ORIGINAL ARTICLE AJO-DO

Root damage and repair in patients with temporary skeletal anchorage devices

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Introduction: The aim of this study was to evaluate the reparative potential of cementum histologically after intentional root contact with a temporary skeletal anchorage device. **Methods:** Seventeen patients (8 male, 9 female; mean age, 16.2 years; range, 13.5-21.6 years) who were scheduled for extraction of 4 first premolars as part of their orthodontic treatment participated in this study. The roots of the premolars were intentionally injured with a temporary skeletal anchorage device. The teeth were extracted at 4, 8, or 12 weeks after the injury. Root contact with the temporary skeletal anchorage device was confirmed by using a stereomicroscope. Histologic samples were prepared. Demineralized serial sections were stained with eosin and hematoxylin, and cementum repair was assessed histomorphometrically. **Results:** Despite varying depths of the injuries, including involvement of dentin, reparative cementum formation was observed in all sections. Healing cementum was almost exclusively of the cellular type; 70% of all the teeth exhibited good repair by the end of week 12. **Conclusions:** This study established that healing of cementum takes place after an injury with a temporary skeletal anchorage device, and it is a time-dependent phenomenon. (Am J Orthod Dentofacial Orthop 2012;141:547-55)

Temporary skeletal anchorage devices have become popular adjuncts in clinical orthodontics because they offer several advantages, including sufficient anchorage for noncompliant patients, simplicity of insertion and removal, relatively low cost, and versatility in clinical applications.[1-5]

The ability to obtain absolute anchorage through bone-anchored devices has enabled orthodontists to eliminate the unwanted side effects associated with conventional approaches and to correct malocclusions that previously required complicated biomechanics or orthognathic surgery.[6]

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Although these devices are available in several sizes and shapes, the most popular and widely used temporary skeletal anchorage device appears to be the miniscrew.[7] They can be placed in several convenient locations, and the most preferred site appears to be the interradicular bone between the roots of adjacent teeth; however, placement carries with it the risk of iatrogenic damage to the adjacent roots. Root damage can occur from either improper placement of the temporary skeletal anchorage device,[8] migration after loading,[9,10] axial deviation during insertion,[11] anatomic variation in root form,[12] or tooth contact with the temporary skeletal anchorage device during orthodontic treatment.[13] Although the literature includes case reports highlighting various clinical applications of temporary skeletal anchorage devices, there is little information regarding iatrogenic damage to tooth roots that are injured during their placement or use.

Asscherickx et al[14] conducted experiments on beagle dogs and reported that healing takes place in approximately 12 weeks after root damage with temporary skeletal anchorage devices, and healing was nearly complete after 20 weeks. In a classic animal study, Chen et al[15] found higher failure rates when temporary skeletal anchorage devices contacted the roots. They also reported repair of roots by cementum deposition and bone regeneration when the temporary skeletal anchorage devices were removed and the roots were allowed to heal.

Both of these studies were in animals, and it is questionable whether the same outcomes can be extrapolated to humans. The best information on root damage and subsequent healing in human subjects emanates from studies pertaining to the use of small screws for the fixation of mandibular fractures and osseous segments placed during maxillofacial surgery.[16-20] Although fixation screws are similar to the temporary skeletal anchorage devices used in orthodontics, they are usually not placed in interradicular areas.

Few clinical studies have addressed damage to the roots either during or after temporary skeletal anchorage device placement.[13,21] This information is limited to case reports or case-series studies, often without sufficient sample sizes. To our knowledge, no study has assessed cementum repair after root contact with temporary skeletal anchorage devices in humans. In view of the current evidence, it is logical to assume that only partial repair occurs after injury with temporary skeletal anchorage devices. This research was designed to validate this hypothesis.

The aims of this prospective study were to establish the healing potential of the root cementum histologically and histomorphometrically after intentional root damage with a temporary skeletal anchorage device, and to determine the differences in healing potential after 4, 8, and 12 weeks in human subjects. We hypothesized that there would be no marked difference in healing between the various phases of healing after damage to the roots, and at best the repair would be incomplete or partial.

