Original Article

Stability of Zygomatic Plate-Screw Orthodontic Anchorage System

A Finite Element Analysis

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ABSTRACT

Objective: To evaluate the biomechanical properties of a standard and a newly designed plate-screw orthodontic anchorage system.

Materials and Methods: A three-dimensional model of the posterior maxilla, including the zygomatic buttress region, was prepared. Insertion of standard and newly designed plates was simulated on the three-dimensional model. The effect of 200 g of orthodontic force on the plate, screws, and zygomatic bone was evaluated in three-dimensional models by finite element analysis. To determine the force distribution, Von Mises stress, principal maximum and minimum stress, and principal maximum and minimum elastic strain values were evaluated.

Results: In all plate models the highest stresses occurred on the threaded bone site where the force application unit was attached.

Conclusion: Changing the plate configuration did not affect the stress distribution in the newly designed plates. To equalize the force distribution, new plate designs that change the location of the force application unit are required.

KEY WORDS: Finite element analysis; Zygomatic anchorage; Stability

INTRODUCTION

Orthodontists use fixed mechanics and intraoral and extraoral forces to correct malocclusion. Optimal anchorage control is essential for successful orthodontic treatment; however, movement of the anchoring units is inevitable. Because the use of only intraoral forces leads to anchorage loss, extraoral appliances are preferred to enhance the stability of the anchoring unit.[1] However, such appliances are esthetically objectionable, must be worn for at least 16 hours a day every day, and require patient compliance.[2]

To eliminate the disadvantages of extraoral appliances, intraoral skeletal anchorage systems, such as miniscrews,[3] mini-implants,[4] palatal implants,[5] and endosseous implants[6] have been introduced. A zygomatic anchorage system consisting of plates and screws, which is the most rigid anchorage system, is a frequently preferred intraoral anchorage method.[7–11]

However, problems may be encountered during the surgical and orthodontic phases of treatment with a zygomatic anchorage system.[7,11,12] The higher the insertion of the plates in the zygomatic buttress region, the better the quality and quantity of bone and the greater the likelihood of long-term success. Yet retraction of the soft tissues and insertion of the upper screws of the vertical component of the miniplate are associated with technical difficulties that can develop during the insertion of the plate, as the procedure is performed under local anesthesia.

Loosening of the screws and inflammation around the anchorage system are common complications that can develop during orthodontic treatment. Inadequate design, nonhomogeneous force distribution along the anchorage system, and emergence of force application units that remain on the nonattached gingiva can cause those complications. Although there are clinical reports about zygomatic anchorage systems,[8–11] to our knowledge the effects of force distribution on areas around the plate and screws have not been reported in the literature.

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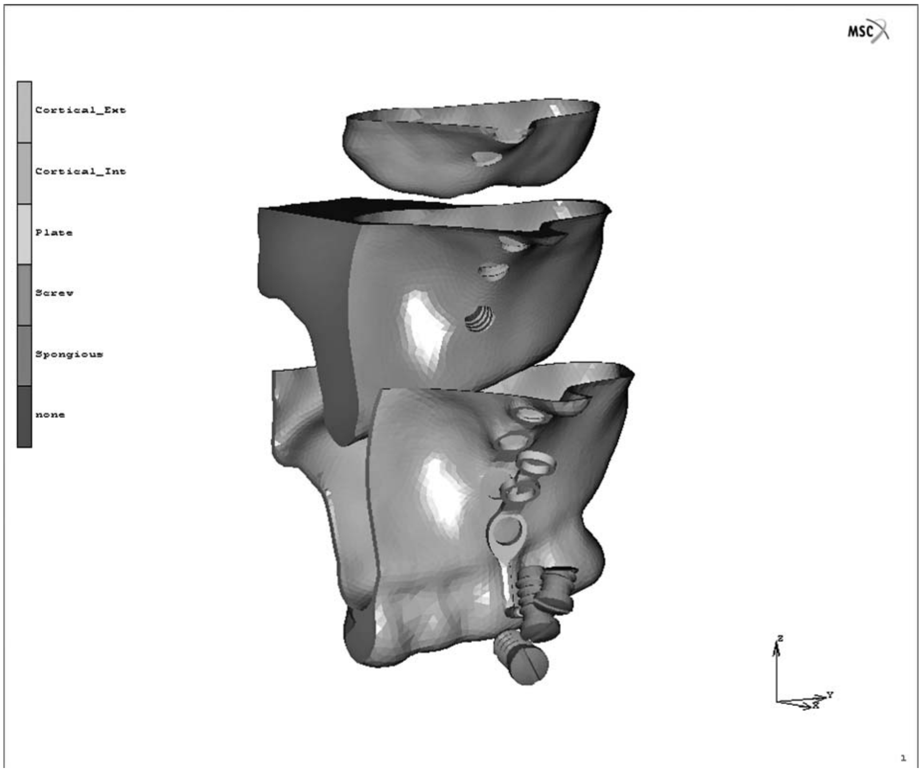

Figure 1. The internal cortical, spongious, and external cortical bone layers and plates and screws inserted to the zygomatic buttress region.

