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Influence of adhesive point dimension and splint type on splint rigidity – Evaluation by the dynamic Periotest method

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Key words: dental trauma splint; adhesive point dimension; splint type; splint rigidity; artificial model; relative splint effect

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Abstract – *Aim*: To evaluate the influence of adhesive point dimension and splint type on the rigidity of wire-composite splints *in vitro*. *Materials and Methods*: A custom-made artificial model was used. The two central incisors served as injured teeth (degrees of loosening III and II) and the two lateral incisors as non-injured teeth (physiological mobility). Horizontal and vertical tooth mobilities were investigated before and after splinting with the Periotest® method; the percent change was taken as the relative splint effect. Teeth were splinted with three types of wire-composite splints: Dentaflex (0.45 mm), Strengtheners (0.8 × 1.8 mm), and Dentaflex completely covered with composite. Four adhesive point dimensions (2, 3, 4, and 5 mm) were evaluated. Normal distribution was tested with the Kolmogorov–Smirnov test. Differences were evaluated with the ANOVA and *post hoc* tests for pair-wise comparisons. Significance level was set at 0.05. *Results*: The adhesive point dimension did not influence splint rigidity, in general ($P = 0.288$). Significant effects were found in non-injured teeth with the Dentaflex ($P < 0.001$) and in injured teeth with the Strengtheners ($P < 0.001$). The Strengtheners splint rigidity increased significantly with increasing adhesive point dimensions. The three splints showed significantly different effects at 5-mm adhesive point dimension ($P < 0.001$). *Conclusion*: Splint rigidity for injured teeth was influenced by adhesive point dimension only when splinting with Strengtheners. We recommend adapting splint rigidity by selecting different wires and reducing the adhesive point dimension to a minimum. Dentaflex can be used for flexible splinting, Strengtheners, and composite covered Dentaflex for rigid splinting.

The treatment of injured teeth varies according to the type of trauma. Splinting is part of the emergency treatment for tooth dislocation and root or bone fractures; the aim is to immobilize teeth or fragments in their anatomical positions and protect them from traumatic forces during the healing period. Splints should allow mastication, oral hygiene, and improved patient comfort (1–7). Splint rigidity should be adapted to the type of trauma (3, 5, 6, 8–10). Flexible splints allow transmission of functional forces; therefore, they are indicated for treating injuries to the periodontal ligament (PDL) like dislocation injuries and infra-alveolar horizontal root fractures (3, 5, 8, 9, 11). Rigid splints are preferred for alveolar process fractures or cervical infra-alveolar horizontal root fractures, because they allow hard tissue healing (3, 12, 13). In general, wire-composite splints and commercially available reinforcement materials, attached with an acid-etch-technique, fulfill most requirements for modern dental trauma splints (3, 4, 10, 13–18).

The rigidity of dental trauma splints has been evaluated *in vivo* on healthy volunteers (2, 10) and injured patients (4) and *in vitro* in animal tissues (18, 19) or artificial models (1, 3, 13–17, 20, 21). Those studies applied different methods for measuring tooth mobility, including periodontometry (18, 22), holographic interferometry (23, 24), laser vibrometry (25), and photogrammetry (26, 27). The methods most frequently used for evaluating dental splint rigidity have been the dynamic Periotest® (1–4, 10, 13–15, 20) and the static universal testing machine (13, 14, 16, 17, 20, 28).

The rigidity of adhesively attached splints can be influenced by the selection of the reinforcement material (2–7, 13, 17, 18, 21) or the splint extension (4, 20). The adhesive point dimension (APD) was also suggested to influence splint rigidity (28).

The aim of this *in vitro* study was twofold: to evaluate the influence of the APD and the splint type on the rigidity of wire-composite splints (WCS). The following null hypotheses were investigated: (i) the adhesive point dimension does not influence the splint rigidity and (ii) the type of wire-composite splint does not influence the splint rigidity.

Materials and methods

The entire splint rigidity evaluation procedure for all APDs is shown as a flow chart in Fig. 1. The detailed description of the method will be given in the following paragraphs with referral to the seven consecutive steps.