MATERIAL AND METHODS

Patients who reported to the Department of Orthodontics at Ragas Dental College and Hospital, Chennai, India, between January and June 2009 were screened for the study. Seventeen patients (8 male, 9 female; mean age, 16.2 years; range, 13.5-21.6 years) who had a severe arch length-tooth size discrepancy warranting first premolar extractions for routine orthodontic fixed appliance treatment were considered for the study. Patients on medication for systemic disorders, pregnancy, or steroid therapy were eliminated from the study. All such adult patients and the parents of those under the age of 18 years received explanations about the study protocol, and their consent was obtained.

The study protocol was approved by the institutional research ethics committee. The ethical consideration in this study was of intentionally inserting a temporary skeletal anchorage device on the first premolar roots in clear-cut extraction cases. This study should be comparable with experimental setups in recent histologic and scanning electron microscope studies on the incidence and repair of root resorption after the application of heavy forces with orthodontic springs to move the teeth against compact cortical bone[22-27] and in caries studies when premolars were used as in-vivo cariogenic models.[28,29]

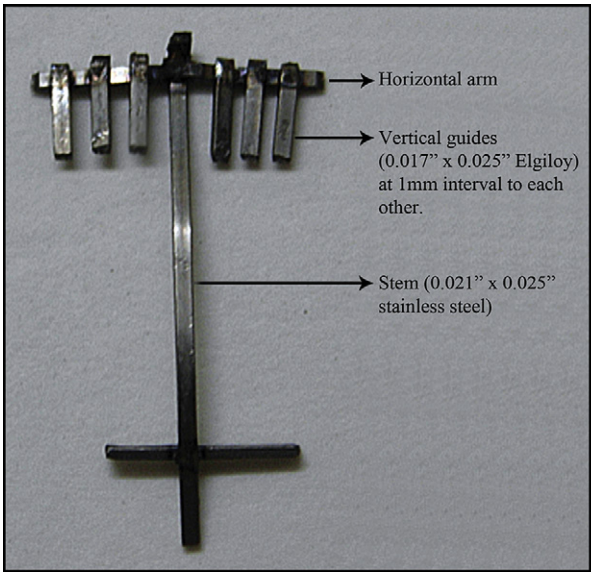

Fig 1. Custom-made wire guide for root contact.

Selection criteria included children and adolescents in the permanent dentition with no history of orthodontic treatment, no caries lesions, and no periodontal breakdown or periapical pathology of the first premolar to be contacted with the temporary skeletal anchorage device, and in which root formation was complete.

A periapical radiograph (paralleling cone technique) was taken to assess the length of the first premolar for the fabrication of a custom-made wire guide (Fig 1). The guide comprised a stem of 0.021 × 0.025-in stainless steel to one end of which a horizontal arm was welded. The horizontal arm carried a series of vertical guides made of 0.017 × 0.025-in cobalt-chromium alloy wire welded at intervals of 1 mm to each other.

The wire guide permitted the seating of the stem in the first premolar bracket to stabilize it and allowed the horizontal arm to rest in the gingival sulcus (Fig 2, *A*). A periapical radiograph (paralleling cone technique) was taken again after the wire guide was stabilized in the first premolar bracket to determine the placement of the temporary skeletal anchorage device, if necessary adjustments were made in the wire guide to ensure root contact (Fig 2, *B*). The image of the wire guide on the periapical radiograph for root contact was verified clinically with the vertical guides facilitating the required mesiodistal positioning of the temporary skeletal anchorage device (Fig 3).

