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Comparison of a new dental trauma splint device (TTS) with three commonly used splinting techniques

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Abstract – Splinting is the standard of care for stabilization of replanted or repositioned permanent teeth following trauma. The present experimental study compared four dental trauma splints in 10 volunteers. The evaluated splints included a wire-composite splint (WCS), a button-bracket splint (BS), a resin splint (RS), and a new device (TTS=Titanium Trauma Splint) specifically developed for splinting traumatized teeth. All splints were bonded to the labial surfaces of the maxillary lateral and central incisors. Splints were left in place for 1 week. After splint removal, the next splint was placed after a 1-week rest period. The sequence of splint application was randomized for each individual. The following parameters were assessed: tooth mobility with horizontal and vertical Periotest values (PTV) before and after splint application and splint removal, respectively; probing depths, plaque and bleeding on probing indices before splint application and removal, and chair time needed for splint application and removal. After splint application, horizontal PTV were significantly lower in central incisors for BS compared to TTS (P=0.04), and for RS compared to TTS (P=0.005) and to WCS (P=0.006). Reduction of lateral tooth mobility (=splint effect) expressed by the difference between horizontal pre- and postoperative PTV was significantly greater in RS compared to TTS and WCS (P<0.05) for central as well as for lateral incisors. However, changes of vertical tooth mobility were not significant across the splinting techniques. Periodontal parameters remained unchanged, reflecting the excellent oral hygiene by the study subjects. The chair time needed for splint application was significantly shorter for TTS (P<0.01). In conclusion, all tested splints appeared to maintain physiologic vertical and horizontal tooth mobility. However, the latter was critically reduced in RS splints.

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Key words: dental trauma splint; splinting method; experimental study; tooth mobility; Periotest

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Dislocation of teeth is a frequent finding following orofacial trauma. It has been estimated that three to four in 10 children sustain injuries to their primary teeth prior to school age. Approximately every third child will also suffer trauma to the permanent teeth before leaving school age (1–3). It is common practice that injured primary teeth are not splinted. Depending on the clinical situation, traumatically displaced primary teeth are left to heal spontaneously or, in case of severe dislocation, are normally extracted (4–6). The same authors also advocate that avulsed primary teeth should not be replanted to avoid damage to the developing permanent teeth.

However, every effort should be undertaken to save traumatized permanent teeth. Traumatically dislocated or avulsed permanent teeth are normally repositioned or replanted, respectively (7–9). Treatment outcome is influenced by several factors, such as degree of dislocation, concomitant dento-alveolar injuries, stage of root formation, time period between trauma and treatment and, for avulsed teeth, duration and medium of storage. An important issue in trauma therapy is the splinting method used for stabilization of injured teeth to support periodontal healing. A large variety of fixation or stabilization techniques have been reported in the literature (Table 1) (10–14). An ideal splint should be passive and semi-rigid, maintaining physiologic tooth mobility after splinting. In addition, the splint should be left in place for as short a period as necessary, i.e. 1–2 weeks. It has been shown in experimental studies that either rigid or prolonged splinting may lead to adverse effects, such as external root resorption and dento-alveolar ankylosis (15–19). In addition, trauma splints should have optimal properties for handling, application and removal. From the patient's perspective, the splint should not interfere with occlusion, oral hygiene and speech.

The authors have developed a new device for splinting traumatized teeth (20). The objective of this experimental study was to compare this new splint with three other splints recommended for stabilization of injured teeth.

Material and methods

The study was conducted in 10 volunteers recruited from the staff of our department. All subjects were female with a mean age of 21 years 6 months (range 17 years 6 months to 34 years 9 months). The study design was approved by the Ethics Commission of the Canton Berne (study-number: ZMK-OC-1/2000) and the clinical study was carried out according to the Helsinki Declaration. The individuals were given oral and written information about the materials and procedures used throughout the study. Prior to enrollment, each volunteer signed a written consent form.

Table 1. Reported techniques for splinting traumatized teeth

Stabilization to teeth
– wire-composite splint
– Kevlar, Fiberglas splint
– bracket splint
– porcelain veneer splint
– arch bar
– interdental ligature wiring
Stabilization to gingiva/mucosa
– suture fixation
– vacuum-formed stent
Stabilization to bone
– fixation to bone screw/plate
– fixation to bone wire

To be included in the study, subjects had to be healthy and presenting no medical contraindications for the planned procedures. All four maxillary incisors had to be free of caries and periodontal disease. Gingiva and oral mucosa adjacent to the maxillary incisors had to show no pathologic conditions.

