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Original Article

Computer simulation on the role of interproximal contacts in occlusal force transmission

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Purpose: This study aimed to investigate how interproximal contacts influence occlusal force transmission in the posterior maxilla using computer simulation. **Materials and Methods:** A three-dimensional model of the right maxillary second premolar, first molar, and second molar was constructed from patient CT data. Teeth and bone were defined as rigid bodies, and periodontal ligaments were represented by axial springs. Dynamic simulations were performed with occlusal forces of 100 N and 200 N applied at three points on the occlusal surface of the first molar for 0.1 s. Displacements of each tooth and the summed ligament forces were recorded and compared. **Results:** The first molar exhibited the greatest displacement and ligament forces, while the second premolar showed smaller secondary responses. Changes at the second molar were negligible. The peak displacement occurred on the mesial crown of the first molar, directed toward the second premolar. Increasing occlusal force from 100 N to 200 N markedly elevated the ligament forces at the first molar, whereas changes at the second premolar remained relatively small. These findings indicate that most additional load was dissipated locally at the first molar rather than transmitted distally, suggesting a limit in the load-sharing capacity of interproximal contacts. **Conclusion:** Occlusal forces applied to a single molar can be transmitted to adjacent teeth through interproximal contacts, and the extent depends on loading direction and contact geometry. Clinically, establishing proper proximal contacts is essential for controlled distribution of occlusal loads and the long-term stability of the dentition. **(J Dent Rehabil Appl Sci 2025;41(4):267-75)**

Key words: interproximal contact; occlusal force; periodontal ligament; computer simulation; dental biomechanics

Introduction

Interproximal contact, which is the area of physical contact between adjacent teeth, is a fundamental anatomic feature of natural dentition. These contacts provide resistance against undesirable tooth movement and play an important role in maintaining dental arch integrity.[1] Properly maintained contacts prevent food impaction. Without proper interproximal contact gingival irritation, periodontal problems, and dental caries can occur. Interproximal contacts are essential to the long-term preservation of tooth

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alignment and occlusal harmony. In addition, they contribute to both functional efficiency and esthetic appearance.[2] When stable contacts are lacking, teeth may move and consequently the health of individual tooth and the balance of the entire masticatory system can be destroyed.

Other than these preventive and stabilizing roles, interproximal contacts also provide a biomechanical route for the transmission of occlusal forces. When an occlusal load is applied to a single tooth, the resulting forces are not confined to that tooth alone; rather, they are transmitted through contact points to adjacent teeth and ultimately to the surrounding alveolar bone. This force-sharing mechanism allows the dentition to act as an integrated unit. It protects individual teeth from overloading and preserves the function of the entire dental arch.[3] The efficiency of mastication and the resistance to occlusal trauma rely on this force distribution system. In fact, occlusal force transmission through contacts is essential for maintaining balanced loading of periodontal structures. It minimizes the risk of localized stress concentrations that can bring about mobility, bone resorption, or restorative failure.[4] From a clinical perspective, the maintenance of optimal proximal contact is therefore indispensable not only for periodontal stability but also for the functional biomechanics of the occlusal system.

The importance of interproximal contacts has been emphasized in numerous experimental and clinical investigations. Studies have reported that loss of proximal contact can lead to food impaction, occlusal discrepancies, and progressive periodontal breakdown.[5] Other investigations underscored the association between contact tightness and tooth migration, stating that improper proximal contact can predispose to pathological tooth drifting and occlusal disharmony.[6] Finite element method (FEM) studies have further demonstrated that the quality of proximal contact significantly influences stress distribution within teeth, periodontal ligament, and alveolar bone.[7] However, while the contribution of proximal contact to periodontal and occlusal health is well established, relatively few studies have focused on its role in quantitatively transmitting occlusal forces across multiple teeth in a functional dental arch.

