Stress Distribution in Reduced Periodontal Supporting Tissues Surrounding Splinted Teeth

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The aim of this study was to analyze the distribution of occlusal stresses for splinted and nonsplinted mandibular anterior incisors and to compare different splinting materials. A mandibular model was generated from a patient's computed tomography scan using three-dimensional (3D) software. The mandibular model presented with four periodontally compromised incisors and two canines with optimal bone support (two-thirds crown-root ratio). Three different splint materials (composite resin, metal-reinforced, and fiber-reinforced) were selected. Vertical and transverse loads were applied, and stress levels around the periodontal structures and splint materials were analyzed with 3D finite element analysis. The results showed that when bone levels around teeth decreased, the stress on the canine increased. Tested splinting materials were successful in stress distribution, and metal was better than the other splinting materials at distributing the stresses. (Int J Periodontics Restorative Dent 2014;34:e93–e101. doi: 10.11607/prd.1899)

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Periodontal disease is considered to be an inflammatory disease caused by the interaction between bacterial plaque and a host response.[1–3] As a result of the inflammatory periodontal process there is disorganization of periodontal fibers, induction of bone resorption, and destruction of epithelial cell attachment.[4] Occlusal forces also play a role in this process. Occlusal forces may exacerbate a preexisting periodontal lesion.[5,6] In cases of frequent loading, there may be insufficient time for bone remodeling, resulting in bone resorption.[7] Reduced periodontal attachments can result in tooth mobility and migration, causing misaligned occlusal forces that hinder the balance between bone resorption, bone remodeling,[8] and reorganization of periodontal fibers.[9]

Periodontal disease and occlusal trauma are most prevalent in the mandibular incisor region. Although occlusal forces are lower in the mandibular incisor region compared with the mandibular canine and molar regions,[10–13] stress levels might be higher due to reduced bone thickness.

Table1 Study group configurations

Configuration	Description	Bone levels (%)			Loading (N) Transverse	Vertical
1	Six teeth; no splinting	40	70	100	100	100
2	Six teeth; composite resin splinting	40	70	100	100	100
3	Six teeth; metal-reinforced splinting	40	70	100	100	100
4	Six teeth; fiber-reinforced splinting	40	70	100	100	100

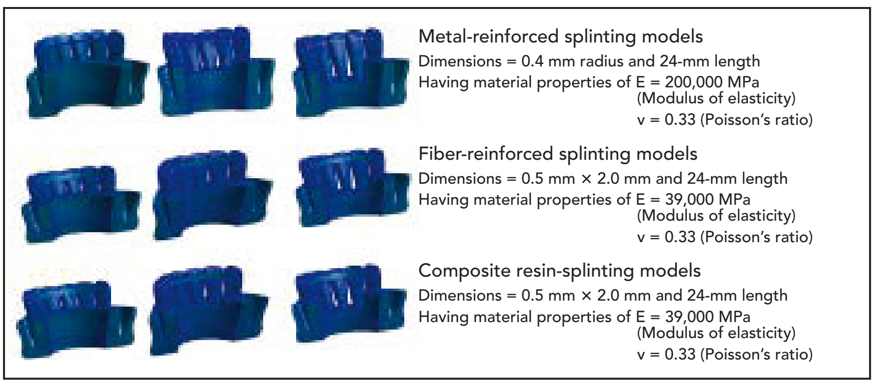


Fig 1 *Study models and splinting cross-sectional properties.*

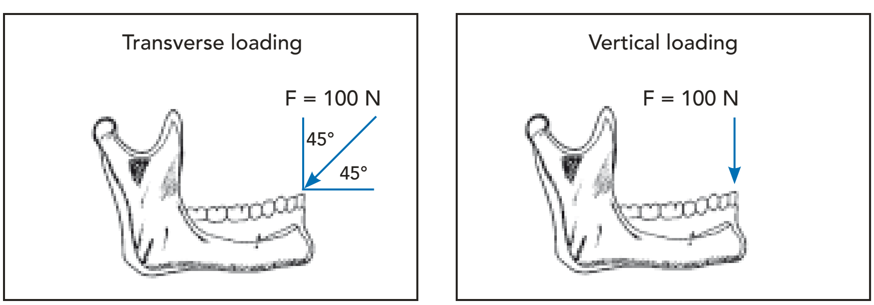


Fig 2 *Loading conditions. F = force.*

Treatment of tooth mobility in periodontal disease is a combination of periodontal therapy, occlusal adjustments, and tooth restraints for stability.[1,14] Stability accomplished by periodontal splinting redistributes functional and parafunctional forces.[7] This helps the process of reorganization of the gingival tissues, periodontal fibers, and alveolar bone, thus maintaining patient comfort.[4,5,15]

Various techniques have been used for periodontal splinting: composite resin in combination with adhesive systems, orthodontic wire, orthodontic wire in combination with composite resin, and fiber-reinforced composite in combination with composite resin.

