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Estimation of Ultimate Tensile Strength of dentin Using Finite Element Analysis from Endodontically Treated Tooth

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Abstract. Endodontically treated teeth were simulated by finite element analysis in order to estimate ultimate tensile strength of dentin. Structures of the endodontically treated tooth cases are flared root canal, restored with different number of fiber posts {i.e. resin composite core without fiber post (group 1), fiber post No.3 with resin composite core (group 2) and fiber post No.3 accessory 2 fiber posts No.0 with resin composite core (group 3)}. Elastic modulus and Poisson's ratio of materials were selected from literatures. The models were loaded by the average fracture resistances load of each groups (group 1: 361.80 N, group 2: 559.46 N, group 3: 468.48 N) at 135 degree angulation in respect to the longitudinal axis of the teeth. The stress analysis and experimental confirm that fracture zone is at dentin area. To estimate ultimate tensile strength of dentin, trial and error of ultimate tensile strength were tested to obtain factor of safety (FOS) equal to 1.00. The result reveals that ultimate tensile strength of dentin of group 1, 2, 3 are 38.89, 30.96, 37.19 MPa, respectively.

1. Introduction

Finite element analysis (FEA) is a computational technique widely used to estimate the behavior of structures under loading. It is particularly valuable to investigate those conditions which cannot be studied directly by experiment, and therefore, provides valuable information that cannot be obtained in more direct ways. This technique uses a series of small elements which are connected at nodal points, to computer-generate a morphological structure. The elements can be assigned properties that are indicative of the tissue properties that small areas of the biological structure have, either relying on measurements that have been made of the properties of the material, or in those cases in which the properties have not been measured, estimating them based on the available data [1].

The physical properties of tooth which is highly mineralized tissues based on their composition and micro morphology [3]. Enamel, dentin and dentin–enamel junction are parts of tooth with different strength. However, most of the tooth structure is consisted of dentin which is a hydrated biological composite composed of 70% inorganic material, 18% organic matrix and 12% water (wt%), with properties and structural components that vary with location [4]. Recently, the experiment on

endodontically treated teeth reveals that the fracture normally occurs in dentin area as a weak point [2]. Although, the microtensile technique is a good tool to determine the ultimate tensile strength (UTS) of both materials and tooth substrates [3], alternatively, finite element technique could be used indirectly to estimate the UTS of tooth from result of non-conformed standard of fracture resistance test.

The aim of this research is to estimate ultimate tensile strength of dentin from existing experimental data in dentistry [2] by finite element analysis.

2. Methodology

2.1. Existing Experimental Data

In 2015, Puengpaiboon et al. conducted the research which is determination of fracture resistance of endodontically treated teeth with flared root canal, restored with different number of fiber posts [2]. The samplings includes 3 groups; group 1 was restored with a resin composite core material (Multicore Flow), group 2 was restored with a single fiber post and resin composite core (FRC Postec Plus No.3, Multicore Flow), and group 3 was restored with 3 fiber posts and resin composite core (1 FRC Postec Plus No.3 and 2 fiber posts No.0, Multicore Flow) as shown in Figure1.