In recent years, computer-based simulations have become increasingly important in dental research as powerful and efficient investigative tools. Biomechanical models for computer simulations allow researchers to replicate complex anatomical structures, including enamel, dentin, periodontal ligament, and alveolar bone, under controlled experimental conditions.[8] These models offer unique advantages compared to in vivo or in vitro experiments. They provide reproducible results, allow for precise isolation of individual variables, and enable the visualization of stress and displacement patterns that are difficult to measure directly.[9] Additionally, computational models make it possible to explore hypothetical situations. With computer simulations it is possible to change the variables easily. For example, it is not difficult to vary the magnitude or direction of occlusal forces or to modify the properties of periodontal structures without the ethical or logistical limitations associated with human or animal studies. With the introduction of new restorative materials and implant systems, the demand for biomechanical analysis has increased and computer simulation has become an indispensable method for improving both scientific understanding and clinical practice.

Since the early 2000s, several open-source simulation platforms were developed and have contributed significantly to the advancement of biomechanics in dentistry. Among these, ArtiSynth (Artisynth; University of British Columbia, Vancouver, Canada) was introduced as a versatile framework for combined multibody and finite element simulation.[10] The platform enables the construction of anatomically detailed models that integrate rigid and deformable components and it has been applied in craniofacial biomechanics. With its ability to simulate muscle activation, joint mechanics, and soft tissue deformation, ArtiSynth provides an accessible environment to investigate complex dental and maxillofacial problems. In addition, the platform is capable of handling contact interactions between structures.

Interproximal contacts play a critical role in maintaining dental arch stability and distributing occlusal loads. However, the biomechanical mechanisms un-

derlying their influence need to be explored further. The purpose of this study was to investigate how interproximal contacts influence the transmission of occlusal forces using computer simulation. By clarifying these effects, this study aims to provide biomechanical insights that may contribute to improving treatment planning in restorative dentistry. The null hypothesis of this study was that interproximal contacts do not affect the transmission of occlusal forces among adjacent teeth.

Materials and Methods

Model preparation

A three-dimensional computational model was constructed based on patient computed tomography (CT) data. From the CT dataset, bone and teeth were segmented and exported as stereolithography (STL) files using a segmentation software (Mimics 19.0; Materialise NV, Leuven, Belgium). With exported files the computer model was fabricated using computer-aided engineering software (Visual Mesh 2024.0; ESI Group, Santa Rosa, US). The model was composed of bone, teeth, and periodontal ligament. The bone model was represented as cancellous bone only and the crown portions of the teeth, including occlusal and proximal surfaces, were reconstructed using computer-aided design (CAD) software. Both teeth and bone were defined as rigid bodies for the purposes of the simulation. The final model included the right maxillary second premolar, the right maxillary first molar, and the right maxillary second molar. This study was approved by the Institutional Review Board of Seoul National University Dental Hospital.

The finished meshes were imported into open-source biomechanical simulation platform (Artisynth; University of British Columbia). To replicate the periodontal ligament (PDL), a bundle of radial AxialSpring elements which is a linear spring element used in Artisynth was generated between the virtual inner surface of the tooth root and the corresponding outer surface of the alveolar socket. This provided an elastic interface for force transmission between tooth and bone and it allows the measurement of tensile and compressive forces as well. The entire model consisted of 33,666 nodes and 67,214 triangular surface elements, ensuring sufficient resolution for biomechanical analysis. The overall geometry of the model is illustrated in Fig. 1.

