Biomechanical Rationale for Intentionally Inclined Implants in the Posterior Mandible Using 3D Finite Element Analysis

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Purpose: *Since natural dental arches usually form Monson or Spee occlusal curvatures among the posterior teeth, they tend to incline in mesial and lingual directions. The purpose of this study was to examine the biomechanical rationale for placing implants according to these curvatures in the mandibular posterior region.* ***Materials and Methods:*** *A 3-dimensional finite element model was created in which 2 implants were placed in the mandibular molar area. Stress distribution in the bone around the implants was analyzed under different distal implant inclinations.* ***Results:*** *Stress in the cervical area of the mesial and distal implants and the surrounding bone was higher when the implants were placed parallel to each other compared to when the distal implant was placed with a mesial or mesiolingual inclination.* ***Discussion:*** *The slightly smaller effect of a mesiolingual inclination compared to a mesial inclination can be explained by the large cantilever on the buccal side of the superstructure.* ***Conclusion:*** *Within the limitations of this study, it was suggested that there is a biomechanical rationale for placing implants in the posterior mandible area with a mesial inclination similar to that of natural teeth. It was also suggested that too much lingual inclination can put the implant at risk of overload.* INT J ORAL MAXILLOFAC IMPLANTS 2005;20:533–539

Key words: *biomechanics, finite element method, intentionally inclined implants, posterior mandible*

Since natural dental arches usually form Monson or Spee curvatures among posterior teeth,[1] the teeth tend to incline in a mesial and lingual direction. The direction of implant placement is closely related to the transfer of the occlusal force, and it is considered desirable to place implants into the jawbone as parallel as possible to achieve structural stability and a precise fit to the superstructure.[2] However, it is quite difficult to place 2 or more implants in the posterior mandible in a parallel manner because of restrictions such as the lack of mouth opening distance for instrumentation. It has been reported that the average angular divergence among implants placed in the posterior mandible is 10 degrees.[2] In natural dentition, the axes of the mesial and lingual teeth are inclined in accordance with Monson's spherical theory, which may have some functional and dynamic rationale.[3]

Using 3-dimensional (3D) finite element analysis, the main objective of this study was to find out whether implant placement in the posterior mandible with mesial or lingual inclinations according to Monson's spherical theory has a biomechanical rationale.

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MATERIALS AND METHODS

The form of an edentulous posterior human mandible was scanned and 3-dimensionally digitized with a high-speed laser (Surfacer; UNISN, Osaka, Japan). The data were then transferred to Patran Version 2001 (MSC, Santa Ana, CA). From the data, a

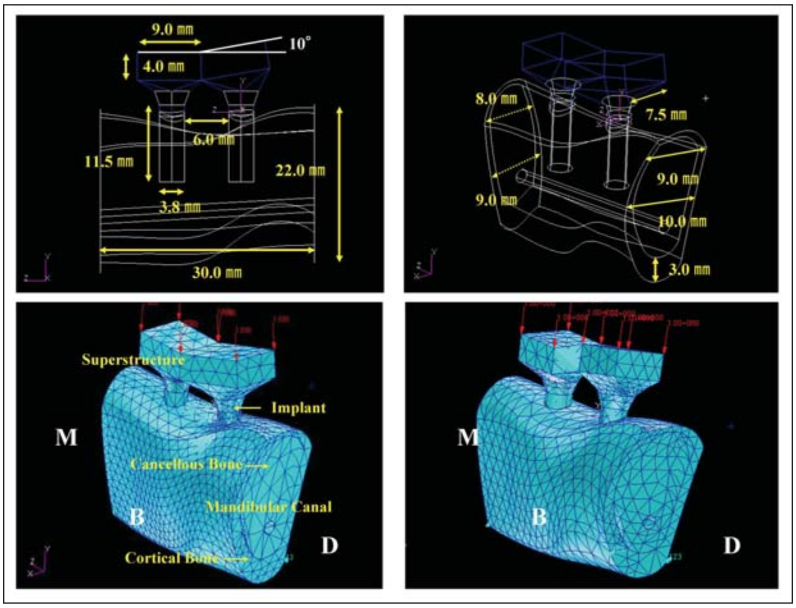

Fig 1 Structure of a 3-dimensional finite element model. *(a and b)* Structure and dimensions of the model. *(c)* Appearance of the model used in experiment 1. *(d)* Appearance of the model used in experiment 2. In experiment 2, the occlusal curve of the superstructure was set to 10 degrees mesiolingually. M = mesial; D = distal; B = buccal.