The aims of this study were (1) to assess, on three-dimensional models subjected to simulated orthodontic forces, the force distribution along the plate-and-screw system inserted into the zygomatic bone, and (2) to evaluate the design of new plate-and-screw systems that eliminate the clinical and biomechanical problems described and ensure homogenous force distribution.

MATERIALS AND METHODS

A solid model of posterior part of maxilla, including the zygomatic buttress region, was constructed from serial axial sections (0.5 mm apart) from a 14-year-old patient that were obtained via a two-dimensional computed tomographic study performed with I-DEAS Artisan 4.0 Cad-Cam Software (Structural Dynamics Research Corp, Milford, Ohio).

Then, free meshing was used to generate a three-dimensional model with MSC-Marc Menthat 2005 software (MSC Software Corporation, Santa Ana, Calif). Three-dimensional surface models of the screws and plates were generated from photographs, and finite element models were created. Zygomatic anchorage titanium plates and screws (1.5 mm, Bollard Zygoma Anchor, Surgi-Tec, Bruges, Belgium) were inserted into the zygomatic buttress via simulation (Figure 1). All materials were assumed to be homogenous and linear elastic (isotropic). Three-dimensional quadratic tetrahedral elements were used to create the finite element model. Elasticity ratios and Poisson's ratios consistent with the age of the patient were used in this study (Table 1).[13]

Table 1. Characteristics of the Materials Used[13]

Material Type	Elasticity Coefficient	Poisson's Ratio
Cancellous bone	1500	0.3
Cortical bone	15,000	0.33
Titanium	117,000	0.34

The models were assumed to be fixed. A static, horizontal, posteroanteriorly directed 200 *g* force was applied to the system (Figure 2). The displacement and the maximum and minimum stress and strain values of the cortical and cancellous bone, plates, and screws were evaluated and compared individually. In the second part of the study, four geometrically different plates were modeled and simulated. Plates 1 and 2 were the standard vertical plates that are routinely used in clinical practice for zygomatic anchorage, and plates 3 and 4 (L-shaped and horizontal) were designed for our study (Figure 3).

RESULTS

Von Mises stress was used to determine the mean stress values, principal maximum and minimum stress

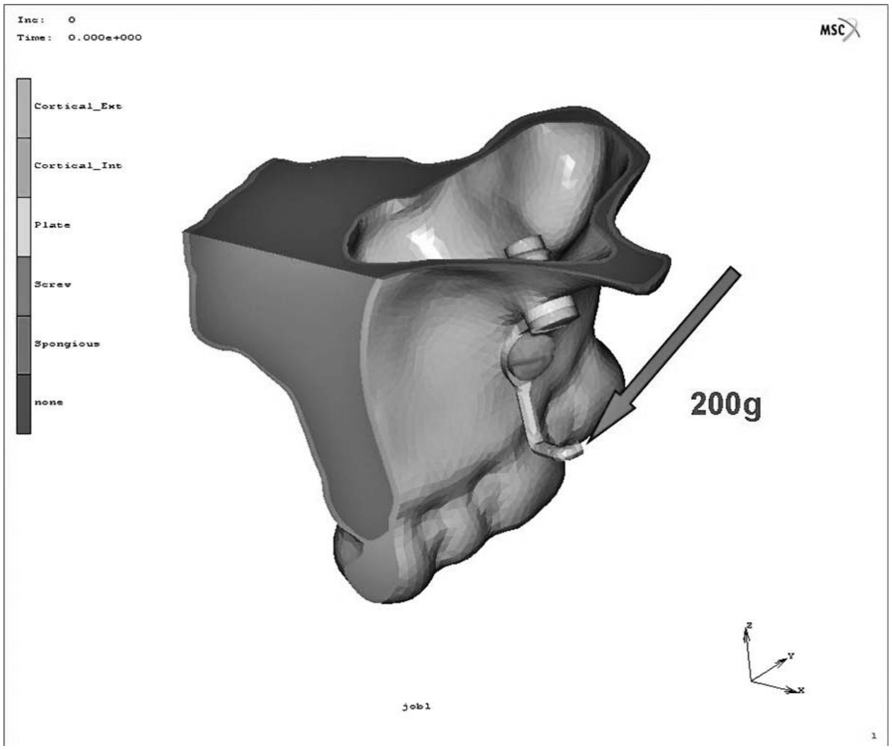

Figure 2. The direction and amount of force applied.