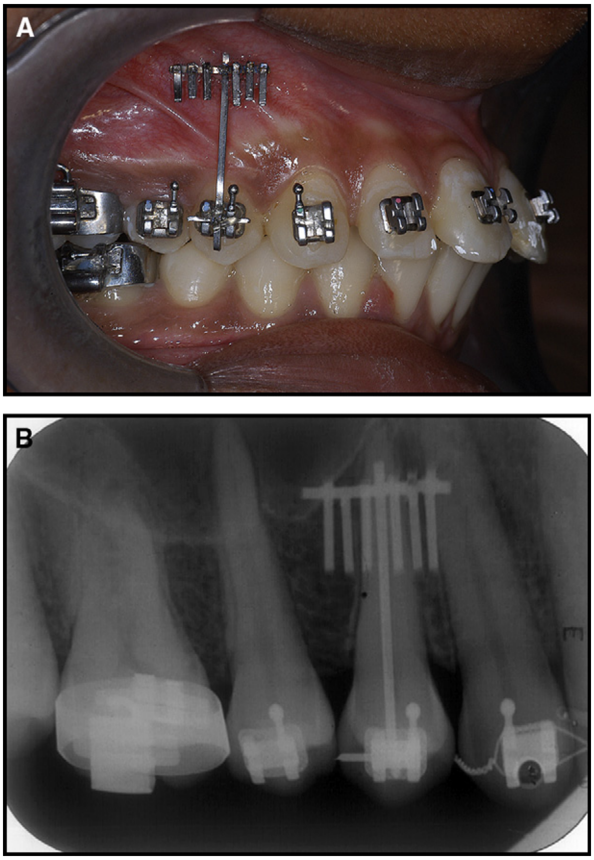

Fig 2. A, Clinical photograph and **B,** periapical radiograph with wire guide placed in the first premolar area.

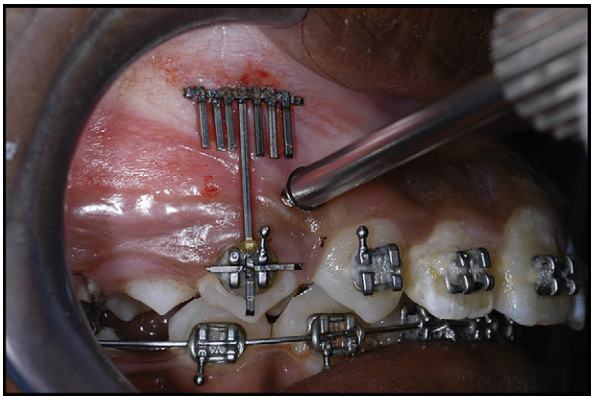

Fig 3. Clinical representation of root contact with a temporary anchorage device.

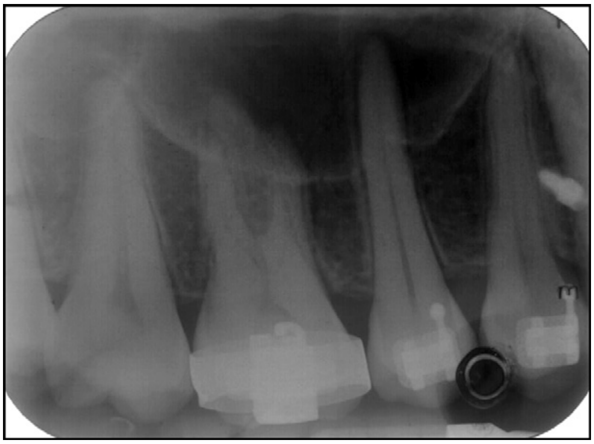

Fig 4. Proximity of the temporary anchorage device and the first premolar root is evident in a periapical radiograph (paralleling cone technique).

The temporary skeletal anchorage devices used for intentional root contact were a self-drilling design, 1.5 mm in diameter and 8 mm in length (Dentos, Daegu, Korea). For each patient, 1 temporary skeletal anchorage device was inserted on the mesial side and the other on the distal side of the buccal root surface of the first premolar. Both were inserted under local anesthesia (2% lignocaine with 1:100,000 epinephrine) on the same day based on the radiographic assessment. A hole of 0.9 mm in diameter was drilled with a number 2 round bur to make an indentation through the cortex with a slow-speed hand piece under continuous saline-solution irrigation. Care was taken to ensure that there was only 1 contact. The temporary skeletal anchorage devices were placed by using a manual torque tester. The resistance felt during placement indicated that contact with the root had occurred, and this was further confirmed with a periapical radiograph (Fig 4). The temporary skeletal anchorage devices were immediately removed after establishing root contact. The repair of the periodontal apparatus and the root structure that was damaged was allowed to take place for varying lengths of time. Based on the healing period, the teeth were classified as 4, 8, or 12 weeks. The experimental design is shown in Figure 5. Immediately after extraction, the damaged surfaces were identified on the mesial and the distal root surfaces of the first premolar by using a stereomicroscope (Laborlux B; Wetzlar, Germany) (Fig 6).