Step 1 – Model and tooth mobility adjustment

The artificial model used in this *in vitro* study was previously described in detail by Berthold et al. (1). The model base was made of aluminum and had six conical drill-holes, arranged in a half circle, to simulate the alveolar sockets. The simulation teeth were manufactured from stainless steel. The two middle sockets (central incisors, teeth 11 and 21, international numbering system) were enlarged to simulate the clinical situation of widened sockets after dislocation injuries. In the model, the PDLs for the non-injured, lateral incisors (12 and 22) and the canines (13 and 23) were made of silicon. For simulating injured teeth, the central incisor PDL consisted of silicon for the apical third and rubber foam for the coronal two-thirds of the root. Apical adjusting screws were used for fine adaptation of tooth mobility. Bovine tooth facets, with different mesio-distal widths (2, 3, 4, and 5 mm), could be adhesively attached to the coronal part of the stainless steel teeth (Fig. 2). The enamel surfaces of the tooth facets allowed adhesive bonding of the splints with an acid-etch technique and flowable composite. The APD was predefined by the mesio-distal width of the tooth facets. Before inserting a new splint, tooth mobility was set with defined horizontal Periotest® (Gulden, Modautal, Germany) values (PTVs) (1, 13, 14, 20). The injured teeth received increased mobility, and the non-injured teeth received physiological mobility. The degrees of loosening (DoL) were defined in the manufacturer's instructions (DoL 0: −8 to +9, DoL I: +10 to +19, DoL II: +20 to +29, DoL III: +30 to +50) (3). For this *in vitro* study, we applied the following predefined horizontal PTVs before inserting a new splint: tooth 11:DoL III = 35 ± 2; tooth 21: DoL II = 25 ± 2; teeth 12 and 22:DoL 0 = 5 ± 2. Teeth 13 and 23 were not used in this study. The vertical PTVs implemented before splinting resulted from adjusting the horizontal PTVs (Fig. 2).

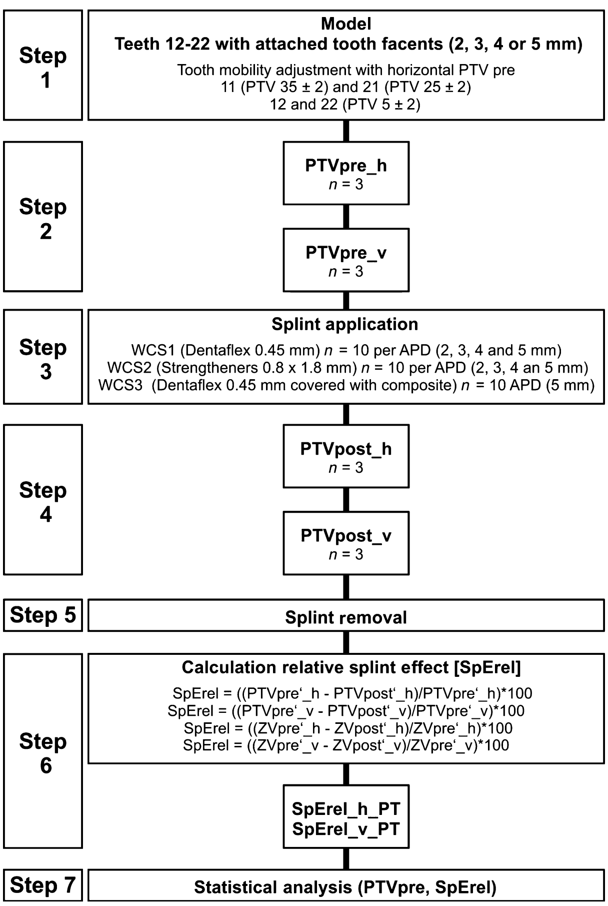

Fig. 1. Flow chart shows the testing procedure. Detailed information about the different steps of the testing procedure is given in the materials and methods section. PT, Periotest; Vpre, value before splinting; Vpost, value after splinting; SpErel, relative splint effect; H, horizontal; V,vertical; WCS, Wire-composite splint.

