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Influence of post design and elastic modulus mismatch between dentin and post-core on stress distribution in endodontically treated teeth: a finite element analysis study

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Abstract

Background: ParaPost Fiber Posts are made to use resin-based cement and core build-up materials to provide an optimal Monoblock between the dentin-post-crown, resulting in one cohesive restoration.

Aim: To evaluate the stress distribution pattern of a Severely damaged maxillary central incisor restored with ParaPost Taper lux, fiber lux and E-max crown using Finite element analysis.

Materials and methods: Two 3-D FEA models of maxillary central incisor were simulated with anatomy-based geometric structures. Different Glass Fiber reinforced composite posts (PTL and PFL) and full coverage restorations (Lithium disilicate) were used. The paracore (dual-cured glass-reinforced composite material) was used for core build-up and cementation of both the Posts and full coronal restorations to create an optimal Monoblock effect.

MODEL 1: Parapost Taper Lux (PTL), Paracore & Lithium disilicate Full coverage restoration. (LidiS).

MODEL 2: Parapost Fiber Lux (PFL), Paracore & Lithium disilicate Full coverage restoration. (LidiS).

A 3D model of the maxillary central incisor area, including restorative components, was created. The normal masticatory load of 100 N were applied at a 5mm distance from the incisal edge, at an angle of 45° in relation to the long axis of the tooth was simulated onto the imported models. Von Mises [Vm] stresses generated at the Post–Core assembly, Coronal & Radicular dentin were numerically recorded, color-coded, and compared.

Results: The maximum stresses were evidenced both at the mid and coronal thirds of the labial aspects of radicular dentin, and the least stresses were observed at the palatal aspect of apical 3rd.

Conclusion: Parallel-sided post (Parapost Fiber Lux) showed the greatest stress distribution on the middle third of the labial radicular dentin.

Keywords: Fiberlux, Taperlux, Parapost, Finite element analysis.

1. Introduction

Restoring root-filled teeth is critical for clinical success, function, and aesthetics. Endodontically treated teeth differ structurally from untreated live teeth. Major changes following treatment include tissue modifications at different levels, including tooth composition, dentin microstructure, and tooth macrostructure. This indicates that it is critical to understand the implication of such features on tooth biomechanics, as they will largely influence the restorative approach of such teeth [1]. Posts can be broadly categorized as custom/cast posts with cast core & prefabricated posts, primarily with a composite core [2]. Prefabricated posts do not require this intermediate phase and allow the whole restoration to be performed in one visit, which makes it an easier and less expensive technique [3,4].

The Glass Fiber post (GFR) has been reported to exhibit high fatigue strength, high tensile strength, and a modulus of elasticity (MOE) closer to dentin than that of Carbon Fiber posts (CFR). Treating the post with airborne particle abrasion, hydrogen peroxide, hydrofluoric acid, and silane improves the bonding between the core and post [5-7]. The variation between the elastic modulus of dentine and the post material may be a source of stress for root structures [8,9].

Parapost (PP) Fiber Lux and Taper Lux (Coltène/Whaledent Inc.) are made of a translucent, light-transmitting glass-fiber resin matrix. This allows immediate fixation to dual- and light-cured resin cement and core materials using light polymerization without any pre-treatment required to the post. All ParaPost Fiber Posts are made of translucent or opaque fiber resin materials that reflect the tooth's natural hues and eliminate shadows through all-ceramic crowns or composite restorations at the gingival/crown interface. Rounded, multi-head designs minimize stress in the core material due to polymerization shrinkage. Manufacturers proclaimed that ParaPost Fiber Posts are made to use resin-based cement and core build-up materials (e.g., ParaCore) to provide an optimal Monoblock between the dentin-post-crown, resulting in one cohesive restoration. Paracore (Coltène/Whaledent Inc.) is a dual-cured, glass-reinforced composite for post-cementing, core build-ups, and crown & bridge cementation. Using one material for cementation and core build-ups provides an optimal monobloc bond interface between the dentin-post-crown, resulting in one cohesive restoration.

In recent years, all- ceramic crowns manufactured by Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) were with better strength and homogenous structure to improve the restorations retention and longevity. The common all-ceramic CAD/CAM materials are lithium disilicate zirconia [10].