The root was bisected into mesial and distal segments with a diamond-coated disk, taking necessary precautions to ensure that the intentional root defect caused by contact with the temporary skeletal anchorage device was not adjacent to the disk. The mesial segments were placed in 10% neutral buffered formalin and fixed for 48 hours. They were completely decalcified in 10% ethylenediaminetetraacetic acid. After ensuring complete decalcification, the roots were embedded in paraffin blocks. Serial sections 5 μm thick through the

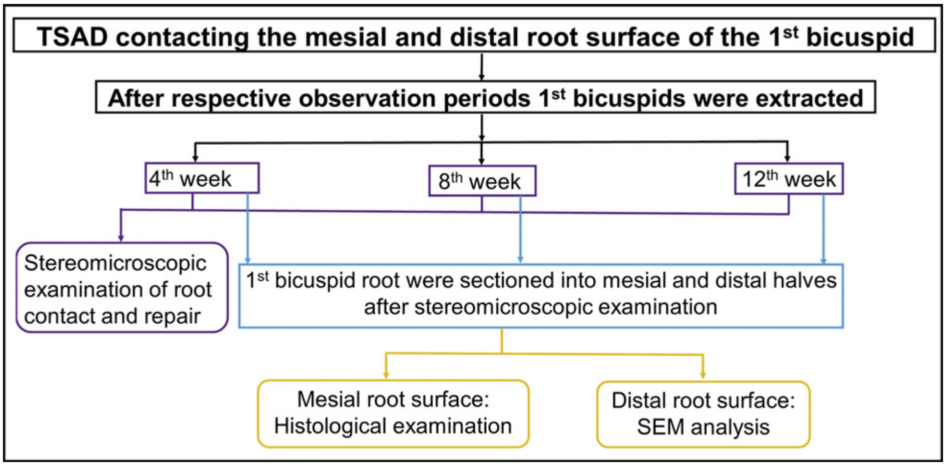

Fig 5. Study design.

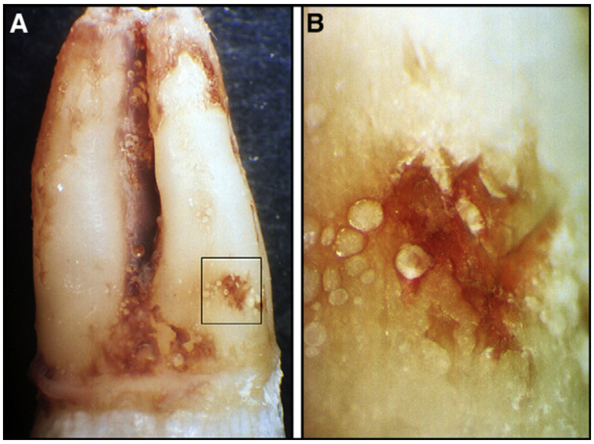

Fig 6. Stereomicroscope shows root contact at various magnifications: **A,** 15 times; **B,** 45 times.

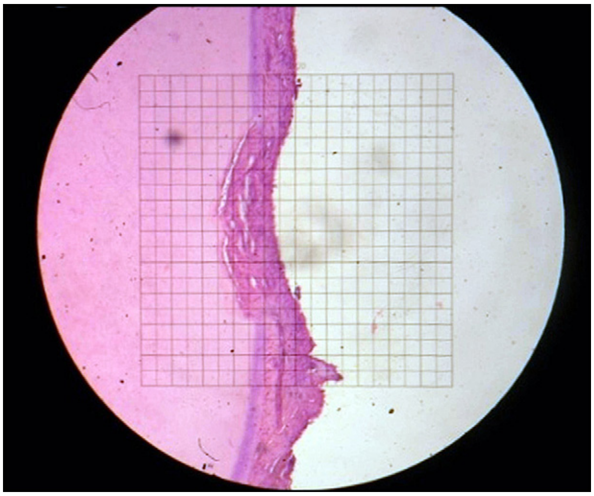

Fig 7. Histologic section with the counting grid.

axiobuccolingual direction were stained with hematoxylin and eosin for histologic examination. The distal segment was stored and examined with a scanning electron microscope; this outcome will be reported separately.

