Theoretical Efficacy of Preventive Measures for Pathologic Fracture After Surgical Removal of Mandibular Lesions Based on a Three-Dimensional Finite Element Analysis

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Purpose: Pathologic fracture of the mandible after removal of a lesion historically has been a clinical problem. The present study aimed to evaluate mandibular strength after removal of a lesion and to illustrate the theoretical efficacy of preventive measures against pathologic fracture based on a 3-dimensional finite element (FE) analysis.

Materials and Methods: A computed tomographic (CT)-based FE model of the mandible of a patient with a dentigerous cyst including a third molar was constructed. Using this model, the decrease of mandibular strength after virtual removal of the lesion was analyzed. The effect of the decrease of occlusal force and reinforcement by a miniplate was analyzed using a simple FE model of the mandible. Based on these analyses, removal of the cyst with the third molar was performed with a decrease of occlusal force and reinforcement by a miniplate. The validity of these procedures was analyzed using a CT-based FE model constructed after surgery.

Results: The von Mises stress in a CT-based FE model after virtual removal of the cyst with the third molar was markedly greater than that in the original FE model. In the analysis using a simple FE model, the stress around the fenestrated area was decreased after premolar loading compared with that after molar loading. In addition, miniplate placement around the fenestrated area markedly decreased the stress. Based on these results, the cast crowns of the first and second molars were removed and the fenestrated area of the mandible was reinforced with a 1.5-mm locking miniplate in the actual surgery. The von Mises stress in the fenestrated area was decreased and primarily borne by the miniplate in the analysis of a CT-based FE model constructed after surgery.

Conclusion: The present study illustrated the theoretical efficacy of plate application for the decrease of stress on the mandible after surgical removal of a cyst including a third molar based on a simulation by FE analysis.

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Cystic and tumorous lesions in the mandible are frequently encountered in oral and maxillofacial surgery. Pathologic fracture of the mandible sometimes occurs after the surgical removal of these lesions. It has been reported that 81.8% of mandibular pathologic fractures are associated with radiolucent lesions,[1] particularly those associated with a third molar.[2-4] Although fracture occurs from the decrease of mandibular strength after surgery, the risk of fracture has not been evaluated by objective examinations. Therefore, the evaluation of mandibular strength after surgery and the exploration of preventive measures for pathologic fractures are required.

The finite element (FE) method has been used to simulate the behavior of the object in question in various situations, for example, under loading conditions.[5] The authors previously reported that the fracture site of the mandible is closely related to the site of stress concentration in FE analysis.[6] Another study also predicted the possibility of pathologic fracture after removal of the mandibular third molar in FE analysis.[5] However, no reports have investigated the strength of the mandible after the removal of a pathologic lesion and the effect of reinforcement.

The purposes of the present study were to evaluate mandibular strength after the removal of a cyst including a molar and to illustrate the theoretical efficacy of preventive measures for pathologic fracture based on a simulation by FE analysis. The authors hypothesized that plate application and the decrease of occlusal force would lessen the risk of fracture. The specific aims of the study were to evaluate mandibular strength after removal of a lesion by computed tomographic (CT)-based FE analysis before surgery, to explore an effective method of plate application, and to evaluate efficacy of the plate application by CT-based FE analysis after surgery.

Materials and Methods

PATIENT

A 47-year-old male patient scheduled to undergo surgery for a dentigerous cyst including a third molar in the right mandible at the Department of Oral Maxillofacial Surgery, Hattori Memorial Hospital (Nara, Japan) was the subject of the study. The patient had undergone panoramic x-ray photograph (X-P) and cone-beam CT (CBCT) X-P (Alioth; Asahi, Kyoto, Japan; Fig 1). CT data were obtained from the right premolar region to the right posterior border of the ramus with a slice thickness of 0.1 mm. This study was conducted based on the principles outlined in the Declaration of Helsinki and was approved by the Hattori Memorial Hospital human subjects protection committee. The patient was informed of the purposes of the study and signed a consent form before participating.

RISK ANALYSIS OF PATHOLOGIC FRACTURE AFTER REMOVAL OF THIRD MOLAR AND CYST USING A CT-BASED FE MODEL BEFORE SURGERY

A CT-based FE model (Fig 2A), which incorporated information on 3-dimensional architecture and bone density distribution, was constructed for the precise assessment of the strength of the mandible. This model was constructed using bone strength–analyzing software (Mechanical Finder; Research Center of Computational Mechanics, Inc, Tokyo, Japan). Trabecular bone, cortical bone, and teeth were modeled using a 1-mm linear tetrahedral element. In addition, triangular shell elements on the outer surface of the cortex were adapted to accurately represent the thin cortical shell. The thin shell elements were created with a thickness of 0.05 mm. There were 92,656 tetrahedral elements, 13,647 triangular shell elements, and 19,579 nodes.

A second FE model, which simulated the mandible after virtual removal of the third molar, was constructed (Fig 2B). A third FE model, which simulated the mandible after removal of the cyst with the third molar under fenestration of the buccal cortical bone, was constructed (Fig 2C). The area of buccal cortical bone removal was defined from the top of the crestal bone to the vertical level of the crown of the third molar at its maximum diameter.

For the boundary condition, the node in the condylar region was constrained in all directions and the node in the medial cross section was constrained perpendicular to this plane. A bite force of 287.2 N was applied in these FE models as a point load on the first molar in the direction perpendicular to the occlusal plane. The magnitude of the molar and premolar bite forces was determined according to the patient's bite force measured by an Occlusal Force Meter GM10 (Nagano Keiki, Tokyo, Japan).

To allow for bone heterogeneity, the mechanical properties of each element were computed from the Hounsfield unit value. The Young modulus of each tetrahedral element was calculated using the equations proposed by Keyak et al.[7] The Poisson ratio for each element was set as 0.3. From another study,[8] the authors assessed whether the maximal principal stress exceeded the element ultimate tensile stress, which was 80% of the element compressive yield stress, and whether the negative value of the minimal principal strain exceeded −10,000 microstrain ($\mu\varepsilon$). Linear FE static analyses were performed. To evaluate mechanical stress on the mandible, von Mises stresses, the rate of maximal principal stress to critical stress (tensile stress strength rate), and the rate of equivalent stress to yield stress (compressive stress strength rate) were