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Intentional replantation of adhesively reattached vertically fractured maxillary single-rooted teeth

N. Nizam[1], M. E. Kaval[2], Ö. Gürlek[1], A. Atila[1] & M. K. Çalışkan[2]

[1]Department of Periodontology, School of Dentistry; and [2]Department of Endodontology, School of Dentistry, Ege University, Izmir, Turkey

Abstract

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Aim To evaluate the clinical outcomes of intentionally replanted maxillary single-rooted teeth with vertical root fractures (VRFs) after being repaired extraorally using 4-methacryloxyethyl trimellitate anhydride/methacrylate-tri-n-butyl borane (4-META/MMA-TBB) resin cement.

Methodology Twenty-one root filled maxillary single-rooted teeth with VRFs were evaluated. After atraumatic extraction, fractured fragments were adhesively cemented. The teeth were then replanted and splinted to the neighbouring teeth for 2 weeks. Plaque index (PI), gingival index (GI), probing depth (PD) and clinical attachment level (CAL) were assessed at baseline, 6 and 12 months, and radiographic evaluations were made using PAI scores at baseline and 12 months. Mobility was evaluated using periotest values (PTV) at baseline, 1, 3, 6 and 12 months. Replanted teeth, contralateral teeth (control teeth) and adjacent teeth were analysed statistically using repeated measures one-way ANOVA, unpaired *t*-tests and Wilcoxon matched-pairs signed-rank tests.

Results Two teeth were extracted in the first month after surgery. PI, GI, CAL and PD scores of the replanted teeth were significantly lower at 6 month ($P < 0.0001$ for all) and 12 month ($P < 0.0001$ for all) postoperatively when compared to baseline, but the values were not significantly different from those of the control and adjacent teeth. PTV of the test teeth increased significantly ($P < 0.0001$) after the intervention and decreased to baseline levels by month 12. PTVs were significantly higher ($P < 0.05$) at baseline, 1, 3 and 6 months in the test teeth when compared with the control teeth, but were not significantly different at month 12. PAI scores of teeth with VRF were significantly lower ($P < 0.05$) at 12 months compared with baseline.

Conclusions Adhesive cementation and intentional replantation were an effective treatment modality for this group of vertically fractured maxillary single-rooted teeth. The clinical periodontal parameters decrease by month 6, and the mobility returned to the physiological limits of natural teeth 12 months after replantation.

Keywords: adhesive bonding, intentional replantation, periodontal healing, vertical root fracture.

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Introduction

Vertical root fracture (VRF) is a longitudinal fracture of the root, extending throughout the entire thickness of dentine from the root canal to the periodontium. It is initiated in the crown or at the root apex, or at a point along the root between these two points (Pitts & Natkin 1983). Excessive loss of dentine during canal or post-space preparation, high lateral and/or vertical compaction forces applied during canal filling and excessive pressure applied during post-insertion together with moisture loss after the completion of root canal treatment are amongst the important risk factors for VRFs (Sedgley & Messer 1992).

Correspondence: Nejat Nizam, Department of Periodontology, School of Dentistry, Ege University, 35100, Izmir, Turkey (Tel.:+90 232 3881105; Fax:+90 232 3880325; e-mails: nejat.nizam@ege.edu.tr, nejatnizam@hotmail.com).

VRF may cause extensive breakdown of periodontal tissues resulting in pain, swelling, pus and sinus tract formation, deep periodontal pockets, increased tooth mobility, and vertical bone resorption. Resecting the affected root and preserving the remaining tooth structure can be a treatment approach in a multirooted tooth with VRF (Pitts & Natkin 1983). However, a single-rooted tooth is considered to have a hopeless prognosis, and therefore, extraction is generally recommended (Schetritt & Steffensen 1995).

Although the treatment approaches for VRFs such as extraction and replacement with dental implants (Malhotra *et al.* 2011) and utilization of lasers have been described (Dederich 1999), no specific treatment protocol has yet been established (Özer *et al.* 2011). Successful reconstruction of VRFs with adhesive resin cement has been demonstrated in several case reports with a follow-up period between 18 and 48 months (Arıkan *et al.* 2008, Oztürk & Unal 2008, Özer *et al.* 2011). The same treatment approach has also shown promising results especially in incisors in a short-term (follow-up between 4 and 45 months) and in a long-term (follow-up between 4–76 months) clinical study by Hayashi *et al.* (2002, 2004). In that technique, the tooth was extracted and replanted after adhesive cementation of the fractured segments extraorally. Dual cured resin cements (Arıkan *et al.* 2008, Oztürk & Unal 2008, Özer *et al.* 2011) as well as chemical cured cements (Hayashi *et al.* 2002, 2004) were successfully used for these purposes. 4-Methacryloxyethyl trimellitate anhydride/methacrylate-tri-n-butyl borane (4-META/MMA-TBB) is a chemically cured resin cement and has been shown to have a certain tolerance to the water content of dentine and surface moisture (Tagami *et al.* 1990, Tao *et al.* 1991). Therefore, 4-META/MMA-TBB might have advantages in the treatment of VRFs if the proper moisture control is not achievable.

