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Photoelastic Study of the Effects of Occlusal Surface Morphology on Tooth Apical Stress from Vertical Bite Forces

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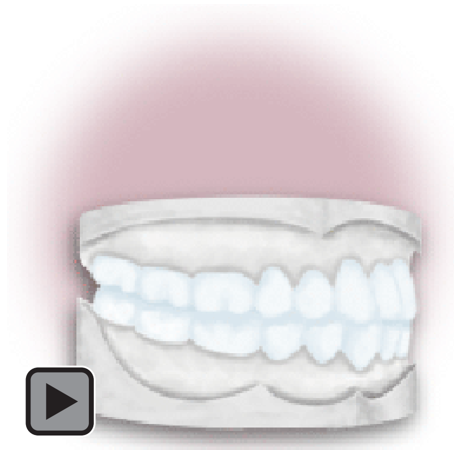

Abstract

The aim of the study was to determine how the morphology of occlusal surfaces might affect occlusal loading that is transferred to the tooth apex. Photoelastic methods were used to assess apical stress generated by seven variations of occlusions. A test assembly with a 2 kg weight was applied to teeth to create a vertical load. By analyzing the direction and magnitude of the apical principle stress under the polar light that was measured at the apexes of mandibular teeth, the occlusal loading position of each tooth and its direction was obtained based on general mechanical principles. It was found distal incline planes (or slopes) of cusps and lingual incline planes (or slope) of buccal cusps of mandibular posterior teeth carried the greatest occlusal load in normal occlusion. In the other six variations of occlusion presented in this study, the principle apical stresses changed more or less as a result of the different occlusal contact relationships. The magnitude of principle apical stress increased considerably in the flat surface occlusion because of the lack of distribution of occlusion loading by the smooth dentition surface. It is concluded the occlusal surface morphology has a significant effect on the direction and magnitude of apical stress. To establish a suitable relationship of occlusion that can conduct favorable occlusal loading physiologically is very important.

Keywords: Occlusion, photoelastic methods, biomechanics, masticatory system, bite forces.

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Introduction

Biting force refers to the power coming from masticatory muscles that is endured by the teeth and periodontal tissues when the maxillary and mandibular teeth contact each other. The size of the occlusal contact area is much bigger than that of the transection area of the crowns of posterior teeth due to the cusp-to-fossa, multi-curled form of their occlusal surfaces. It is desirable to maximize masticatory efficiency to improve the digestive process. However, the nature of the contact between the upper and lower teeth when they occlude produces a load on the teeth in a different direction from that of the muscle contraction. This results in a dispersal of stress around the apices of teeth according to mechanical law. Obviously, the form of the occlusal surface can greatly influence the direction of the apical stress of teeth. In order to investigate physiological loading associated with the occluding posterior teeth, it is important to understand the characteristics and guidance rules related to occlusion. This understanding will be helpful in providing rational treatment of occlusal disease through a more accurate occlusal adjustment. In this present study a photoelastic method was used to correlate occlusal load with the resulting apical stress.

Figure 1. Teeth preparation methods. A six teeth negative mold with only two teeth inserted.

A. **Preparation of the root part of the negative mold:** Using a wax container, silicone rubber was perfused in liquid form and placed around the teeth roots to about 4 mm below the cervical level and allowed to solidify before the negative aspect of the lower part of the mold was created.
B. **Preparation of the crown part of teeth negative model:** After wiping a thin layer of separating reagent on the silicone rubber surface of the lower section, the liquid silicone was perfused into the wax container to form the negative silicone rubber model of the crowns and the cervical parts of the roots.
C. **Completion of the negative silicone rubber model:** The upper and lower parts of the negative silicone rubber model were separated after solidification.
D. **Preparation of the plastic teeth:** The real teeth in "c" were taken out from the negative silicone rubber mold and the impressions were filled with self-curing resin in liquid. After solidification, the positive plastic teeth were replicated as shown above. Due to the favorable flexibility of the silicone rubber, the negative mold could be used repeatedly.

Materials and Methods

Teeth Preparation

Thirty-two permanent teeth extracted from an unpreserved cadaver of a recently deceased person were adapted to replicate several sets of identical plastic teeth (including the crown and the root). The mandibular first molars had one distal and one medial root, while the second and third molars had only one fused root. Silicone rubber was utilized to create the two parts of a negative mold of the crown and the root and then self-curing resin was used to fill the silicone rubber mold to replicate the teeth (Figure 1).

Materials and Methods

Wax Occlusal Rim Preparation

With the teeth prepared as indicated above, they were mounted separately on seven 35 mm high wax rims with variations in the occlusion using the same type of articulator. A 20 mm space was kept under the root apexes to observe the stress distribution. These variations in occlusion included the following:

- **Normal occlusion (NO):** Both the overbite and overjet of the anterior teeth were set at less than 3 mm in a Class I or neutral occlusal relationship of the first molar teeth. Two models were prepared; one of them with thirty-two teeth called an 8-8 dentition (NO1) and the other with twenty-eight teeth called a 7-7 dentition (NO2), without four third molars.
- **Distal occlusion (DO):** The overbite was set at 7 mm and the overjet 3 mm. The first molar teeth were set in a Class II or distal relationship bilaterally. Two models were prepared as NO: one with an 8-8 dentition (DO1) and the other with a 7-7 dentition (DO2).
- **Unilateral partial posterior teeth cross-bite occlusion (CB):** Two of the most posterior molars on the right side were set in cross-bite, in a Class III or medial relationship, while the contra-lateral side was set in a neutral relationship. Two models were prepared: one with an 8-8 dentition (CB1) and the other with a 7-7 dentition (CB2).
- **Unilateral upper third molar hypererupted occlusion (8A):** The maxillary right third molar tooth was positioned 2 mm above the occlusal plane and its opposing tooth, the right lower third molar tooth was set 2 mm below the occlusal plane. The anterior overbite and overjet were both set less than 3 mm. The first molar teeth were set in a neutral relationship bilaterally.
- **Unilateral lower third molar hypererupted occlusion (8C):** The right lower third molar tooth was positioned 2 mm above the occlusal plane and the opposing right upper third molar was set 2 mm below the occlusal plane. The anterior overbite and overjet were all less than 3 mm. The first molar teeth were set in a neutral relationship bilaterally.
- **Unilateral partial posterior teeth missing occlusion (TM):** The right mandibular second and third molars were left out of the mock dentition by design. The anterior overbite and overjet were both set at less than 3 mm. The first molar teeth were set in a neutral relationship bilaterally.
- **Flat surface occlusion (FS):** All of the occlusal surfaces of the posterior teeth were flat. No cusps or grooves remained intact. A neutral relationship of the first molar teeth was approximated.

Epoxy Resin Model Preparation

Silicone rubber and its cross-linking agent (produced by the Chenguang Chemical Institution, Xi'an City, China) were used to produce the negative models or impressions of the mandibular dentitions. Using an appropriate optical and mechanical apparatus with a convenient running and adjustable modulus, epoxy resin was poured into the impressions to create the mandibular dentitions. The maxillary dentitions were made of dental plaster (Figure 2).

Two epoxy resin models of each symmetrical occlusion (NO, DO, and FS) were prepared, one with a 7-7 dentition and the other with an 8-8 dentition. Similarly, two identical copies of epoxy resin models were made of the asymmetrical occlusions of 8A, 8C, CB, and TM. A total of 14 occlusion models of mandibular epoxy dentitions along with their maxillary dental plaster counterparts were produced.

To ensure the occlusal surfaces of the reproduced dentitions would closely contact with opposing teeth, self-curing resin was utilized to overlay a thin layer on the occlusal surfaces of the mandibular dentition set-up. The mandibular dentition was made to resemble the bite with the corresponding maxillary dentition in terms of intercuspal position (ICP) to obtain the maximal occlusal contact relationship. A fissure bur was used to eliminate the excess self-curing resin, such as that found in the occlusal embrasures.

Loading and Stress Solidification

The maxillary plaster model was made to occlude with the mandibular epoxy resin model in ICP which was fixed on a mechanical stationary articulator with the occlusal plane paralleling both the horizontal plane and the bottom of the model. The entire assembly was loaded with 2 kg weight (Figure 2), including the weight of the maxillary plaster cast. Each of the 14 models was put into the drying oven for stress solidification to take place according to the solidification temperature curve.

Figure 2. The test articulator with a 2 kg weight to create a vertical load.

Slice Preparation of the Solidification Model

The symmetrical occlusion, the model made with epoxy resin, was sliced linguobuccally on one side and mesiodistally on the other side. The two models of each type of asymmetrical occlusion were bilaterally sliced, one model linguobuccally and the other model mesiodistally. To prevent additional stress, the models were all sliced using a 3.5 mm width manual saw, cooled by water during the slicing procedure. The sections were observed within 3 hours to prevent any marginal effect.

Figure 3. Visible apical stress using polarized light.

Testing Method and Index

A projection photoelastic machine was used to observe the apical stress distribution (Figure 3). The integral stress stripe at each apical point was traced on mesiodistal section and linguobuccal section, respectively.

Determination of the direction of the principle stress: As shown in Figure 4, tangents L1 and L2 were drawn through the most protruding points of the stress stripes on both mesiodistal plane and linguobuccal plane. Then line S1 and S2 were drawn through the points of tangencies A1 and A2, respectively. The angle between S1 and the vertical line of the occlusal plane (OP) was labeled “a” and the angle between S2 and the vertical line of the occlusal plane (OP) was labeled “r.”

When rotating the polarizing microscope, the stress stripe with equal difference moved. When the integral stress stripe nearest to the tested point passed through that point, the rotating angle was recorded. The stripe grade of the tested point could then be calculated according to the corresponding formulas.

