Dental Traumatology

Dental Traumatology 2011; **27**: 422–431; doi: 10.1111/j.1600-9657.2011.01033.x

Influence of wire extension and type on splint rigidity – evaluation by a dynamic and a static measuring method

Christine Berthold[1], Friedrich Johannes Auer[2], Sergej Potapov[3], Anselm Petschelt[1]

[1]Dental Clinic 1 – Operative Dentistry and Periodontology, Friedrich-Alexander-University, Erlangen; [2]Dental Clinic Dr. Wiedenmann, Nuremberg; [3]Institute for Medical Informatics, Biometry and Epidemiology, Friedrich-Alexander-University, Erlangen, Germany

Correspondence to: Christine Berthold, Dental Clinic 1 – Operative Dentistry and Periodontology, Friedrich-Alexander-University Erlangen-Nuremberg, Glueckstr.11, 91054 Erlangen, Germany
Tel.: +49 9131 85 34638
Fax: +49 9131 85 33603
e-mails: berthold@dent.uni-erlangen.de; christine_berthold@yahoo.de

Accepted 24 May, 2011

Abstract – *Objectives*: To evaluate the influence of wire dimension and wire length on the splint rigidity of wire-composite splints *in vitro*. *Materials and Methods*: A custom-made artificial model was used. The central incisors simulated ‘injured’ teeth with increased mobility, and the lateral incisors and canines served as ‘uninjured’ teeth with physiological mobility. To assess horizontal and vertical tooth mobility before and after splinting, the Periotest and Zwick methods were applied. Teeth 13–23 were splinted using wire-composite splint 1 (WCS1; Dentaflex 0.45 mm) and wire-composite splint 2 (WCS2; Strengtheners 0.8 × 1.8 mm). Splint length was varied by successively shortening the wire. The influence of wire dimension was tested using *t*-test and Wilcoxon–Mann–Whitney test with the Bonferroni-Holm procedure ($\alpha = 0.05$). To test the influence of wire length, ANOVA and Kruskal–Wallis tests as well as Tukey range and Wilcoxon test with Bonferroni-Holm procedure were applied ($\alpha = 0.05$). *Results*: Wire dimension significantly influenced splint rigidity ($P < 0.05$). The wire length significantly influenced the splint rigidity of WCS1 in the horizontal dimension and WCS2 in the horizontal and vertical dimensions ($P < 0.05$). Splint rigidity was significantly reduced when splinting only ‘injured’ teeth compared with splints including ‘uninjured’ adjacent teeth ($P < 0.05$). No differences were found between splints including one or two ‘uninjured’ teeth on each side ($P > 0.05$). *Conclusion*: WCS1 is flexible compared with the more rigid WCS2. The wire length influences the rigidity. To ensure adequate fixation and reduce the risk of enamel damage during splint removal, the splint should include only one ‘uninjured’ tooth bilaterally.

Dislocation injuries and hard tissue injuries, such as alveolar bone and root fractures, are treated by splinting the affected teeth. The aim is to prevent accidental inhalation or ingestion of the injured teeth and to protect the teeth and surrounding tissues while they are vulnerable during the healing period (1–3). Splint rigidity varies depending on the type of trauma. In the case of periodontal ligament (PDL) injuries, after dislocation, the teeth should be flexibly splinted to allow transmission of functional forces (1–6). Hard tissue injuries require semi-rigid to rigid fixation (2, 5). The splints should ensure an adequate fixation of the teeth or fragments in their original position, enable hygiene and mastication, and reduce pain, thereby increasing the patient’s comfort. Modern adhesively attached trauma splints consisting of various reinforcement materials fulfill most of these requirements (1–3, 6–10).

Splint rigidity can be objectively evaluated *in vivo* on healthy (1, 7) or injured subjects (8) as well as *in vitro* on animal (9, 11) or artificial models (2, 6, 12–17). We developed a new model consisting of bovine tooth facets to allow adhesive splint application with an acid-etch technique. Tooth mobility can be individually adjusted to simulate ‘injured’ and ‘uninjured’ teeth approximating the clinical situation (6, 12). To evaluate *in vitro* splint rigidity, different tooth mobility-assessment methods are available (2, 6, 9, 11–15, 17) such as the dynamic Periotest method (2, 6, 9, 11–13) or the static technique using a universal testing machine (6, 14, 15, 17).

A big disadvantage of adhesively attached trauma splints is the risk of damaging the enamel during splint removal (1, 18). Therefore, the goal should be to include as few ‘uninjured’ adjacent teeth in the splint as possible to assure adequate fixation. Studies focusing on the influence of splint extension on the rigidity of dental trauma splints are rare (8).

The aim of this *in vitro* study was to evaluate the influence of wire extension and wire dimension on the rigidity properties of wire-composite splints. The following null hypotheses were investigated: (1) the dimension and material properties of the splint have no influence on splint rigidity for ‘injured’ teeth when measuring tooth mobility with (i) a dynamic or (ii) a static measurement method; (2) the extension of the wire does not influence