Even though limited clinical data suggest that intentional replantation of adhesively reattached fractured segments should be accepted as an alternative treatment modality to extraction especially in incisor teeth, prospective clinical studies evaluating the outcome of single-rooted teeth are lacking. It was also not demonstrated whether the treatment would have an effect on the neighbouring teeth and whether the clinical periodontal parameters of the treated teeth would differ from natural teeth. Therefore, the aim of this prospective clinical study was to evaluate the long-term clinical outcome of intentional replantation of maxillary vertically fractured single-rooted teeth, after extra-oral adhesive bonding of the fractured fragments.

Materials and methods

Study population

The study was approved by the Ethics Committee of Ege University, School of Medicine and was conducted in full accordance with ethical principles, including the Declaration of Helsinki, as revised in 2002. The study protocol, the procedures and the possible risks were thoroughly explained to the patients, and written informed consent statements were received.

A total of 26 patients (11 males and 15 females age range between 27 and 55 years) referred to Department of Endodontology, School of Dentistry, Ege University between January 2010 and February 2013 complaining of VRF-related symptoms were recruited for the study based on the following inclusion criteria: (i) having VRF in a root filled maxillary single-rooted tooth, (ii) with clinically detectable fracture lines, (iii) presenting dislocated fragments or fragments that separated during the surgery, (iv) not containing more than two separated fragments, (v) having no history of previous periodontal or endodontic surgical intervention, (vi) being >18 years of age, and (vii) systemically healthy.

A total of 27 teeth (12 incisors, 6 canine and 9 premolars) fulfilling the inclusion criteria were scheduled for the treatment in the Department of Periodontology of the same university.

Preoperative clinical and radiographic assessment

The patients were evaluated clinically and radiographically and preoperative symptoms were noted. VRFs were diagnosed by detection of the fracture lines with radiographic examination, visual inspection under × 3.5 magnification and tactile sensation using probes. The treatment options including their advantages and disadvantages were explained, and the patients were instructed in oral hygiene practices and were offered at least two appointments to evaluate their ability to maintain adequate oral hygiene.

Before the surgical intervention, the plaque (Silness & Loe 1964) (PI) and gingival index (Loe & Silness 1963) (GI) were recorded, and probing depth (PD) and clinical attachment levels (CAL) were measured by means of a periodontal probe (Michigan O Color-

Coded Probe, Hu-Friedy, Chicago, IL, USA) and rounded up to the nearest 0.5 mm in each tooth with VRF, in the neighbouring teeth and the contralateral tooth. The teeth with VRF formed the test group and the contralateral teeth served as the control group. To evaluate the effect of the treatment on the neighbouring teeth, mean clinical parameters of the two adjacent (one mesial and one distal site) teeth were calculated. PD and CAL were measured from the VRF line, and when there were two fracture lines, the mean of the PDs and CALs was recorded. In the contralateral teeth, PD and CAL measures were made at the same sites corresponding to the breakage lines of the VRF, and in the neighbouring teeth, however, the same parameters were measured at proximal sites facing the tooth with VRF and the mean values were then recorded. Mobility was assessed in three times using periotest values (PTVs) measured by Periotest M (Medizintechnik Gulden, Moodautal, Germany), and the mean values were calculated. Before the surgical stage, the access cavity of each tooth was prepared, and when it was possible, root canal filling materials were also removed.

Surgical procedures

The access cavity was prepared (Fig. 1a), and the surgical site was anaesthetized with 2% lidocaine with 1 : 100 000 adrenaline. Intrasulcular incisions were made circumferentially using number 15c blades (Swann-Morton Ltd., Sheffield, UK) around the tooth with VRF. The teeth were carefully and atraumatically extracted avoiding trauma to periodontal ligament remnants on the root (Fig. 1b). The granulation tis-