Table 1 Modulus of Elasticity and Poisson's Ratio of Materials Used to Contruct 3D Finite Element Model

	Modulus of elasticity (MPa)	Poisson's ratio
Titanium	110,000	0.35
Cortical bone	15,000	0.30
Cancellous bone	1,500	0.30
Gold alloy	96,600	0.35

Titanium was the implant material; gold alloy was the superstructure material.

Table 2 Model Setups Used in Experiments

Experiment	
1	2
0M: Two implants were placed parallel to each other	0ML: Two implants were placed parallel to each other
5M: The distal implant was mesially inclined by 5 degrees	5ML: The distal implant was mesiolingually inclined by 5 degrees
10M: The distal implant was mesially inclined by 10 degrees	10ML: The distal implant was mesiolingually inclined by 10 degrees
20M: The distal implant was mesially inclined by 20 degrees	20ML: The distal implant was mesiolingually inclined by 20 degrees

model of the mandible with cortical and cancellous bone was reconstructed with 2 implants supporting a superstructure (Fig 1). With regard to implant nodes and the mandibular model, a fixed implant-bone band was assumed on all interfaces, and bond strength was set so as not to allow node separation.[4–6] Considering analytical efficiency, cylindric implants with a simple morphology were used.[6–8]

The occlusal curve of the superstructure surface in the model was set to 10 degrees in a mesial or mesiodistal direction. Loading conditions were applied as follows: a 50-N static load was applied vertical to the occlusal surface of the superstructure and distributed at every node of the occlusal surfaces of the mesial and distal implants; ie, a maximum clenching situation was assumed (Fig 1). Furthermore, for mesh production, tetrahedral solid elements were used to construct each model. With regards to the material constants, Young's modulus and Poisson's ratio (Table 1) were used, as in previous studies.[4,9–13]

With these analytical configurations, data were exported to Nastran (MSC), and stress analysis was performed using von Mises stress[3,5,8,11] as an index (Fig 1). In experiment 1, where the influence of a mesial inclination was examined, 2 implants were placed parallel to each other in model 0M, after which the distal implant was mesially inclined by 5, 10, and 20 degrees in models 5M, 10M, and 20M, respectively.

In experiment 2, where mesiodistal and bucco-lingual inclinations were tested in addition to mesial inclination, 2 implants were placed parallel to each other in model 0ML, after which the distal implant was mesiolingually inclined by 5 degrees, 10 degrees, and 20 degrees in models 5ML, 10ML, and 20ML, respectively (Table 2). The occlusal curve of the