Table 2. Highest Stress and Strain Values in the External and Internal Cortical Bone, the Spongious Bone, and the Plate and Screws[a]

	Von Mises Stress (MPa)	Maximum Stress (tension) (MPa)	Minimum Stress (compression) (MPa)	Maximum Strain (μstrain)	Minimum Strain (μstrain)
Model 1					
External cortical bone	4.38	1.66	−2.66	141.96	−188.04
Spongious bone	0.32	0.08	−0.28	80.43	−184.00
Internal cortical bone	0.44	0.36	−0.34	22.97	−23.55
Plate 1	39.46	37.63	−39.99	307.44	−328.39
Screw	5.21	4.44	−5.57	36.15	−45.04
Model 2					
External cortical bone	9.37	7.67	−5.57	464.39	−298.10
Spongious bone	0.33	0.08	−0.26	95.16	−162.57
Internal cortical bone	0.50	0.39	−0.38	25.99	−25.72
Plate 2	55.47	67.07	−43.48	484.67	−364.11
Screw	11.24	9.59	−4.25	63.35	−37.48
Model 3					
External cortical bone	4.47	2.13	−3.31	150.36	−237.25
Spongious bone	0.38	0.08	−0.33	112.35	−230.31
Internal cortical bone	0.38	0.29	−0.37	20.33	−24.78
Plate 3	71.08	85.81	−69.36	614.92	−562.14
Screw	6.38	4.99	−6.52	41.95	−52.12
Model 4					
External cortical bone	5.39	2.67	−3.38	204.72	−239.87
Spongious bone	0.57	0.34	−0.33	289.87	−285.26
Internal cortical bone	0.34	0.32	−0.33	21.09	−21.41
Plate 4	88.46	94.13	−63.68	756.47	−507.07
Screw	2.40	2.10	−2.44	17.54	−18.67

[a] MPa indicates megapascal; μstrain, microstrain.