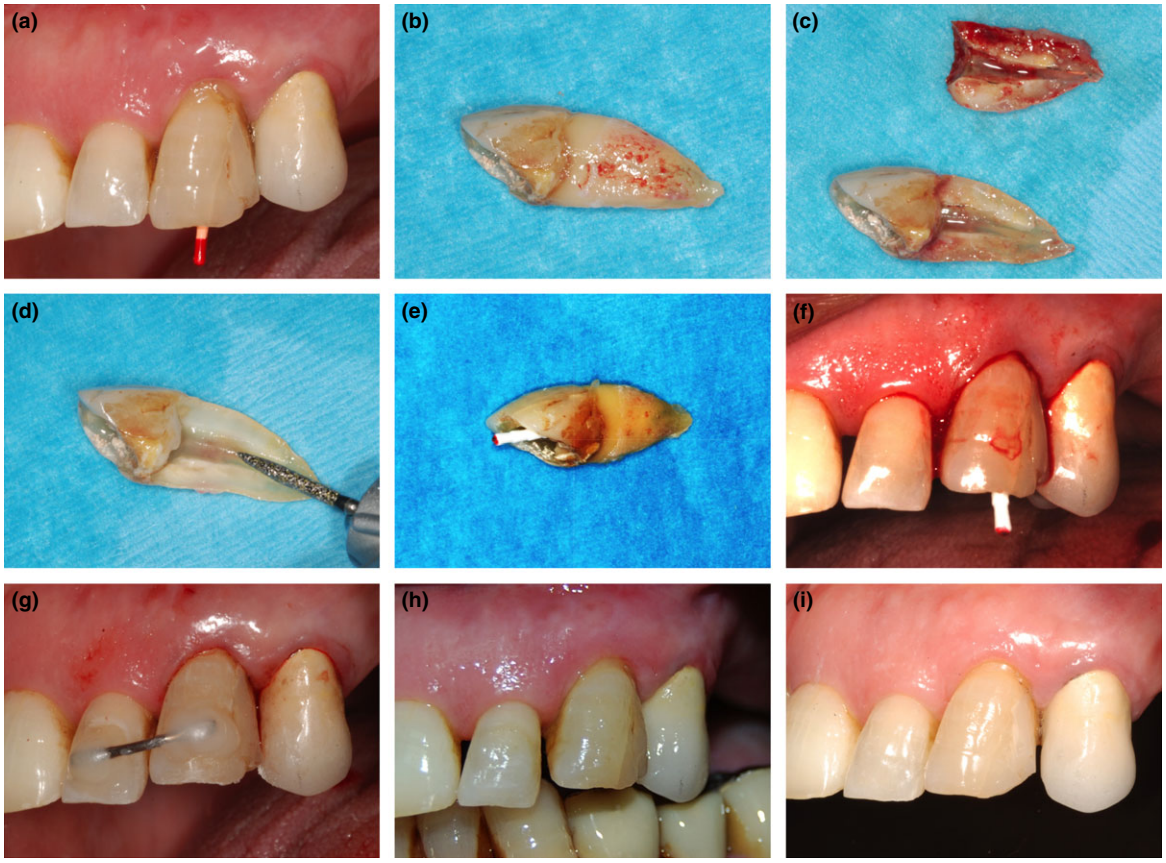

Figure 1 The treatment procedure and 12-month follow-up of a maxillary left canine with VRF. (a) The tooth with open access cavity just before the surgical procedure, (b) atraumatically extracted canine, (c) separated fragments, (d) preparation of the root canal and fractured surfaces, (e) adhesive bonding of the fragments and simultaneous fibre post insertion, (f) intrasocket preservation of the tooth during cement setting, (g) just after the fabrication of the provisional splint, (h) postoperative 14 day just after the removal of the splint and (i) the clinical appearance at 12 months.

sue attached to the root surface, if it existed, was excised and the tooth or the fractured fragments were immediately placed in 0.09% sterile saline. The granulation tissue in the extraction socket was removed, and the bony defect corresponding to the fracture line was curetted and thoroughly rinsed with saline solution, but the unaffected extraction socket walls were not touched.

The teeth without dislocated segments were placed on sterile gauze soaked with saline, a scalpel was placed in the centre of the fracture line, and pressure was applied to separate the fragments (Fig. 1c). The separated surfaces were then gently prepared using a diamond bur and a 1 : 2.7 contra-angle handpiece (W&H, Bürmoos, Austria) under saline irrigation to eliminate the rough surfaces that could prevent the proper adaptation of the fragments (Fig. 1d). Guttapercha and/or sealer remnants and bacterial biofilms were also removed using a fine-grained dental bur. Antibacterial agents were not used to decontaminate the surfaces. For the cementation procedures, 4-META/MMA-TBB cement (Super Bond C & B, Sunmedical Co., Moriyama, Shiga, Japan) was used according to the manufacturer's instructions. To remove the smear layer without excessive modification of the underlying dentine and to dissolve less hydroxyapatite and minimize damage to dentine collagen, dentine acid (10% citric acid and 3% ferric chloride) was applied for 10 s to the fractured surfaces and root canal and then washed and air-dried gently. After the application of resin cement (either opaque or translucent), the fragments were reattached using digital pressure applied over a moist sterile gauze, and in the cases with wide root canals, a fibre post was also placed simultaneously (Fig. 1e). The resin material filled the empty canal and therefore sealed the canal to its terminus. Then, the tooth was placed into the extraction socket (Fig. 1f), and when the cement had set in the extraction socket, the tooth was removed, excess material was excised, and the root surfaces close to the fracture (1 mm each site) line were planed using number 15c blades. The tooth was replanted again and fixed to the neighbouring teeth using orthodontic wire and composite resin (Fig. 1g). Finally, the occlusion was checked and adjusted to avoid traumatic occlusion during the healing period. The tooth was out of the mouth for a maximum of 15 min, and during these procedures, care was taken to avoid dehydration of periodontal ligament remnants on the root surface. Teeth that withstood the pressures exerted by the scalpel and remained as a single unit were treated using a different treatment protocol and excluded from the study. Briefly, a thin channel through to the root canal was prepared along the fracture using a diamond bur with a 1 : 2.7 contra-angle (W&H, Bürmoos, Austria) under saline irrigation. The root canal and the channel were filled with 4-META/MMA-TBB, and the tooth was then replanted following the same protocol. Teeth with more than two separated fragments were extracted and excluded. To enhance visual acuity, all the procedures were carried out × 3.5 magnification. Three clinicians were involved in the surgical interventions. One surgeon (NN) performed the surgery and two clinicians (ÖG and AA) were involved in the bonding and fixation procedures.

Postoperative care

Amoxicillin and clavulanic acid (Amoklavin BID 625 mg, 2 × 1, Deva Holding AS, Istanbul, Turkey) were prescribed for 5 days, and the patients were instructed to keep the operation area out of function and to consume a soft diet. During the healing period, the patients cleaned the surgical field gently with a postoperative dental brush (GUM® Delicate Post-Surgical Toothbrush, Sunstar Americas inc, Chicago, IL, USA) and were re-evaluated every 3 days until the removal of the splint on day 14 (Fig. 1h). Then, the patients were seen every second week until the end of the second month and every second month until the end of month 12 (Fig. 1i). Radiographs were taken at 12 months and annually for teeth with longer follow-up.

