Original Article

Anchorage Effect of Osseointegrated vs Nonosseointegrated Palatal Implants

Fengshan Chen[a]; Kazuto Terada[b]; Kooji Hanada[c]; Isao Saito[d]

ABSTRACT
Palatal implants can be used with a transpalatal arch (TPA) connected with the second premolar to provide anchorage. The purpose of this study was to compare the anchorage effects of an osseointegrated palatal implant (OPI) with a nonosseointegrated palatal implant (NOPI), using finite element analysis. One model, which was composed of two maxillary premolars, periodontal ligament (PDL), alveolar bone, a palatal implant, palatal bone, a bracket, band, and TPA, was created on the basis of the clinical situation. The palatal implant was treated as either NOPI or OPI. The force on the premolars was investigated under three conditions: a distomesial horizontal force, a buccolingual horizontal force, and a vertical intrusive force. The PDL stress was calculated and compared with a model without an implant. The result showed that OPI could reduce PDL stress significantly. (The average stress was reduced by 14.44% for the distomesial horizontal force, 60.28% for the buccolingual horizontal force, and 17.31% for the vertical intrusive force.) The NOPI showed almost the same anchorage effect as OPI. The stress on the NOPI surface was higher than that on the OPI surface, but the stress was not high enough to result in failure of the implant. These results suggested that waiting for osseointegration might be unnecessary for an orthodontic implant.

KEY WORDS: Implant; Anchorage; Finite element analysis

INTRODUCTION

Anchorage is one of the main factors for determining the success of orthodontic treatment. Headgears and Nance appliances are routinely used to establish anchorage during clinical treatment. However, many patients reject headgear wear because of social and esthetic concerns, and the success of this treatment greatly depends on patient cooperation.[1] In most of the studies on Nance appliances, anchorage loss was unavoidable, and reduced hygiene under the acrylic resin button led to inflammation of soft tissues.[2,3]

Advances in implants in general dentistry have made it possible to use them as a means of anchorage in adult orthodontic patients. Some studies[4,5] have shown that dental implants placed in the alveolar bone were resistant to the orthodontic force. However, there is no available site for implant placement because orthodontic patients generally have complete dentition. Thus, some other anatomic locations such as the palatal region have been used as alternative sites.

Block and Hoffman[6] introduced a subperiosteal disc of 10 mm diameter. Keles et al[7] used a screw-type implant with a height of eight mm and a width of 4.5 mm, whereas Wehrbein et al[8,9] introduced a small 3.3-mm-diameter implant with a low to medium four and six mm length. Almost all these studies showed that a palatal implant could offer sufficient anchorage effect.

However, these implants must be loaded after a period of approximately 12 to 24 weeks to allow healing and osseointegration, and waiting for osseointegration is inconvenient for both the orthodontist and patients.

Some studies[10,11] have shown the number of days from implantation to force application is not associated with stability of the implant and recommended imme-

[a] Graduate student, Division of Orthodontics, Graduate School of Medical and Dental Sciences, Niigata University, Niigata, Japan.
[b] Associate professor, Polyclinic Intensive Oral Care Unit, Niigata University Medical and Dental Hospital, Niigata, Japan.
[c] Professor, Meririn College for Dental Technology, Dental Hygiene and Speech, Niigata, Japan.
[d] Professor and chairman, Division of Orthodontics, Graduate School of Medical and Dental Sciences, Niigata University, Niigata, Japan.
Corresponding author: Dr. Fengshan Chen, Division of Orthodontics, Graduate School of Medical and Dental Sciences, Niigata University, 2-5274 Gakko cho-Dori, Niigata 951, Japan (e-mail: chenfengshan@hotmail.com)

Accepted: June 2005. Submitted: February 2005.

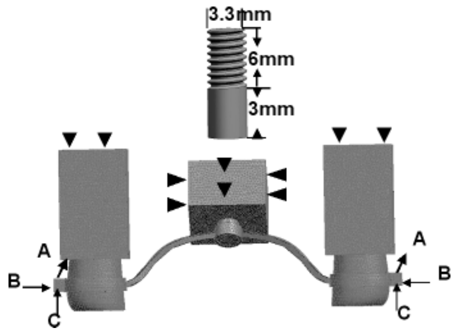

FIGURE 1. Three-dimensional finite element model with implant. The top is the simplified implant model. Boundary conditions were fixed in place (▲). The five-N force was applied at the bracket. (A) Distomesial direction. (B) Buccolingual direction. (C) Vertical intrusive direction.

diate loading to the implant. The possibility of such immediate loading is attributed to the successful Mechanical interdigitation between the implant and the bone. However, it is questionable whether the implant loaded before osseointegration has the same anchorage effect as the implant loaded after osseointegration because the degree of implant osseointegration and direction of force applied have not been well documented in these studies.