Four different splinting methods were evaluated in each individual, resulting in a total of 40 splints. The sequence of splint application was determined at random. Each splint was left *in situ* for 7 days. After removal, at least 1 week elapsed before the next splint was placed.

Preliminary experiments

Preliminary *in vitro* experiments were undertaken to test the bond strength after four applications of the adhesion procedure used later in the clinical investigation (see below). Between application and removal, the samples were aged for 7 days and thermocycled (300×) between 5° and 55°C. The results showed no change of the bond strength during the whole period of 28 days.

Splint application

All splints were bonded to the labial aspect of all maxillary incisors. By placing the splints coronally, Periotest® (Gulden, Bensheim, Germany) measurements could be taken in the cervical area of the teeth, and the splints were kept away from the gingival margin and the papillae.

After placing cotton rolls in the vestibule, the maxillary incisors were dried with air. Etching of the enamel surface was performed with 35% phosphoric acid gel for 30 s (Ultra-Etch®, Ultradent Products Inc., South Jordan, UT, USA). Subsequently, the gel was rinsed off with water from the dental unit and the etched surfaces were dried again. A thin layer of bonding agent (Optibond®, Kerr, Scafati, Italy) was applied using a microbrush. The bonding agent was left for 20 s prior to polymerization with a light source for another 40 s. Finally, the splints were placed with the techniques described below.

Titanium Trauma Splint (TTS)

The TTS was cut to the desired length and manually bent to the facial aspects of the maxillary incisors. Per tooth, one rhombus of the TTS was filled with light-curing composite (Tetric® Flow Chroma, Vivadent, Schaan, Liechtenstein) (Fig. 1) with 30 s of polymerization.

Wire Composite Splint (WCS)

A 0.16″×0.22″ wire (Standard Edgewise Wire, American Orthodontics, Sheboygan, WI, USA) was cut to the desired length. The wire was then adapted

Fig. 1. TTS titanium trauma splint bonded to each maxillary incisor with light-cured composite.

Fig. 3. Bracket splint with bonded button brackets and braided 0.3-mm wire connecting the four maxillary incisors.

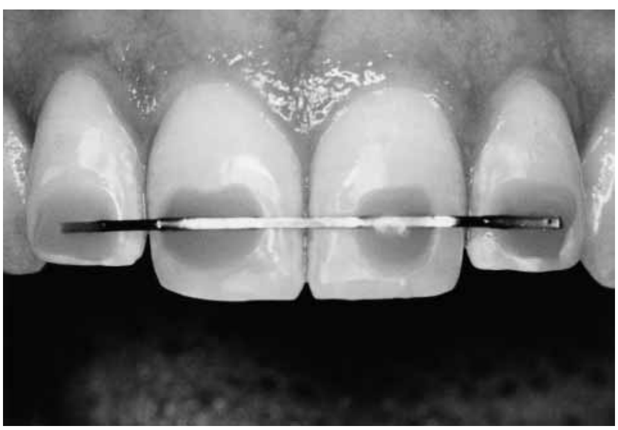

Fig. 2. Wire-composite splint using a rectangular orthodontic wire (0.16″×0.22″) fixed with composite.

Fig. 4. Resin splint bonded directly to the surfaces and connecting all four maxillary incisors.

to the curvature of the maxillary incisors using pliers. The splint was secured with identical light-curing composite (Fig. 2).

Bracket Splint (BS)

Button brackets (Buttons for direct bonding flat base, Dentaurum, Ispringen, Germany) were bonded with the same light-curing composite. Thereafter, a 0.3-mm soft wire (Remanium®, Dentaurum) was braided from button to button to connect the four incisors. Care was taken to avoid any orthodontic force when twisting the ligature wire. Finally, the wire was secured to each button with composite (Fig. 3).

Resin Splint (RS=PTS)

The resin (Protemp®II, ESPE Dental AG, Seefeld, Germany) was mixed according to the manufacturer's instructions. Using a syringe, the material was continuously applied to the facial crown aspects connecting all four maxillary incisors (Fig. 4). The total working time from mixture initiation to complete set of the resin was 7 min.