Crowns were refabricated only for the teeth that had been restored with a crown previously or damaged during the extraction and/or follow-up; however, the teeth with intact crowns were left either untouched or restored with composite resin.

If the patients did not comply with oral hygiene during the follow-up, reinstruction in oral hygiene procedures was given, and a follow-up appointment was made to provide adequate plaque control. Professional supragingival tooth cleaning was undertaken if needed; however, subgingival instrumentation was not performed after the surgery.

Clinical and radiographic follow-up measurements

The clinical periodontal parameters used to evaluate the outcome were PI, GI, PD, CAL and PTVs, whereas the radiographic parameters were the modification of PAI index (Ørstavik *et al.* 1986) measurements.

PI, GI, PD and CAL were measured at baseline, 6 and 12 months, and the PTVs and percussion sounds were evaluated at baseline, 1, 3, 6 and 12 months. The clinical evaluation interval was 6 months thereafter.

The radiographs were exposed using a long-cone technique with standardized exposure times (60 kV, 7 mA, 0.125s) preoperatively and at 12 months to evaluate the PAI index, the adhesion of the reattached fragments, surrounding bone healing and the signs of replacement root resorption at proximal sites (Figs 2,3 and 4). The PAI index (Ørstavik *et al.* 1986) was adapted not only to evaluate the periapical tissues but the entire periradicular area during the follow-up period as follows: 1. normal periradicular structure, 2. small changes in periradicular bone structure, 3. changes in periradicular bone structure with some mineral loss, 4. periodontitis with well-defined periradicular radiolucent area and 5. severe periodontitis with exacerbating features.

The clinical periodontal parameters and PAI scores were recorded by the same examiners (NN and MEK, respectively), who achieved 'very good' strength of agreement between consecutive PD and PAI assessments (Cohen's Kappa 0.90 and 0.82, respectively).

Statistical analyses

The primary outcome variable was selected as periotest values (PTVs). The minimum sample size was calculated considering a difference of 4 units in mean PTV in comparison with control teeth and assuming the standard deviations to be 75% of the means and accepting a power of 90%, *P*-value of 5% in study groups. Sample size calculation analysis revealed that the minimum required sample size was 19.

A commercially available statistical software program (GraphPad Prism version 6.00c for Mac OS X, GraphPad Software, La Jolla, CA, USA) was used for statistical analyses. Clinical parameters of the fractured tooth (the test tooth), the neighbouring teeth and the contralateral tooth (the control tooth) were used in the statistical comparisons. The distribution of the variables was validated by D'Agostino-Pearson omnibus normality test. The differences within groups for PI, GI, PD, CAL and PTV were evaluated using repeated measures one-way ANOVA test, with Greenhouse–Geisser correction, and Holm–Sidak's multiple comparisons test, with individual variances computed for each comparison. The differences between the test and the control group for the same parameters were assessed using unpaired *t*-tests with Welch's correction. PAI scores in the test teeth were evaluated using Wilcoxon matched-pairs signed-rank test. All the tests were performed at $\alpha = 0.05$ significance level. Due to insufficient numbers of teeth with follow-up more than 12 months, only the first year data are included in the statistical analyses.

Results

Prior to the surgical intervention, all patients complained of discomfort, seventeen patients had mild-to-moderate pain, nine individuals presented with sinus

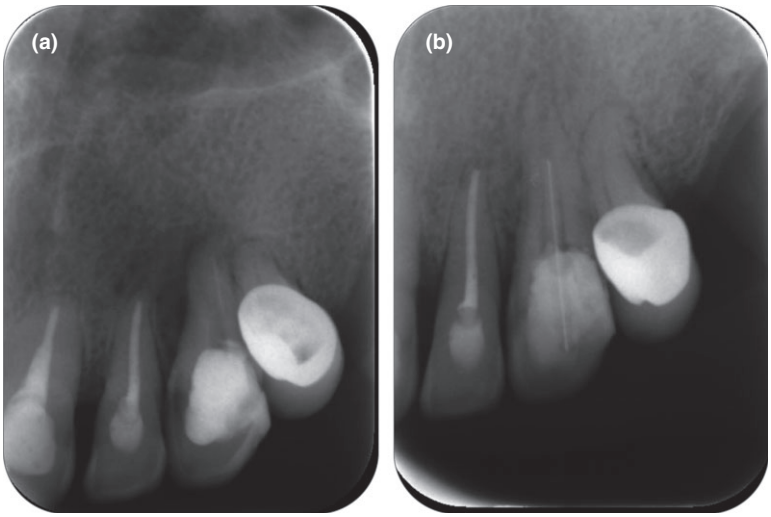

Figure 2 Periapical radiographs (a) Preoperative and (b) postoperative 12-month radiographs of the canine.