It is generally accepted that anchorage is related to periodontal stresses;[12] for an implant to modify anchorage, it must also modify the stress of the periodontal ligament (PDL) of the premolar connected with the palatal implant. Such modifications could result in the redistribution of stress values to a level below the physiologic threshold at which movement is believed to occur. However, it is virtually impossible to measure accurately periodontal stress distribution in vivo.

Finite element analysis (FEA) has become an increasingly useful tool for prediction of the effects of stress on the tissues pertinent to orthodontic force. FEA is a mathematical method in which the shape of complex geometric objects and their physical properties are computer constructed. Physical interactions of various components of the model are then calculated in terms of stress and strain.

The purpose of this study was to compare the anchorage effect of osseointegrated and nonosseointegrated palatal implants (NOPI), using FEA.

MATERIALS AND METHODS

Model

Two models were created in this study. Model 1 (Figure 1) was composed of two maxillary premolars, PDL, alveolar bone, a palatal implant, palatal bone, a bracket, band, and transpalatal arch (TPA). A maxillary second premolar was created by manually designing the tooth according to the dimensions and morphology found in a standard dental anatomy textbook.[13] The outermost boundary of the tooth was defined two dimensionally at first, and sectioning the tooth into cross sections created the third dimension. Three-dimensional coordinates were input into the Unigraphics NX 1.0 (Unigraphic Solutions Inc, Cypress, Calif) to create a CAD model of the tooth. Next, the PDL, alveolar bone, palatal implant, palatal bone, bracket, band, and TPA were created. The bracket, band, and TPA were combined as one connected device to simulate a bracket and TPA welded to the band in the clinic. The PDL width was 0.25 mm, and the alveolar cortical bone was 1.0 mm. A cylinder implant was 3.3 mm in diameter and nine mm in length, and the abutment was three mm long. The subperiosteal part with a thread surface was six mm in length. The TPA was a 0.8 $\times$ 0.8–mm rectangular arch wire;[8,9] the distance between the centers of the two premolars was 42.8 mm. The palatal bone had a cortical surface thickness of 2.0 mm for the oral-palatal cortical bone, a cancellous thickness of 5.5 mm, and a cortical surface of 1.0 mm in the direction of the nasal floor.[14] Model 2 was the same as model 1 but had neither an implant nor palatal bone.

TABLE 1. Nodes and Elements in the Study[a]

	Nodes	Elements
Model 1		
OPI	85,143	403,064
NOPI	90,628	388,070
Model 2	75,455	362,884

[a] OPI indicates osseointegrated palatal implant; NOPI, nonosseointegrated palatal implant.

Elements and nodes

Elements and nodes were created by Unigraphics NX volume mesher. Tetrahedral three-dimensional elements were used in this study. Four-node linear cells were used because they are good at meshing arbitrary geometries.[15] Small elements of similar size were used to mesh the area of interest (PDL, implant) uniformly for the stress analysis (Table 1).

A tooth-band interface and implant-TPA interface were created as a fully bonded surface to simulate the cemented band and fixed contact between the TPA and the implant. Bone-implant interfaces were treated either as fully bonded (osseointegrated implant) or frictional (nonosseointegrated implant) surfaces. A fully bonded surface was achieved by creating common faces at the interface to simulate a condition where the bodies were ‘‘welded’’ or ‘‘glued’’ together, which ensured that the connectivity would be maintained at the interface.[16]

The frictional surface was modeled using nonlinear

TABLE 2. Material Properties for the Constituent Materials

Material	Young's Modulus (MPa)	Poisson's Ratio
Dentin[b]	19,600	0.30
PDL[c]	1	0.45
Cortical bone[b]	13,700	0.26
Cancellous bone[b]	1370	0.30
Steel[d]	193,000	0.30
Titanium pure[d]	107,000	0.30

[a] PDL indicates periodontal ligament.
[b] From Vasquez et al.[18]
[c] From Jones et al.[15]
[d] From Unigraphic user manual.[16]

frictional contact elements, which allow minor displacements between the implant and the bone. The contact zone thus transferred pressure and tangential forces (ie, friction) but no tension. The surface texture of the implants was considered in the analyses by including a Coulomb frictional interface with a coefficient of 0.3. This frictional surface was proved consistent in in vivo data.[17]

Material properties

Each material was defined as homogenous and isotropic. The physical properties of the constituent materials comprising the model were based on a review of the literature[15,16,18] (Table 2).