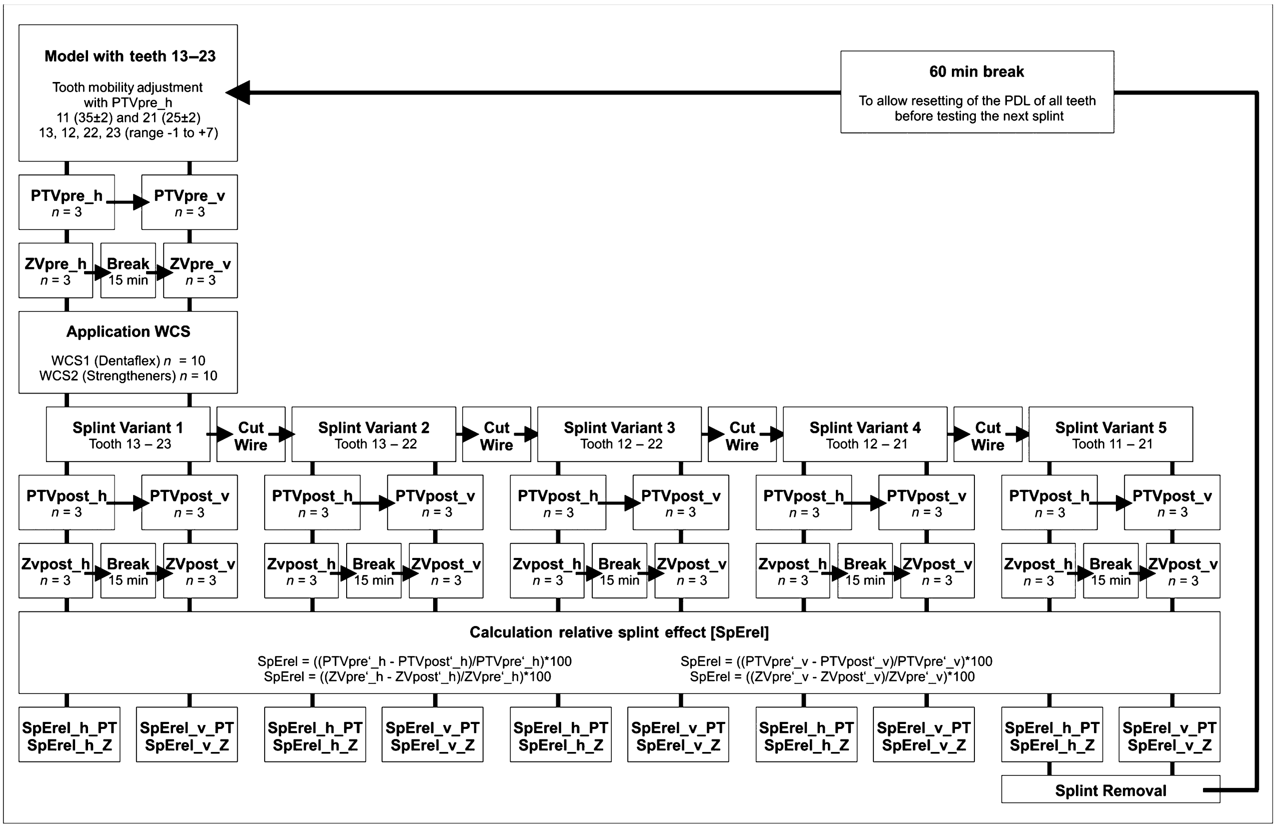

Fig. 1. Flow chart of the testing procedure. The PTVpre was measured before the ZVpre. After splint insertion, the PTVpost and ZVpost were evaluated with the splint *in situ*. The splint effect was calculated based on the Vpre and Vpost. Z, Zwick; PT, Periotest; Vpre, value before splinting; Vpost, value after splinting; SpErel, relative splint effect; h, horizontal; v, vertical.

splint rigidity within the 'injured' teeth when assessing tooth mobility with (i) a dynamic or (ii) a static measurement method.

Materials and methods

The schematic of the entire splint rigidity evaluation procedure is shown in Fig. 1.

Model and tooth mobility adjustments

For this *in vitro* study, a newly developed artificial model, described in detail in Berthold et al. (6, 12), was used. The model consists of a round aluminum base with six alveolar sockets arranged in a half-round arc to mimic the dental arch. The two middle sockets are enlarged compared with the other sockets to simulate the clinical situation of a dislocated tooth. The simulated PDL of the 'injured' teeth consists of silicon in the apical third and rubber foam in the middle and cervical root areas. The PDL of the 'uninjured' teeth was made entirely of silicon. Bovine tooth facets were adhesively attached to the coronal part of the stainless steel teeth to allow an acid-etch technique to be used for adhesive splint bonding. Tooth mobility could be finely adjusted using apical screws. Before inserting a new splint, the tooth mobility was always set using horizontal Periotest values before splinting (PTVpre_h) (6, 12). The Periotest values corresponding with the degree of loosening were gathered from the Periotest operating manual (degree of loosening: 0 = PTV_h −8 to 9, I = 10–19, II = 20–29, III = 30–50). The 'injured' teeth presented with increased tooth mobility (tooth 11 degree of loosening III at PTVpre_h 35 ± 2, tooth 21 degree of loosening II at PTVpre_h 25 ± 2). The 'uninjured' teeth 13, 12, 22, 23 presented with physiological mobility and were set at 0 degree of loosening (PTVpre_h range −1 to +7), according to an *in vivo* investigation on healthy volunteers (1). The vertical Periotest values (PTVs) resulted from the adjustment process.

Splinting

The model was placed in the model holder during the splinting procedure with the tooth facets facing upwards (12). Two previously investigated wire-composite splints (WCS), WCS1 (Fig. 2; Dentaflex 0.45 mm, sixfold, straight wires, Dentaurum, Pforzheim, Germany) (1, 2, 6, 11, 12) and WCS2 (Fig. 3; Strengthens 0.8 × 1.8 mm, Dentaurum) (1, 2, 11, 12), were inserted from tooth 13–23. Both splint types were applied 10 times.

After cutting the wires to their designated lengths, they were prepared to fit passively into the dental arch. The Dentaflex was pulled over a mirror handle to achieve a near half-round shape. The strengtheners were 'bent to

Fig. 2. The wire-composite splint 1 (WCS1; Dentaflex 0.45 mm, sixfold, straight wires, Dentaurum, Pfortzheim, Germany) is attached to the dental arch (tooth 12–22) of a healthy volunteer with flowable composite (Grandio flow wo, VOCO, Cuxhaven, Germany).

Fig. 3. The wire-composite splint 2 (WCS2; Strengtheners 0.8 × 1.8 mm, Dentaurum) is attached to the dental arch (tooth 12–22) of a healthy volunteer with flowable composite (Grandio flow wo, VOCO).

fit' using orthodontic pliers. For fine adjustment, finger pressure was used. The central enamel surface area of the bovine tooth facets was etched for 15 s (Total Etch; Ivoclar Vivadent, Schaan, Liechtenstein) and bonded (Heliobond, Ivoclar Vivadent) following the manufacturer's instructions. The wires were attached to the teeth (sequence: tooth 13, 23, 12, 11, 21, 22) using flowable composite (Tetric EvoFlow Bleach XL; Ivoclar Vivadent).

Tooth mobility assessment

Tooth mobility was evaluated before (pre) and after (post) splint insertion using the dynamic Periotest method (PT) (1, 2, 6, 12) (Gulden, Modautal, Germany) and a universal testing machine (Z) (Zwicki 1120, Zwick, Ulm, Germany) as a static measurement technique (Fig. 4) (6). For the Zwick method, the load (0–10 N) was applied with a custom-made stainless steel rod (Ø 3 mm) at a cross-head speed of 2 mm min^{-1}. Load and

Fig. 4. The model is placed in the holder for the horizontal Zwick measurement before splint insertion. The custom-made rod is attached to the Zwick universal testing machine and aligned with the middle of the vestibular tooth surface.

tooth displacement were recorded using testXpert software (Zwick). The measurements for both methods were taken in the horizontal (h; middle of the vestibular tooth surface) and vertical (v; middle of the incisal edge) dimensions at reproducible measurement points (1, 6, 12). All measurements were consecutively repeated three times per tooth.