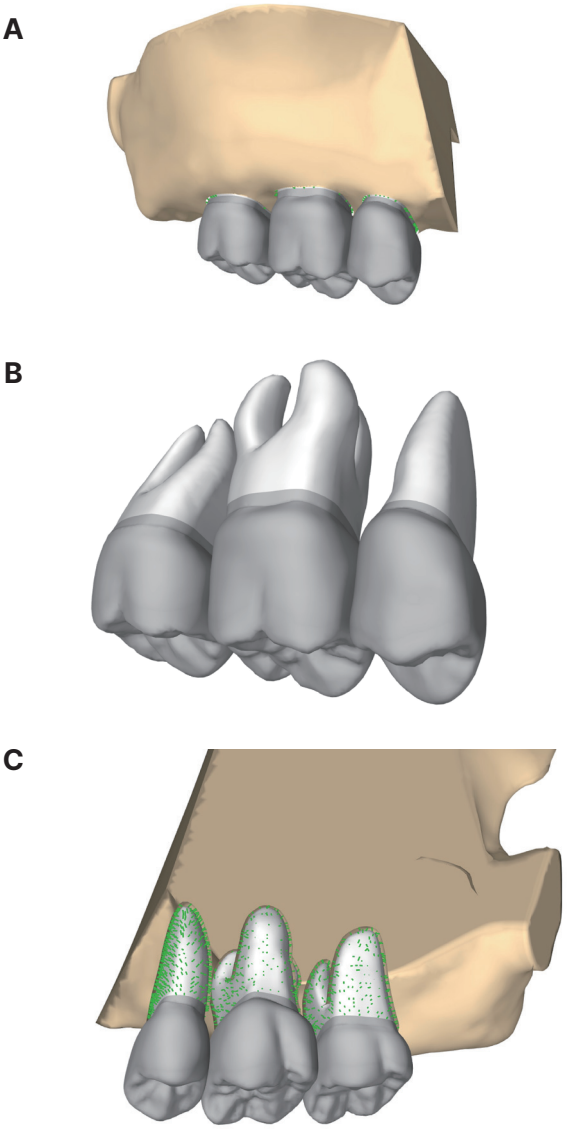

Fig. 1. Three-dimensional computational model used for simulation. The model includes the right maxillary second premolar, first molar, and second molar in relation to a segment of the maxilla. Teeth and bone were defined as rigid bodies, and the periodontal ligament was represented by bundles of axial spring elements between the root surfaces and the alveolar socket. (A) Buccal view showing the overall configuration, (B) Buccal view focusing an isolated view of the teeth, (C) Palatal view highlighting the periodontal ligament representation.

Simulation procedure

A transient dynamic simulation was performed over a total duration of 0.3 s.[11] During the initial 0.1 s, no external load was applied to allow the model to stabilize. From 0.1 s to 0.2 s, occlusal forces of 100 N and 200 N were applied to the occlusal surface of the right maxillary first molar at three functional contact points, located at the distal marginal ridge, mesial marginal ridge, and the palato-mesial cusp tip (Fig. 2), representing a tripod occlusal contact pattern. These load magnitudes were selected to represent physiological light (100 N) and moderate (200 N) clenching conditions, as reported in earlier biomechanical and finite element studies.[12] The direction of force application was determined according to a previously published study, with direction vector components of 0.32, 0.42, and 0.85 along the x-, y-, and z-axes, respectively (Fig. 3).[13]

Data analysis

Following simulation, the node exhibiting the maximum displacement in each tooth was identified. The three-dimensional coordinates of this node were tracked over time to evaluate how occlusal forces were transmitted through the interproximal contacts. For each structure, the node exhibiting the greatest displacement was identified and the magnitude of this displacement was analyzed. In addition, the response of the periodontal ligament for the second premolar, the first molar, and the second molar was quantified. For each tooth, the magnitudes of the axial forces in all ligaments attached to the root was summed at each time step, and total values were averaged under 100 N and 200 N occlusal loads.