However, in some advanced cases of periodontal compromise, instead of splinting teeth, other options such as extraction with fixed partial denture placement or bone augmentation with implant restorations should be considered. Determination of the threshold for splinting periodontally compromised teeth versus extraction and restoration would be helpful to clinicians during treatment planning.

The objectives of this study were to analyze the distribution of occlusal stresses for splinted and nonsplinted mandibular anterior incisors and to compare different splinting materials at different bone levels using nonlinear finite element analysis (FEA).

Method and materials

The study was conducted under four different configurations. The material and cross-section properties of the splinting configurations are displayed in Table 1 and Fig 1, respectively. Each configuration was analyzed with 100%, 70%, and 40% mandibular bone resorption levels under two different loading conditions defined as 100 N vertical and 100 N transverse loading on each tooth crown (Fig 2).

All three bone resorption levels were investigated under the conditions of nonsplinted tooth orientation and splinted tooth orientation with three different splint materials. All the results were grouped according to loading and reinforcing boundary conditions and the effect of loading direction; bone level and splinting performances were investigated by stress comparison.

Three-dimensional (3D) complex tooth and mandible computer-aided design models were scanned and numerically modeled with the help of Rhinoceros 4.0 (McNeel) software, and the data was transferred to Patran (MSC) software, which is used as a graphic user interface in order to build 3D finite element models of the teeth and mandibular bone. Static nonlinear analyses were performed on Nastran 2007r1 (MSC) and MARC 2008 (MSC) commercial FEA software that uses Direct Matrix Abstraction Programming (DMAP).

When generating the models, three bone resorption configurations were used for each splinting material, as seen in Table 1. In total, 12 separate models were generated for the analysis. Each model consisted of 165,000 to 186,200 tetrahedral 3D elements connected by a total of 37,500 to 38,800 nodes.

The generated models were grouped based on their material properties, and every element was designated according to its material characteristics, as defined in Table 2.

For static analysis, the realistic boundary condition has to be defined to react to the loads. The configurations in the study are constrained from the mandibular regions that simulate the boundary conditions most similar to the anatomical constraints. The interface between mandibular bone and teeth was numerically solved with MARC using nonlinear contact conditioning.

In this study, the static stress results are stated and compared as minimum principal stress. In strength analysis, this maximum 3D stress estimation method can be defined as the maximum/minimum combination of 3D tensile/compression stresses and shear stresses occurring in three dimensions as seen in Fig 3.

Table 2 Material properties

Material	Young modulus (MPa)	Poisson ratio	Shear modulus (MPa)	References
Dentin	18.60	0.31		Ko et al, 1992[16]
Enamel	41.00	0.30		Ko et al, 1992[16]
Spongy bone	1.37	0.30		Ko et al, 1992[16]
Cortical bone	13.70	0.30		Ko et al, 1992[16]
Steel wire	17.9×10^4	0.33		Geramy et al, 2012[17]
Hybrid composite	2.20×10^4	0.27		Yokoyama et al, 2012[18]
Glass fiber				
Longitudinal	X 3.90×10^4	X 0.35	X 1.40×10^4	Yokoyama et al, 2012[18]
Transverse	Y 1.20×10^4	Y 0.11	Y 0.54×10^4	Yokoyama et al, 2012[18]
Transverse	Z 1.20×10^4	Z 0.11	Z 0.54×10^4	Yokoyama et al, 2012[18]