Constraints and loads

All nodes on the lateral edges of the palatal-bone mesh were fully constrained so that no displacement could occur; on the bottom of the bone volume, no restrictions to the nodal displacements were imposed, allowing the bone to bend.[19] The boundary conditions were fixed at the base of the alveolar bone.[20,21]

The force on the premolars was investigated under three conditions: a distomesial horizontal force, a buccolingual horizontal force, and a vertical intrusive force. The magnitude of force was five N.

Von Mises stress (kPa) was calculated and presented in colorful contour bands. Von Mises stress was selected because it is a scalar quantity that includes all components of the stress tensor and allows a comprehensive comparison between models.[22]

RESULTS

Because there was no significant difference on stress magnitude and distribution between the right and left PDL in all models, the left premolar was extracted to compare PDL stress. Stress magnitudes were denoted by a series of colors, as shown in the spectrum display to the right of the plot. In all cases, the greatest point of interest lay in the stresses produced in the PDL in the direction of the force application.

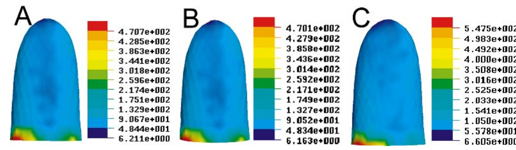

FIGURE 2. Von Mises stress in the mesial periodontal ligament of the left maxillary second premolar subjected to a five-N distomesial force. (A) With osseointegrated implant. (B) With nonosseointegrated implant. (C) Without implant.

TABLE 3. Maximum PDL Stress (MPS) and Average PDL Stress (APS)[a]

	Model 1 With OPI[b]	Model 1 With NOPI[b]	Model 2
Distalmesial direction			
MPS (kPa)	513.23 (15.46%)*	509.24 (16.19%)*	607.67
APS (kPa)	129.81 (14.44%)*	131.25 (13.49%)*	151.72
Buccallingual direction			
MPS (kPa)	145.55 (54.74%)*	147.35 (54.19%)*	321.62
APS (kPa)	35.11 (60.28%)*	36.12 (59.14%)*	88.41
Vertical intrusive direction			
MPS (kPa)	487.21 (16.51%)*	489.26 (16.01%)*	582.51
APS (kPa)	70.09 (17.31%)*	71.02 (16.22%)*	84.77

[a] PDL indicates periodontal ligament; OPI, osseointegrated palatal implant; and NOPI, nonosseointegrated palatal implant.
[b] ( )*: The reduced stress percentage when the model was compared with model 2.

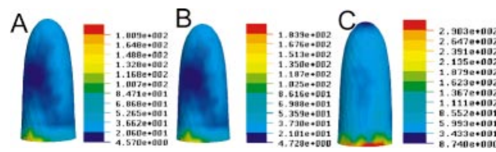

FIGURE 3. Von Mises stress in the lingual periodontal ligament of the left maxillary second premolar subjected to a five-N buccolingual force. (A) With osseointegrated implant. (B) With nonosseointegrated implant. (C) Without implant.

Figure 2 shows PDL stress when the premolars were subjected to the five-N distomesial horizontal force. In each model, the highest stress was in the PDL at the cervical margin. The location of the maximum stress was not changed by the implant. The stress decreased toward the apex, and it was almost the same in the models with the implant. The maximum PDL stress (MPS) and average PDL stress (APS) were 607.67 and 151.72 kPa, respectively, in model 2. The stress was reduced more than 13% by the implant (Table 3). APS is the average stress of all nodes in the PDL (Unigraphic software can calculate average stress in a solid body).