All Samples were tested at 135 degree angulation in respect to the longitudinal axis of the teeth using a Universal testing machine as shown in Figure2 (a). The average fracture resistances were as follows: group 1: 361.80 ± 93.16 N, group 2: 559.46 ±155.12 N, group 3: 468.48±155.17 N [2]. The facture of specimens are illustrated in Figure2 (b).
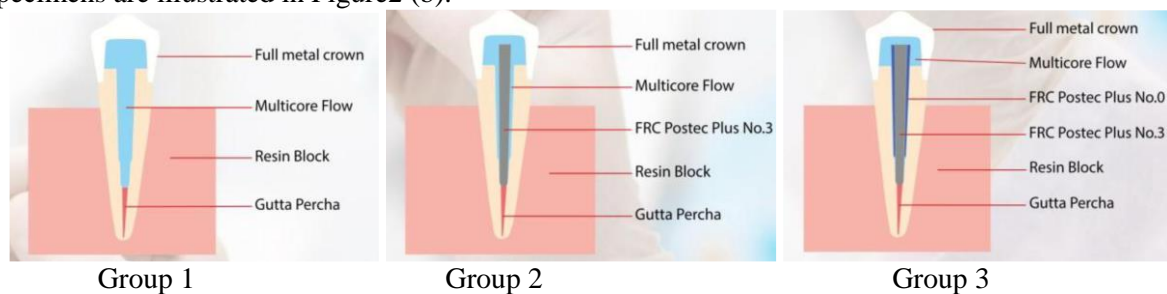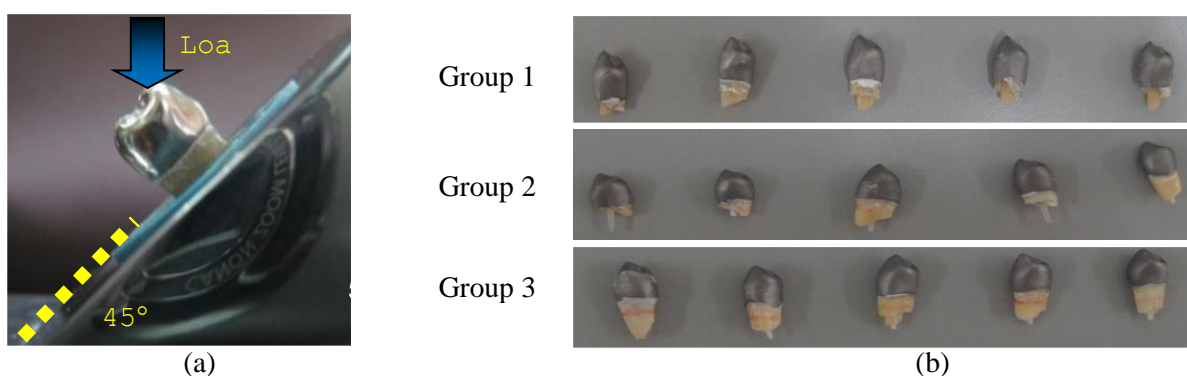

Figure 1. The existing tested samplings [2].

Figure 2. (a) Test direction, (b) facture of specimens of group 1, 2, 3 [2].

2.2. Finite Element Model and Analysis

The simulation are based on linear elastic, isotropic and homogenous material. Dimension of mandibular single-root premolars was obtain from CT scan (approximately length is 22 mm. and 9 mm. in diameter). Simplified geometry of endodontically treated teeth with flared root canal, tooth

model and full models show in Figure3. Elastic modulus and Poisson's ratio of materials used in the model are shown in Table 1.

Estimation of ultimate tensile strength of dentin was done by trial & error from analysis factor of safety (FOS) until maximum of FOS is one. The critical control stress used in this trial & error is principal tensile stress and the limit strength of material is ultimate tensile strength of dentin as shown the flow chart in Figure4. In addition, from preliminary analysis, ultimate tensile strength of other parts are quite higher than maximum principal tensile stress at that parts. In other words, FOS of other parts is always higher than one. Therefore, fracture part in located only in dentin.
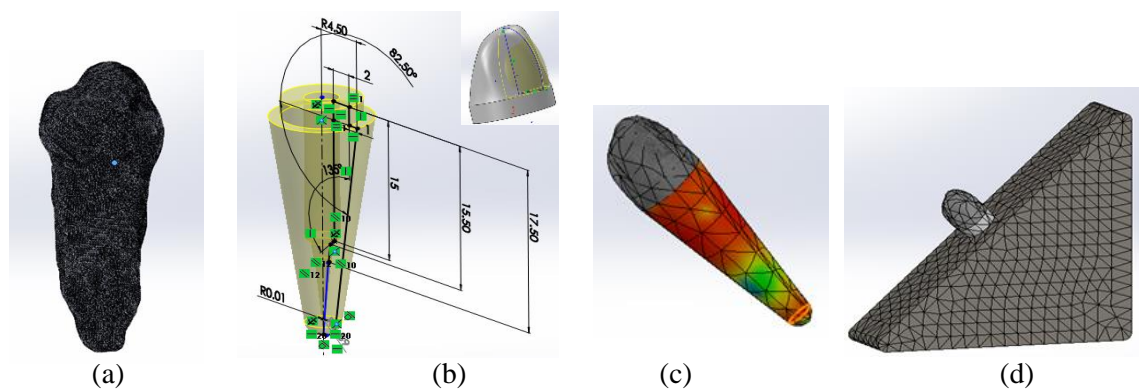

(a)	(b)	(c)	(d)