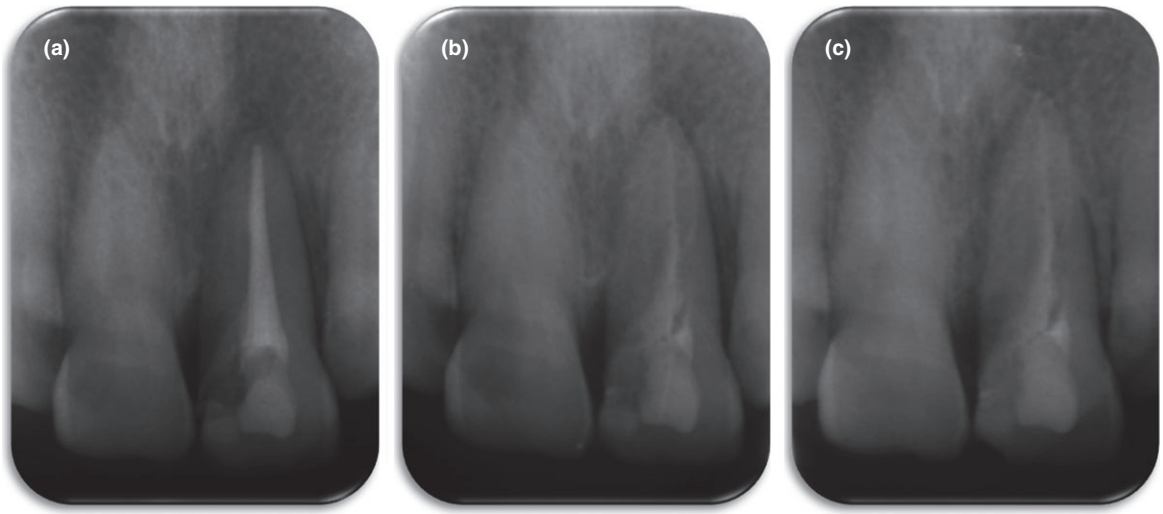

Figure 3 Periapical radiographs of a patient with VRF in a maxillary left central incisor. (a) Preoperative, (b) at 1-month and (c) 12-month radiographs.

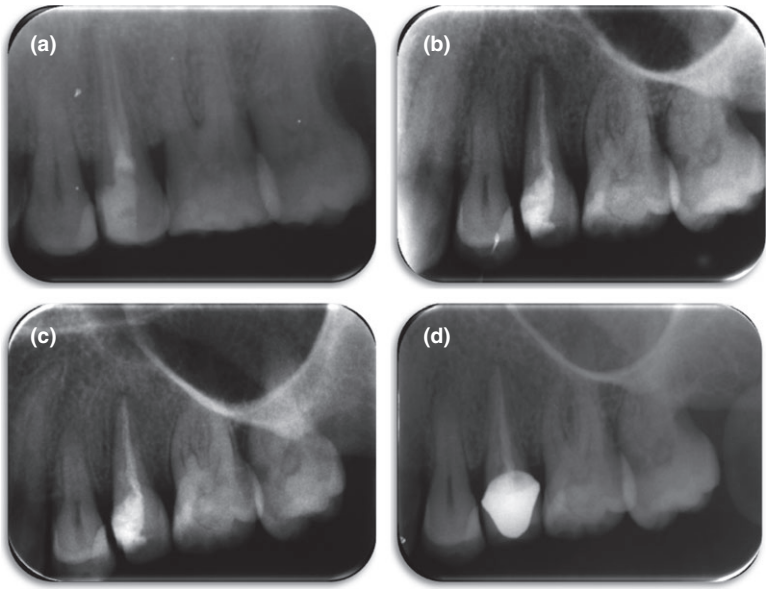

Figure 4 Periapical radiographs of a patient with VRF in the maxillary left second premolar. A crown was prepared during the second year after replantation because of a crown crack. (a) Preoperative, (b) at 1-month, (c) 12-month and (d) 36-month radiographs.

tracts, eleven patients reported a sudden and sharp pain during chewing, nineteen patients had tenderness to percussion, and six patients had mild swelling.

Five teeth contained single breakage lines that withstood the pressures exerted by the scalpel during the surgical intervention, and one tooth had three separated fragments; therefore, six teeth were not included in the analyses. None of the patients was excluded due to noncompliance, and hence, 21 teeth of 27 (77.8%) diagnosed as VRF were evaluated (mean follow-up ± SD: 19.4 ± 8.9 months, between 12 and 36 months).

Two teeth were extracted during the follow-up period. One tooth because of chronic infection with

an unhealed sinus tract around the fracture line of a central incisor observed during the second week of postoperative healing, and another due to an unrepairable oblique crack in the crown region of a first premolar detected one month after surgery. Healing was uneventful with no other complication or sign of ankylosis during the follow-up. Therefore, the overall survival rate of the treated teeth was 90.5%.

The distribution of the clinical periodontal parameters between the test and the control teeth is demonstrated in Table 1. PI and GI scores of teeth with VRFs were significantly higher at baseline compared with the contralateral teeth ($P = 0.002$ and $P < 0.0001$, respectively). PI and GI scores were significantly lower in the test teeth at 6th months ($P < 0.0001$ for both) and 12th months ($P < 0.0001$ for both) compared to baseline. Vertically fractured teeth had significantly higher PD and CAL measurements at baseline compared with the control teeth ($P < 0.0001$ for both). Both PD and CAL in the test teeth were significantly lower at 6th months ($P < 0.0001$ for both) and 12th months ($P < 0.0001$ for both) compared with the baseline. Clinical periodontal parameters of the neighbouring teeth revealed no significant difference during the follow-up period ($P > 0.05$) (Table 2).