Figure 3 shows PDL stress when the premolars were subjected to the five-N buccolingual horizontal

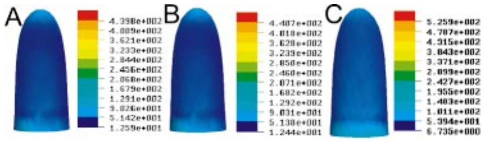

FIGURE 4. Von Mises stress in the buccal periodontal ligament of the left maxillary second premolar subjected to a five-N vertical intrusive force. (A) With osseointegrated implant. (B) With nonosseointegrated implant. (C) Without implant.

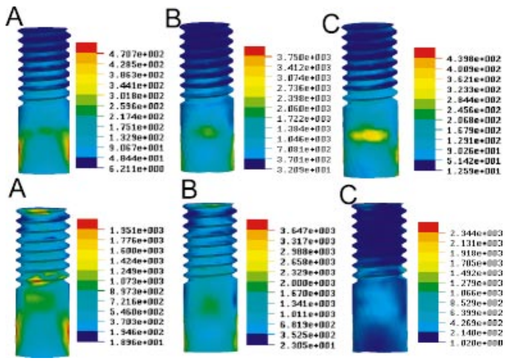

FIGURE 5. Von Mises stress in the implant. The top shows osseointegrated implants; the bottom shows nonosseointegrated implants. (A) Distomesial force. (B) Buccolingual force. (C) Vertical intrusive force.

force. In each model, the highest stress was in the PDL at the cervical margin. The stress decreased sharply toward the apex, and again it was almost the same in the models with implant. MPS and APS for model 2 were 321.62 and 88.41 kPa, respectively. The APS was reduced about 60% by the implant (Table 3).

Figure 4 shows PDL stress when the premolars were subjected to the five-N vertical intrusive force. In each model, the highest stress was in the PDL at the cervical margin. The stress decreased sharply toward the apex, and again it was almost the same in the models with the implant. MPS and APS for model 2 were 582.51 and 84.77 kPa, respectively. The stress was reduced about 16% by the implant (Table 3).

Figure 5 shows stress in the implant-bone interface. The difference in the maximum stress in the NOPI and the osseointegrated palatal implant (OPI) was less than 5% for the horizontal force, whereas the maximum stress in NOPI was far higher than OPI for the vertical force. The average stress in NOPI was far higher than that in OPI (Table 4).

DISCUSSION

The purpose of this investigation was to use a finite element analysis to compare the anchorage effect of palatal osseointegrated and nonosseointegrated implants, under a horizontal and vertical force. To accomplish this analysis, osseointegrated and nonosseointegated bone-implant interfaces were constructed separately in the same model. The same boundary condition was used for alveolar bone; the same size and type element were created for the same material; the same mesh refiner was performed in the same place until the percentage error of the resultant stress was lower than 5%, which is the widely accepted level of confidence for the stress percentage error.[16] The resultant stress in a model without an implant was compared with stress produced in the model with implants.

TABLE 4. Maximum Stress and Average Stress in the Implant

	Distomesial Force	Bucco-lingual Force	Vertical Intrusive Force
Osseointegrated implant			
Maximum stress (kPa)	2,258.11	4,163.33	487.22
Average stress (kPa)	295.05	528.81	117.69
Nonosseointegrated implant			
Maximum stress (kPa)	2,166.23	4,049.18	2,604.12
Average stress (kPa)	1,094.16	2,065.78	586.89

The limitations of our model included an approximation in the material behavior and shapes of the tissues. As in previous studies,[21,23] the PDL was modeled as a 0.25 mm layer of uniform thickness and was treated as linear elastic and isotropic, although the PDL exhibits anisotropy and nonlinear viscoelastic behavior because of tissue fluids.[24] The PDL value was selected because it agreed with human tooth movement.[15] The tooth was simplified as a homogeneous body without tips because the force transmitted to the PDL was not significantly affected by adding the internal and external tooth structure.

Palatal-bone height (two mm in oral-palatal and one-mm nasal-palatal cortical bone, and 5.5-mm cancellous bone thickness) has been proved suitable for biomechanical investigations with regard to anatomical structures and deformation under stress.[14] In this study, the bone size, 12 $\times$ 12 mm, was decided by trial runs. Modeling the palatal bone greater than 12 $\times$ 12 mm did not result in any significant change of the stress (5% as the criteria).