PTVpre and ZVpre

To evaluate tooth mobility before inserting a new splint, the tooth mobility adjustment was reconfirmed and readjusted when necessary according to the horizontal PTVs. The initial values were assessed with the Periotest method (h and v) and the Zwick method (h and v) (6). Between the horizontal and vertical Zwick measurements, a 15-min pause was included to allow the PDL to reset after the measurements. All measurements were taken in the same sequence (tooth 13, 12, 11, 21, 22, 23).

PTVpost and ZVpost

After splinting, tooth mobility was measured with the Periotest method (h and v) and the Zwick method (h and v). As for the ZVpre, a 15-min pause was included between the horizontal and vertical Zwick measurements. To evaluate the influence of splint extension, the PTVpost and ZVpost were measured for five different extension variants of the same splint. These variants resulted after successively reducing the number of splinted teeth by separating the wire with a diamond bur (881KS, NTI, Kahla, Germany) at the approximal gap (Fig. 5). The following splint variants (SpV) were tested (Fig. 6):

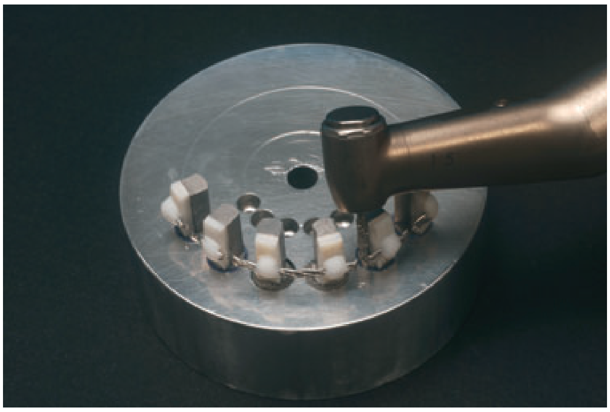

Fig. 5. The wire-composite splint 2 (Strengtheners) is attached to the dental arch from tooth 13–23. The splint extension was successively shortened by separating the wire with a diamond bur. The displayed status is splint variant five, including only the 'injured' teeth 11 and 21.

SpV1 (6 teeth, 2 'injured' and 4 'uninjured', teeth 13–23)
SpV2 (5 teeth, 2 'injured' and 3 'uninjured', teeth 13–22)
SpV3 (4 teeth, 2 'injured' and 3 'uninjured', teeth 12–22)
SpV4 (3 teeth, 2 'injured' and 1 'uninjured', teeth 12–21)
SpV5 (2 teeth, 2 'injured' and 0 'uninjured', teeth 11 and 21).

All measurements were taken following the same sequence (tooth 13, 12, 11, 21, 22, 23), but only for the teeth included in the respective splint variant.

Splint removal

After tooth mobility was assessed for all five splint variants, the splint residuals were removed. First, the resin composite was reduced without touching the enamel (881KS, NTI) to remove the wire. Then, the composite remnants were ablated using a tungsten carbide bur (HM23R, Hager & Meisinger, Neuss, Germany).

Relative splint effect

The mean horizontal and vertical PTV and Zwick values (ZV) were calculated. Before evaluating the splint effect, the Periotest scale was adjusted from the original range (−8 to +50) to a scale with only positive values to avoid division by zero. All PTVs were transformed (PTV' = PTV + 9), and the resulting PTV' was used to calculate the relative splint effect [SpErel] in percent (6, 12).

The SpErels were calculated using the following equations: SpErel_PT [%] = ([PTV'pre − PTV'post]/PTV'pre)*100 and SpErel_Z [%] = ([Zpre − Zpost]/Zpre)*100.

Statistical analysis

Descriptive analysis was performed. PTVpre, ZVpre, SpErel_PT, and SpErel_Z in the vertical and horizontal dimension for teeth 13–23 were graphically displayed as box plots. Using the Shapiro-Wilk test, the normal distribution was tested (Tables 1 and 2). For normally distributed data, parametric tests were used, and for non-normally distributed data, nonparametric tests were used. The general level of significance was set at $\alpha = 0.05$. For multiple testing, the Bonferroni-Holm procedure was used to antagonize the α-error-accumulation. To test the influence of the splint dimension on the rigidity within one splint variant, the *t*-test (parametric test) and the Wilcoxon–Mann–Whitney test (nonparametric test) with Bonferroni-Holm procedure were applied. To test the influence of the splint extension per splint type on the rigidity, analysis of variance (ANOVA) (parametric test) and the Kruskal–Wallis test (nonparametric) were conducted. When statistically significant differences ($P < 0.05$) were found by ANOVA and equality of variances was proven (Levene test; $P > 0.05$), the Tukey post hoc test was conducted to compare the different splint variants. In the case of statistically significant differences within the data tested with the Kruskal–Wallis test, pairwise comparisons using the Wilcoxon test with the Bonferroni-Holm procedure were carried out. Data were recorded using acquisition sheets and transferred to IBM SPSS Statistics 19.0 (IBM Corp., Somers, NY, USA). Statistical analysis was performed using the R Project for Statistical Computing (version 2.11.1, R Development Core Team, 2010, http://www.r-project.org).

Results

We recorded a total of 9600 values, 4800 for each tooth mobility-assessment method. Three consecutively repeated Vpre and Vpost measurements per assessment method, dimension, and tooth were averaged; all calculations and statistical comparisons were based on the resulting mean.

PTVpre

The PTVpre_h (Fig. 7) ranged within the targeted limits described in 'Materials and Methods.' The 'injured' tooth 11 showed a degree of loosening III (PTVper_h 35.3 ± 2), whereas tooth 21 showed a degree of loosening II (PTVpre_h 26.3 ± 1.3). The PTVpre_h of the 'uninjured teeth' represented degree of loosening 0 (PTVpre_h tooth 13: -0.2 ± 0.6; tooth 12: 0.7 ± 1.0; tooth 22: 5.1 ± 1.4; tooth 23: 0.6 ± 1.3).