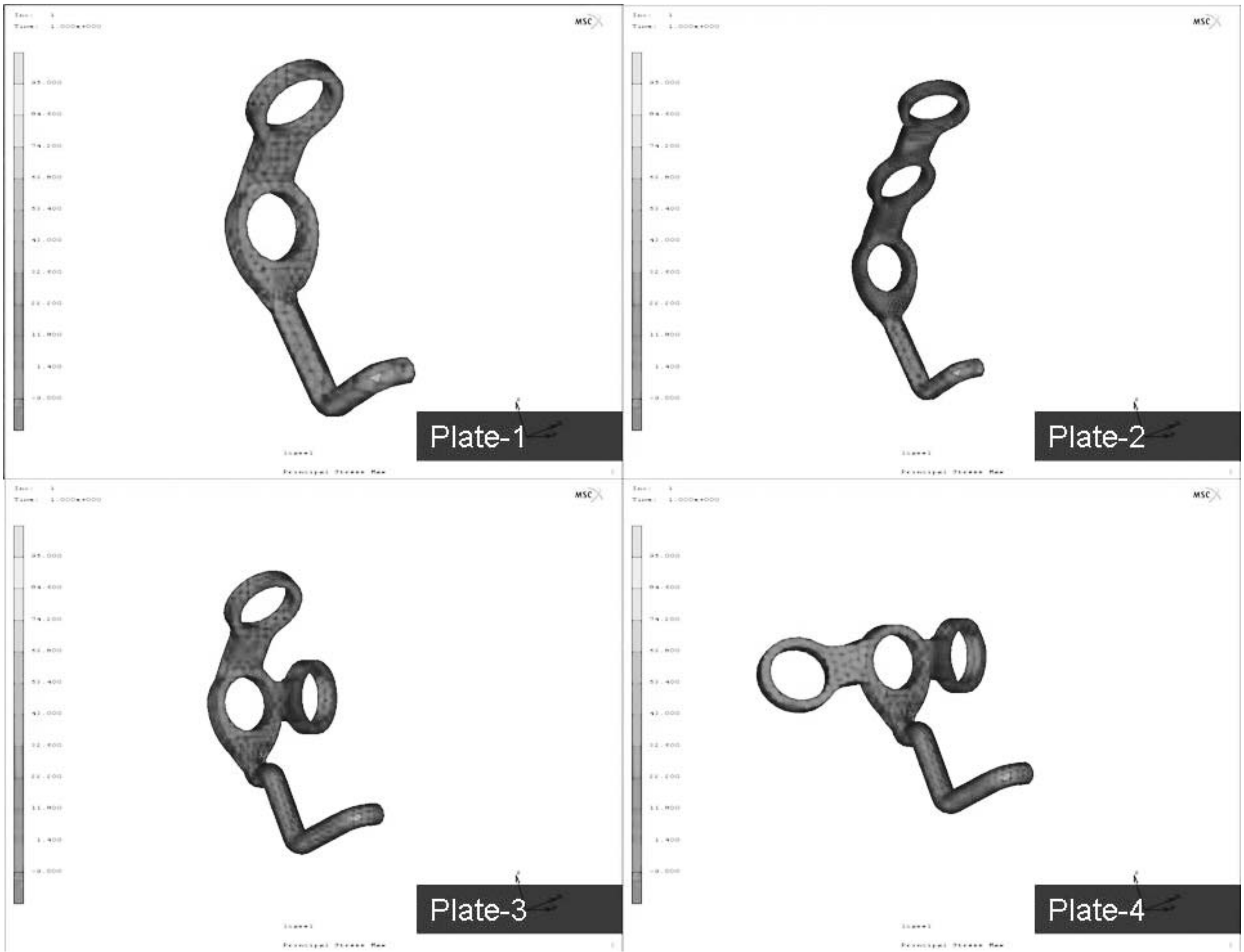

Figure 3. Mesh models of plates 1 and 2 (standard vertical plates that were used in this study) and plates 3 and 4 (the newly designed L-shaped and horizontal plates studied).

values were used to determine the tension and compression stress, and principal maximum and minimum elastic strain values were used to establish the forthcoming deformation. The stress and strain distributions noted are shown in the Figure 4, and the numeric values are shown in the Table 2. These numeric values represent the highest tension and compression strain and stress values that occurred on the plates, screws, internal-external cortical, and spongious bone. The localization of these values was demonstrated on figures (Figure 4).

Mathematical values of stress and strain in newly designed (L-shaped and horizontal) plates showed little decrease compared with the standard plates. In both the standard (plate 1 and 2) and newly designed (plate 3 and 4) plates, the highest stress and strain distribution was noted on the threaded bone site adjacent to the emerging part of the force application unit.

DISCUSSION

Endosseous implants, palatal implants, mini-implants, miniscrews, and miniplates are used as intraoral skeletal anchorage units in orthodontic treatment.[3–6] The zygomatic anchorage system is one of the most rigid and relatively safe anchorage methods.[7–11] The main indications for the use of a zygomatic bone anchorage system are the distal movement of the anterior and posterior segments, regardless of whether extraction is required; the mesial movement of the posterior teeth; the intrusion of a single tooth or a group of a teeth; the uprighting of a mesially inclined lower second and/or third molars; the loss of dental anchorage resulting from tooth loss; periodontitis; and orthopedic intermaxillary traction.[2] The zygomatic buttress, the nasal process of the maxilla, the canine region of the mandible, and the molar region of the mandible are anatomic sites at which a miniplate system can be inserted.[2]