Photoelastic stress analysis was also used to evaluate stresses responsible for the failure of a structure. The model needs to be made with similar conditions to the actual structure in terms of its geometry, support system, and the direction and strength of applied forces [11]. The distribution of internal stresses in the model should also be similar to those existing in the actual structure, regardless of the material. The calculations required to separate the principal stress values at a general interior point are very complicated. For precise stress analysis in large components, expensive equipment is needed. Also, 3D photoelasticity experiments are very time-consuming and tedious [12,13]. Finite element analysis (FEA) is a modern tool for numerical stress analysis, with the advantage of applying it to solids of irregular geometry, which could contain heterogenous material properties.

Various *in-vitro* and FEA simulated studies were done earlier to evaluate the stress distribution in teeth restored with several post and core systems. There was no monobloc concept at all the interfaces, i.e., dentin-post-crown. So, the present study was designed to evaluate the stress distribution in simulated experimental Finite element (FE) models of severely damaged maxillary central incisor restored with Parapost Taper lux and Parapost Fiber lux followed by Lithium disilicate (LidiS) IPS e.max CAD as full coronal restorations. Paracore was used as both luting cement and core material. Then, these models were subjected to finite element analysis.

2. Materials and methods

Two different glass fiber reinforced composite posts, Parapost Taper Lux (PTL, Coltène/Whaledent, Switzerland) and Parapost Fiber Lux (PFL, Coltène/Whaledent, Switzerland) Were used in the study. Lithium disilicate (LidiS) IPS e.max CAD (Ivoclar Vivadent, Switzerland) was used as full coverage restorations. The dual-cured glass reinforced composite material, Paracore (Coltène Whaledent, Switzerland) was used for both core build-up and cementation of the posts and full coverage restorations.

2.1 Specimen preparation

A cone-beam computed tomography (CBCT) image of the right maxillary central incisor region was captured by a CBCT imaging machine (VGI Evo, Italy). The CBCT images were imported into the program MIMICS and materialized for segmentation. After segmentation, the polygonal model was saved in stereolithographic (.STL) format and transferred to a reverse engineering program. The computer-aided three-dimensional interactive application (CREO) was done for the generation of a solid model.

Four 3D- Finite Element (FE) models of endodontically treated maxillary central incisor with two different posts and full coverage restorations with the same core material for the core build-up, cementation of both the posts and full-coverage restorations were designed for the analysis of stress distribution induced by applying the loads by using of the ANSYS 14.5 software program, USA.

The size and shape of the tooth were consistent with those of the anatomical atlas. The crown was 10.5 mm in length, with a medial distal width of 8.5 mm and a root length of 13 mm (the tooth was 23.5 mm long). A 0.2 mm thick periodontium was modelled around the root of the tooth.
The tooth model was positioned within a system of coordinates in such way, that the Z-axis was parallel to the long axis of the tooth, the X-axis showed the mesial side, and the Y-axis was directed towards the vestibular aspect (Figure 1). After the creation of the basic tooth model, a transversal tooth section was made 3.5 mm above the CEJ (ferrule effect), followed by endodontic treatment with Hyflex rotary instruments, Coltene, Switzerland (size 40 and taper of 6% of the endodontic instruments), and gutta-percha filling was simulated.

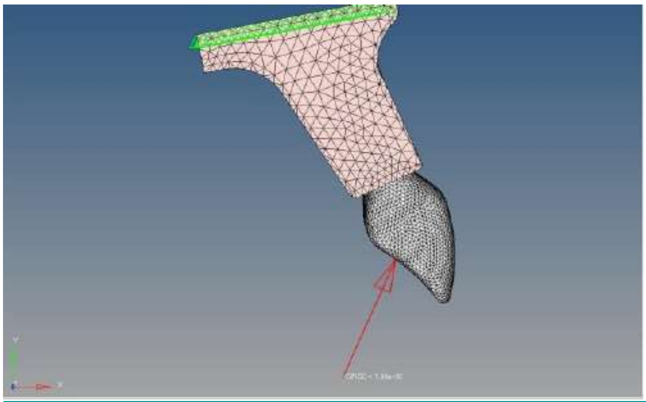

Figure 1. Fixation and loading conditions of the model.