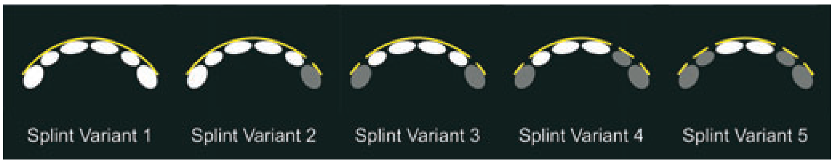

Fig. 6. Schematic images of the five splint variants. The wire was successively cut. The mobility of the gray teeth was not evaluated after they were no longer integrated in the splint.

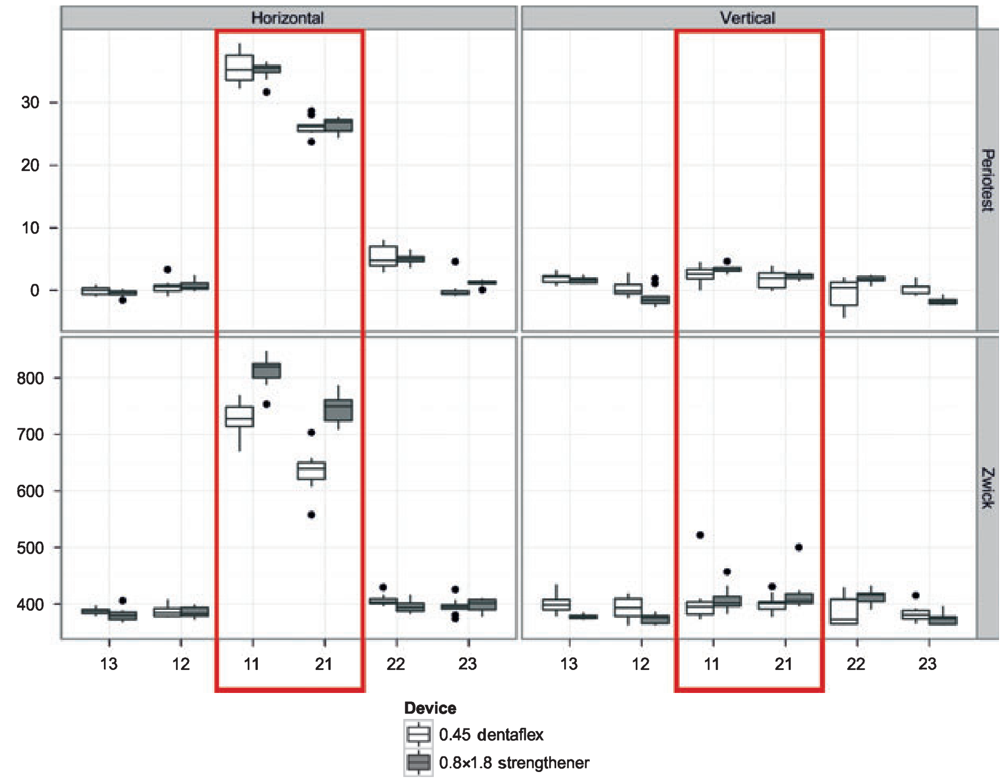

Fig. 7. Horizontal and vertical Periotest and Zwick values before splinting, subdivided by the splint type for ‘injured’ teeth 11 and 21 (red frames) and ‘non-injured’ teeth 13, 12, 22, and 23. The box (IQR = interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5 to 3 times the IQR) and extreme values (asterisk; more than three times the IQR).

The vertical PTVpre (Fig. 7) resulted from the adjustment procedure in the horizontal dimension. The PTVpre_v was slightly higher for the ‘injured’ teeth (PTVpre_v tooth 11: 3.0 ± 1.1; tooth 21: 2.1 ± 1.1) than for the ‘uninjured’ teeth (PTVpre_v tooth 13: −1.8 ± 0.7; tooth 12: −0.4 ± 1.5; tooth 22: 0.7 ± 2.0; tooth 23: −0.7 ± 1.3).

ZVpre

The horizontal Zwick values (Fig. 7) for the ‘injured’ teeth were distinctively higher (ZVpre_h tooth 11: 769.9 ± 50.5 μm; tooth 21: 690.5 ± 65.2 μm) than for the ‘uninjured’ teeth (ZVpre_h tooth 13: 383.8 ± 9.6 μm; tooth 12: 386.1 ± 9.4 μm; tooth 22: 401.1 ± 11.7 μm; tooth 23: 397.2 ± 12.3 μm). The vertical ZVpre (Fig. 7) of the ‘injured’ (ZVpre_v tooth 11: 406.2 ± 33.5 μm; tooth 21: 409.15 ± 25.1 μm) and ‘uninjured’ teeth (ZVpre_v tooth 13: 388.8 ± 16.4 μm; tooth 12: 383.3 ± 17.6 μm; tooth 22: 399.9 ± 24.2 μm; tooth 23: 378.2 ± 13.1 μm) did not distinctively differ from each other.

Periotest SpErel

After adjusting the Periotest scale, the percentage SpErel was calculated. The SpErel-values for the horizontal and vertical dimensions subdivided by the splint type and splint variant are shown in Fig. 8.

When comparing the SpErel of the two splint types for ‘injured’ teeth 11 and 21 within one splint variant, statistically significant differences were found for all splint variants in the horizontal and vertical dimensions (Table 3; *t*-test and Wilcoxon–Mann–Whitney test, $P < 0.05$).

The comparison of the horizontal SpErel of the five splint variants within one splint type for both ‘injured’ teeth was statistically significantly different for WCS1 and WCS2 (Table 4; ANOVA and Kruskal–Wallis test, $P < 0.05$). The pairwise comparison of the splint variants within the WCS1 showed significant differences between SpV 5 and SpV1, SpV2, and SpV3 as well as between SpV4 and SpV1 and SpV2 (Table 5; Tukey test, $P < 0.05$). Statistically significant differences were found for WCS2 between SpV5 and SpV1, SpV2, SpV3 (teeth 11 and 21), and SpV4 (tooth 11) as well as SpV4 and SpV1, SpV2, and SpV3. No significant differences were detected between SpV1 and SpV2 and SpV3 as well as between SpV2 and SpV3 (Table 5; Wicoxon test; $P < 0.05$).

In the vertical dimension, statistically significant differences were detected only for WCS2 (Table 4; ANOVA, $P < 0.05$), between SpV5 and SpV1, SpV2, and SpV3 (Table 5; Tukey test; $P < 0.05$).

Zwick SpErel

The SpErel-values (percentages) for the horizontal and vertical dimensions subdivided by the splint type and splint variant are shown in Fig. 9.