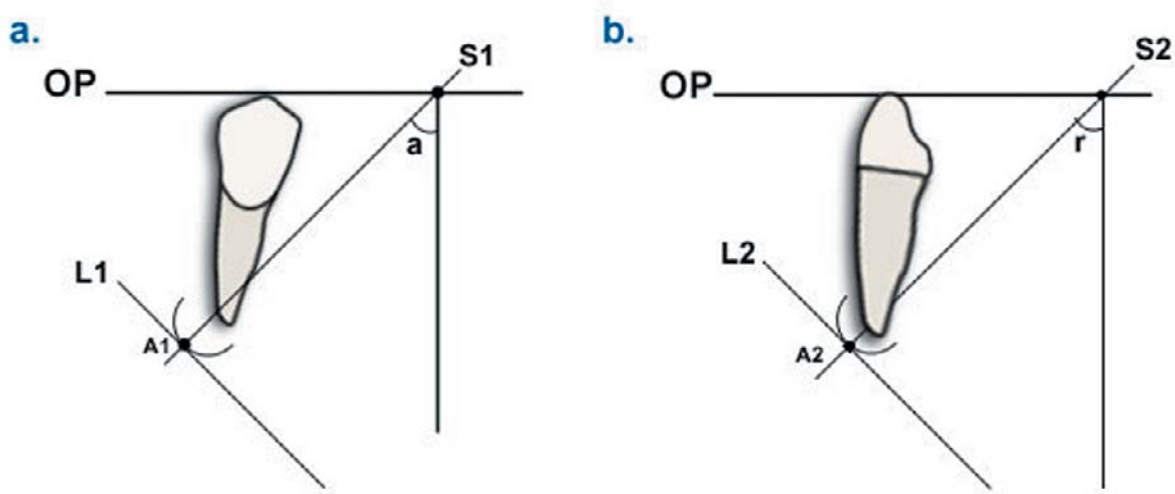


Figure 4. Determination of the direction of the principle stress. a. Mesio-distal direction; b. Buccal-lingual direction. Tangents L1 and L2 were drawn accordingly through the most protruding points, A1 and A2 separately, of the stress stripes on both mesio-distal plane and buccal-lingual plane. Then line S1 and S2 vertical to L1 and L2 accordingly were drawn through the points, respectively. The angle between S1 and the vertical line of the occlusal plane (OP) was a and that between S2 and the vertical line of the occlusal plane (OP) was r.

Because the overlapping and interfering of the stress stripes of adjacent teeth in a mesiodistal section would affect the corresponding recording accuracy, the maximal principle stress values were all recorded from the linguobuccal section. The stress level of the first molar tooth was initialized as 100%, and the percentage of those of other apical points of the same model were calculated according to the ratio of their stripe grade to that of this first molar tooth.

Root Axis Inclination

The line that represents the long axis of the tooth was drawn, and both angles formed by the long axis of the teeth to the vertical line of OP on the mesiodistal section and linguobuccal section were all measured and used as parameters of tooth inclination.

Statistical Analysis

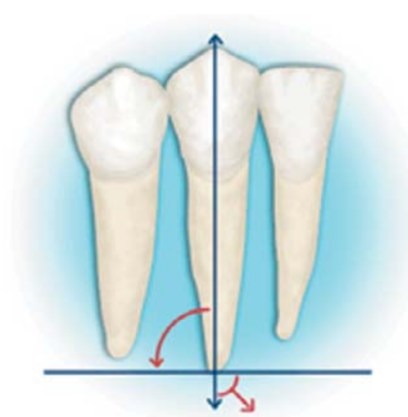
The paired t-test was utilized for comparison of the tooth long axis inclination, stress direction, and stress value among different occlusions with NO. Linear correlation was adopted for analyzing the long axis inclination relative to stress directions for each of the different occlusions.

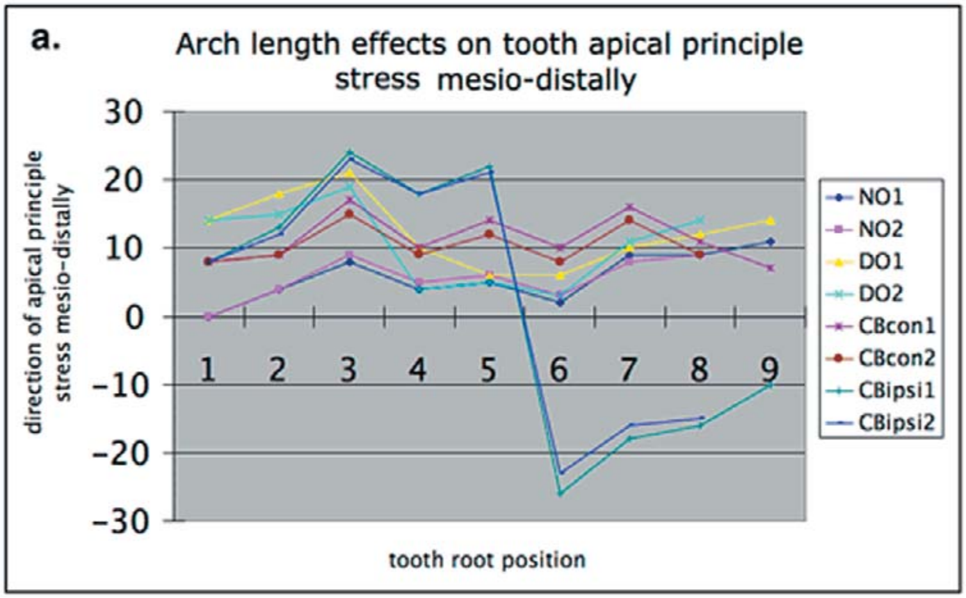
Results

Arch length effects - comparison between 7-7 dentition and 8-8 dentition

Three kinds of occlusions in this present study, i.e., NO, DO, and CB were both occluding with dentitions of 7-7 and 8-8:

- **Tooth long axis inclination comparison:** The inclination between the long axis of the tooth, in any two sets of models, was compared to each of the three kinds of occlusions.