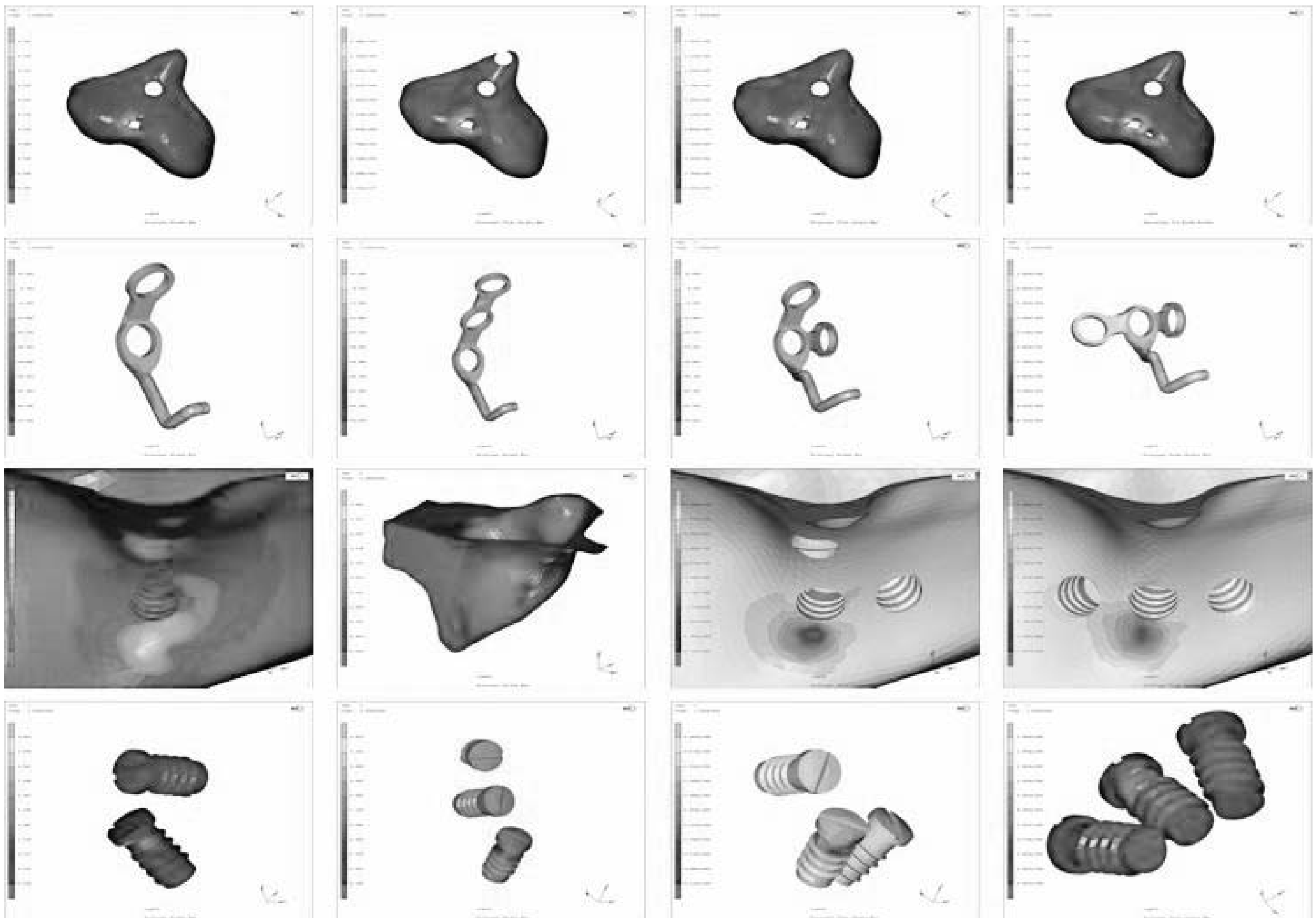

Figure 4. Models with a variable scale showing the stress distribution in the internal and external cortical bone and in the plates and screws. Note that the highest stress values are on the inferior screw and on the threaded bone site at which the force application unit was attached.

Compared with extraoral devices, zygomatic bone anchorage systems have two main advantages: They are not visible, and they require less patient compliance. Those systems also provide space for orthodontic treatment in the dentoalveolar region, permit desirable movement of the anchoring teeth, do not interfere with adjacent teeth, enable immediate loading, require simple handling, involve a minimally invasive surgical procedure, and ensure that dental hygiene is easy to maintain.[1,2,11] However, some complications (such as inflammation around the plates) have been reported with zygomatic bone anchorage systems, especially when the plates have been placed too high in the vestibule.[2,11] Although it has not been reported in the literature, screw loosening and mobility of the anchorage system may also occur as a result of biomechanical problems and the effects of stress over the screws.