Results

Simulations under 100 N and 200 N loading conditions were successfully performed. The occlusal load primarily displaced the maxillary first molar, with secondary transmission to the adjacent maxillary second premolar. The maxillary second molar showed low displacement. Under a load of 100 N, the maxillary first molar exhibited a displacement of 62.76 μm, the second premolar showed 18.31 μm, while the second molar demonstrated negligible movement. The peak displacement occurred on the mesial aspect of the occlusal surface of the maxillary first molar, that is, toward the second premolar. The results were consistent with a load vector that compresses the first molar and the second premolar contact, while the first molar and the second molar contact showed

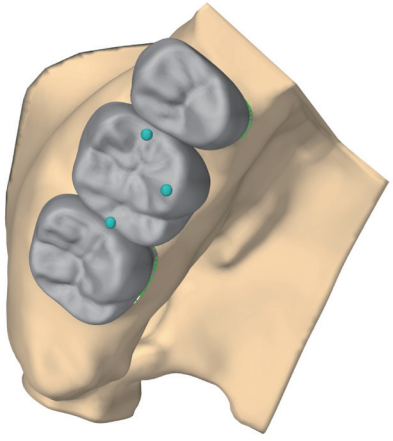

Fig. 2. Occlusal view of the model showing the loading points. Blue dots indicate force application sites on the maxillary first molar. These sites are the distal marginal ridge, the mesiopalatal cusp, and the mesial marginal ridge.

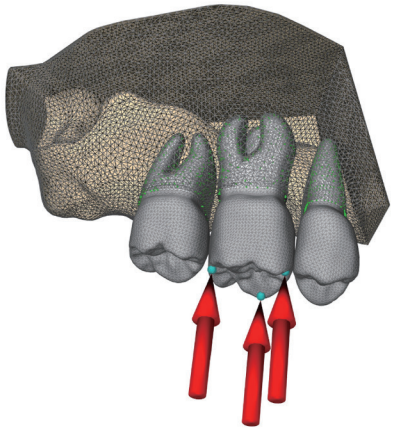

Fig. 3. Illustration of occlusal loading. Forces were applied at the blue dots shown in Fig. 2 and the loading directions are indicated by red arrows.

opening and thus transmitted little force. Increasing the load from 100 N to 200 N generally increased the displacement magnitude, however the pattern of deformation remained similar. Under the 200 N load, the first molar exhibited a displacement of 113.03 μm, the second premolar 19.27 μm, while the second molar showed insignificant displacement. Fig. 4 shows the displacement results.

The periodontal ligament exhibited the expected coexistence of tension and compression. The ligament forces were highest at the first molar, followed by the second premolar, while the forces observed at the second molar were substantially lower in magnitude compared to the other teeth. Increasing the occlusal load from 100 N to 200 N increased the ligament force at the first molar and the second premolar. However, the magnitude of change at the second premolar was relatively small compared with the first molar. The quantitative values of ligament forces are shown in Fig. 5.

Discussion

The results of these simulations indicate that an occlusal load applied to a single molar can be transmitted through proximal contacts to neighboring teeth, producing measurable displacement outside the loaded unit. In this simulation, loading the maxillary first molar generated the largest motion at the loaded tooth, a smaller but detectable response at the second premolar, and negligible motion at the second molar. This pattern indicates that the occlusal load was mainly transmitted through the contact between the first molar and the second premolar under the present load vector. However, the contact between the first molar and the second molar played only a minor role. This finding demonstrates that the direction of the occlusal load is a critical factor in force transmission. The lower displacement observed at the second molar was not solely due to the loading direction. The distal contact tended to open under the applied force vector, resulting in limited load transfer to the second molar. Additionally, the geometry of the occlusal contact points concentrated the load toward the mesial side, which favored load transmission to the second premolar. These factors collectively explain the reduced displacement of the second molar under the same loading conditions. The observed pattern is consistent with whole-arch FE results showing that even small changes in occlusal contact distribution can alter force transmission and influence tooth position.[14] Comparable trends have been observed in experimental and computational literature. In a photoelastic experiment the results