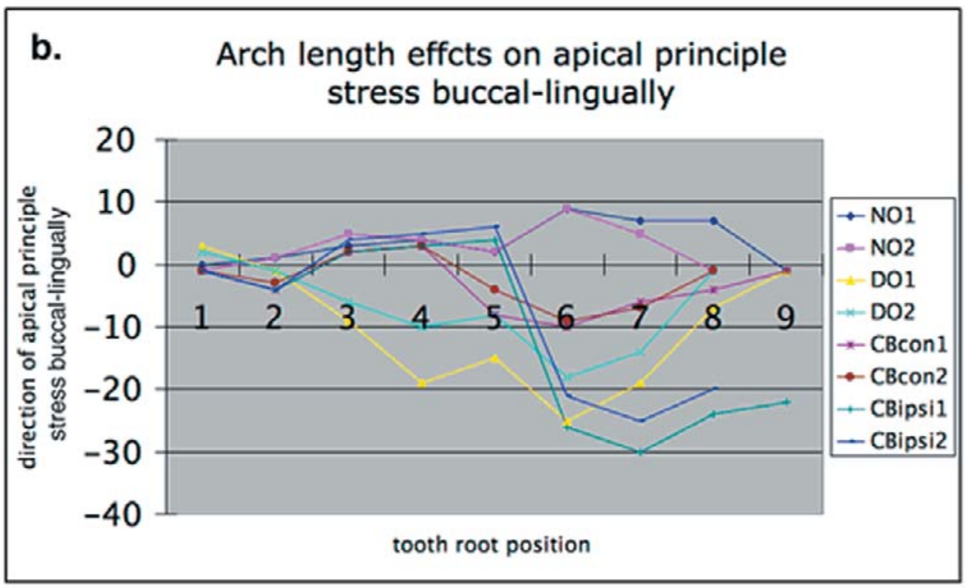
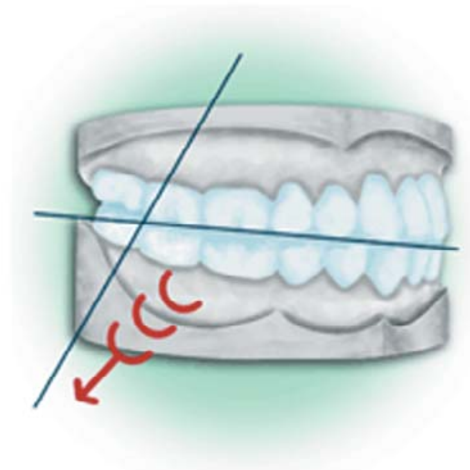


Figure 5. The direction of the apical principle stress comparison between the dentitions with and without the third molar tooth in three types of occlusion that are, normal occlusion (NO), distal occlusion (DO), and molar cross-bite occlusion (CB). The existence or not of the third molar tooth did not affect significantly the medial-distal (a) or lingual-buccal (b) directions. Ipsi: ipsi-lateral side, con: contra-lateral side, 1: 8-8dentition, 2: 7-7 dentition.

- **The direction of the apical principle stress comparison:** The existence or not of the third molar teeth did not significantly affect the mesiodistal or linguobuccal directions (Figure 5 a, b).

- **Magnitude of principle stress:** In general, the third molar tooth existing or not gave no obvious effects on the principle stress value (p>0.05). Although, the stress values, excepting the second molar tooth, showed almost no changes in the situation with or without the third molars (Figure 6), the results for the second molar root apex was much lower when the third molar was present in the dentition (p<0.01). So the existence or not of the third molar tooth had no obvious affects on the stress value on most of the teeth, except for the second molar tooth.



The results here also proved the method adopted in the present study was able to be reproduced. Therefore, the following results were all from the 8-8 dentition models.

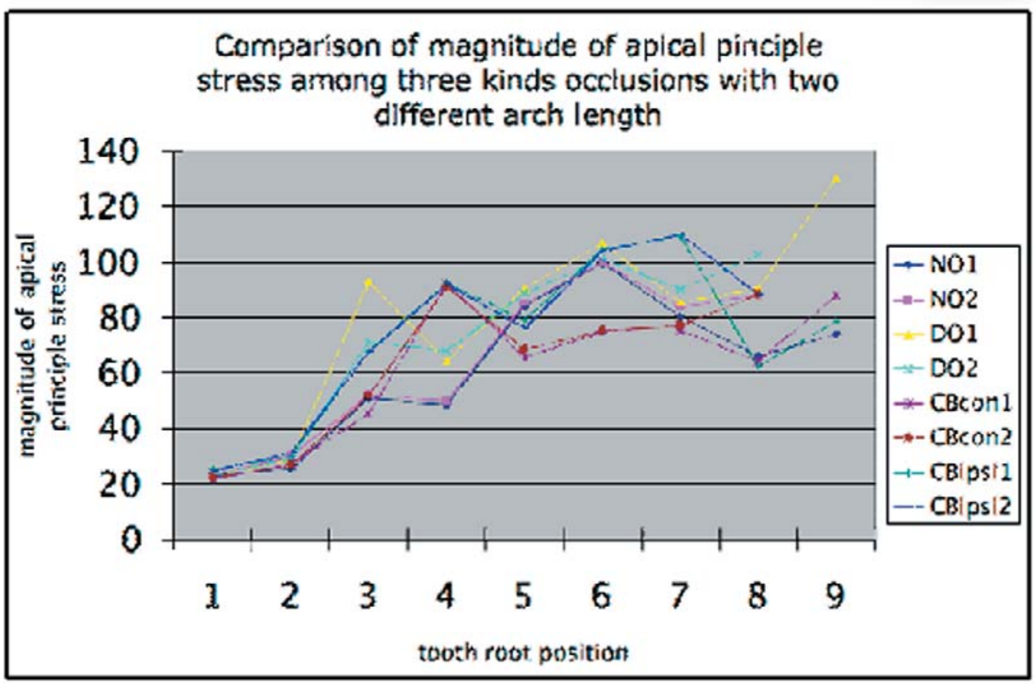
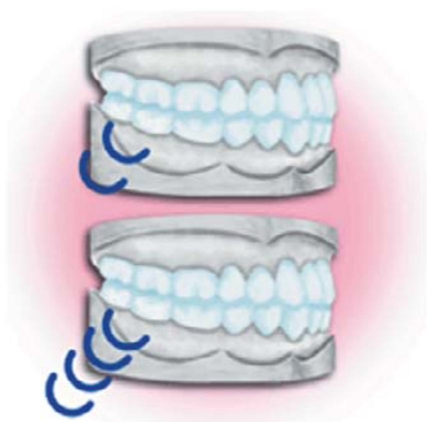