All splints were finished if necessary. Any sharp edges and afflux material were removed to prevent irritation of the adjacent soft tissues.

Splint removal

A high-speed bur was used to cut the wires and the resin at the interdental area to separate the splints. The TTS was not separated but rather "peeled off" from the tooth surfaces after grinding the composite down to the titanium. Button brackets were removed with debonding pliers. Any remaining composite was chipped off with a curette or a special bur (Adhesive remover H22; Brasseler-Komet, Lemgo, Germany). A thin residual layer of bonding material was sometimes not removed to avoid repeated damage to the enamel surface, until removal of the last splint. After each removal procedure, a 1% fluoride solution

Table 2. Working time for splint application and removal

Splint	Application	Removal
Titanium Trauma Splint	8.5±0.76 min[a,b,c]	3.7±0.48 min[e]
Wire Composite Splint	10.1±1.29 min[b,d]	6.4±2.34 min[e]
Bracket Splint	13.1±0.94 min[a,d]	5.2±1.46 min
Resin Splint	12.4±2.1 min[c]	4.5±1.35 min

[a,b,c,d,e] $P<0.001$. [b] $P<0.01$. Same letter=significant difference.

(Elmex® fluid, Gaba AG, Therwil, Switzerland) was applied to the teeth for surface remineralization.

Study parameters

Tooth mobility

Vertical and horizontal PTV were recorded for each tooth immediately before and after splint application. The same measurements were taken 1 week later, immediately before and after splint removal. According to the manufacturer's instructions, each measurement was taken three times and averaged for further analysis. Change of tooth mobility (ΔPTV=splint effect) was defined as the difference between the pre- and postapplication PTV. Throughout the study period, a total of 3840 Periotest measurements were taken.

Periodontal parameters

Periodontal parameters included probing depth, plaque and bleeding on probing (BOP). Scoring of plaque and BOP was done according to Mombelli et al. (21). Readings were taken at three labial sites, mesio-buccal, mid-buccal and disto-buccal, before splint application and 1 week later before splint removal.

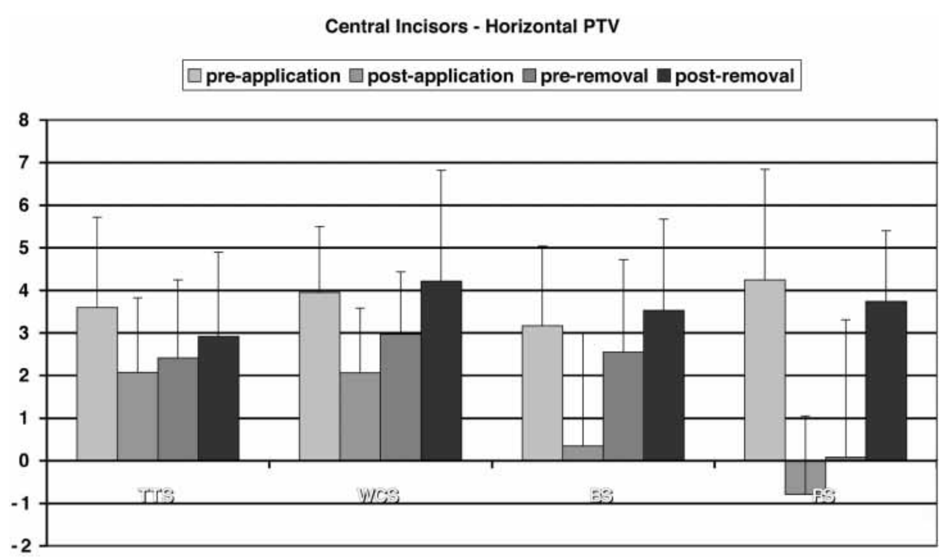

Fig. 5. Horizontal Periotest values for central incisors.