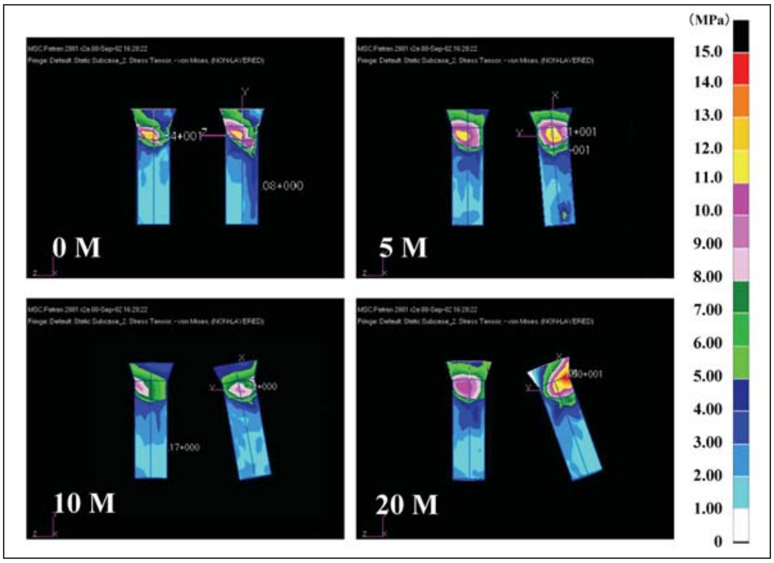

Fig 2 Comparison of the stress values at the implant surface in experiment 1.

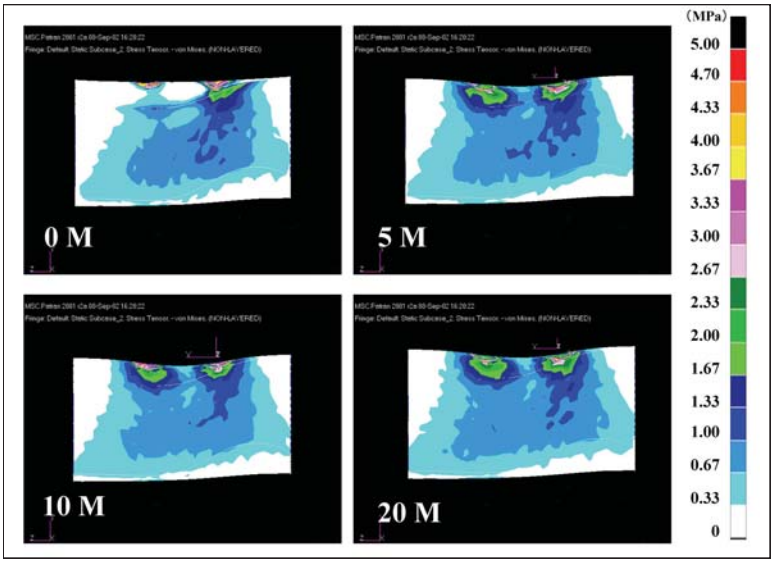

Fig 3 Comparison of the stress values at the surface layer of the cancellous bone in experiment 1.

superstructure in experiment 2 was set to 10 degrees both mesially and distally.

Comparisons of stress were conducted using the maximum von Mises stress values and their coefficients of variance (CV), determined using the formula CV = SD/$\bar{x}$, where SD = standard deviation, for every element in each material. For example, there were 17,174 elements in the cancellous bone material used in experiment 1. When a load was applied to the occlusal surface, stress was analyzed for every one of these elements.

Standard deviations cannot be compared in absolute magnitudes in instances where the distributions compared have very different means. To compensate for this situation, it was necessary to rely on the CV. A small CV value for a material indicated that stress is more evenly dispersed in that material.

RESULTS

Experiment 1: Mesial Inclination

Stress in the Implant. Stress was highly concentrated in the cervical area of the implant with 0M and 5M. Stress decreased with 10M, dispersing in areas other than the cervical area. However, the stress value increased from 10M to 20M, showing a shift in the stress distribution to the implant's distal surface (Fig 2).

Stress in the Surface Layer of the Cancellous Bone. Although stress in the surface layer of the cancellous bone was lower than in the implant, it was high in the distal cervical area of the implant with 0M. However, stress was widely distributed not only around the cervical area of the distal implant, but also around the cervical area of the mesial implant with 5M, 10M, and 20M (Fig 3).

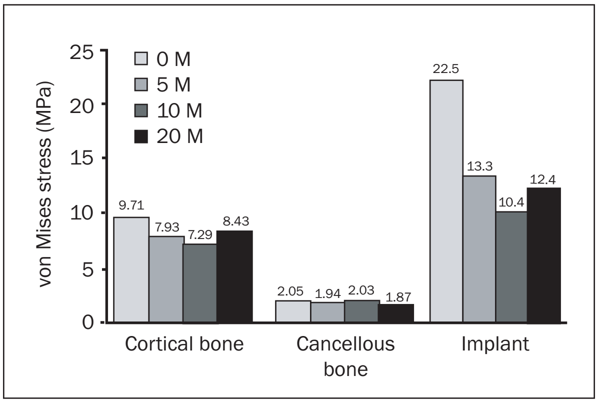

Fig 4 Maximum von Mises stress values in experiment 1.