Figure 6. Magnitude of principle stress in three types of occlusion with or without the third molar tooth. In general, the two curves from 7-7 dentition and 8-8 dentition in each type of occlusion coincide well, excepting the second molar tooth, the value of which was much lower when the third molar was present in the dentition.

The Effects of the Direction of the Long Axis of the Tooth

- **Individual tooth effect:** From eighteen pairs of data (9 medial-distally and 9 lingual-buccally) from 9 tooth roots, in which the first molar had one medial root and one distal root, relative analysis were made between the apical stress direction and the tooth inclination. The results showed that 6 groups had correlativity (p<0.05), the ones mesiodistally to the lateral incisor (r=0.704), to the second premolar (r=0.704), to the distal root of the first molar (r=0.613), to the third molar (r=0.695), and the ones linguobuccally to the lateral incisor (r=0.611) and to the canine (r=0.640). The other 12 groups showed no correlativity. As to the stress values in the anterior part of the dental arch, the canine was larger than the lateral incisor, and this last one larger than the central incisor (p<0.05). But, in the posterior part of the dental arch, there was a great variation of the stress level in different occlusion between the canine and all the posterior teeth and no regularity could be found statistically.
- **Occlusion effect:** Correlativity was found between long axis inclination and the corresponding stress direction mesiodistally in NO (r=0.868, <0.01) but not linguobuccally. While in both DO and the contra-lateral side of TM, the correlativity was found either in mesiodistally direction (rDO=0.790, p<0.05, r_{TM}=0.859, p<0.01) or in linguobuccally direction (rDO=0.859, p< 0.01, r_{TM}=0.707, p<0.05). In FS, bilateral sides of CB, the ipsilateral side of TM, bilateral sides of 8A and 8C, no significant correlation were found between the tooth long axis inclination and stress direction either mesiodistally or linguobuccally (p>0.05).



Only 4 units out of 14 occlusion units (mediodistally and linguobuccally) out of 7 types of occlusions, showed correlativity in tooth long-axis inclination mesiodistally and linguobuccally and their associated stress directions. The stress levels in different types of occlusions will be compared separately below.

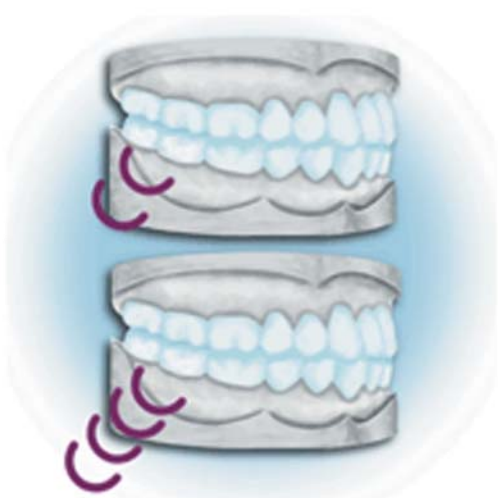
The Effects of Horizontal Occlusal Relationship on Apical Stress

In order to compare NO with DO representing different mesiodistal relationships and with CB representing different linguobuccal relationships, the comparisons were made as below:

- **NO features of apical principle stress direction:** In general, the apical stress was directed distally in all and labially in anterior teeth and lingually in posterior teeth.
- **Tooth long axis inclination comparison:** In the medial-distal direction, the tooth long axis inclination of both DO and the contra-lateral side of CB showed to be more distally inclined than that of NO (p<0.01). But for the ipsilateral side of CB there was no difference to that of NO (p>0.05). The tooth long axis of the contra-lateral side showed more distally inclined than that of the ipsilateral side of CB (p<0.01). In the lingual-buccal direction, the tooth long axis of the contra-lateral side of CB showed more buccally inclined than NO (p<0.01). Significant difference was also found between both sides of CB (p<0.01), but not between NO and DO (p>0.05), or between the ipsilateral side of CB and NO (p>0.05).
- **Apical principle stress direction comparison:** In the medial-distal direction, the stress direction of both DO and the contra-lateral side of CB showed more distally than that of NO (p<0.01). But the stress direction of the molars in the ipsilateral side of CB did not differ significantly from that of NO (p>0.05). No difference was found bilaterally in CB (p>0.05). In the lingual-buccal direction, the stress direction of DO and both sides of CB showed buccally instead of lingually as that of NO (p<0.05). No difference was found between that of both sides of CB (p>0.05).
- **Stress magnitude comparison:** There was no significant difference between NO and any of DO and both sides of CB (p>0.05).