Post space preparations was modeled up to a depth of 8 mm from the CEJ, leaving a minimum apical seal of 5 mm gutta-percha within the canal space after post space preparation. 8mm length of the post body was inserted into the root and the remaining 3 mm was incorporated within the coronal dentin. The post head were left outside the tooth structure to be incorporated within the core buildup material. Modelling of Parapost Taper Lux and Fiber Lux with Paracore luting cement of 0.1 mm thickness all around the post was done, followed by modelling of Core build-up with Paracore of 5 mm in height.

Tooth Preparation was modelled according to the dimensions of the all-ceramic crown preparation for the full coronal coverage. Tooth reduction was modelled as 2 mm circumferentially and 2 mm of incisal reduction. The shoulder was kept as a finish line. The all-ceramic crown was modelled to fit the abutment. The all-ceramic crowns simulated in this study were Lithium disilicate (LidiS).

2.2 FE analysis

The 3D-modelling of the maxillary central incisor region along with restorative components was done using the software CREO 3.0, PTC, USA. The FE Models was obtained by importing the solid models into ANSYS14.5 FEM software, USA. The models were then loaded with normal masticatory loads of 100 N at a distance of 5mm from the incisal edge, at an angle of 45° to the longitudinal axis of the tooth in coronal- apical and palatal-buccal directions.

Von Mises (Vm) stresses generated at the post and core assembly, coronal & radicular dentin were numerically recorded, colour-coded, and compared amongst the various models. As a result, the effect of the post design and shape and difference in the material properties of full coronal restorations and optimal Monoblock effect on dentinal stress distribution of maxillary central incisor under normal masticatory loading was evaluated.

The portion of the maxillary central incisor region was modelled using 3D-modelled software (CREO3.0). Four FE models of Endodontically treated Maxillary central Incisors restored with two different Posts (Parapost Taper Lux, Fiber Lux) & 2 different Full Coverage Restorations (Zirconia &E-Max) were created using 3D finite element software (ANSYS 14.5).

Model 1 (Figure 2): Finite element analysis (FEM) of endodontically treated maxillary central incisors with parapost taper lux, paracore & LidiS full coverage restoration.

Model 2 (Figure 3): Finite element analysis (FEM) of endodontically treated maxillary central incisors with parapost fiber lux, paracore & LidiS full coverage.

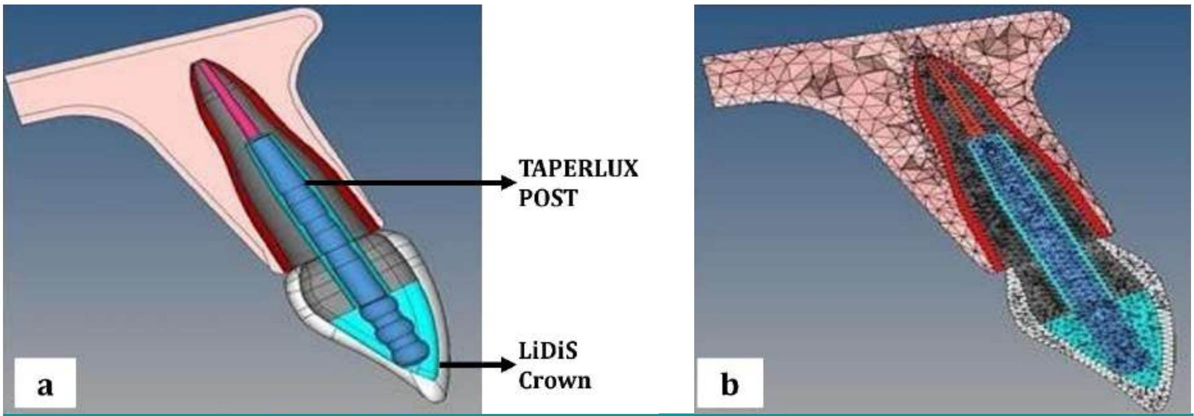

Figure 2. a. 3-D Virtual Geometric model of Model 1, and b. 3-D Finite element Meshing of Model l.