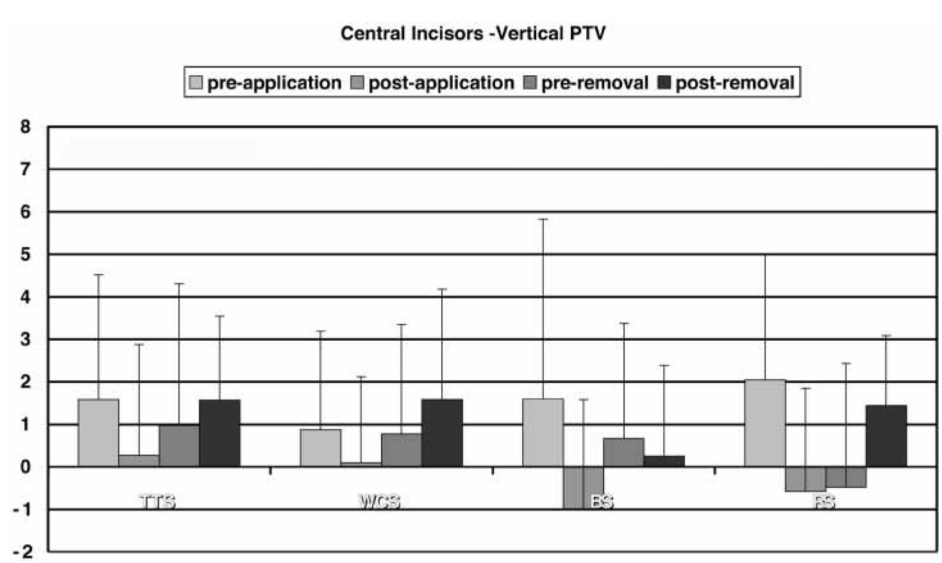

Fig. 6. Vertical Periotest values for central incisors.

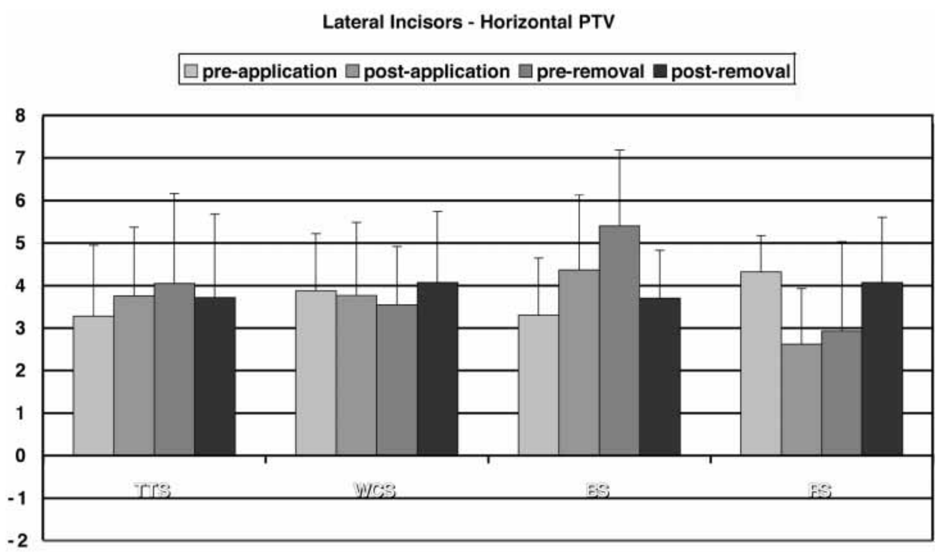

Fig. 7. Horizontal Periotest values for lateral incisors.