Figure 3. (a) CT scan of mandibular single-root premolars, (b) simplified geometry of endodontically treated teeth with flared root canal, (c) model of the endodontically treated teeth tooth, (d) full model with resin support.
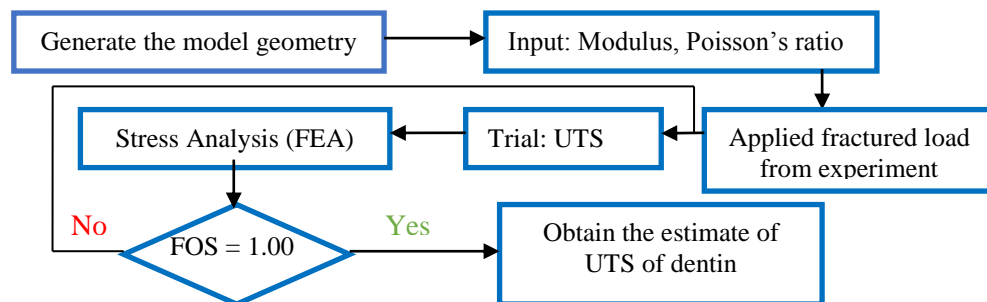

Figure 4. Flowchart to estimate UTS of dentin.

Table 1. Elastic modulus and Poisson's ratio of materials

Material	Young's Modulus (E) MPa	Poisson's ratio	Reference
Dentin	18,600	0.31	[5]
Gutta percha	0.69	0.45	[6]
Resin Composite	16,600	0.24	[7]
Metal Crown	96,600	0.35	[6]
FRC Post	21,000	0.30	[8]
Resin (Block)	20,000	0.30	[9]

3. Results and Discussion

3.1. Group 1 (restored with a resin composite core material)

Figure 5 (a) displays the model's components which are metal crown, dentin, resin composite, gutta percha and resin support block. Principal stress of endodontically treated teeth group 1 is demonstrated in Figure 5 (b). The maximum compressive stress located in metal crown whereas the maximum tensile stress occurs in dentin. Factor of safety (FOS) are defined as stress divided by strength of material at each point in model. If principal tensile stress caused by external load equals to ultimate tensile strength of material, FOS will be unity. To obtain FOS equals to one, tensile strength of dentin was applied as 38.89 MPa to get FOS in Figure5 (c)
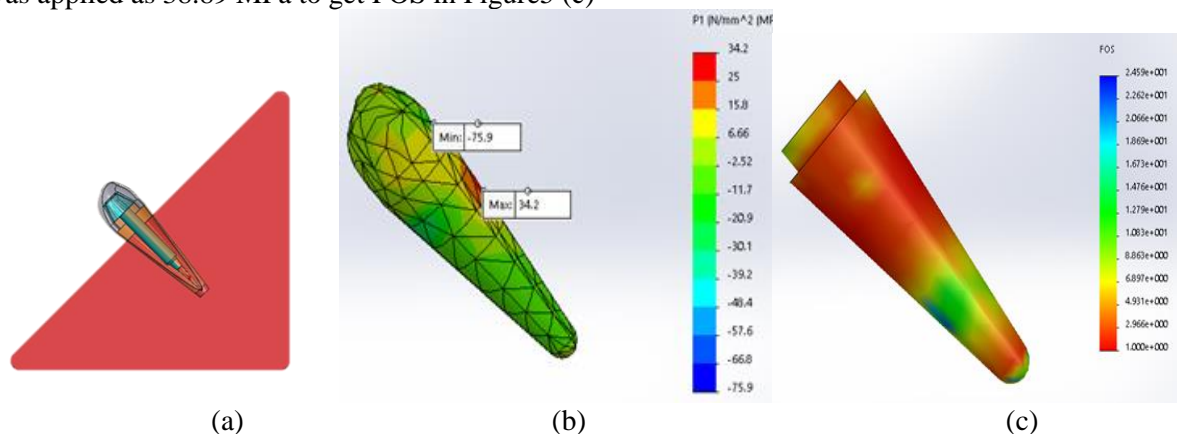

(a)   (b)   (c)

Figure 5. Group 1, (a) full part of model, (b) principal stress of endodontically treated teeth (c) FOS.