OPI assumed that a 100% implant-bone interface was established.[21] However, the percentage of direct bone-to-implant contact varied from 34% to 93%, with an average value of 75.5%.[9] A 100% bone apposition was almost never obtained at the surface of the dental implant.[25] The boundary condition was assumed fixed at the base of the alveolar bone[20,21] and all nodes on the lateral edges of the palatal bone[19] because there was no agreement for giving a boundary condition for bone segments.

In each model, the highest stress concentration in the PDL was localized at the cervical margin. This might be because of the fact that the orthodontic force was applied in the buccal bracket of each premolar. Because the line of force was not through the center of resistance of the tooth, the tooth exhibited a tipping movement. These findings were essentially consistent with previous studies.[18,26]

The implant markedly reduced the stress of the PDL. In engineering terms, an implant acts like a bar elastically supported by the surrounding bone. The anchorage loads were transmitted from the tooth to the implant because of the rigid connection of the TPA. In this study, the differences in stress were less than 2% between the model with OPI and the model with NOPI, and the stress distribution was the same for the same direction of force. If one accepts the premise that orthodontic anchorage is based on periodontal stress and 5% as a criterion to indicate significance, then the results of this study suggest that osseointegration does not serve to enhance the anchorage effect.

Osseointegration can lead to lower stress in the implant-bone interface (Figure 5). This can be explained by the observation that the stress was withstood by more bone in OPI than that in NOPI. It is interesting to note that the MPS in the implant-bone interface is almost same for horizontal forces. This might be because of the local shape of the element. Although the stress in the NOPI surface is higher than that in the OPI surface, it is important to point out that both of these are of such low magnitude that they are unable to produce a failure in the implant.[18] Therefore, the NOPI is able to function as adequate anchor units as is the OPI.

An orthodontic load is usually made up of continuous, horizontal forces of low value (from 20 or 40 g to a few hundred). The orthodontic implant is used only in the early stages of treatment. According to our results, it is reasonable to conclude that there is no need to wait for osseointegration. The anchorage effect of a palatal implant might be related more to the diameter and the length of the implant, the quality of the bone, and the rigidity of TPA rather than the degree of osseointegration.

Mellal et al[17] compared osseointegrated and nonosseointegrated implants, using models which included only bone and implants; they also found that the stress in the nonosseointegrated implant surface was higher than that in the osseointegrated implant when the implant was subjected to the same force.

Histologic analyses[27,28] also found that nonosseointegration did not compromise the clinical stability of the implant during treatment. The authors also consider nonosseointegration favorable because it can facilitate surgical removal of the implant at the end of treatment.

Some points, such as the biomechanical nature of the osseointegrated lamellar bone and the process of bone remodeling, remain to be determined when using a palatal implant to provide anchorage. This study is only a primary one. In the future, additional accurate models should be created. However, this analysis does provide quantitative results of the complex three-dimensional stress caused by different orthodontic loads. It allows comparisons of the anchorage effect of OPI with NOPI primarily, and these are considered to be relevant in understanding the implant as an anchorage unit. It should be noted that this theoretical study, which has no empirical basis for clinical application, involved some assumptions; the findings may be changed if the assumptions were unrealistic. Therefore, the resulting values should be interpreted only as a reference to aid clinical judgment.

CONCLUSIONS

A model with a different implant-bone interface was compared with a model without an implant. According to the FEA, the implant significantly lowered the PDL stress. OPI and NOPI showed the same anchorage effect. It is suggested that waiting for osseointegration might be unnecessary for an orthodontic implant.

REFERENCES

1. Egolf RJ, BeGole EA, Upshaw HS. Factors associated with orthodontic patient compliance with intraoral elastic and headgear wear. *Am J Orthod Dentofacial Orthop.* 1990;97:336–348.
2. Bondemark L, Kurol J. Distalization of maxillary first and second molars simultaneously with repelling magnets. *Eur J Orthod.* 1992;14:264–272.
3. Keles A, Sayinsu K. A new approach in maxillary molar distalization: intraoral bodily molar distalizer. *Am J Orthod Dentofacial Orthop.* 2000;117:39–48.
4. Chen J, Chen K, Garetto LP, Roberts WE. Mechanical response to functional and therapeutic loading of a retromolar endosseous implant used for orthodontic anchorage to mesially translate mandibular molars. *Implant Dent.* 1995;4:246–258.
5. Melsen B, Lang NP. Biological reactions of alveolar bone to orthodontic loading of oral implants. *Clin Oral Implants Res.* 2001;12:144–152.
6. Block MS, Hoffman DR. A new device for absolute anchorage for orthodontics. *Am J Orthod Dentofacial Orthop.* 1995;107:251–258.
7. Keles A, Erverdi N, Sezen S. Bodily distalization of molars with absolute anchorage. *Angle Orthod.* 2003;73:471–482.
8. 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.
9. Wehrbein H, Merz BR, Hammerle CH, Lang NP. Bone-to-implant contact of orthodontic implants in humans subjected to horizontal loading. *Clin Oral Implants Res.* 1998;9:348–353.
10. Park HS. *The Orthodontic Treatment Using Micro-implant: The Clinical Application of MIA (Micro-implant Anchorage).* Seoul, Korea: Narae Publishing; 2002:15–21.