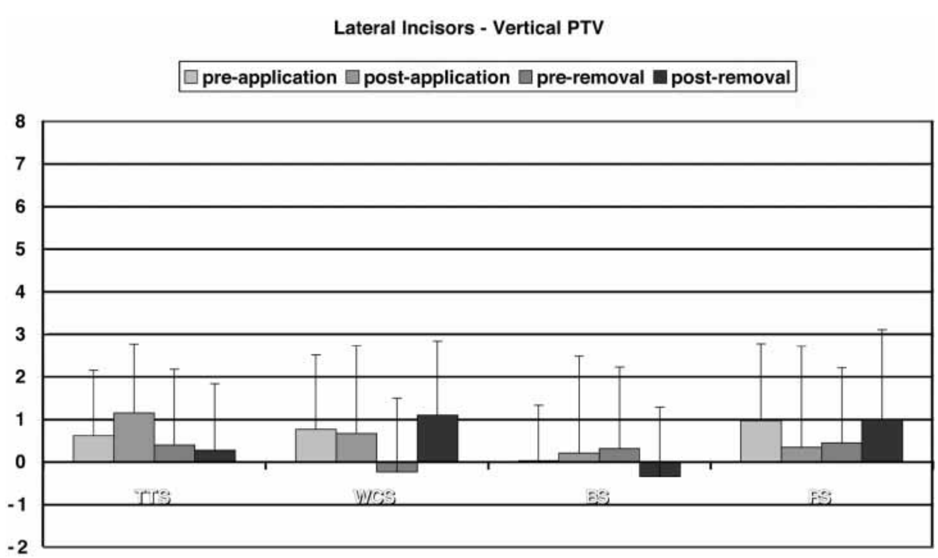

Fig. 8. Vertical Periotest values for lateral incisors.

Chair time

The working time needed for application and removal of each splint was recorded with a stop-watch.

Data acquisition and statistical analysis

In each session (splint application and splint removal), a special form was used for data recording. First, all data were analysed by descriptive methods using box plots (Systat 5.2, Systat Inc., Evanston, IL, USA). As they were not normally distributed, the Kruskal-Wallis one-way analysis of variance and the Mann-Whitney U-Test were used for the comparison of independent (unpaired) comparisons and the Wilcoxon test for paired comparisons. When employing multiple comparisons, the *P*-values were corrected using the Bonferroni adjustment procedure. The significance level chosen in all statistical tests was 0.05.

Results

None of the subjects withdrew from the study; a total of 40 splints could therefore be evaluated. Chair time for splint application and splint removal is given in Table 2. Overall, the shortest working times were recorded for the TTS method for application (8.5 min) as well as for removal (3.7 min) of the splint. In contrast, the BS method took 13.1 min for placement, and the WCS needed 6.4 min for removal.

The PTV are given separately for lateral and central incisors. The horizontal and vertical PTV for all splints are shown in diagrams (Figs. 5–8). The splint effects (ΔPTV) are shown in Tables 3 and 4.

Table 3. Splint effects (ΔPTV) for central incisors

Splint	ΔPTV horizontal	ΔPTV vertical
Titanium Trauma Splint	1.52±0.63[a]	1.31±1.06
Wire Composite Splint	1.88±1.54[b]	0.86±1.60
Bracket Splint	2.82±2.68	2.58±3.81
Resin Splint	5.03±2.74[a,b]	2.62±2.09

ΔPTV=(pre-application PTV) – (post-application PTV).
Positive values represent tightening (decreased tooth mobility), negative values loosening (increased tooth mobility).
[a,b]$P<0.05$. Same letter=significant difference.

Table 4. Splint effects (ΔPTV) for lateral incisors

Splint	ΔPTV horizontal	ΔPTV vertical
Titanium Trauma Splint	−0.47±0.64[a]	−0.53±1.26
Wire Composite Splint	0.12±1.65[b]	0.10±1.82
Bracket Splint	−1.07±2.19	−0.18±1.60
Resin Splint	1.70±1.37[a,b]	0.62±1.36

ΔPTV=(pre-application PTV) – (post-application PTV).
Positive values represent tightening (decreased tooth mobility), negative values loosening (increased tooth mobility).
[a,b]$P<0.05$. Same letter=significant difference.

Table 5. Probing depth (labial measurements pooled)

Splint	Pre-application	Pre-removal
Titanium Trauma Splint	1.78±0.49	1.83±0.49
Wire Composite Splint	1.84±0.50	1.8±0.49
Bracket Splint	1.8±0.38[a]	1.95±0.50[a]
Resin Splint	1.8±0.39	1.72±0.51

[a]$P<0.05$. Same letter=significant difference.

Central incisors

Horizontal PTV

Splinting resulted in decreased lateral tooth mobility with significant changes within all tested trauma splints ($P=0.005$ to $P=0.009$). However, comparison of postoperative PTV across treatment methods showed significantly more reduction of lateral tooth mobility with BS and RS methods than with TTS and WCS ($P=0.04$ to $P=0.006$). Postremoval readings were similar to baseline readings (*ns*).

Horizontal splint effect (ΔPTV)

Change of tooth mobility remained below two Periotest units for TTS and WCS. In contrast, RS (with a ΔPTV of greater than 5) significantly decreased tooth mobility compared to TTS and WCS ($P<0.05$).