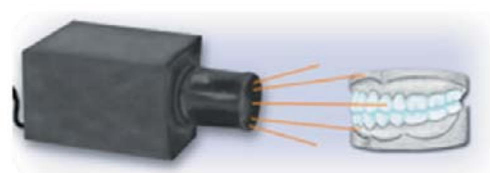
The Effects of the Hypererupted Third Molar Tooth on Apical Stress

- **Long axis inclination:** In the medial-distal direction, the long axis of the tooth inclination in both sides of either 8A or 8C showed no difference to that of NO ($p>0.05$). In the lingual-buccal direction, the inclination of this axis on the ipsilateral side of 8A was not as buccally as compared to those in NO ($p<0.05$). The contra-lateral side of 8A and both sides of 8C all showed no differences to that of NO ($p>0.05$).
- **Stress direction:** In the medial-distal direction, the apical stress direction of the contra-lateral side of 8A showed more distally than that of NO ($p<0.01$), while the apical stress directions of the ipsilateral side of 8A and both sides of 8C all showed no differences as compared to that of NO ($p>0.05$). In the lingual-buccal direction, the apical stress direction of the ipsilateral side of 8A and the contra-lateral side of 8C showed to be more lingually than NO ($p<0.01$). The contra-lateral side of 8A and the ipsilateral side of 8C showed no difference to that of NO ($p>0.05$).
- **Stress magnitude level:** The apical stress magnitude of the contra-lateral side of 8A and the ipsilateral side of 8C were higher than that of NO, while that of the ipsilateral side of 8A and the contra-lateral side of 8C were lower than NO ($p<0.05$). Significant difference was found between the both sides for either 8A or 8C ($p<0.01$).



The Effect of Molar Teeth Missing to Apical Stress

- **Long axis inclination:** The tooth long axis inclination of the contralateral side of TM showed to be more buccally oriented than the NO ($p<0.05$). Compared with NO, the long axis inclination of either side in TM showed a significant difference medial-distally ($p>0.05$). There were significant differences between the two sides of TM, either medial-distally or lingual-buccally ($p<0.05$), however, the long axis inclination of the ipsilateral side of TM showed to be more medial-lingually.
- **Stress direction:** There was no significant difference in the stress directions between NO and either sides of TM. This was also true in the stress directions between the both sides of TM ($p>0.05$).
- **Stress magnitude:** There was no significant difference in the stress magnitude between NO and either sides of TM. The stress magnitude of the ipsilateral side of TM was much lower than that of the contra-lateral side ($p<0.05$).



The Effect of a Flat Surface of Teeth on Apical Stress

When FS was compared to NO, there was a significant difference in the direction and magnitude of apical stress.

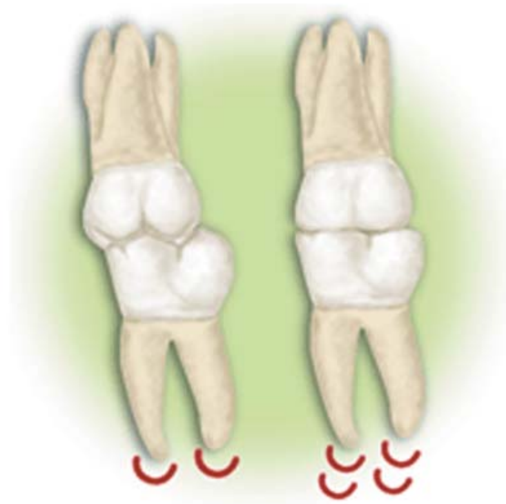
- **Long axis inclination:** There was no significant difference in the medial-distal inclination of the tooth long axis between NO and FS ($p>0.05$). But lingual-buccally the long axis inclination of FS directed more buccally oriented than NO ($p<0.05$).
- **Stress direction:** The direction of apical stress in FS showed to be more medially than NO ($p<0.01$). But lingual-buccally the stress direction of FS showed no significant difference from that of NO ($p>0.05$).
- **The stress magnitude:** It was much higher in FS than NO ($p<0.05$).

Discussion

The masticatory system works as a kinetic system in which the dentition serves as the resistance loading position. The apical stress, which comes from occlusal force, is featured following the general mechanical principles with three basic elements: magnitude, direction, and action point and is influenced by many factors. Three dimensional photoelastic stress analytics have been widely used in the dental biomechanics. Only a few of them were focused on the whole dentition, instead of on a local part of dentition, i.e., the implant area (Nishimura,et al.[1] and Guichet et al.[2]). A two dimensional analysis had been applied to alveolar bone (Karasz et al.[3], Moulding et al.[4]). dos Santos et al.[5] had used a mechanical model simulating a system in function that provided a vectorial analysis based on a static equilibrium of forces generated in a mandible at 10 different positions. They concluded cusp inclines have a profound influence on the forces acting within the dentition. The aim of our study was to measure and analyze the rules of the directions and magnitudes of the apical stress that was directed from vertical load on the whole dentition and was transferred though occlusal contact points and along the long axes of the teeth to the apical area. From the analysis of apical stress directions, the complete loading position and direction of occlusal force was intended to be deduced.