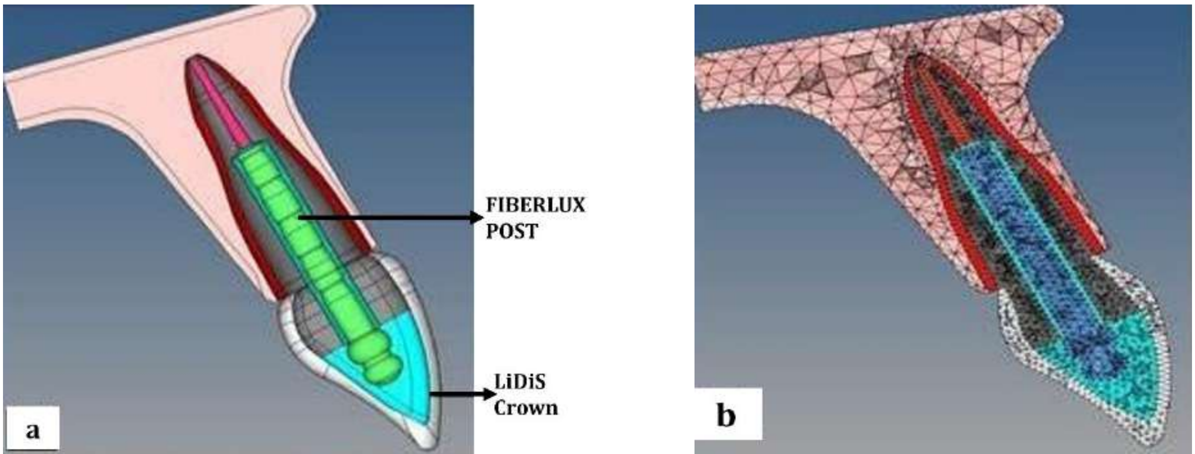

Figure 3. a. 3-D Virtual Geometric model of Model 2, and b. 3-D Finite element Meshing of Model 2.

The stress generated, i.e., the maximum equivalent Von Mises (mvM) on each component, was numerically recorded, colour-coded, and assessed around the Post, Dentin, Core and Full coverage restoration. This study was conducted by considering the 3-D Von Mises criteria and the formula is given below [11].

$$Vm = \frac{1}{\sqrt{2}}\sqrt{(St-S2)^2 + (S2-S3)^2 = (S3-S2)^2}$$

Where, S1, S2 and S3 are the principal stresses along the X, Y and Z axis, respectively. The Von Mises formula results in a value that is always positive.

The Von Mises stresses, which were estimated using the model for each point, were represented using a colour scale-Cool colours (Low stresses) and Warmer colours (Higher stresses). The evaluation of the results took into account with multiple views. To group the results of the two models, a standard view of a mid-sagittal section from each model was provided. Moreover, the peak values of the different anatomical and restorative components of each model were also provided [11].

3. Results

Tables 1, 2 and 3 describe the comparative evaluation of maximum Von Mises equivalent stresses (MPa) within the post, the radicular dentin, and the coronal among the Two 3D– FE Models, respectively.

Table 1- Comparative Evaluation of Maximum von Mises equivalent stresses (MPa) within the Post among the Two 3D– FE Models in this study.

Model	Post tip	Apical (3m)	Middle (4mm)	Coronal (4mm)	Post Head
Taper Lux	50.65	50.65	50.65	12	6.5
Fiber Lux	52.25	36.05	30.66	14.4	3.66

Table 2. Comparative Evaluation of Maximum von Mises equivalent stresses (MPa) within the Radicular Dentin among the Four 3D–FE Models in this Study.

Model	Labial Cervical Third	Middle Third at Post Tip	Apical Third	Palatal Cervical Third	Middle Third atPost Tip	Apical Third
Taper Lux	42.71	54.43	19.22	30.96	36.83	7.48
Fiber Lux	42.41	53.71	19.01	30.57	42.14	7.44

Table 3. Comparative Evaluation of Maximum von Mises equivalent stresses (MPa) within the Coronal Dentin among the Two D– FE Models in this Study

Model	Coronal dentine on the labial side at the level of Finish line	Coronal dentine on the lingual side at the level of finish line
Taper Lux	13.35	7.48
Fiber Lux	13.22	7.42

At the tip of the post body, the highest stress concentration was observed for Fiber Lux (52.25) and the lowest values were observed for Taper Lux models (50.65). At Apical 3mm of the post body, the greatest stresses were observed for Taper Lux models (50.65), and Fiber Lux models exhibited lower stress values (36.05). At Mid 3mm of the Post body, the greatest stresses of similarity were observed for Taper Lux models (50.65), and Fiber Lux models exhibited lower stress values (30.66). At the Coronal 4mm of the post body, the highest stress concentration values were observed for the Fiber Lux model (14.4) compared to the Taper Lux model (12) (Table 1). Overall, within the Post, the highest stress values were observed at the tip and lower stress values at the head of the post.