11. Takano-Yamamoto T, Miyawaki S, Koyama I. Can implant orthodontics change the conventional orthodontic treatment? *Dent Diamond.* 2002;27:26–47.
12. Proffit WR. *Contemporary Orthodontics.* St Louis, Mo: CV Mosby; 1986:227–245.
13. Scott JH, Symons NBB. *Introduction to Dental Anatomy,* 8th ed. Edinburgh, UK: Churchill Livingstone; 1977:75.
14. Gedrange T, Bourauel C, Kobel C, Harzer W. Three-dimensional analysis of endosseous palatal implant and bones after vertical, horizontal, and diagonal force application. *Eur J Orthod.* 2003;25:109–115.
15. Jones ML, Hickman J, Middleton J, Knox J. A validate finite element method study of orthodontic tooth movement in the human subject. *J Orthod.* 2001;28:29–38.
16. Unigraphic solutions Inc. *User manual*. Cypress, Calif: Unigraphic Solutions Inc; 2002:212–270.
17. Mellal A, Wiskott HW, Botsis J, Scherrer SS. Stimulating effect of implant loading on surrounding bone comparison of three numerical models and validation by in vivo data. *Clin Oral Implants Res.* 2004;15:239–248.
18. Vasquez M, Calao E, Becerra F, Ossa J. Initial stress difference between sliding and sectional mechanics with an endosseous implant as anchorage: a 3-dimensional finite element analysis. *Angle Orthod.* 2001;71:247–256.
19. Van Oosterwyck H, Duyck J, Vander Sloten J, Vander Perre G. The influence of bone mechanical properties and implant fixation upon bone loading around oral implant. *Clin Oral Implants Res.* 1998;9:407–418.
20. Bobak V, Christiansen RL, Hollister SJ, Kohn DH. Stress-related molar responses to the transpalatal arch: a finite element analysis. *Am J Orthod Dentofacial Orthop.* 1997;112:512–518.
21. Chen FS, Terada K, Hanada K. Anchorage effect of various shape palatal osseointegrated implants: a finite element study. *Angle Orthod.* 2005;75:378–385.
22. Tada S, Stegaroiu R, Kitamura E, Miyakawa O, Kusakari H. Influence of implant design and bone quality on stress/strain distribution in bone around implants: a 3-dimensional finite element analysis. *Int J Oral Maxillofac Implants.* 2003;18:357–368.
23. Tanne K, Nagataki T, Inoue Y, Sakuda M, Burstone CJ. Patterns of initial tooth displacements associated with various root lengths and alveolar bone heights. *Am J Orthod Dentofacial Orthop.* 1991;100:66–71.
24. Toms SR, Eberhardt AW. A nonlinear finite element analysis of the periodontal ligament under orthodontic tooth loading. *Am J Orthod Dentofacial Orthop.* 2003;123:657–665.
25. Cochran DL. The scientific basis for and clinical experiences with Straumann implant including the ITI dental implant system: a consensus report. *Clin Oral Implants Res.* 2000;11:33–58.
26. McGuinness N, Wilson AN, Jones M, Middleton J, Robertson NR. Stresses induced by edgewise appliances in the periodontal ligament—a finite element study. *Angle Orthod.* 1992;62:15–22.
27. Costa A, Raffainl M, Melsen B. Miniscrews as orthodontic anchorage: a preliminary report. *Int J Adult Orthod Orthognath Surg.* 1998;13:201–209.
28. Melsen B, Verna C. A rational approach to orthodontic anchorage. *Prog Orthod.* 1999;1:10–22.