The comparison of the SpErel for WCS1 and WCS2 for the ‘injured’ teeth within one splint variant showed

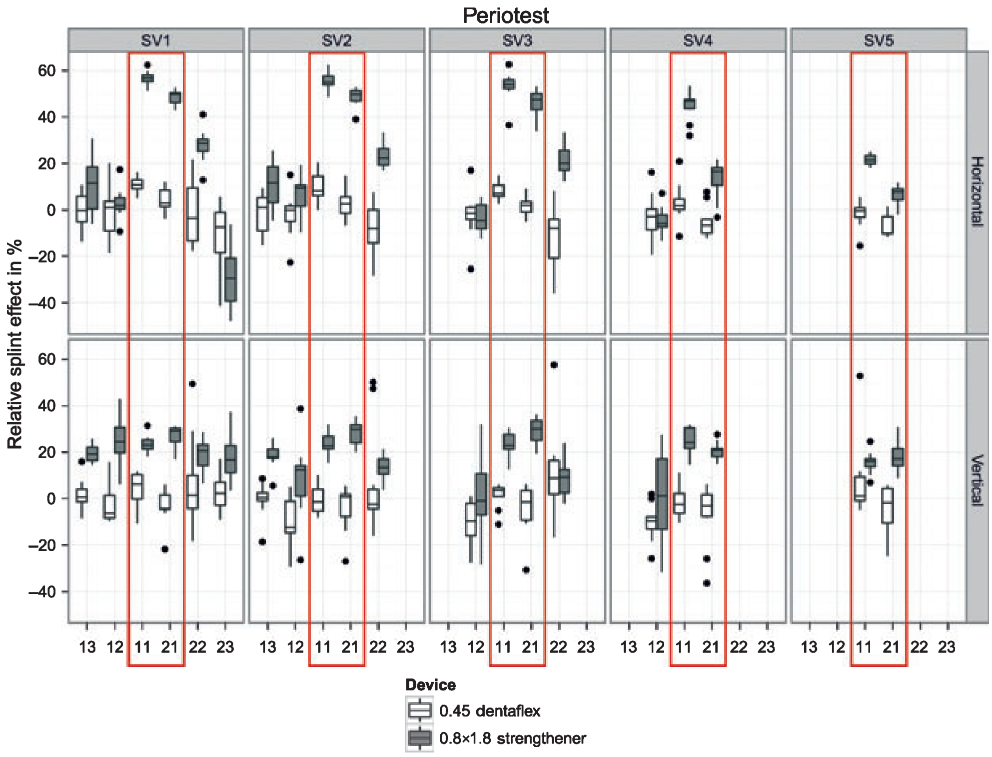

Fig. 8. Horizontal and vertical relative splint effects (Periotest method) subdivided by the splint variant. The 'injured' teeth 11 and 21 are shown in red frames. The box (IQR = interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5–3 times the IQR) and extreme values (asterisk; more than three times the IQR).

statistically significant differences in the horizontal dimension for all splint variants (Table 3; *t*-test and Wilcoxon–Mann–Whitney test, $P < 0.05$).

Testing the influence of the wire extension (splint variant) within one splint type was only significant for WCS2 in the horizontal dimension (Table 4; Kruskal–Wallis test, $P < 0.05$). Pairwise comparisons of the splint variants revealed statistically significant differences between SpV5 and SpV1, SpV2, and SpV3 (teeth 11 and 21) and SpV4 (tooth 11) as well as SpV4 and SpV1 and SpV2 (teeth 11 and 21) and SpV3 (tooth 21) (Table 5; Wicoxon test; $P < 0.05$). No significant differences were detected between SpV1 and SpV2 and SpV3 as well as between SpV2 and SpV3 (Table 5; Wicoxon test; $P > 0.05$).

Discussion

Methodological factors

Splint rigidity evaluation studies have been conducted *in vivo* (1, 7, 8) and *in vitro* using different models (2, 6, 9, 11–17). The advantages of *in vivo* testing on human volunteers are the presence of a natural PDL and the possibility to use enamel for the adhesive splint attachment. However, the absence of increased tooth mobility and the risk of damaging sound enamel in uninjured subjects (1, 7) can be a disadvantage. In addition, tooth mobility varies between individuals (1, 19, 20). Therefore, *in vitro* animal (9, 11) and artificial models (2, 6, 12–14, 16, 17) were introduced. Artificial models made of resin (2, 13, 14, 16, 17) or metal (1, 6) are always available and tests can be repeated without limit. The models consist of a simulated PDL, and tooth mobility can be individually adjusted. The lack of an etchable surface such as enamel is always considered a disadvantage of resin models (1, 2, 6, 7, 11, 12). This problem was solved by introducing bovine tooth facets into our newly developed model. In addition, we enlarged two of the six alveolar sockets and partially replaced the silicon PDL with rubber foam to mimic the clinical situation of a dislocated tooth with a ruptured fiber apparatus, and hematoma within the periodontal gap (6, 12).

Depending on the type of trauma, splint rigidity varies between flexible, semi-rigid, and rigid (2, 7, 9, 13, 15). To investigate the influence of splint extension, we selected two wire-composite splints (WCS), which were previously tested in terms of splint rigidity (1, 2, 12). The WCS1 (Dentaflex 0.45, sixfold, Dentaurum) is considered flexible, whereas the WCS2 (Strengtheners 0.8×1.8) is defined as rigid, but still allows minimal flexibility compared with composite splints (2). These two splint types were used in our clinic for more than 10 years depending on the type of trauma. The WCS1 is indicated for splinting teeth after dislocation injuries and the WCS2 for hard tissue injuries such as horizontal root fractures and alveolar process fractures.

To test the rigidity properties of dental trauma splints, different tooth mobility-assessment methods were utilized *in vitro* such as the Periodontometer (9), optical methods (21), universal testing machines (6, 14–17), and the Periotest-device (2, 9, 11, 13). As shown in previous

Table 1. *P*-values calculated with the Shapiro-Wilk test for normal distribution of the relative splint effect (Periotest) per splint variant and splint type for the 'injured' teeth 11 and 21. *P*-values >0.05 (white fields) predict normal data distribution

	Splint variant 1		Splint variant 2		Splint variant 3		Splint variant 4		Splint variant 5	
Tooth	11	21	11	21	11	21	11	21	11	21
WCS1_h	1.000	0.797	0.846	0.827	0.345	0.634	0.345	0.078	0.077	0.011
WCS2_h	0.704	0.303	0.805	0.098	0.026	0.175	0.159	0.024	0.755	0.208
WCS1_v	0.064	0.053	0.555	0.020	0.010	0.048	0.770	0.030	0.000	0.159
WCS2_v	0.671	0.042	0.906	0.445	0.540	0.544	0.399	0.721	0.796	0.623

WCS1, wire-composite splint 1 (Dentaflex 0.45 mm); WCS2, wire-composite splint 2 (Strengtheners 0.8 × 1.8 mm); h, horizontal; v, vertical.