The PTV during the first year is demonstrated in Fig. 5. The PTV of the test teeth increased after surgery and a significantly higher PTV was detected at one month compared with all evaluation time-points ($P < 0.0001$ for all). The PTV of the treated teeth decreased thereafter and no significant difference was found at month 6 compared with baseline ($P > 0.05$). Even though the teeth with VRF had higher PTV compared with the control teeth at baseline ($P < 0.0001$), no difference was found at the 12-month observation ($P > 0.05$).

Table 2 Distribution of clinical periodontal parameters in neighbouring teeth

	Neighbouring Teeth		
	Baseline	6th month	12th month
PI	0.74 ± 0.65	0.63 ± 0.60	0.64 ± 0.61
GI	0.95 ± 0.62	0.42 ± 0.51	0.58 ± 0.46
PD (mm)	2.32 ± 0.48	2.21 ± 0.42	2.31 ± 0.43
CAL (mm)	2.47 ± 0.70	2.42 ± 0.61	2.48 ± 0.62

Values are demonstrated as mean ± standard deviation.

Percussion sound was similar in the control, and the test teeth during the follow-up period and PAI scores were significantly lower at month 12 compared with baseline ($P < 0.0001$) (Fig. 6).

Discussion

Even though tooth extraction has long been accepted as a treatment modality for teeth with VRF (Schetritt & Steffensen 1995), adhesive reattachment of the fractured segments and intentional replantation of the affected teeth yield promising clinical outcomes (Hayashi *et al.* 2002, 2004, Arıkan *et al.* 2008, Oztürk & Unal 2008, Özer *et al.* 2011). However, results based on objective measures are scarce (Sugaya *et al.* 2001), and previously, the clinical parameters were not compared with healthy control teeth. In this manner, the aim of the present study seems to be achieved since it evaluated the clinical parameters of adhesively reattached intentionally replanted maxillary single-rooted teeth compared to that of healthy control teeth.

Successful bonding of the separated fragments was achieved previously either using dual cured resin (Arıkan *et al.* 2008, Oztürk & Unal 2008, Özer *et al.* 2011) or chemically cured adhesives (Hayashi *et al.* 2002, 2004). Dual cured adhesives require a certain

Table 1 Distribution of clinical periodontal parameters between test and control teeth

	Teeth with VRF			Contralateral Teeth		
	Baseline	6th month	12th month	Baseline	6th month	12th month
PI	1.32 ± 0.67[a]	0.42 ± 0.60	0.54 ± 0.49	0.63 ± 0.60[b]	0.63 ± 0.68	0.63 ± 0.68
GI	1.74 ± 0.45[a]	0.42 ± 0.60	0.39 ± 0.54	0.47 ± 0.61[c]	0.32 ± 0.48	0.67 ± 0.58
PD (mm)	8.90 ± 2.26[a]	2.63 ± 0.68	2.47 ± 0.61	1.90 ± 0.74[c]	2.16 ± 0.60	1.95 ± 0.62
CAL (mm)	9.16 ± 1.92[a]	2.84 ± 0.76	2.68 ± 0.67	2.11 ± 0.81[c]	2.26 ± 0.56	2.00 ± 0.58

Values are demonstrated as mean ± standard deviation.
[a]Significant difference compared to 6th month and 12th month within group ($P < 0.0001$).
[b]Significant difference between groups ($P = 0.002$).
[c]Significant difference between groups ($P < 0.0001$).

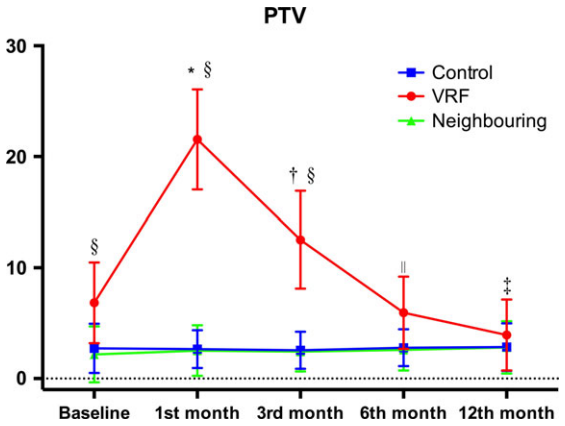

Figure 5 Changes in PTVs in test, control and neighbouring teeth during follow-up period. *Significant difference compared to baseline, 3, 6 and 12 months in the VRF group ($P < 0.0001$). †Significant difference compared to baseline, 1, 6 and 12 months in the VRF group ($P < 0.0001$). ‡Significant difference compared to 6 months in the VRF group ($P < 0.016$). §Significant difference between VRF and control teeth. ($P < 0.0001$). ||Significant difference between VRF and control teeth ($P < 0.001$).

