% Tapered Hand Files*




*XY Shear Stress Comparison for Unprepared and Prepared Canals*

*XY shear stress distribution prepared Canal with RotaryTapered Files*

Fig.11: Shear Stress Intensity Within the Canal

The investigation demonstrates that the site of likely failure was the same in both unprepared and prepared canals, but the magnitude rises with the increase in force, as shown in figure 11.When compared to the force applied to the root canals, the shear stress values are lowest in canals produced using 25.06 hand files, next rotary files, and finally, 25.04 hand files, which were determined to be extremely close to ideal and approximate normal practice following discussion with experts in the area. The magnitude of stress and force were shown to be linearin a graphical comparison; nevertheless, there was no tendency for the magnitude of stress to rise. Figure 13 depicts the exact relationship between the magnitude of the force and the amount of shear stress generated concerning force stress variation along the canal length and curvature,demonstrating that the maximum stress in the prepared canals increased with increasing force,but the initial stress for the same showed that after 8-9N, the values dipped and spiked again, requiring further evaluation.

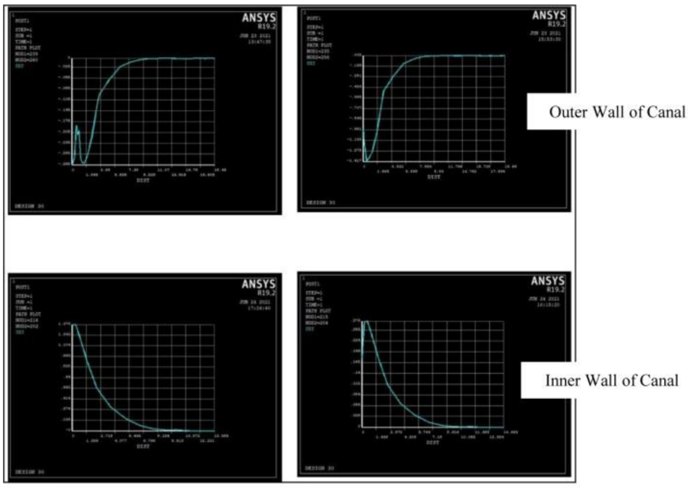



Fig No.13: Shear Stress Vs Canal Distance

Fig No.13: Shear Stress Vs Canal Distance

## IV. CONCLUSION

The research effort performed and the conclusions discovered via the numerical study are compatible with the survey results proposed by the researcher and the opinions provided by academics and experts in the area of dentistry. The conducted research effort intentionally excludes the presence of minor lateral canals and focuses on the primary canal, indicating the following points,

i. Evaluation of RVG's of molar and premolar and compared with biomechanically preparedendo training blocks, the canal curvature lies within the moderate i.e. Class-II category.

ii. The possibility of failures in the middle part of the canal on account of vertical condensation mentioned in the literature was well governed in the middle region of the canal on account of vertical condensation is well established by FE simulation results.

iii. The maximum stress in the prepared canals kept on increasing with increasing force but for initial stress for the same showed that after 8-9N the values again dipped and spiked somewhat indicating that the force around 8-9N is optimum in terms of Compaction forceto be applied on the material during filling.

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