Table 2. *P*-values calculated with the Shapiro-Wilk test for normal distribution of the relative splint effect (Zwick) per splint variant and splint type for the 'injured' teeth 11 and 21. *P*-values >0.05 (white fields) predict normal data distribution

	Splint variant 1		Splint variant 2		Splint variant 3		Splint variant 4		Splint variant 5	
Tooth	11	21	11	21	11	21	11	21	11	21
WCS1_h	0.953	0.604	0.509	0.472	0.317	0.230	0.771	0.631	0.454	0.718
WCS2_h	0.774	0.261	0.181	0.004	0.009	0.007	0.029	0.235	0.502	0.440
WCS1_v	0.524	0.579	0.618	0.164	0.875	0.662	0.002	0.000	0.060	0.535
WCS2_v	0.869	0.001	0.035	0.056	0.076	0.000	0.525	0.002	0.141	0.110

WCS1, wire-composite splint 1 (Dentaflex 0.45 mm); WCS2, wire-composite splint 2 (Strengtheners 0.8 × 1.8 mm); h, horizontal; v, vertical.

Table 3. Influence of wire dimension on splint rigidity

Splint Variant	Dimension	11 Periotest	11 Zwick	21 Periotest	21 Zwick
1	Horizontal	0.000	0.000	0.000	0.000
2		0.000	0.000	0.000	0.000
3		0.000	0.000	0.000	0.000
4		0.000	0.000	0.000	0.000
5		0.000	0.000	0.001	0.002
1	Vertical	0.000	0.221	0.001	0.098
2		0.000	0.116	0.000	0.184
3		0.000	0.062	0.000	0.005
4		0.000	0.062	0.001	0.062
5		0.005	0.221	0.000	0.221

Comparison of the relative splint effects of the two splint types (wire-composite splints 1 and 2) within the splint variants per tooth, and the dimension for the 'injured' teeth 11 and 21. For normally distributed data (white fields), the *t*-test was used, and the Wilcoxon–Mann–Whitney test (gray fields) was used for non-normally distributed data. *P*-values <0.05 indicate statistically significant differences.

Table 4. Influence of wire extension on splint rigidity

Splint type	WCS1 (Dentaflex 0.45 mm)		WCS2 (strengtheners 0.8 × 1.8 mm)	
Tooth	11	21	11	21
Periotest horizontal	**0.001**	**0.001**	**0.000**	**0.000**
Periotest vertical	1.000	1.000	**0.011**	**0.000**
Zwick horizontal	0.337	1.000	**0.000**	**0.000**
Zwick vertical	1.000	1.000	1.000	1.000

Comparison of the relative splint effect for the five splint variants within the two splint types per tooth, measurement method, and dimension ('injured' teeth 11 and 21). For normally distributed data (white fields), ANOVA was used, and the Kruskal–Wallis test (gray fields) was used for non-normally distributed data. *P*-values <0.05 (bold values) indicate statistically significant differences.

studies, reproducible results can be obtained with the Periotest method (1, 6) and the universal testing machine (6). No correlation was found when the results of the two methods are compared. Both methods provide different kinds of valuable information about tooth mobility. The Periotest method mainly describes the damping characteristics of the PDL, whereas the universal testing machine reveals quantitative metric data (6). Therefore, both assessment methods were selected for use in this study.

The influence of the splint extension on the splint effect was investigated by Ebeleseder et al. (8) on injured patients with a mean age of 17 ± 11 years. The splinting was adapted to the clinical situation after the injury, resulting in unilaterally or bilaterally splinted teeth with one or two neighboring healthy teeth. Before and right after removing the splint, tooth mobility was assessed, and the splint effect was calculated as the difference in mobility of the un-splinted and splinted tooth. The study by Cehreli et al. (18) indicated that removing adhesively attached splints causes damage to the enamel surface regardless of the method and instruments used. The goal, when inserting dental trauma splints, is to include only as many healthy teeth as necessary to ensure adequate fixation of the injured teeth and at the same time reduce the risk of enamel damage.

To investigate the influence of the splint extension in our study, we discussed two possible approaches. One possible protocol was to insert splints of various lengths to include different numbers of teeth. Tooth mobility should always be assessed before and after splinting. The second approach was to assess tooth mobility before splinting followed by the application of the splint over the length of all six teeth. After measuring the tooth

Table 5. Influence of wire extension on splint rigidity

Test method	Dimension	Splint type	Tooth	SpV1 SpV2	SpV1 SpV3	SpV1 SpV4	SpV1 SpV5	SpV2 SpV3	SpV2 SpV4	SpV2 SpV5	SpV3 SpV4	SpV3 SpV5	SpV4 SpV5
Periotest	Horizontal	WCS1	11	0.983	0.820	**0.040**	**0.000**	0.984	0.135	**0.001**	0.350	**0.004**	0.321
			21	0.993	0.859	**0.006**	**0.001**	0.980	**0.021**	**0.004**	0.082	**0.017**	0.969
		WCS2	11	0.651	0.421	**0.002**	**0.002**	0.651	**0.002**	**0.002**	**0.014**	**0.002**	**0.002**
			21	1.000	1.000	**0.002**	**0.002**	1.000	**0.002**	**0.002**	**0.002**	**0.002**	0.125
	Vertical	WCS2	11	1.000	0.999	0.994	**0.007**	0.998	0.996	**0.006**	0.960	**0.015**	**0.002**
			21	0.984	0.900	0.073	**0.005**	0.996	**0.020**	**0.001**	**0.007**	**0.000**	0.843
Zwick	Horizontal	WCS2	11	0.677	0.558	**0.004**	**0.002**	0.558	**0.003**	**0.002**	0.069	**0.002**	**0.002**
			21	1.000	1.000	**0.002**	**0.002**	1.000	**0.002**	**0.002**	**0.002**	**0.002**	1.000

WCS1, wire-composite splint 1 (Dentaflex 0.45 mm); WCS2, wire-composite splint 2 (Strengtheners 0.8 × 1.8 mm); SpV1, Splint variant 1 (tooth 13–23); SpV2, Splint variant 2 (tooth 13–22); SpV3, Splint variant 3 (tooth 12–22); SpV4, Splint variant 4 (tooth 12–21); SpV5, Splint variant 5 (tooth 11–21).
Pairwise comparisons of the relative splint effect for the five splint variants within the two splint types per tooth, measurement method, and dimension ('injured' teeth 11 and 21). For normally distributed data (white fields), the Tukey range test was used, and the Wilcoxon test with Bonferroni-Holm procedure was used for non-normally distributed data (gray fields). *P*-values <0.05 indicate statistically significant differences.