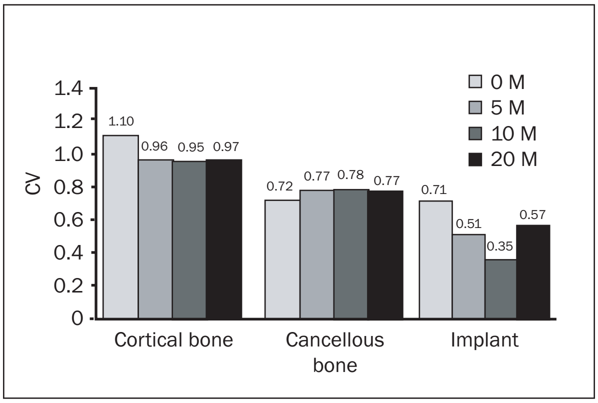

Fig 5 CV values in experiment 1.

Von Mises Stress Values and CV Values. The von Mises stress values in the cortical bone and the implant were highest with 0M and lowest with 10M. In the cancellous bone, the von Mises stress value was lowest with 20M. In the cancellous bone, differences in values among 0M, 5M, 10M, and 20M were small in comparison with differences in values for the cortical bone and implant (Fig 4).

The CV value in the implant was lower with 10M than with 0M, 5M, or 20M. In the cancellous bone, it was lower with 0M than with 5M, 10M, and 20M. In the cortical bone, it was higher with 0M than with 5M, 10M, or 20M (Fig 5).

Experiment 2: Mesiolingual Inclination

Stress in the Implant. Stress was found mainly in the cervical area of the implant with 0ML and was lower and more dispersed in areas other than the cervical area. The maximum value of stress increased and became distributed over the implant's distal surface with 20ML. The stress distribution patterns for each model were similar to those observed for the mesial inclination models (Fig 6).

Stress in the Surface Layer of the Cancellous Bone. Stress was lower in the surface layer of the cancellous bone than in the implant, where a high stress level was observed in the cervical area of the distal implant with 0ML. Widely distributed stress was observed not only around the cervical area of the distal implant, but also around that of the mesial implant with 5ML, 10ML, and 20ML (Fig 7).

Comparison of the Von Mises Stress Values and the CV Values. The highest von Mises stress value was found with 0ML. In the cortical bone, von Mises stress was lowest with 20ML. In the cancellous bone and the implant, it was lowest with 10ML (Fig 8). The CV values in the cancellous bone and implant were lowest with 5ML. Differences in the stress values for the implants were small among the mesiolingual models compared to those of the mesial inclination models in experiment 1. The CV values in the cortical bone and implant were highest with 0ML (Fig 9).

DISCUSSION

There are several methods for the biomechanical analysis of implant restorations. The models with strain gauges employed in previous reports had some advantages. For example, comparisons between intraoral application and experimental results were possible.[14–16] Furthermore, it was possible to measure the strain on the implant abutment surface with this method. However, stress in the implant area and the bone around the implant could not be evaluated. To analyze the influence of implant inclination on stress distribution in the bone around the implant, 3-D finite element models were used.

Sato and associates[17] reported that the results obtained using the homogenous structure of the cancellous bone should be carefully evaluated with 3D finite element analysis. However, there were some limitations with the 3D models used in this study. For example, all interfaces in the models were assumed to be fully bonded, and the implants were of a simple cylindric shape.[3,6,12,18] Stress values would be markedly different with threaded implants in low-density bone models.[18] However, since the model of this study, which imitated the form of an actual edentulous posterior human mandible, was very complicated, and there were already about 34,147 to 35,511 elements, the implants were modeled with a cylindric shape to make calculations easier. Therefore, it was possible to use the model in biomechanical predictions of clinical outcomes in the mandible with cancellous bone of normal density.