Vertical PTV

Significant changes for vertical tooth mobility after splint application were found for TTS ($P=0.007$) and RS ($P=0.008$). No significant differences were noted across the various treatment methods.

Vertical splint effect (ΔPTV)

No change of vertical tooth mobility was found with TTS and WCS compared to BS and RS. Differences across the treatment methods were not significant.

Lateral incisors

Horizontal PTV

A significant reduction of lateral tooth mobility was only observed for RS ($P=0.007$) after splint application. Significantly increased lateral tooth mobility was seen for BS before splint removal compared to baseline readings ($P=0.03$). Across the various splinting methods, pre-removal values were significantly higher for BS compared to WCS and RS ($P=0.03$, $P=0.008$).

Horizontal splint effect (ΔPTV)

The least change of horizontal tooth mobility was calculated for TTS and WCS. RS showed significantly more reduction of horizontal tooth mobility than TTS and WCS ($P<0.05$).

Vertical PTV

Within and across the various splinting techniques, no significant changes of vertical tooth mobility were found after splint application.

Vertical splint effect (ΔPTV)

All splinting techniques showed only minimal change of vertical tooth mobility. Differences across treatment methods were not significant.

With regard to the periodontal parameters, measurements were similar for all three labial sites, and were therefore pooled per tooth. Probing depths remained stable throughout the study period for all

Table 6. Plaque index (labial measurements pooled)

Splint	Pre-application	Pre-removal
Titanium Trauma Splint	0.15±0.45	0.16±0.22
Wire Composite Splint	0.15±0.27	0.25±0.63
Bracket Splint	0.09±0.19	0.14±0.23
Resin Splint	0.23±0.31	0.27±0.27

Table 7. Bleeding on probing (labial measurements pooled)

Splint	Pre-application	Pre-removal
Titanium Trauma Splint	0.23±0.27	0.22±0.24
Wire Composite Splint	0.22±0.19	0.14±0.18
Bracket Splint	0.25±0.30	0.22±0.23
Resin Splint	0.18±0.19	0.28±0.46

tested splints except for the BS method ($P<0.03$) (Table 5). In general, oral hygiene was excellent, as reflected by the very low plaque and BOP scores (Tables 6 and 7). No significant changes were noted for plaque and BOP readings following splint application.

Discussion

The present study investigated four different dental trauma splints in non-injured maxillary incisors of 10 volunteers. The main objective of this experimental study was to analyse clinical changes in tooth mobility and periodontal parameters following placement of dental trauma splints. We realize that all splints were placed on healthy, non-traumatized teeth. However, since all groups were tested under the same conditions, differences found between them are expected to be valid. A physiologic splint should be firm enough to stabilize a traumatized tooth in its original position in the socket. On the other hand, the splint should be flexible enough to functionally stimulate periodontal healing. It has been shown in experimental studies that replanted teeth stabilized with a physiologic semi-rigid or flexible splint show less replacement resorption and better organized ligament fibers compared to rigidly fixed teeth (15–18). But it has also been shown experimentally that non-splinted teeth performed equally well compared to physiologically splinted teeth following replantation or repositioning (22, 23). However, from a medico-legal aspect, splinting is necessary to avoid repeated displacement during periodontal healing, not to mention aspiration or swallowing of a replanted or repositioned tooth.

The chosen method for measuring tooth mobility, the Periotest technique, is a well established physical assessment of tooth mobility and may have a place as a diagnostic tool in dental traumatology (24–29). The Periotest measures the reaction to a reproducible impact applied to the tooth crown (30). The Periotest value (PTV) depends to some extent on tooth mobility, but mainly on the damping characteristics of the periodontium. Normal horizontal PTV for maxillary incisors in grown-up females (all study subjects were female and older than 17) range between 3 and 13 for central incisors and between 3 and 10 for lateral incisors (30). Initial horizontal PTV in the present study ranged from 3.17 to 4.33, reflecting the excellent periodontal status of the examined teeth. The Periotest method is of special interest for follow-up examinations to identify changes of tooth mobility; for instance, disease augmentation or treatment course can be monitored with the method. It has been shown that the Periotest device is a useful tool in monitoring mobility of splinted teeth to optimize the splinting time (27) or to detect early replacement resorption in replanted avulsed teeth (31).