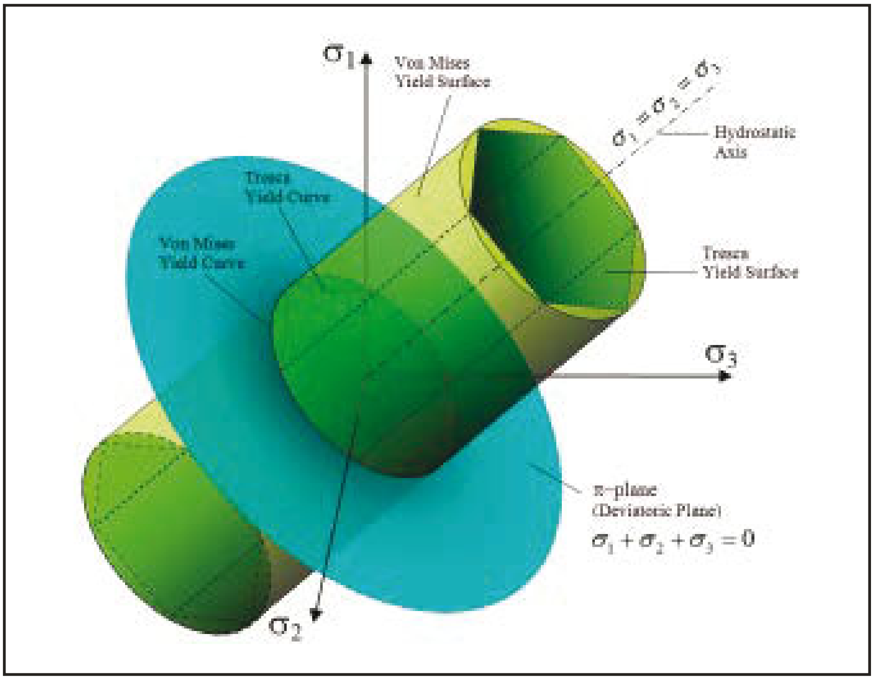


Fig 3 *The von Mises stress resultant vector in principal stress coordinates. ©2007 by Sanpaz at the English language Wikipedia. This image is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license.*

Results

Minimum principal stress results for the nonsplinted model are displayed in Fig 4. In the nonsplinted model, stress to the canines does not change with incisor alveolar

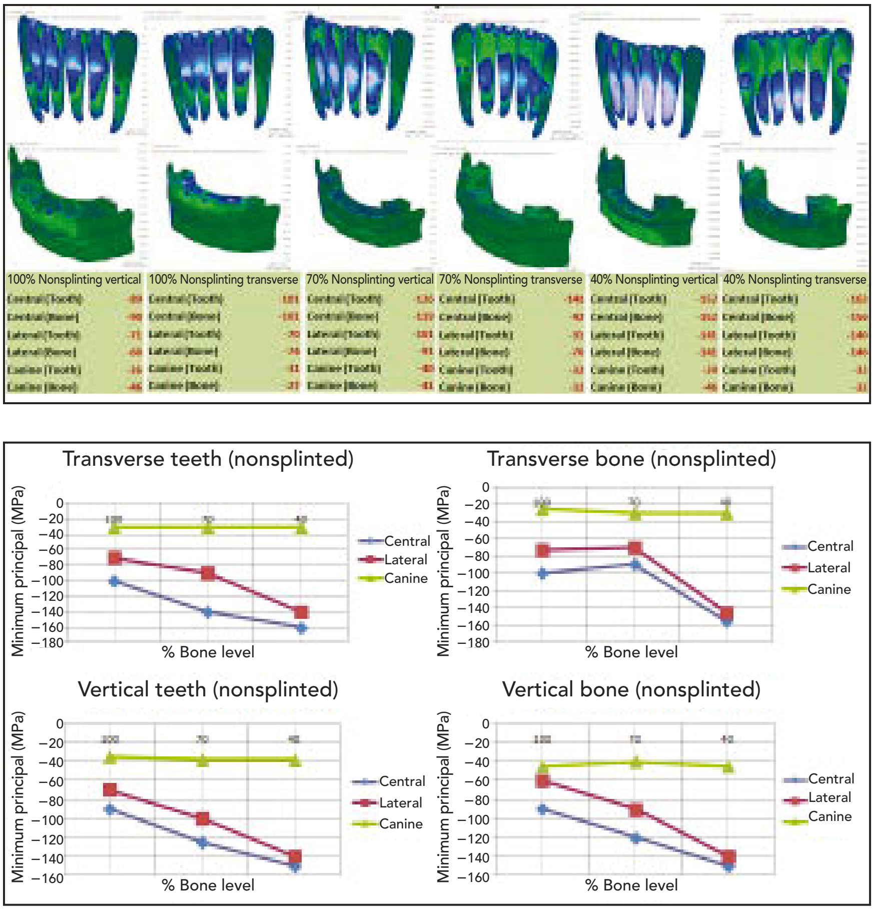


Fig 4 (a and b) *Stress states on teeth and bone with no splinting under transverse and vertical loading at 100%, 70%, and 40% bone levels.*