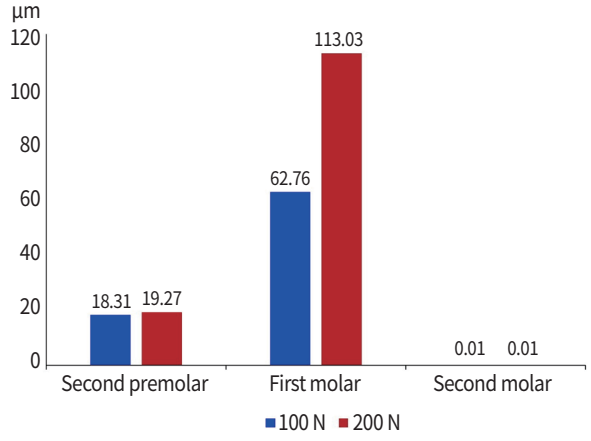

Fig. 4. Maximum tooth displacement under 100 N and 200 N loading conditions. The first molar showed the largest displacement, followed by the second premolar, while the second molar exhibited negligible movement.

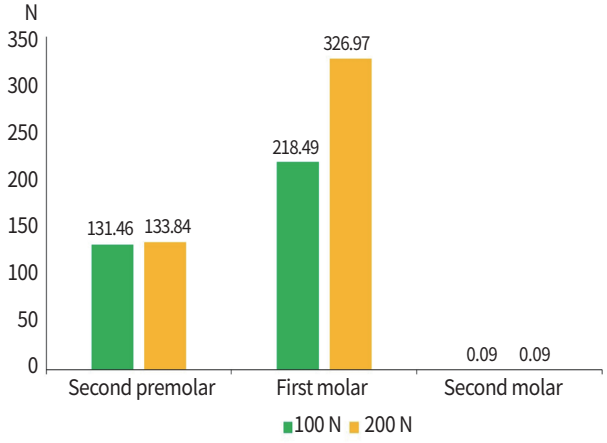

Fig. 5. Periodontal ligament forces generated under 100 N and 200 N loading conditions. The first molar showed the highest values, the second premolar exhibited lower responses, and the second molar remained negligible.

showed that maintaining a distal proximal contact altered load transfer under posterior crowns, underscoring the role of interproximal contact as a load-sharing interface rather than a passive boundary.[15]

When the applied load increased from 100 N to 200 N, the periodontal ligament force at the first molar increased markedly. However, the response at the second premolar remained nearly unchanged. This discrepancy can be explained by differences in load path and contact geometry. As the external force was introduced directly at the occlusal contacts of the first molar, most of the additional load was dissipated through its crown-bone interface and periodontal ligament. In contrast, transmission toward the premolar depended on the mesial interproximal contact between the two teeth. This indicates that the amount of load carried through an interproximal contact has an upper limit, beyond which additional force is not effectively transferred. Clinically, this suggests that even relatively small occlusal loads can be sufficient to influence the neighboring premolar when a tight contact is maintained, underscoring the importance of establishing proper proximal contacts for controlled load sharing and tooth stability.

Periodontal ligament tissues remodel actively under loading. Rapid collagen turnover and fibroblast-mediated matrix synthesis and degradation occur. Studies on transseptal fibers also show that they can remodel and help stabilize neighboring teeth, providing a soft-tissue pathway that supports small interproximal force transmission.[16,17] Together, these reports are in agreement with the results of this study that local loading at the maxillary first molar can induce a secondary response at the second premolar when the contact map and load direction favor mesial transfer.

Moreover, the predictions were highly sensitive to how the periodontal ligament was modeled. Under dynamic loading, it was shown that representing the periodontal ligament as a viscoelastic material allowed it to absorb energy and thereby lowered cancellous bone stress compared with elastoplastic or purely hyperelastic models, which dampened stress propagation away from the loaded tooth.[18] Other studies also demonstrated that local stress patterns depended strongly on the specific material properties assigned to the periodontal ligament.[19] Clinically, studies on interproximal contact loss around implants have shown that changes in contact conditions can alter the way forces are transmitted and may lead to problems such as food impaction.[20,21] These findings emphasize that contact mechanics act as an important factor influencing load transfer, rather than as a simple pathway.