The Labial portion of the Apical 3rd of the radicular dentin almost has similar values (19.22 MPa for Taper Lux and 19.01 for Fiber Lux). On the Labial portion of the Mid-3rd of the radicular dentin, the maximum stress concentration of 53.71Mpa was observed for Fiber Lux models, and almost similar stress values were observed for Taper Lux models, which was 54.43Mpa. On the Labial portion of the Cervical 3rd of the radicular dentin – the maximum stress concentration of 42.71 MPa was observed for Taper Lux, and almost similar stress values of 42.41 MPa were observed for Fiber Lux models. On the Palatal side, almost similar patterns of stress distribution values were observed at the Cervical, mid, and Apical 3rd of radicular dentin in all models. The labial portion of the mid-3rd and the palatal portion of the apical 3rd exhibited the highest and lowest stresses, respectively, across all models. Overall, on coronal dentin at the level of the finish line, the highest and least stress values were observed at the labial and palatal side.

4. Discussion

Restoring endodontically treated teeth is imperative to achieve clinical success and to restore function and esthetics. It is important to realize that endodontically treated teeth are structurally different from non-treated vital teeth [1].

The maxillary central incisor was selected because of its likelihood of being subjected to oblique occlusal stresses. The principal stresses are in fact normal stresses that act on principal planes on which the shearing stresses are zero [2]. Studies have reported that coronal dentin above the shoulder decreases stress concentration in dentin. So, in the modelling process of this study, a ferrule design was created in the proximal, lingual and buccal surfaces at the cervical region [14].

In the current study, the combination of a tooth-coloured core and restorative material was modelled considering that a ceramic crown should restore an endodontically treated tooth to achieve optimum esthetic outcome. The Posts modelled in this study were Parapost Taper Lux (PTL) and Parapost Fiber Lux (PFL), and both are glass fiber-reinforced composite posts. Parapost Taper Lux (PTL) is cylindro-conical in shape with a three-head design for optimal core retention and has a 4% tapered end that provides a good apical fit and prevents the over-preparation of the canal. Parapost Fiber Lux (PFL) is cylindrical in shape with two head designs for optimal core retention, and it is parallel sided making it ideal for universal post application. Parapost Posts are made to use resin-based cement and core build-up materials (e.g., Paracore) to provide an optimal Monoblock between the Dentin-Post-Crown, resulting in one cohesive restoration with durability and strength.

Finite element analysis, (FEA) is a modern tool for numerical stress analysis, with the advantage of applying to solids of irregular geometry, which could contain heterogenous material properties. The steps followed are generally finite element models, specifying appropriate material properties, loading and boundary conditions so that desired settings can be accurately simulated. The results of an FEA are expressed as stresses distributed in the structures under study. Von Mises stress is a value used to determine if a given material will yield or fracture [15,16].
So, in the current study the models were studied as follows:
Model 1: A Finite Element model (FE model) of Endodontically treated maxillary central incisor restored with Parapost Taper Lux (PTL), Paracore & Lithium disilicate Full coverage restoration (LidiS).
Model 2: A Finite Element Model (FE model) of Endodontically treated maxillary central incisor restored with Parapost Fiber Lux (PFL), Paracore & Lithium disilicate Full coverage restoration (LidiS).

The rationale behind opting for the Von Mises criteria is its generation of tensile-type normal stress, which corresponds with the predominant mode of failure observed in brittle materials such as teeth [2].

Through Finite Element analysis, the effects of two dowel-and-core approaches and canal flaring on stress distribution in endodontically treated teeth were investigated, comparing them with sound teeth. The study identified maximum stresses at both the mid and coronal thirds of the buccal aspect and palatal aspects of radicular dentin in the intact maxillary central incisor. Our findings mirrored this stress distribution pattern across all models, affirming the validity of the Monoblock concept [18].