bone loss, whereas central incisor bone stress decreases from –100 to –160 MPa under transverse loading and decreases from –90 to –150 MPa under vertical loading (see Fig 4b). Minimum principal stresses are displayed in Fig 5 for metal-reinforced splint, Fig 6 for composite resin splint, and Fig 7 for fiber-reinforced splint. In the metal-reinforced model, due to the load transfer, canine stress decreases from –75 to –150 MPa under transverse loading and decreases from –40 to –150 MPa under vertical loading (see Fig 5b). All stress levels under vertical and transverse loading are displayed in Fig 8. In composite resin and fiber-reinforced models, the load-carrying capability of the splint decreases due to the lower modulus of elasticity compared with the metal-reinforced model (see Fig 8).

Discussion

Rehabilitation of masticatory ability in patients with bone loss is a challenging procedure in dentistry.[19] Extraction of teeth and replacement with complete dentures or implant-supported prostheses may not always be the best treatment option for severely advanced periodontal destruction. Splinting or periodontal treatment may be a more appropriate method to regain and maintain proper function in situations where periodontal tissue support is reduced.[19]

Therefore, it is very important to assess whether dental splinting would prevent further bone loss, and at which bone level it has to be applied to make the teeth function properly. In addition, splinting material selection is very important for creating an appropriate splint application with the optimal perfor-

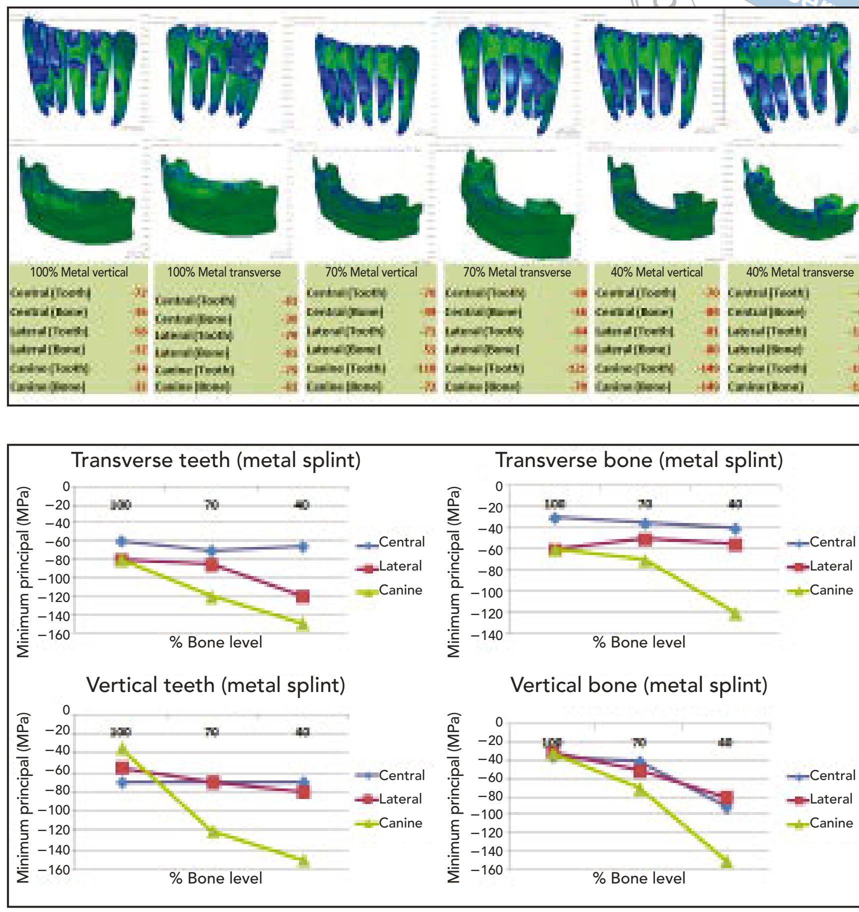


Fig 5 (a and b) *Stress states on teeth and bone with metal-reinforced splint under transverse and vertical loading at 100%, 70%, and 40% bone levels.*

mance to transfer occlusal loads to teeth and supporting tissues without creating excessive stress. Accordingly, the results of this study may help clinicians select the optimal material for splinting and the bone level at which the splinting method works effectively.