Methodologically, multibody simulation used in this simulation offers several strengths for studying force transmission through interproximal contact. Modeling the bone and teeth as rigid bodies simplifies the system, removes the interfering effects from internal deformation, and allows the analysis to focus on load transfer. In addition, this method reduces computational cost while preserving the essential features of occlusal force distribution. As a platform for testing hypotheses prior to finite element analysis, this approach provides speed, numerical stability, and interpretability.

There are limitations that should be considered when interpreting these findings. Only three teeth including the second premolar, the first molar, and the second molar were modeled instead of the full dental arch, and no antagonistic teeth were included. In addition, in this study the periodontal ligament was modeled in a simplified way using linear axial springs. Under real conditions periodontal ligament shows non-linear and time-dependent behavior. It would ideally be represented by a finite element model. Using a detailed finite element representation of the PDL could capture its viscoelastic properties, provide more realistic damping and improve the accuracy of predicted load transmission. Finally, the loading vector was too simplified relative to mastication. A more realistic representation of masticatory vectors can provide deeper insights into interproximal load transmission and generate findings with greater clinical relevance. Future studies should incorporate a full-arch model with opposing dentition to simulate occlusal force distribution more comprehensively, and apply a viscoelastic finite element representation of the periodontal ligament to better reflect its time-dependent biomechanical response. Additionally, the implementation of multi-directional and dynamic

masticatory loading vectors would enable a more realistic replication of physiological mastication and provide findings with greater clinical relevance.

Conclusion

This study demonstrated that occlusal loading applied to a single molar can be transmitted through proximal contacts to adjacent teeth, resulting in measurable displacement beyond the loaded unit. The load was primarily transferred from the first molar to the second premolar, whereas the second molar exhibited a comparatively lower response under the tested conditions. These findings highlight that the direction and magnitude of occlusal loading, as well as the morphology of interproximal contacts, are critical determinants of force transmission within the dental arch.

Taken together, these results indicate that interproximal contacts function as active biomechanical interfaces that redistribute occlusal forces to maintain functional stability. This emphasizes the importance of achieving appropriate proximal contact relationships during restorative and prosthetic treatments to optimize occlusal load distribution and enhance long-term clinical outcomes.

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교합력 전달에서 인접면 접촉의 역할에 관한 컴퓨터 시뮬레이션

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목적: 본 연구의 목적은 상악 구치부에서 인접면 접촉이 교합력 전달에 미치는 영향을 컴퓨터 시뮬레이션으로 규명하는 것이다.

연구 재료 및 방법: 환자의 CT 자료를 기반으로 상악 우측 제2소구치, 제1·2대구치의 3차원 모형을 제작하였다. 치아와 골은 강체로, 치주인대는 축방향 스프링 요소로 정의하였다. 제1대구치 교합면 세 지점에 100 N 및 200 N의 교합력을 0.1초 동안 가하여 동적 시뮬레이션을 수행하고 각 치아의 변위와 치주인대 힘을 비교하였다.

결과: 교합력은 제1대구치에서 가장 큰 변위와 힘을 보였으며, 제2소구치에서 이차적 반응이 관찰되었다. 제2대구치에서는 변화가 미미하였다. 최대 변위는 제1대구치 근심부에서 발생하여 제2소구치 방향으로 향했다. 교합력이 증가하면 제1대구치 치주인대 힘은 크게 증가했으나 제2소구치의 변화는 제한적이었다. 이는 하중이 국소적으로 흡수되고 인접치 전달에는 한계가 있음을 보여준다.

결론: 단일 대구치의 교합력은 인접면 접촉을 통해 분산될 수 있으나 정도는 하중 방향과 접촉 기하학에 좌우된다. 임상적으로 보아 올바른 접촉 형성은 교합력의 조절된 분산과 치열 안정성 유지에 필수적이다.

(구강회복응용과학지 2025;41(4):267-75)

주요어: 인접면 접촉; 교합력; 치주인대; 컴퓨터 시뮬레이션; 치과생체역학

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