From the mesial root segment, approximately 300 μm of the mesiodistal width of the teeth was examined by an author (K.S.A.V.) by light microscopy (Fig 7). The areas of damage and repair were histomorphometrically measured by using a previously published method.[30] Histomorphometric analysis was carried out at 10 times magnification with a light microscope by using a 10-mm square grid that divided the field into 100 equal parts. The grid was placed over the area of damage. The intersecting squares of the damaged area were counted. Only squares that involved more than 50% were counted. Similarly, the numbers of squares in the areas of healing were calculated. For each section, the repair was expressed as a percentage of the ratio of the repaired area to the damaged area.[30]

The mean repair was calculated for each tooth by using a software package (Excel; Microsoft, Redmond, Wash). Healing of the cementum was further graded as mild (≤33.33%), moderate (33.33%-66.66%), good (66.66%-90%), or excellent (≥90%). The patients' ages were classified as above and below 16 years. Patient demographics of age, sex, healing period in weeks, and the mean repair were analyzed by using SPSS software (version 16.0; SPSS, Chicago, Ill). Descriptive statistics included age, standard deviation, range, sex, and frequency as percentages. The Kruskal-Wallis test was done to assess repair of the cementum by grades in the various phases. Comparisons of mean healing percentages for the different periods of the study were performed with one-way analysis of variance (ANOVA). The post-hoc test of Bonferroni was used to assess the mean difference. A *P* value of 0.05 or less was considered to be statistically significant.

RESULTS

Seventeen subjects (68 teeth) fulfilling the inclusion and exclusion criteria were enrolled for this prospective study. No subject complained of undue pain after the trauma. Extraction of 1 first premolar was done in weeks 4, 8, and 12. Seventeen teeth were planned for extraction in weeks 4, 8, and 12. In weeks 4 and 8, 17 teeth were extracted as planned. However, it was possible to extract only 14 teeth in week 12. Premature extractions were required in the remaining 3 patients before week 12 for their orthodontic treatment to progress. The remaining first premolars were extracted according to the protocol and were not included in the study. Hence, 48 teeth were included in the study.

Stereomicroscopic examinations confirmed the root damage and subsequent healing in all the samples. Table I indicates the number of teeth and subjects who had extractions during the study period. Nearly 50% of the patients (n = 8) showed repair greater than 50% by weeks 4 and 8, whereas only 1 subject had repair less than 50%. These findings indicate that most of the repair took place by week 8 (Figs 8 and 9).

Of the 48 teeth evaluated histologically, it was evident that the dentin in all specimens was damaged, although the quanta of damage and repair were variable. No pulpal damage or evidence of root resorption (internal or external) was seen in any histologic section. There was no ankylosis as evidenced by extraction of the teeth and the clinical test of extrusion. The teeth exhibited a normal repair process by recruitment of cells that suggested cementoblasts (as evidenced by the processes of cementoblasts) (Fig 10). The periodontium appeared to cover the defect area.

No special stains were used to confirm the nature and quality of the repairs. Under hematoxylin and eosin staining, there was no evidence of collagen during any phase of the study. It was further observed that the thickness of the periodontal ligament increased in week 8 compared with week 4. By week 12, the periodontal ligament decreased in thickness. The repair of cementum was 59.6% by the end of week 4, and it was about 73.1% by the end of week 12.

Table II indicates the graded cementum repair. There was no statistical difference between the grades of cementum repair in each phase. The difference in grades among the phases of the study was not statistically significant ($P \geq 0.05$).

Table I. Numbers of teeth extracted according to the schedule, classified by age and sex

	Week 4	*Week 8*	*Week 12*
Sex			
Male	8	8	7
Female	9	9	7
Age group			
<16 y	6	6	5
≥16 y	11	11	9
Overall	17	17	14