The stresses on bone and splinting materials under vertical and transverse loads were stated as minimum principal stress scales and in units of MPa in this study. Since the sections of extreme stress are the contact areas of tooth and bone models, the minimum principal stresses are dominant in the results. To estimate minimum principal stresses on teeth and bone, the Mohr-Coulomb principal stress approach has been used because this approach is more appropriate for nonductile materials. The critical stresses of teeth under occlusal loads are estimated as contact stresses in this study.

According to the results of this study, an increased stress state was observed on mandibular bone and the teeth from 100% bone level to 70% and 40% on nonsplinted models. This is an expected result.[20] Because the tooth loses bone support, the load applied could create higher moment due to increased loading moment arm. Reduced bone support could create higher coupling reaction forces, as seen in the results (see Fig 4).

The applied load on incisors was selected as 100 N for the analysis, since the maximum occlusal load on incisors were reported to vary between 40 and 200 N.[10] A 100-N load level is within physiologic limits.

At 70% bone level and under vertical loading, the stress on the central incisor decreases 44% when metal splinting is compared to nonsplinted conditions. The stress drop is about 28% in composite

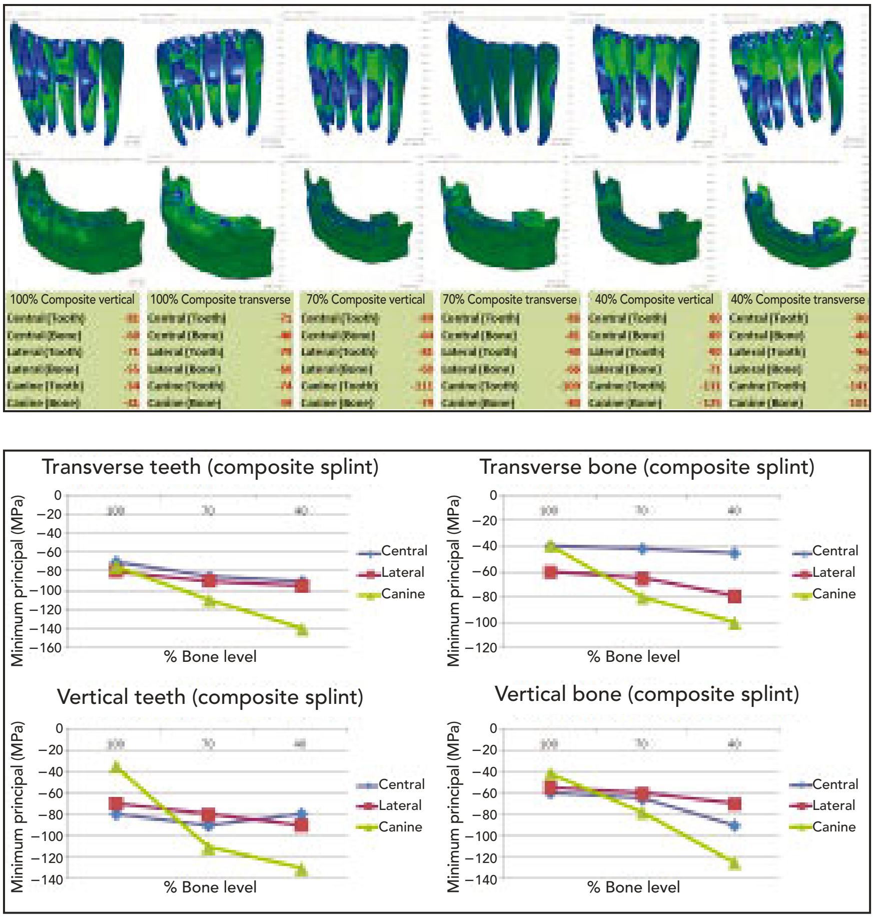


Fig 6 (a and b) *Stress states on teeth and bone with composite splint under transverse and vertical loading at 100%, 70%, and 40% bone levels.*

resin and fiber-reinforced splinting conditions. If the lateral incisor is evaluated, the stress drop is 44% in metal-reinforced and 36% and 28% in composite resin and fiber-reinforced splinting conditions, respectively. On the other hand, the stress increase on the canine is 216% with metal reinforcement and approximately 190% with composite resin and fiber reinforcement options.