The inclination or placement angle of the implant has a significant role in biomechanics.[13,19] Celletti

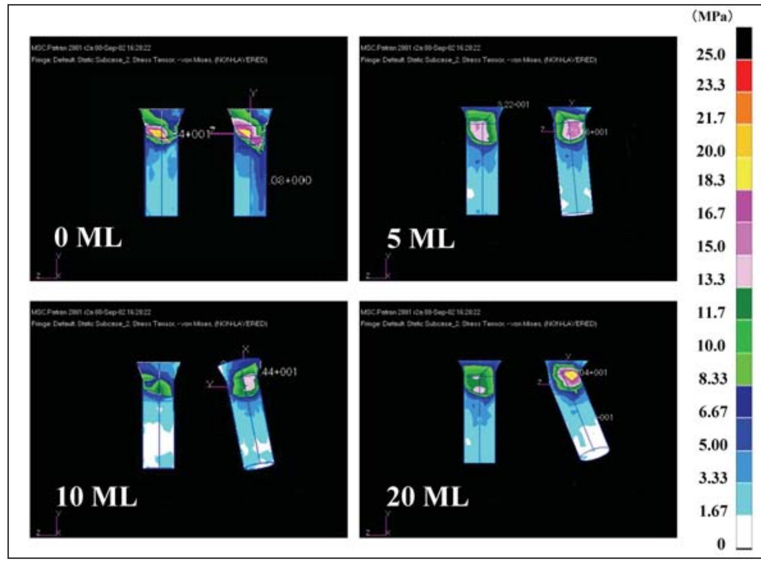

Fig 6 Comparison of the stress values at the implant surface in experiment 2.

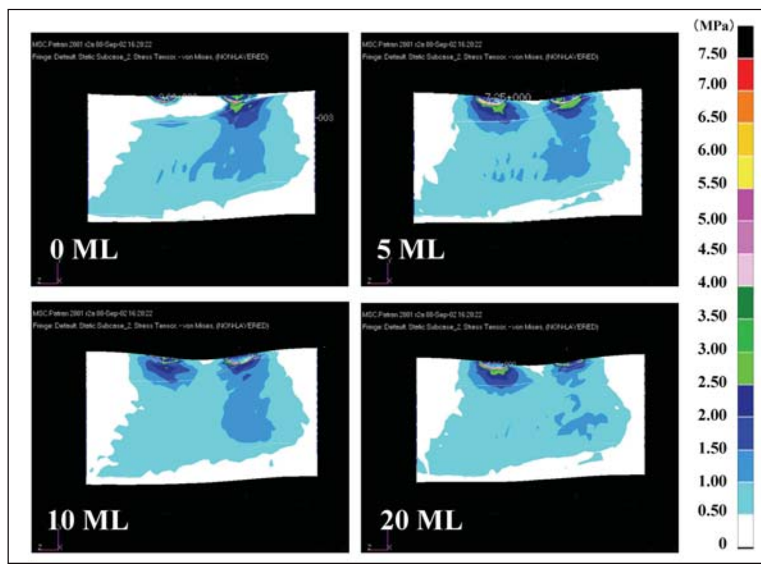

Fig 7 Comparison of the stress values at the surface layer of the cancellous bone in experiment 2.

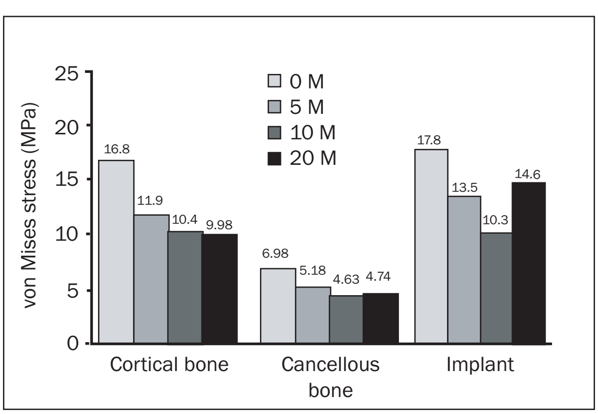

Fig 8 Maximum Von Mises stress values in experiment 2.