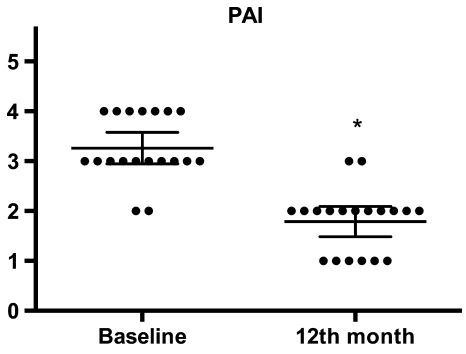

Figure 6 Changes in PAI scores of teeth with VRF. Each dot represents an individual tooth pre- and postoperatively in the same order. *Significant difference compared to baseline $P < 0.0001$.

amount of moisture control, contain a bonding stage and might be cytotoxic (Schmid-Schwap *et al.* 2009). However, 4-META/MMA-TBB is biocompatible (Maeda *et al.* 1999), is not affected by blood contamination (Miles *et al.* 1994) and has a tolerance to moisture and the water within dentine (Tagami *et al.* 1990, Tao *et al.* 1991). Also, the polymerization of 4-META/MMA-TBB may be achieved in the extraction sockets to eliminate the disadvantages of the material in relation to the longer polymerization time compared with dual cured adhesives. Because of such advantages, 4-META/MMA-TBB was used instead of dual cured resin cements in the current study. The present results support both *in vitro* (Nurrohman *et al.* 2011) and *in vivo* (Tagami *et al.* 1990, Tao *et al.* 1991, Sugaya *et al.* 2001) data, which encourage the use of 4-META/MMA-TBB as the adhesive cement in VRFs as no debonding and any side effect were observed during the follow-up period.

Hayashi *et al.* (2004) suggested that the reconstruction of VRF with dentine-bonded resin might be considered as a treatment technique especially for incisors. The success rate in incisor teeth could be related to the anatomical features of the tooth as the root length and shape might affect the tensile strength achieved after adhesive bonding of the fragments (Tamura *et al.* 2011). To apply the same surgical and bonding technique to the same types of VRFs and to limit local variables, only maxillary single-rooted teeth were included in the present study. Also, all the teeth had separated fragments or were intentionally separated before bonding. Even though treatment of similar fractures seems to be important for standardization, it must be recognized that the results of the present study may differ and/or may not be applicable in multirooted and mandibular teeth.

The clinical outcomes of intentionally replanted teeth with VRFs after being repaired using 4-META/MMA-TBB resins have been documented previously (Sugaya *et al.* 2001, Hayashi *et al.* 2002, 2004). Hayashi *et al.* (2002, 2004) included different types of cracks and both single and multirooted teeth in their studies. Sugaya *et al.* (2001) compared the extraoral and intraoral cementation techniques for the same purposes; however, only single-rooted teeth with separated fragments were evaluated in the present study. Since the follow-up periods, the tooth variables and bonding techniques are quite different, the results of these studies are not comparable.

Ankylotic areas on the root surface can be observed radiographically when they are located on the proximal root surfaces; however, if they develop on the buccal or palatal surfaces, they cannot be detected (Andersson *et al.* 1984). As the initial location of ankylosis is often on the buccal and/or palatal root surfaces (Andersson *et al.* 1984, Stenvik *et al.* 1990), radiographic examination cannot be a reliable approach for the early detection of ankylosis due to the two-dimensional nature of the radiographic images (Stenvik *et al.* 1990). Therefore, the presence of ankylosis in the present study was assessed using percussion tests and PTVs, but radio-

graphs were also used to evaluate only the proximal root surfaces.

Root resorption might be expected to occur if the teeth are held in dry conditions during reconstruction (Hayashi *et al.* 2002) and if the extraoral time exceeded 15 min (Pohl *et al.* 2005). Therefore, handling the root surfaces with wet gauze, minimizing extraoral time and preserving the tooth in the extraction socket might have prevented ankylosis in the present study. This finding is in line with a previous study by Sugaya *et al.* (2001) who also did not observe ankylosis during the follow-up period. Although the absence of ankylosis at the end of the first year suggests a good long-term prognosis (Özer *et al.* 2011), monitoring a replanted tooth for a longer period of time is appropriate. It must be recognized that ankylosis could be diagnosed even after 5 and 10 years in rare cases (Andreasen *et al.* 1995), and therefore, a strict follow-up is required in such patients.

Two teeth were extracted one because of chronic infection and the other because of a crack in the crown region. Even though the tooth with the crown fracture was accepted as a failure in the present study, the complication was not related to the surgical treatment of the case. It must be recognized that the survival rate of the present study is based on the clinical follow-up of 21 teeth, which had separated fragments or/and that were intentionally separated, but not of all teeth scheduled for treatment. Five teeth required a distinct treatment approach and one had to be extracted. Therefore, the survival rate of the present study should be interpreted with caution.

PTV, that ranges from −8 (clinically firm) to +50 (very loose), is a unit of mobility. The negative values usually indicate ankylosis of a natural tooth or the ankylotic healing of a dental implant (Schulte 1989). Therefore, a decrease in PTV, which remained in the positive range during the follow-up in the present study, may be indicative of nonankylotic healing. PTV was significantly higher in the VRF group compared with the control teeth at baseline, probably because of infection and bone loss around fracture lines. It was increased after the surgery and decreased to the levels of the control teeth at the 12-month evaluation. These findings may suggest that VRF might increase tooth mobility, which will certainly decrease to normal limits by month 12 if the treatment strategy is similar to that of the present study.

CAL and PD scores during the follow-up period were significantly decreased after surgery in the test teeth, whereas there was no difference in the control teeth. However, Sugaya *et al.* (2001) reported higher PD scores in their study. The differences between the two studies are probably due to the differences in VRF characteristics, local factors and surgical techniques. It is likely that the treatment modality in the present study together with strict plaque control, as confirmed by low PI and GI scores, resulted in periodontal healing corresponding to the VRF line, and it did not impair the periodontal status of neighbouring teeth.