At the same 70% bone level, under transverse loading, the stress level on the central incisor is shown to decrease 50% in metal reinforcement but 39% and 36% in composite resin and fiber reinforcement conditions, respectively. The stress level did not change in composite reinforcement, and there was a 5% increase in fiber and 5% decrease in metal reinforcement when the stress is compared with a nonsplinted condition. The estimated stress on the canine was increased 267% in composite resin and fiber reinforcement when compared with a nonsplinted configuration, and it was shown to be 300% in the metal reinforcement configuration. According to these results, it can be stated that the load transfer from central and lateral incisors toward the canine by metal reinforcement is higher compared with the other alternatives.

For a nonsplinted model, according to the fact that high stress in the contact areas accelerates the bone loss,[20] and because the bone loss increases stress, the phenomenon causes an exponential increase of stress in the critical areas. Therefore a material failure and tooth loss may be inevitable in case of no dental intervention.

This study showed that under loads, the stress on central and lateral incisors with reduced bone support due to periodontal reasons

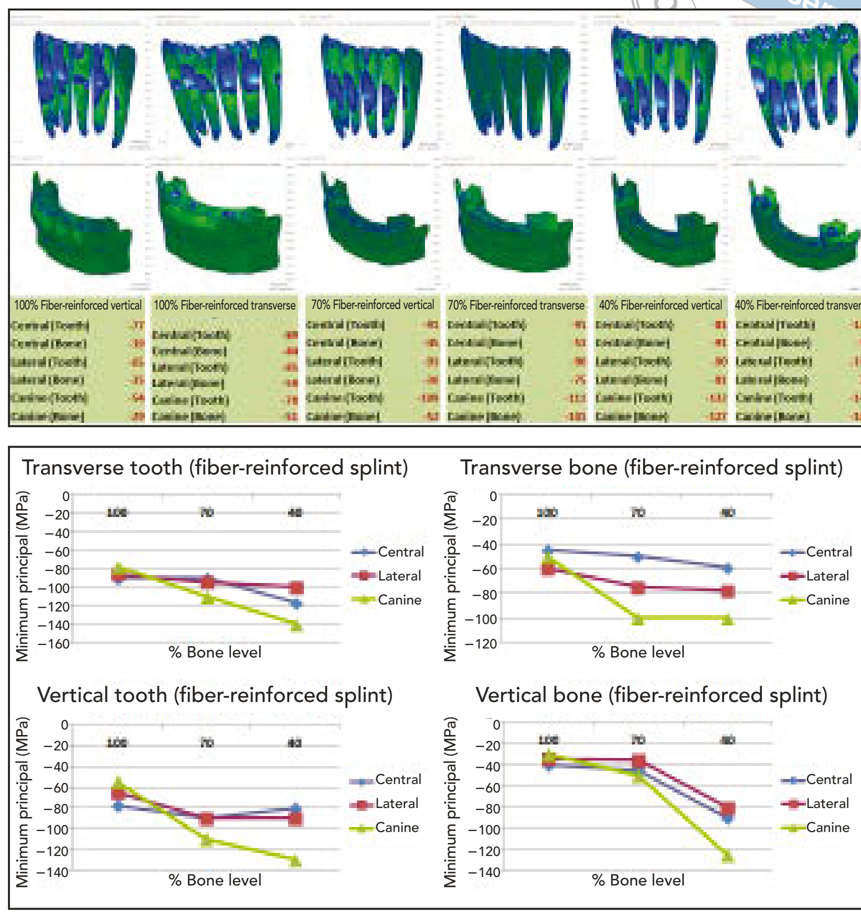
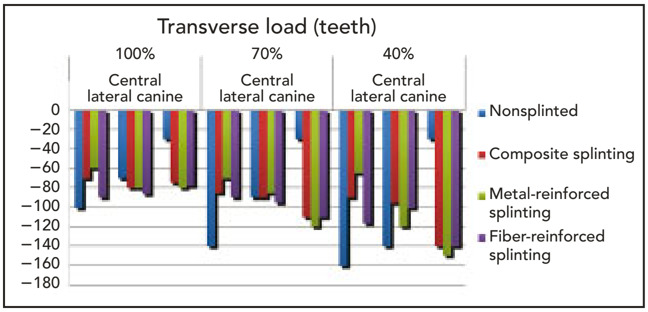