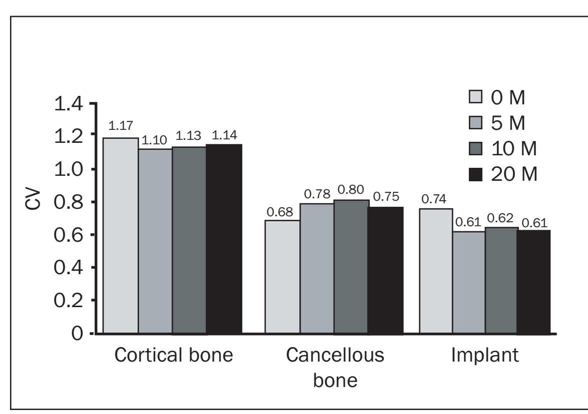

Fig 9 CV values in experiment 2.

and associates[20] reported that the angle of implant placement did not contribute to the initiation of disintegration or bone resorption unless inflammation coexisted. Furthermore, Sethi and coworkers[21] indicated that implants with angled abutments showed an even higher survival rate than those that were nonangled. Krekmanov and colleagues[22] also reported the efficacy of distally inclined implant placement in enlarging the supporting area of the occlusal face. Brunski and Hurley[23] elaborated on the biomechanics of placing 2 implants in relation to the posterior mandible but did not refer to implant inclinations. Although there have been numerous reports documenting implants with 3D finite element models, few researchers have examined the influence of inclination on implants placed in the mandibular molar region using 3D finite element models.

It is reasonable to suppose that the occlusal force transmits most efficiently in the direction of the tooth's axis.[3,24] The mesial and distal roots of mandibular second molars usually have inclinations of approximately 10 degrees when compared with the mesiodistal and buccolingual root inclinations of mandibular first molars.[25] Consequently, loads applied to the distal implant superstructure in this experiment were inclined at 10 degrees in mesial or lingual directions.

Stress levels in the cervical area of the mesial and distal implants and the surrounding bone were higher with 0M than 5M, 10M, and 20M. The maximum value of stress in 0M was approximately twice that with 10M (Fig 4). These results suggest the biomechanical advantage of mesially inclined distal implants when loads act perpendicularly to the occlusal surface.

Von Mises and CV values in the bone were smallest with 10M, indicating that distal implants placed with a certain degree of mesial inclination have an advantage over those placed in a parallel manner in terms of stress distribution. Differences of 10 degrees in regard to mesial inclination are usually found in natural teeth such as the first and second mandibular molar, corresponding to the natural inclination of Spee's curvature.

Stress values in the cervical area of the mesial and distal implants and the surrounding bone were higher with 0ML than with 5ML, 10ML, and 20ML. These results suggest the biomechanical advantage of both mesial and mesiolingual inclination of the distal implant, when loads act perpendicularly to the occlusal surface.

The maximum von Mises stress value observed in this study was not so large that it would cause immediate loss of osseointegration.[5,8] However, in clinical situations, there may be increased premature contact and overloading as a result of bruxism, and therefore the possibility of loss of osseointegration cannot be ignored.[7,8,12,23,26,27]

These results suggest that a mesiolingual inclination is biomechanically advantageous with both mesial and distal implants. It was also revealed that a mesial inclination similar to the direction of the occlusal force is desirable, and that stress occurring in the implant and surrounding bone increases when the angle increases.

CONCLUSION

Within the limitations of this study, it can be suggested that there is a biomechanical rationale for placing implants in the posterior mandible area with a mesiolingual inclination similar to that of natural teeth. It is recommended that the distal implant be placed in a mesially-inclined manner along the curve of the natural dentition.

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