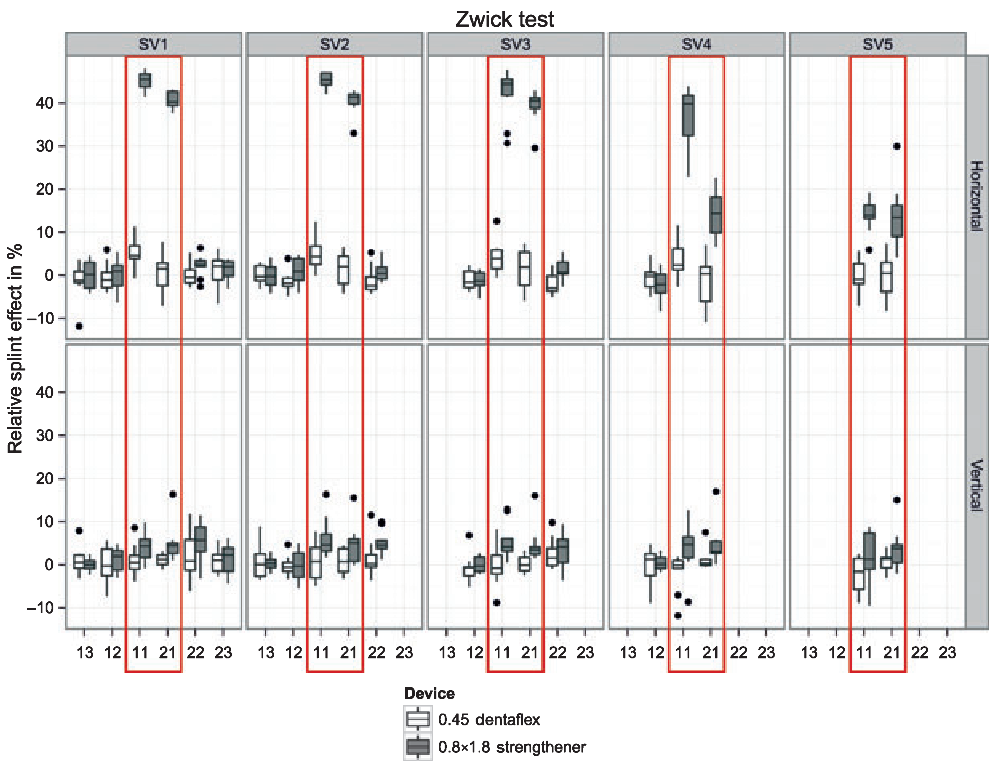

Fig. 9. Horizontal and vertical relative splint effect (Zwick method) subdivided by the splint variant. The 'injured' teeth 11 and 21 are shown in red frames. The box (IQR = interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5–3 times the IQR) and extreme values (asterisk; more than three times the IQR).

mobility, the splint was successively shortened by one tooth at the time then tooth mobility was reassessed. The advantage we found with the second method was that influencing factors such as splint location, placement of the adhesive points, and values before splinting did not vary.

Study outcome

Different studies showed that the splint effect is positively correlated with the initial tooth mobility values. The splint effect is more distinctive in teeth with high initial tooth mobility values compared with teeth with low initial values within the same splint (2, 6, 8, 12, 15). Therefore, to reduce the influence of the initial values on the splint effect, the relative splint effect was used in this study (6, 12).

Comparing the two splint types, WCS1 and WCS2 in terms of relative splint effect, significant differences were found for the Periotest method in the vertical and horizontal dimensions (Table 3 and Fig. 8) and for the Zwick method (Table 3 and Fig. 9) in the horizontal dimension. The WCS2 showed distinctively higher splint effect values, meaning that the WCS2 was more rigid than the WCS1. These results conform with previous findings from studies where tooth mobility was assessed using the Periotest method (1, 2, 12). Regarding the Zwick method, no comparable data from former studies were available for WCS2 (6). The different outcomes of the comparison between WCS1 and WCS2 when using the Periotest and Zwick methods to assess tooth mobility could be explained by the different principles of operation and force application of the two methods (6).

The wire extension (splint variant) influenced the horizontal splint rigidity of the WCS1 for the 'injured' teeth when assessing with the Periotest method (Table 4 and Fig. 8). The wire of the WCS1 was thin and highly flexible compared with that of the WCS2, which consisted of a wider and more rigid wire. Therefore, tooth mobility was only slightly restricted when WCS1 was used. As a result of the model and socket design, the tooth movement was distinctively less in the vertical dimension than in the horizontal dimension (Fig. 9). Therefore, the wire extension does not influence the splint rigidity in the vertical dimension, but does have an influence in the horizontal dimension when measured by the Periotest method. The Periotest method evaluates the damping characteristics of the PDL by applying small forces for tooth deflection compared with the Zwick method, where we continuously loaded the tooth with 10 N. The Periotest method appears to be more sensitive in discriminating minimal differences, especially in case of the highly flexible WCS1 (1, 6, 22–24). The wire length significantly influenced the splint rigidity in the horizontal (Periotest- and Zwick method) and vertical dimensions (Periotest method) of the more rigid WCS2 for the 'injured' teeth 11 and 21 (Table 4, Figs 8 and 9).

For treating trauma involving PDL injuries, the splint should ensure adequate fixation in the original anatomical position as well as enable the transmission of functional forces (1–3, 6–10). In the case of dislocation injuries, the alveolar socket is often enlarged. Therefore, the splint should fix the tooth in the horizontal dimension and simultaneously allow movement in the vertical dimension. The results for pairwise comparisons of the splint variants within WCS1 (Table 5 and Fig. 8) showed that no significant differences occurred between SpV1 and SpV3, whereas significant differences were found between SpV5 and SpV1, SpV2, and SpV3 in the horizontal dimension. Therefore, the bilateral attachment of the splint to two 'uninjured' adjacent teeth is not beneficial compared with attaching the splint to only one adjacent 'uninjured' tooth on each side. The extension of the wire including only the 'injured' teeth resulted in distinctively less stabilization in the horizontal dimension compared with the splint including one adjacent 'uninjured' tooth on each side. These findings are in accordance with the results of Ebeleseder et al. (8). The rigidity in the vertical dimension was not influenced, independent of the included teeth.