Step 2 – Tooth mobility assessment before splinting

Tooth mobility was assessed with the procedure previously described in detail by Berthold et al. (13, 14, 20). Tooth mobility was evaluated before (pre) splint insertion with the Periotest method (PT), following the manufacturer's instructions (1–3, 13, 14, 20). Reproducible measuring points were marked on each model with a template and permanent marker. Three replicate measurements were taken in the horizontal (h; middle of the vestibular tooth surface) and vertical (v; middle of the incisal edge) dimensions (1, 2, 13, 14, 20). All three replicate measurements followed the same sequence along the measuring points. All information and data were recorded in individual data sheets.

Step 3 – Splinting

The artificial tooth model was placed in a holder during the splinting and mobility measurement procedures,

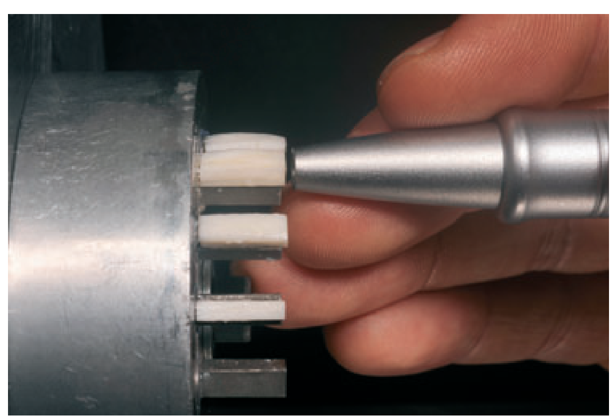

Fig. 2. The model, used in this *in vitro* study, is placed in the holder during the initial Periotest measuring procedure in the vertical dimension (PTVpre_v). The four adhesive point dimension (APD) are exemplarily shown (tooth 12 = 2 mm, tooth 11 = 3 mm, tooth 21 = 4 mm, tooth 22 = 5 mm).

with the tooth facets facing up (1, 13, 14, 20). The splint extension included injured teeth (11 and 21) and non-injured teeth (12 and 22) (4, 20).

Three different types of wire-composite splints were compared in this study (Fig. 3a–c). Two were previously investigated wire-composite splints, the flexible WCS1 (Dentaflex 0.45 mm, sixfold, straight wires; Dentaurum, Pforzheim, Germany) (1–3, 13, 14, 19, 20) and the rigid WCS2 (Strengtheners 0.8 × 1.8 mm; Dentaurum) (1–3, 13, 19, 20); the third, WCS3, was the WCS1 completely covered with flowable composite (Grandio Flow wo; VOCO, Cuxhaven, Germany). All splints were applied to the model in replicates of 10 for each tested APD. The WCS1 and WCS2 were tested with four APDs (2, 3, 4, and 5 mm), and the WCS3 was tested with only one APD (5 mm).

The wires were cut to the appropriate lengths to extend from tooth 12 to 22. The flexible WCS1 was pulled over a mirror handle to fit passively onto the half-circle tooth model. The rigid WCS2 was adapted to the tooth model shape with orthodontic pliers and finger pressure for fine adaption.

The middle part of the tooth facets were etched for 15 s (Total Etch; Ivoclar Vivadent, Schaan, Lichtenstein) and bonded (Heliobond; Ivoclar Vivadent). Next, the wires were attached with flowable composite (Grandio Flow wo), in the same order (teeth 12, 22, 11, and 21) for each splint.