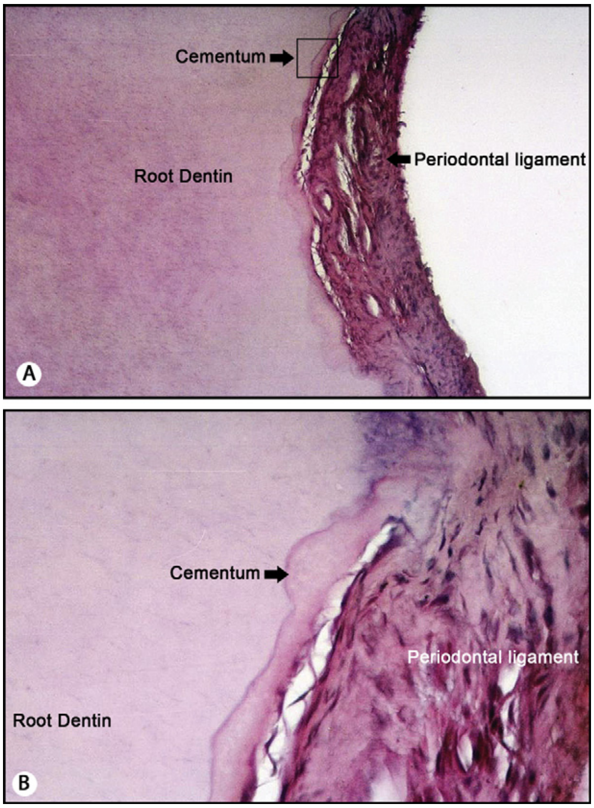

Fig 8. Demineralized section of healing after week 4: **A,** a break in the continuity of the mature cementum and early sign of repair with reattachment of the periodontal ligament fiber to the root dentin after root contact with the temporary anchorage device, with an increase in the thickness of the periodontal ligament fibers (10 times original magnification); **B,** fibers of the periodontal ligament inserted perpendicularly into a thin layer of newly formed reparative cementum (40 times original magnification).

There was a significant trend in the mean histologic repair during the study period as indicated in Figure 11. Results of the one-way ANOVA are shown in Table III. The difference between the mean healing percentages was significant.

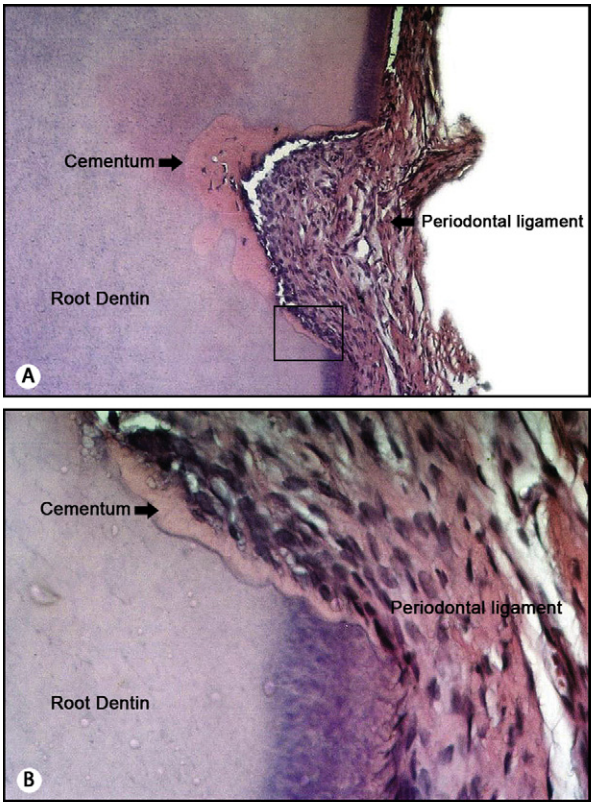

Fig 9. Demineralized section of healing after week 8: **A,** periodontal ligament fiber reorganization is taking place at the bottom of the resorptive crater, and newly formed reparative cementum (eosinophilic material laid between the periodontal ligament and the denuded root dentin) (10 times original magnification); **B,** newly formed reparative cementum is continuous with existing immature and mature cementum crater (40 times original magnification).

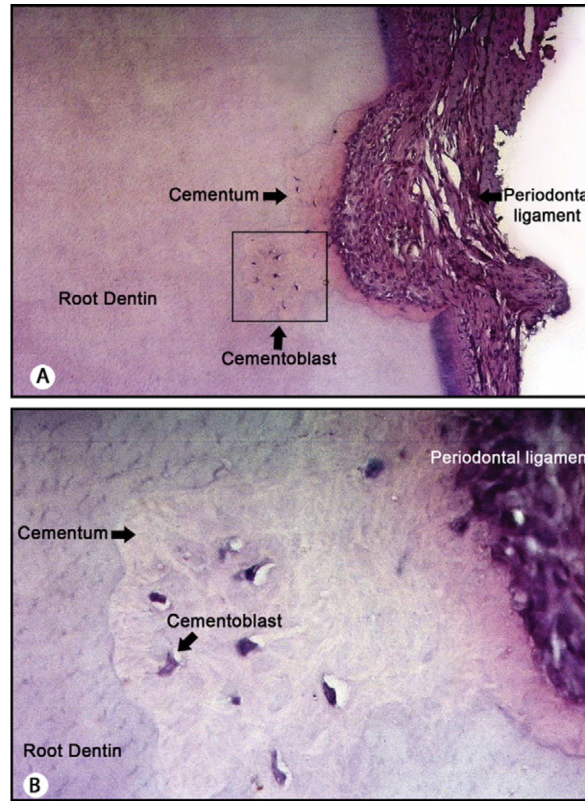

Fig 10. Demineralized section of healing after week 12: **A,** advanced stage of reparative cementum formation. The cementum thickness has increased, and a mineralization front demaracates the repaired mineralized cementum from the root dentin (10 times original magnification). **B,** Hemotoxyphilic nucleated cells embedded in the mineralized structure suggest cementoblasts with their processes directed toward the cellular periodontal ligament (40 times original magnification).