Conclusions

Adhesive cementation using 4-META/MMA-TBB together with intentional replantation was an effective treatment modality for root filled maxillary single-rooted teeth with VRFs. The treatment resulted in similar PD and CAL at 6 months and PTVs by 12 months comparable to that of control teeth, if the optimum plaque control is provided. Bone fill was found in the periradicular area, at least, during the first year, and the treatment technique did not have a negative clinical impact on neighbouring teeth.

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References

Andersson L, Blomlöf L, Lindskog S, Feiglin B, Hammarström L (1984) Tooth ankylosis. Clinical, radiographic and histological assessments. *International Journal of Oral Surgery* **13**, 423–31.

Andreasen JO, Borum MK, Jacobsen HL, Andreasen FM (1995) Replantation of 400 avulsed permanent incisors. 4. Factors related to periodontal ligament healing. *Endodontics and Dent Traumatology* **2**, 76–89.

Arıkan F, Franko M, Gürkan A (2008) Replantation of a vertically fractured maxillary central incisor after repair with adhesive resin. *International Endodontic Journal* **41**, 73–9.

Dederich DN (1999) CO_2 laser fusion of a vertical root fracture. *Journal of the American Dental Association* **130**, 1195–9.

Hayashi M, Kinomoto Y, Miura M, Sato I, Takeshige F, Ebisu S (2002) Short-term evaluation of intentional replantation of vertically fractured roots reconstructed with dentin-bonded resin. *Journal of Endodontics* **28**, 120–4.

Hayashi M, Kinomoto Y, Takeshige F, Ebisu S (2004) Prognosis of intentional replantation of vertically fractured roots reconstructed with dentin-bonded resin. *Journal of Endodontics* **30**, 145–8.

Loe H, Silness J (1963) Periodontal disease in pregnancy. I. Prevalence and severity.. *Acta Odontologica Scandinavica* **21**, 533–51.

Maeda H, Hashiguchi I, Nakamuta H, Toriya Y, Wada N, Akamine A (1999) Histological study of periapical tissue healing in the rat molar after retrofilling with various materials. *Journal of Endodontics* **25**, 38–42.

Malhotra N, Kundabala M, Acharaya S (2011) A review of root fractures: diagnosis, treatment and prognosis. *Dental Update* **38**, 615–6, 619-20, 623–4.

Miles DA, Anderson RW, Pashley DH (1994) Evaluation of the bond strengths of dentin bonding agents used to seal resected root apices. *Journal of Endodontics* **20**, 538–41.

Nurrohman H, Nikaido T, Sadr A *et al.* (2011) Long-term regional bond strength of three MMA-based adhesive resins in simulated vertical root fracture. *Dental Materials Journal* **30**, 655–63.

Ørstavik D, Kerekes K, Eriksen HM (1986) The periapical index: a scoring system for radiographic assessment of apical periodontitis. *Endodontics and Dental Traumatology* **2**, 20–34.

Özer SY, Ünlü G, Değer Y (2011) Diagnosis and treatment of endodontically treated teeth with vertical root fracture: three case reports with two-year follow-up. *Journal of Endodontics* **37**, 97–102.

Oztürk M, Unal GC (2008) A successful treatment of vertical root fracture: a case report and 4-year follow-up. *Dental Traumatology* **24**, 56–60.

Pitts DL, Natkin E (1983) Diagnosis and treatment of vertical root fractures. *Journal of Endodontics* **9**, 338–46.

Pohl Y, Filippi A, Kirschner H (2005) Results after replantation of avulsed permanent teeth. II. Periodontal healing and the role of physiologic storage and antiresorptive-regenerative therapy. *Dental Traumatology* **21**, 93–101.

Schetritt A, Steffensen B (1995) Diagnosis and management of vertical root fracture. *Journal of the Canadian Dental Association* **61**, 607–13.

Schmid-Schwap M, Franz A, König F *et al.* (2009) Cytotoxicity of four categories of dental cements. *Dental Materials* **25**, 360–8.

Schulte W (1989) The Periotest method. *Deutsche Zahnärztliche Kalendar*, 107–26.

Sedgley CM, Messer HH (1992) Are endodontically treated teeth more brittle? *Journal of Endodontics* **18**, 332–5.

Silness J, Loe H (1964) Periodontal disease in pregnancy. II. Correlation between oral hygiene and periodontal condition. *Acta Odontologica Scandinavica* **22**, 121–35.

Stenvik A, Beyer-Olsen EM, Abyholm F, Haanaes HR, Gerner NW (1990) Validity of the radiographic assessment of ankylosis. Evaluation of long-term reactions in 10 monkey incisors. *Acta Odontologica Scandinavica* **48**, 265–9.

Sugaya T, Kawanami M, Noguchi H, Kato H, Masaka N (2001) Periodontal healing after bonding treatment of vertical root fracture. *Dental Traumatology* **17**, 174–9.

Tagami J, Tao L, Pashley DH (1990) Correlation among dentin depth, permeability, and bond strength of adhesive resins. *Dental Materials* **6**, 45–50.

Tamura Y, Tsubota K, Otsuka E *et al.* (2011) Dentin bonding: influence of bonded surface area and crosshead speed on bond strength. *Dental Materials Journal* **30**, 206–11.

Tao L, Tagami J, Pashley DH (1991) Pulpal pressure and bond strengths of SuperBond and Gluma. *American Journal of Dentistry* **4**, 73–6.