The WCS2 is rated semi-rigid to rigid; therefore, it can be utilized to treat horizontal infra-alveolar root fractures or alveolar process fractures (2, 5). In the horizontal and vertical dimensions, attaching the splint bilaterally to two or one 'uninjured' tooth on each side did not influence the splint rigidity. However, the splint rigidity was significantly reduced when the splint was attached to only to the 'injured' teeth without including 'uninjured' teeth.

Conclusions

Within the limitations of this *in vitro* study, the following conclusions can be drawn: (1) the WCS1 (Dentaflex 0.45) is flexible compared with the more rigid WCS2 in the vertical and horizontal dimensions; (2) for the flexible WCS1, the wire extension and number of included teeth only influence the splint rigidity for the 'injured teeth' in the horizontal dimension. To ensure adequate tooth positioning of the 'injured' teeth, one 'uninjured' tooth on each side should be included in the splint. The transmission of functional forces in the vertical dimension is guaranteed; (3) the wire extension influences splint rigidity in the horizontal and vertical dimensions in the case of WCS2. Including one 'uninjured' tooth on each side ensures adequate fixation compared with only splinting the 'injured' teeth. Including two adjacent 'uninjured' teeth on each side is not beneficial for splint rigidity; (4) to reduce the risk of damaging the enamel surface during splint removal, the WCS1 and WCS2 should include the 'injured teeth' and one 'uninjured' adjacent tooth on each side; (5) the results achieved with the two tooth mobility measurement methods are somewhat different. The Periotest method seems to be more sensitive than the Zwick method.

Acknowledgements

The invaluable help of Hans Loew of the dental workshop, University Erlangen, during the model manufacturing procedure is highly acknowledged.

References

1. Berthold C, Holst S, Schmitt J, Goellner M, Petschelt A. An evaluation of the periotest method as a tool for monitoring tooth mobility in dental traumatology. Dent Traumatol 2010;26:120–8.
2. Berthold C, Thaler A, Petschelt A. Rigidity of commonly used dental trauma splints. Dent Traumatol 2009;25:248–55.
3. Oikarinen K. Tooth splinting: a review of the literature and consideration of the versatility of a wire-composite splint. Endod Dent Traumatol 1990;6:237–50.
4. Flores MT, Andersson L, Andreasen JO, Bakland LK, Malmgren B, Barnett F et al. Guidelines for the management of traumatic dental injuries. II. Avulsion of permanent teeth. Dent Traumatol 2007;23:130–6.
5. Flores MT, Andersson L, Andreasen JO, Bakland LK, Malmgren B, Barnett F et al. Guidelines for the management of traumatic dental injuries. I. Fractures and luxations of permanent teeth. Dent Traumatol 2007;23:66–71.
6. Berthold C, Auer FJ, Potapov S, Petschelt A. *In vitro* splint rigidity evaluation - comparison of a dynamic and a static measuring method. Dent Traumatol 2011; doi: 10.1111/j.1600-9657.2011.01034.x.
7. von Arx T, Filippi A, Lussi A. Comparison of a new dental trauma splint device (TTS) with three commonly used splinting techniques. Dent Traumatol 2001;17:266–74.
8. Ebeleseder KA, Glockner K, Pertl C, Städtler P. Splints made of wire and composite: an investigation of lateral tooth mobility *in vivo*. Endod Dent Traumatol 1995;11:288–93.

9. Oikarinen K, Andreasen JO, Andreasen FM. Rigidity of various fixation methods used as dental splints. Endod Dent Traumatol 1992;8:113–9.
10. von Arx T, Filippi A, Buser D. Splinting of traumatized teeth with a new device: TTS (Titanium Trauma Splint). Dent Traumatol 2001;17:180–4.
11. Berthold C. Untersuchungen zur Schienungstherapie dentoalveolärer Verletzungen. Halle, Saale: Universitäts- und Landesbibliothek; 2002. p. 1–80.
12. Berthold C, Auer FJ, Potapov S, Petschelt A. Development of new artificial models for splint rigidity evaluation. Dent Traumatol 2011; doi: 10.1111/j.1600-9657.2011.01010.x.
13. Filippi A. Reimplantation nach Zahntrauma: einfluss der Schienung auf die Zahnbeweglichkeit. Z Zahnaerztl Implantol 2000;16:8–10.
14. Mazzoleni S, Meschia G, Cortesi R, Bressan E, Tomasi C, Ferro R et al. *In vitro* comparison of the flexibility of different splint systems used in dental traumatology. Dent Traumatol 2010;26:30–6.
15. Oikarinen K. Comparison of the flexibility of various splinting methods for tooth fixation. Int J Oral Maxillofac Surg 1988;17:125–7.
16. Schwarze J, Bourauel C, Drescher D. Frontzahnbeweglichkeit nach direkter Klebung von Lingualretainern. Fortschr Kieferorthop 1995;56:25–33.
17. Stellini E, Avesani S, Mazzoleni S, Favero L. Laboratory comparison of a titanium trauma splint with three conventional ones for the treatment of dental trauma. Eur J Paediatr Dent 2005;6:191–6.
18. Cehreli ZC, Lakshmipathy M, Yazici R. Effect of different splint removal techniques on the surface roughness of human enamel: a three-dimensional optical profilometry analysis. Dent Traumatol 2008;24:177–82.
19. Andresen M, Mackie I, Worthington H. The periotest in traumatology. Part I. Does it have the properties necessary for use as a clinical device and can the measurements be interpreted? Dent Traumatol 2003;19:214–7.
20. Mackie I, Ghrebi S, Worthington H. Measurement of tooth mobility in children using the periotest. Endod Dent Traumatol 1996;12:120–3.
21. Burcak Cengiz S, Stephan Atac A, Cehreli ZC. Biomechanical effects of splint types on traumatized tooth: a photoelastic stress analysis. Dent Traumatol 2006;22:133–8.
22. Lukas D, Schulte W. Periotest-a dynamic procedure for the diagnosis of the human periodontium. Clin Phys Physiol Meas 1990;11:65–75.
23. Lukas D, Schulte W, Konig M, Reim M. High-speed filming of the periotest measurement. J Clin Periodontol 1992;19:388–91.
24. Schulte W, Lukas D. The periotest method. Int Dent J 1992;42:433–40.