The present study shows that the Periotest method was able to detect changes of tooth mobility both following splint application and after splint removal. Although most changes of PTV following splint application were significant within a given splint (particularly for horizontal PTV), the absolute changes in Periotest units remained low. This is clinically relevant, as maintenance of physiologic tooth mobility is a requirement for dental trauma splints. In addition, central incisors showed more changes (reduction) of tooth mobility than lateral incisors. This is of clinical importance because the central incisors in the present study represent a central position within a splint, i.e. a tooth to be stabilized, whereas the lateral incisors represent the non-injured, adjacent firm teeth. Given a clinical situation in a true trauma case, the splint effect (ΔPTV) is much higher, as has been shown by Ebeleseder et al. (27). The same authors also demonstrated that a splinted tooth could not be fixed tighter to the adjacent teeth than the firmest tooth within the splint was fixed in the socket. In addition, they found that unilateral fixation or adjacent tooth gaps reduced the effect of the splint, and no benefit resulted from extending the splint to more than one adjacent firm tooth.

Across the four tested splinting techniques, significant changes were seen for horizontal PTV and horizontal splinting effects for central incisors in BS and particularly in RS splints. Following splint application, horizontal PTV remained above 2 in TTS and WCS splints, whereas in BS and RS splints the horizontal PTV approached or dropped below zero. These readings appear to be non-physiologic according to the Periotest inventors (30). However, periodontal healing does not only depend on physiologic splinting, but on many other factors such as post-traumatic pulpal and periodontal alterations, microbial contamination, medium and time of stored avulsed teeth, etc.. Therefore, splinting must be regarded only as a contributory but not a decisive factor for periodontal healing of injured teeth. From a clinical perspective, it is important that in the present study all PTV returned to normal after splint removal, except for vertical readings following BS removal. This may be explained by the technique of debonding the button brackets using pliers. Since one part of the instrument rested on the incisal edge, an intrusive force appeared to push the tooth into its socket upon loosening the button brackets. The phenomenon was observed in central as well as in lateral incisors (see Figs. 6 and 8).

The tested dental trauma splints are commonly recommended for stabilization of repositioned or replanted permanent teeth. Oikarinen et al. (26) evaluated the rigidity of various splinting techniques *in vitro* in dissected sheep mandibles using vertical and horizontal Periotest measurements. They concluded from their results that a flexible wire-composite splint, and a Protemp splint (Protemp II, Espe, Seefeld, Germany) fulfilled the demands for splinting luxated teeth by allowing vertical flexibility but maintaining adequate lateral support. Similar findings were noted in the present study with more pronounced reduction of horizontal (=lateral tooth support) compared to only slight reduction of vertical tooth mobility following splint application.

All tested splints in the present study fulfill the current requirements of a dental trauma splint, such as direct intraoral application using everyday dental materials such as wires, brackets, composite and resin. In addition, trauma splints should stabilize the traumatized tooth in the original position and bring about adequate fixation for the whole immobilization period (13). Dental trauma splints should be passive and exert no orthodontic forces (32). They should neither damage the gingival tissues nor increase the risk of caries. Further, the splints should not affect hygienic and aesthetic demands of the patient or interfere with occlusion. With all these requirements in mind, the new device, the TTS titanium trauma splint, was specifically designed for fixation of traumatized teeth. When developing this splint, maintenance of physiologic tooth mobility and a tissue-compatible design were of utmost concern (20). In addition, consideration was given to simplify the clinical handling to quickly apply and remove the splint with little or no assistance. The time-consuming procedures of wire bending and stabilization during placement are avoided. The practitioner and the patient alike will benefit from shorter chair time and less stressful procedures reflected by the shorter working times for the TTS method measured in this study.

Conclusions

- Following splint application, horizontal Periotest values were significantly reduced in all tested trauma splints.
- Changes of tooth mobility in absolute periotest units remained very low except for horizontal readings in resin splints.
- Horizontal and vertical PTV returned to normal preoperative values following splint removal, except for vertical measurements in bracket splints.
- Plaque and BOP were not altered by any of the tested splints throughout the investigation period.
- The newly developed TTS appears to be adequate with regard to maintaining physiologic tooth mobility after splint application. Further, ease of application and removal represented by shorter chair time may benefit patient and practitioner alike.

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