In this study, titanium, cortical, and spongious bone was analyzed with different elasticity and poisson values separately with finite element analysis (FEA). However, these structures were assumed to be homogenous individually. The principal difficulty in FEA modeling is simulating the mechanical behavior of the human tissue and its response to applied mechanical force. Certain assumptions need to be made to make the modeling and solving process possible. Material properties greatly influence the stress and strain distribution in a structure. In most reported studies the assumptions were that the materials are homogenous and linear.[14] However, none of the materials was 100% homogenous and linear elastic (isotropic, that is, the characteristic of the materials were the same in all directions) in the nature. In this study homogenous bone models were used, as heterogeneous models (anisotropic models) require a time-consuming and complex process with suitable hardware. The internal structure of the human tissue and their isotropy may vary continuously by many factors, so assumptions in our study may not reflect individual variations. In addition, the results of this analysis may be an approximation of the actual results

The stability of the zygomatic anchorage system depends on the stresses and strains imposed on the plate by the screw heads. If the bone under the plate or around the screws resorbs over time because of improper adaptation, an active force on the bone around the screws may occur. This may cause loosening of the screw(s) in addition to cortical bone resorption induced by excessive pressure over and/or the rotation of the other screw(s), both of which impair the stability of the plate. Mobility of the zygomatic anchorage system can cause an inflammatory response that culminates in infection and an unsuccessful result.

In this study, treatment failure and stress and strain distribution in both standard and newly designed models were evaluated with a finite element model. New plates that theoretically provide a more homogenous force distribution and are simple to insert during surgery were designed and modeled on a computer. The force used most routinely by orthodontists, 200 g, was also used in our study. Although the geometry of the plates was changed in models 3 and 4, the stress distribution on the threaded bone site did not change. In all plate models, the highest stresses and strains occurred on the threaded bone site to which the force application unit was attached.

To homogenize that force distribution, the connection point of the emergence of force application unit can be positioned between the screw holes or placed at the same distance from all holes. However, the homogenization of force distribution was not tested in our study and must be evaluated in future investigations. Stress can directly affect the screws, especially the screw that is closest to the force application unit, and may impair screw stability.

CONCLUSIONS

- The highest stress and strain values were noted on the inferior screw in all models.
- Changing the plate configuration did not affect the stress distribution in the newly designed or the routinely used standard plates.
- To equalize the force distribution, new plate designs that change the location of the force application unit are required.

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REFERENCES

1. Rungcharassaeng K, Kan JY, Caruso JM. Implants as absolute anchorage. *J Calif Dent Assoc.* 2005;33:881–888.
2. De Clerck H, Geerinckx V, Siciliano S. The zygoma anchorage system. *J Clin Orthod.* 2002;36:455–459.
3. Fritz U, Ehmer A, Diedrich P. Clinical suitability of titanium microscrews for orthodontic anchorage-preliminary experiences. *J Orofac Orthop.* 2004;65:410–418.
4. Park HS, Bae SM, Kyung HM, Sung JH. Micro-implant anchorage for treatment of skeletal Class I bialveolar protrusion. *J Clin Orthod.* 2001;35:417–422.
5. Wehrbein H, Merz BR, Diedrich P, Glatzmaier J. The use of palatal implants for orthodontic anchorage. Design and clinical application of the orthosystem. *Clin Oral Implants Res.* 1996;7:410–416.
6. Roberts WE, Engen DW, Schneider PM, Hohlt WF. Implant-anchored orthodontics for partially edentulous malocclusions in children and adults. *Am J Orthod Dentofacial Orthop.* 2004;126:302–304.
7. Erverdi N, Usumez S, Solak A. New generation open-bite treatment with zygomatic anchorage. *Angle Orthod.* 2006;76:519–526.
8. Erverdi N, Acar A. Zygomatic anchorage for en masse retraction in the treatment of severe Class II division 1. *Angle Orthod.* 2005;75:483–590.
9. Erverdi N, Keles A, Nanda R. The use of skeletal anchorage in open bite treatment: a cephalometric evaluation. *Angle Orthod.* 2004;74:381–390.
10. Sugawara J, Kanzaki R, Takahashi I, Nagasaka H, Nanda R. Distal movement of maxillary molars in nongrowing patients with the skeletal anchorage system. *Am J Orthod Dentofac Orthop.* 2006;129:723–733.
11. Umemori M, Sugawara J, Mitani H, Nagasaka H, Kawamura H. Skeletal anchorage system for open-bite correction. *Am J Orthod Dentofacial Orthop.* 1999;115:166–174.
12. Hibi H, Ueda M, Sakai M, Ikemori Y. Orthodontic anchorage system using a locking plate and self-drilling screws. *J Oral Maxillofac Surg.* 2006;64:1173–1175.
13. Nagasao T, Kobayashi M, Tsuchiya Y, Kaneko T, Nakajima T. Finite element analysis of the stresses around endosseous implants in various reconstructed mandibular models. *J Craniomaxillofac Surg.* 2002;30:170–177.
14. Geng JP, Tan KBC. Liu GR: Application of finite element analysis in implant dentistry. *J Prosth Dent.* 2001;85:585–598.