Table IV shows the differences in mean histologic repair by employing post-hoc Bonferroni test. Histologic repair between weeks 4 and 8 was significant ($P \leq 0.046$), whereas the difference between weeks 8 and 12 had poor statistical significance ($P \leq 1$).

DISCUSSION

Repair of cementum after intentional injuries with a temporary skeletal anchorage device has been studied qualitatively in beagle dogs by several authors including Brisceno et al,[6] Hembree et al,[31] and Renjen et al.[32] To the best of our knowledge, quantitative measurements have not been made for assessing cementum repair in humans or animals after damage by temporary skeletal anchorage devices. In this study, we attempted to quantify cementum repair in human permanent dentitions after intentional damage by temporary skeletal anchorage devices.

We used histomorphometry to quantify cementum repair. The use of histomorphometry to study cementum repair has been well documented in the literature.[30]

Under favorable conditions, root repair occurs after intentional damage with temporary skeletal anchorage devices. All the teeth selected in this study exhibited favorable healing at all phases of time. There was significant repair by the end of week 4. By week 4, about 60% of the teeth exhibited moderate repair, which reduced to 35% by the end of 8 weeks and down to 28.6% by week 12; 70% of all teeth exhibited excellent repair by the end of week 12. The difference was statistically significant (Table III). All teeth, despite varying degrees of damage, remained vital and without mobility even 12 weeks after the injury. The amounts of repair increased with time. These findings correlate with previous studies on orthodontically induced root resorption.[22]

Table II. Repair of cementum by grades in the study phases

	Moderate n (%)	Good n (%)	Excellent n (%)	P value (weeks 4 and 8)	P value (weeks 8 and 12)	P value (weeks 4 and 12)
Week 4	10 (58.8)	7 (41.2)	-	0.113*		0.119*
Week 8	6 (35.3)	9 (52.9)	2 (11.8)		0.690*	
Week 12	4 (28.6)	8 (57.1)	2 (14.3)			

*Not statistically significant.

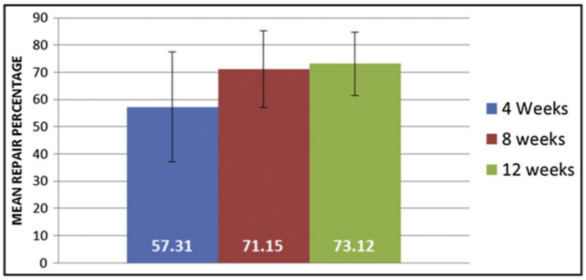

Fig 11. Mean histologic repair (%) in the phases of the study.

Table III. Comparison of mean healing percentages in the periods of the study

	n	Mean	SD	95% CI for mean Lower	95% CI for mean Upper	P value
Week 4	17	57.31	20.22	46.91	67.71	0.014*
Week 8	17	71.15	14.09	63.91	78.40	
Week 12	14	73.12	11.71	66.36	79.88	

*Statistically significant.

The repair process accelerates by week 4 after force removal, and 75% of the repair is completed within 8 weeks.[22] However, the average total healing time might be far longer than 12 weeks, and no sample showed total healing even after week 12.

The histologic findings of this study confirm that a normal repair process was in progress, characterized by the regeneration of the periodontal ligament and a new layer of cementum on exposed dentin that were evident by the end of week 4 (28 days). These results concur with the study of Hellden,[33] who reported the first evidence of cementum deposition by 25 days after injury and evidence of cellular cementum by day 40. Our study also identified cellular elements suggesting cementoblasts by the end of 56 days. On the contrary, Chen et al[15] reported that cementum repair occurs only after a longer period of time (24 weeks). However, their study was carried out on animals, unlike our study.