3.2. Group 2 (restored with a single fiber post and resin composite core)

The model's components (metal crown, dentin, resin composite, fiber post, gutta percha and resin support block) are illustrated in Figure6 (a). Principal stress of endodontically treated teeth group 2 is demonstrated in Figure 6 (b). The stress distribution proves the critical principal stress distribute into the root of tooth, deeper than group 1. It might cause of fracture site at middle 1/3 of the root as reported in Puengpaiboon et al. (2015) [2]. Trial of ultimate tensile strength to get maximum FOS to be one is 30.96 MPa results in the analysis of FOS as shown in Figure6 (c).
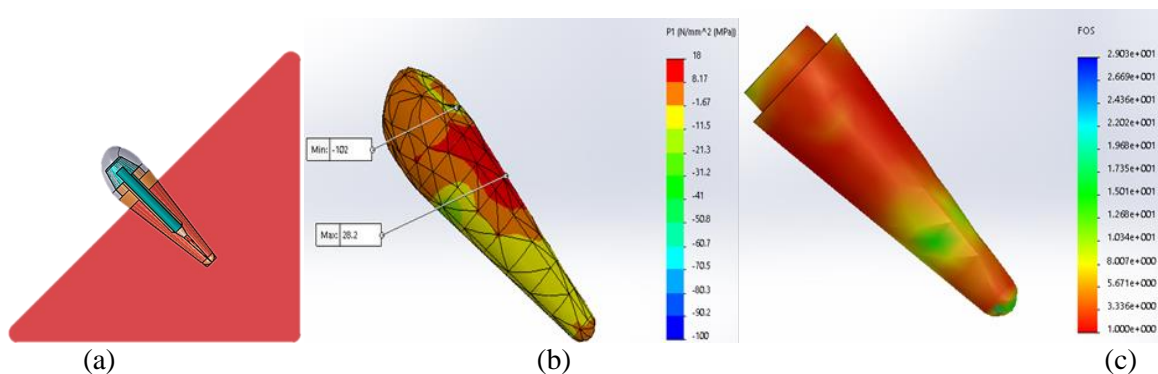

(a)   (b)   (c)

Figure 6. Group 2, (a) full part of model, (b) principal stress of endodontically treated teeth (c) FOS.

3.3. Group 3 (restored with 3 fiber posts and resin composite core)

Figure 7 displays the model's components, principal stress of endodontically treated teeth (only dentin part is presented), and successfully trial FOS diagram. The depth of critical stress distribution is more or less than that of group 2. It might cause of fracture area similar to group 2 [2]. Estimation of ultimate tensile strength of dentin from this group is 37.19 MPa. In summary, the estimation of ultimate tensile strength of dentin from this research are ranged from 31.0 to 38.9 MPa. On the other

hand, Giannini et al. [3] found that ultimate tensile strength of dentin is in the range of 33.9 to 48.7 MPa by microtensile technique of real teeth. In addition, Lertchirakarn et al. found that UTS was lowest (42.0 MPa) when force loading parallel and highest (52.9 Mpa) when angle of loading perpendicular to tubule orientation by diametral test [10]. This work reveals that FEA technique could be used to estimate the ultimate tensile strength of tooth from the existing experimental data.
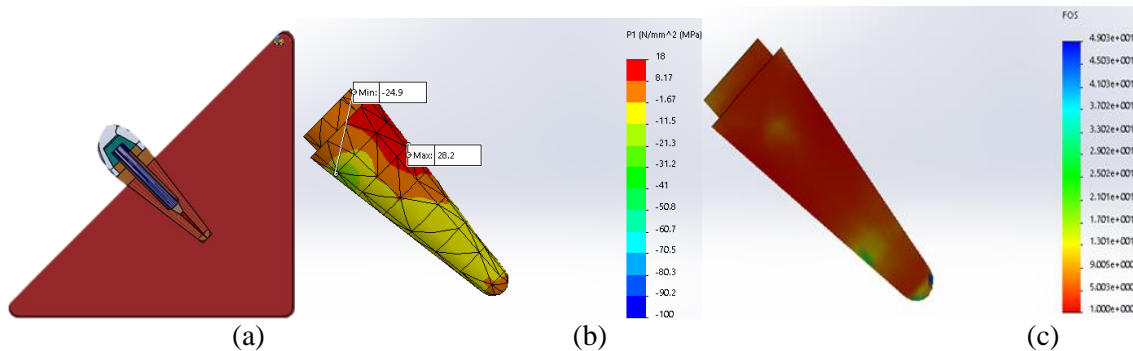

(a)   (b)   (c)

Figure 7. Group 3, (a) full part of model, (b) principal stress of endodontically treated teeth (c) FOS.

4. Conclusions

The estimation of ultimate tensile strength of dentin from this research are ranged from 31.0 to 38.9 MPa. This work reveals that FEA technique could be used to estimate the ultimate tensile strength of tooth from the existing experimental data.

5. Acknowledgements

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