Fig 7 (a and b) *Stress states on teeth and bone with fiber-reinforced splint under transverse and vertical loading at 100%, 70%, and 40% bone levels.*

was reduced with the help of splinting. However, there is a collateral effect of this splinting, which is the increase of stress on the canine. When the stress on each splinted tooth was compared, it was observed that the stress on the central incisor is significantly decreased. There was no significant difference in stress on the lateral incisor; however, there was a stress increase observed on the canine due to the load transfer from the central incisor to the canine.

According to the current results, there is a stress increase in canines and bone for all splint materials up to a 40% bone level. Beyond a 40% bone level, the stress state of the canine usually exceeds the nonsplinted central incisor stress, and the destruction of the canine begins. At a 40% bone level, when metal, composite resin, and fiber splinting materials were applied, the stresses on the canine under vertical loads are –149, –131, and –132 MPa, respectively. The stresses under transverse loading are –148, –141, and –141 MPa, respectively. At a 40% bone level with no splinting, the stress occurring on the canine is –39 MPa under vertical loading and –32 MPa under transverse loading. According to these results it can be stated that the load transfer with all splinting materials increased approximately 380% under transverse loads and 270% under vertical loads compared with a nonsplinted model. In this case, extractions and prosthetic applications can be suggested.

The change in load transfer and stress states in the steel wire splinting group demonstrates that its optimal stress distribution may be because of its stiffness due to a higher modulus of elasticity of the material. In physics, if a force balance



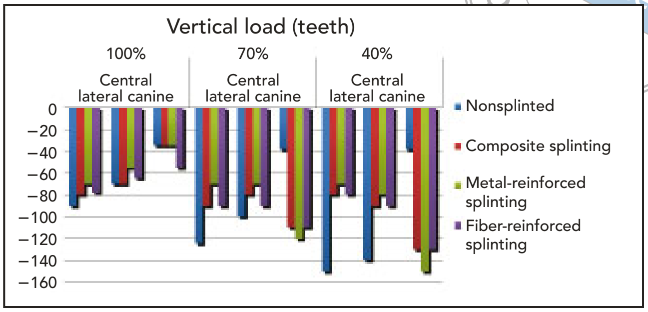


Fig 8 *Comparison of stress on teeth under vertical and transverse loads in 100%, 70%, and 40% bone level conditions for different splint materials.*

is statically indeterminate, the stiffness of the supporting structures play a crucial role in the load path.[21] The bone support and splinting of teeth create a statically indeterminate force balance. Because the stiffness of the support is directly proportional to the ratio of the load-carrying capacity of the support interfaces, naturally, stiffer splinting material would tend to transfer more reaction force. Another property that waffects the stiffness is the cross-sectional area of the support interface. When the cross-sectional area of steel wire splinting is compared to that of other materials, steel has 50% percent less cross-sectional area but 400% higher modulus of elasticity and stiffness. Due to these facts, according to the results, less stress was observed on the central and lateral incisors supported by the wire material splinting compared with other alternatives. The greater stress levels on canines may be due to a high load transfer capability of the wire. According to the comparisons presented in these four graphs (Figs 4b, 5b, 6b, 7b), it can be generally stated that as the splint became stiffer, a better load transfer was seen in the analysis. Accordingly, since the modulus of elasticity of metal splinting is significantly higher than that of the composite resin and fiber splinting, better load transfer performance was observed in this study.

Fatigue and endurance of the splinting material as well as ease of application and cost factors, which play an important role in selecting splinting materials, are outside of the scope of this study. The clinical performance of different splinting materials should be evaluated in future studies.

Conclusions

Bone loss in the anterior mandible increased the stress on the teeth and the remaining bone. Because metal is stiffer than composite resin and fiber, it had a better load transfer performance. With 100% and 70% bone levels, all the splint materials were effective in distributing the loads on splinted teeth. However, at a 40% bone level, the stress on splinted teeth increases, particularly on the canine.

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