Guidance of Cuspal Incline Plane to Vertical Load

As shown in (Figure 7), the apical stress of NO is directed distolingually in the posterior teeth. This illuminated the principal loading positions of the mandibular posterior teeth in NO was on the distal incline planes of the cusps and the lingual incline planes of the buccal cusps. Southard et al.6 have concluded after measuring with a specially designed tension transducer positioned at the mandibular first molar-second premolar contact in 15 subjects, there is a considerable anterior component of occlusal force which is relative to molar inclination and others. The features drawn from the present study that distal incline planes of mandibular molar cusps take the principle occlusion loading coincident with it. The features of force transference were confirmed in the following respects:



- **Stress feature of DO:** The corresponding long axis of the teeth showed to be more distally directed than NO. Therefore, it made the distal incline plane of cusps even prone to endure the vertical load. Then, the apical stress was directed more distally.
- **Stress feature of CB:** The apical stress directed more buccally in CB instead of lingually, as in NO could be explained by Figure 8, where the functional buccal incline plane of lingual cusp of CB endured the load more.

From the analysis above it can be seen the complicated contact relationship of cuspal incline planes, in different types of occlusion, is lead by corresponding guidance at the vertical load. These might be the most important factors to the variation of apical stress directions.

Guidance of Tooth Long Axis Inclination to the Vertical Load

The tooth long axis inclination could partially affect the directions of apical stress. Taking the single tooth as a unit, there were only 6 units, out of a total of 18 units, getting the correlation between the directions of long axis inclination and that of apical stresses, both mesiodistally and linguobuccally. If the occlusion is the unit of interest, then only 4 out of 14 units from 7 different types of occlusions showed a correlation between the directions of long axis inclination and that of apical stress.

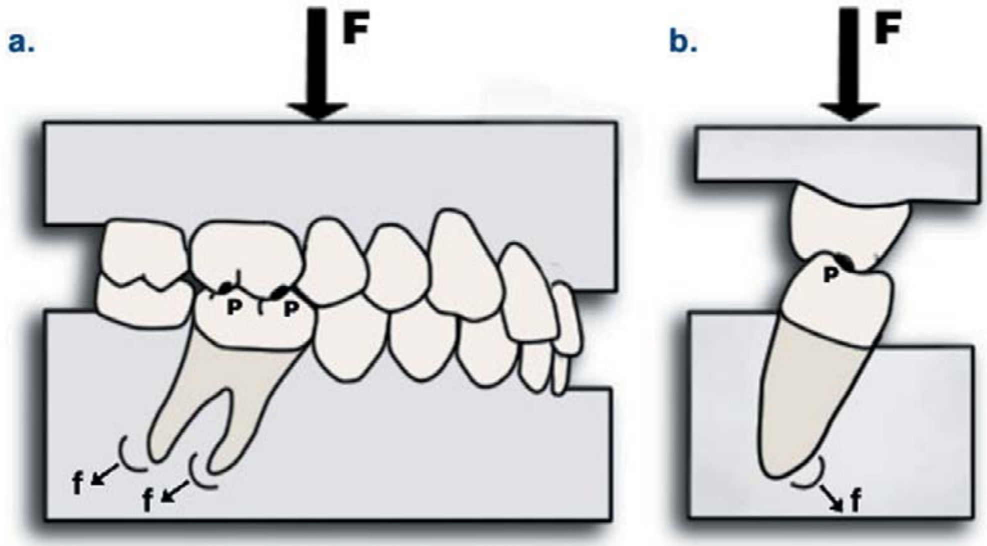


Figure 7. The diagram of the relationship of the direction of apical principle stress and occlusal loading position. The apical stress of normal occlusion (NO) directed distal-lingually in the posterior teeth, which illuminated the principal loading positions (P) of the mandibular posterior teeth in it were incident on the distal incline planes of the cusps (a) and the lingual incline planes of the buccal cusps (b).