To the best of our knowledge, this is the first human study to involve temporary skeletal anchorage devices and cementum repair. As indicated in Table IV, most teeth had significant and substantial increases in the percentages of cementum repair between the phases of the study. Only 23.5% (n = 4) of the teeth had a negative difference compared with the preceding time phase. This could be explained by the phenomenon of differences in the healing capacity of cementum in either the jaws or the side; similar phenomena have been reported in the literature.[22,34]

It was documented by Hellden[33] that cementum repair starts at the periphery and then proceeds to involve the entire defect; this was observed in our study as well. The center of the defect gradually thickens over time. The thickness of the periodontal ligament over the various time phases was similar to those reported in the study of Hellden.

It is well documented in the literature that the incidences of root damage with endosseous implants and fixation screws for orthognathic surgery are 0.47%[17] and 43.3%,[35] respectively. Hence, understanding the exact phenomenon of root repair after placement of a temporary skeletal anchorage device is important. Renjen et al[32] showed that the amount of damage to cementum varies from minor abrasion to root impalement. In our study also, in all the sections studied, cementum continuity was sheared by the temporary skeletal anchorage device. The teeth were subjected to stereomicroscopic studies to confirm the extent of damage before the histologic studies. Damage from the temporary skeletal anchorage device to the root does not occur only when the temporary skeletal anchorage device is oriented perpendicular to the root surfaces at placement. The damage can be greater from the threads of a temporary skeletal anchorage device contacting the proximal surface of a root during placement, after tooth movement, or after migration of the temporary skeletal anchorage device.[32] In our study, a perpendicular placement technique was used. The depth of penetration varied from at least one fourth to one half of the radius of the temporary skeletal anchorage device. The area of damage always involved the dentin. Although there were no complaints of abnormal pain or hypersensitivity by the patients, there were instances of discomfort.

Table IV. Differences in the mean histologic repair (%) during the study phases

			Post-hoc Bonferroni test			
Phase	*n*	*Mean ± SD*	*Phase*	*Mean difference*	*95% CI*	*P value*
Week 4	17	57.31 ± 20.22	Weeks 4-8	13.85	0.21-27.48	0.046*
Week 8	17	71.15 ± 14.09	Weeks 8-12	1.97	12.38-16.31	1
Week 12	14	73.12 ± 11.71	Weeks 4-12	15.81	1.46-30.16	0.026*

*Statistically significant.

Reparative cementum formation was observed in all studied sections. It is well documented that only cells of the periodontal ligament can form new cementum.[32] The increases in the activity and thickness of the periodontal ligament near the injury in different phases of that study period provide ample support for the same in our study. The rate of healing was significant between weeks 4 and 8, but it was not significant between weeks 8 and 12.

Extensive removal of periodontal investing tissue from the root can induce ankylosis, especially if the affected area is large and deep.[36] Although spontaneous resorption and "spot" ankylosis have been reported after trauma by temporary skeletal anchorage devices in beagle dogs, there is a paucity of literature pertaining to human studies. To evaluate whether spot ankylosis had taken place from intentional root contact with the temporary skeletal anchorage device, 2 premolars that were previously injured were intentionally extruded with orthodontic forces. The fact that the teeth showed evidence of extrusion suggests a lack of spot ankylosis. Although such assumptions cannot be validated unless they are confirmed histologically, the report of Renjen et al[32] indicates that ankylosis was observed only when the root injury was accompanied by displacement of fragments.

The temporary skeletal anchorage device used to create the defects in our study was not left in place. Hence, the trauma was transient. However, the literature shows that a temporary skeletal anchorage device left in contact with the root after trauma does not interfere with healing.[32] Despite the varying depths of the injuries, reparative cementum was observed along the periphery of the intentionally induced defect. Areas of reparative cementum are identified by the relatively darker color in contrast to adjoining uninvolved cementum. There is a line demarcating the dentin and the newly forming cementum.

Another observation in this study was that in nearly 50% of the teeth (n = 8) cementum repair greater than 50% occurred by week 4, and, by week 8, only 1 tooth had repair of less than 50%. These findings indicate that most repair takes place by week 8. Our findings were not consistent with those of Brisceno et al[6] in dogs. Interspecies variations could be a reason for the differences in healing periods.

CONCLUSIONS

We rejected the null hypothesis in favor of an alternate hypothesis. It has been established through this study that there is a significant time-dependent healing of cementum after intentional root damage with temporary skeletal anchorage devices. Further studies with larger samples and longer healing periods are essential to confirm the full nature of the repair.

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