A Monoblock unit, "the concept of creating mechanically homogenous units within root dentin," could be achieved with an adhesive Post system. It is believed that the possibility of Monoblock creation helps to transmit applied stresses over the entire tooth, which corroborates with the present study [18].

If the elastic modulus of the core material is equivalent to the post material, a more uniform stress distribution within the entire post-and-core restoration and radicular dentin is achieved, while the restoration's resistance is increased against the high forces of mastication which supports the present study [19]. Nakamura T *et al.* conducted a study which revealed that the stress distribution in maxillary central incisors treated endodontically and restored with a Post and an all-ceramic crown finally it was concluded that the Fiber Post produced less stress on the root dentin and around the Post tip than did the metal Posts thus suggesting reducing the stresses that cause root fracture in our current study. The simulation of the glass fiber reinforced dowels with elastic modulus almost equivalent to dentin was done to simulate a monoblock effect [20].

Post shape, cylindrical or conical, did not influence the mechanical behaviour of endodontically treated teeth with different materials crowns. The post-elastic moduli carbon or glass fiber slightly influenced the stress distribution in the restored teeth. According to the literature, Parallel-sided Tapered-end Post design is the most favourable design biomechanically, and it corroborates with the present study where the Taper lux generated less radicular dentinal stresses on the lingual surface at the level of the middle third [21]. Previous studies had reported a wedging effect attributed to tapered posts, while other research could not demonstrate any differences between parallel-sided and taper-end posts [22].

Previously, a study reported that glass fiber posts exhibited a modulus of elasticity that was far better matched to teeth than metal and ceramic posts [23]. Due to the high modulus of elasticity of zirconia, forces were transmitted directly to the post-tooth interface without stress absorption. This may lead to a decrease in fracture resistance of the tooth [24], which supports the current study.

Differences in stress distribution caused by post material appeared on the labial side of the root around the post tip. Stress on the root dentin around the Post tip was lower with the fiber post than with the metal posts. This was probably because the fiber post with a modulus of elasticity close to that of dentin dispersed the stress, hence, causing less stress concentration on the post or dentin than on the metal posts. The metal posts, with a high modulus of elasticity, caused a large stress concentration not only on the lingual side of the metal post but also on the labial side of the root dentin around the post tip. Root fracture, which occurs at the bottom of the tooth root or in the area around the post tip, is likely to lead to extraction of the tooth. Therefore, the use of fiber posts may be effective in reducing the risk of such root fractures [20].

Studies have stated that tapered dowels when used without a ferrule showed high uneven stress concentrated on the cervical area and may create a wedge effect in the apical 3rd of the root. The stress produced in the cervical dentin was lesser when the ferrule was incorporated, irrespective of the taper of the post [14], which corroborates with the present study.

A laboratory study suggested that the ferrule on the final preparation of a tooth works as a reinforcement tool because it would reduce the wedge effect of the dowel on root walls and allow redistribution and dissipation of occlusal forces. Veríssimo et al. restored the teeth with cast Posts and cores and demonstrated a high concentration of tensile stress within the root canal, which decreased with increasing height of the remaining coronal dentin [26].

An in vitro study conducted by Lazari PC *et al.* (2018) on the survival of extensively damaged root canal-treated incisors restored with different types of posts-and-core foundation restoration material and concluded that survival of extensively damaged root canal-treated incisors without ferrule effect was slightly improved by using a fiber post with a bulk-fill composite resin core restoration. However, none of the post-and-core techniques was able to compensate for the absence of a ferrule. The presence of the posts always adversely affected the failure mode [27].

The placement of a complete crown changes the distribution pattern of the externally applied load to the tooth so that stresses concentrate around the margins excluding the surface of the point of load application [28], which correlates with the current study. The present study showed that the area of greatest stress concentration was observed at the point of load application irrespective of the full coverage restoration material.

6. Conclusion

Within the limitations of the present study, the following conclusions can be drawn.

- Parallel-sided fiber lux (PFL) showed the highest stress concentration at the middle third of labial radicular dentin compared to taper lux.
- The combination of Ferrule and Monoblock effect nullifies the higher stresses transferred from the full coverage restorations and allows uniform stress distribution within the radicular dentin.

Conflicts of interest: Authors declared no conflicts of interest.

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