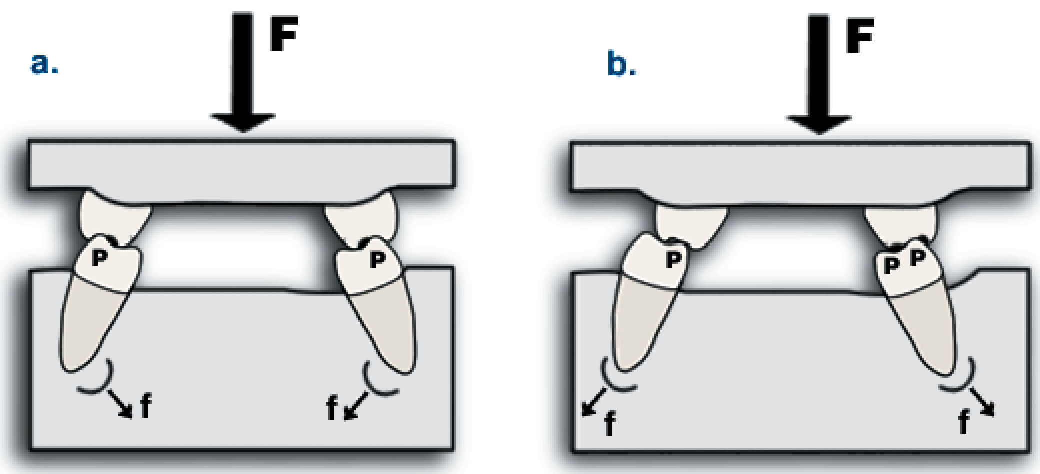


Figure 8. The direction of apical principle stress in a. normal occlusion (NO), and b. posterior cross-bite occlusion (CB). The apical stress directed buccally in CB implied the principle occlusion loading position (P) has changed from lingual incline plane of buccal cusps in NO to buccal incline plane of both buccal and lingual cusps of contra-lateral side of cross-bite and to buccal incline plane of lingual cusp of the ipsi-lateral side of cross-bite.

Some types of occlusions like DO and the contra-lateral side of CB, the tooth long axis inclination showed to be more distally than NO and the apical stress also directed more distally. In the contra-lateral side of CB, the tooth long axis inclination showed to be more buccally than NO, and the apical stress also directed more buccally than the normal one.

Some others like DO and the ipsilateral side of CB, showed no significant difference between their linguobuccal long axis inclination and that of NO, while the apical stress showed to be more buccally than the normal. In FS there were also no differences between the medial-distal long axis inclination and that of NO, while the apical stress directed more medially than NO. In 8A and 8C, the long axis inclination degree showed no differences with that of NO, both mesiodistally and linguobuccally. There was one exception, the long axis of teeth in the ipsilateral side of 8A showed to be not as buccally oriented as that in normal. However, the apical stress direction of the contralateral side of 8A showed to be more distally than NO. Finally, that of the ipsilateral side of 8A and of the contra-lateral side of 8C was directed more lingually than NO.

In some kinds of occlusion like TM, the long axis inclination of the contra-lateral side showed to be more buccally oriented than NO, while there were no differences in their stress directions. Compared with the contra-lateral side, the long axis inclination of the ipsilateral side of TM was directed medial-lingually, while the stress directions showed no difference. In CB, the long axis inclination of the ipsilateral side moved more medial-lingually than the contra-lateral side, while their stress directions showed no differences. Besides, the long axis inclination of FS was oriented more buccally than NO, while the stress direction difference on linguobuccal section did not reach a significant level ($p>0.05$).

Recognizing the poor correlation between the long axis inclination and apical stress direction, as described above, it can be concluded the long axis inclination was not one of the principle factors that affect apical stress directions. The effect it showed might be relative to the corresponding alteration of cuspal incline plane direction. The complex features of occlusal surfaces in a dental arch constructed using various teeth, along with some extension in the direction of the long axis of the teeth, if it exists, might well explain the complexity of apical stress direction.

Factors Affecting Stress Magnitude

The cusp-to-fossa feature of an occlusal surface not only changes the apical stress directions, but also affects its magnitude by counteracting the stresses from different directions. In FS, the apical stress showed obviously higher than NO because of lack of combined function of cusp incline plane.

There was no significant difference in the stress magnitude of DO and CB to that of NO, which may cloud the effects of different horizontal occlusal relationships on the apical stress level because they were not so distinct. In fact the stress level of the ipsilateral side of 8C and the contralateral side of 8A increased significantly more than NO, while that of the contra-lateral side of 8C and the ipsilateral side of 8A decreased; this could be caused by the guidance caused by the hypererupted teeth. The occlusion would give the mandible a component force turning around to the hyper-eruption side when the mandibular third molar hyper-erupted or to the contra-lateral side when the maxillary third molar hyper-erupted. The 8A and 8C, in this study, were all in neutral occlusion, so the distal incline plane of mandibular teeth were in the very position that was enduring the occlusal force under vertical load. When the mandible turned to one side, the load on distal cuspal incline plane of posterior teeth on that side would increase, enhancing the primary effects. While in the contra-lateral side, the load on the distal cuspal incline plane would decrease, weakening the primary effect, and that on the medial cuspal incline plane would increase (Figure 4). It was proved additionally the apical stress directions of the contra-lateral side of 8A were obviously more distally directed. Therefore, the load on the side that the mandible turned to (the ipsilateral side of 8C and the contra-lateral side of 8A) was much higher than the other side.

The third molar as well as other posterior teeth, existing or not, had no significant affect on apical stress magnitude on the whole. Furthermore, having two teeth missing, unilaterally or bilaterally, would not affect the apical stress relative magnitude in percentage. But, the apical stress magnitude of the second molar in the occlusion with the third molar was lower than that of an occlusion without third molars, indicating that the terminal teeth endured a higher load. However, to the TM it was found that although the stress on the terminal tooth (the first molar, in this case) of tooth-missing side was the highest comparing to the others of the ipsilateral side, the general stress level of the side of the dental arch with a tooth missing was lower than the contra-lateral side. Whether this is caused by the symmetry of the dental arch or the different tooth position is worth further investigation.

Conclusion

In general, occlusal surface form and the contact features with the opposite teeth gave important leading and analyzing effect to the occlusal force, which could cause variation of apical stress direction and magnitude. Our study was just an elementary exploration and the relative content is worth further investigation.

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