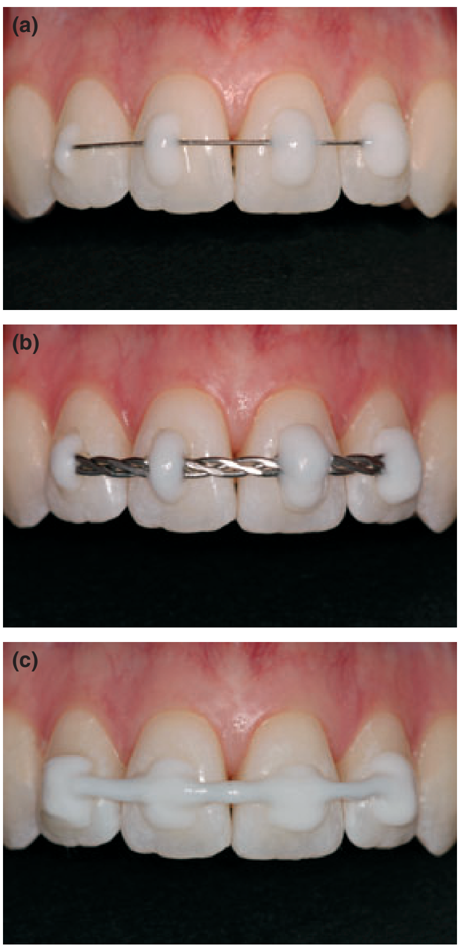

Fig. 3. (a) The wire-composite splint (WCS1; Dentaflex 0.45 mm) is attached to the dental arch (teeth 12–22) of a healthy volunteer with flowable composite (Grandio flow wo) to exemplarily simulate the clinical situation. The four adhesive point dimension (APD) are exemplarily shown (tooth 12 = 2 mm, tooth 11 = 3 mm, tooth 21 = 4 mm, tooth 22 = 5 mm). (b) The wire-composite splint (WCS2; Strengtheners 0.8 × 1.8 mm) is attached to the dental arch (teeth 12–22) of a healthy volunteer with flowable composite (Grandio flow wo) to exemplarily simulate the clinical situation. The four adhesive point dimension (APD) are exemplarily shown (tooth 12 = 2 mm, tooth 11 = 3 mm, tooth 21 = 4 mm, tooth 22 = 5 mm). (c) The wire-composite splint (WCS3; Dentaflex 0.45 mm completely covered with flowable composite) is attached to the dental arch (teeth 12–22) of a healthy volunteer, with 5 mm adhesive points to exemplarily simulate the clinical situation.

Step 4 – Tooth mobility assessment after splinting

Tooth mobility was evaluated after (post) splint insertion with the Periotest method (1–3, 13, 14, 20) using the previously marked reproducible measuring points (Fig. 1, Step 4). Three replicate measurements were taken in the horizontal (middle of the vestibular tooth surface) and vertical (middle of the incisal edge) dimensions (1, 2, 13, 14, 20). All three replicate measurements followed the same sequence along the measuring points. All information and data were recorded in individual data sheets.

Step 5 – Splint removal

After all measurements were performed (PT pre/post), the splint, including the wire and the composite at the adhesive points, was completely removed. We used a diamond-drill (881KS; NTI, Kahla, Germany) and a tungsten carbide bur (HM23R; Hager & Meisinger, Neuss, Germany) to remove all components without touching the enamel.

After splint removal and before the next splint was applied, tooth mobility was adjusted to the predefined horizontal PTVs.

Step 6 – Calculation of the relative splint effect

The three replicate sequential measurements were averaged to calculate the relative splint effect (SpErel) based on the mean horizontal and vertical Periotest (pre and post) values. The Periotest scale was mathematically adjusted from the original range (−8 to +50) to a scale with only positive values (+1 to 59) to avoid dividing by a negative value or zero. The rescaled values (PTV′ = PTV + 9) were used to calculate the percent SpErel (1, 13, 14, 20), as follows: SpErel_PT (%) = ([PTV′pre−PTV′post]/PTV’pre) × 100.

Step 7 – Statistical analysis

Data were recorded with acquisition sheets and transferred to IBM SPSS Statistics 19.0 (IBM Corp., Somers, NY, USA) for statistical analysis.

Descriptive analysis was performed. The vertical and horizontal PTVpre and SpErel_PT were graphically displayed in box plots for the four tested teeth. The Kolmogorov–Smirnov test (KST) was used to test the data for normal distribution. Non-normally-distributed and normally-distributed data were evaluated with non-parametric tests and parametric, respectively. The level of significance was set at $\alpha = 0.05$. To test the influence of the adhesive point dimension on rigidity, we conducted Kruskal–Wallis test (KWT; non-parametric) or analysis of variance (ANOVA; parametric test). When ANOVA indicated statistically significant differences ($P < 0.05$) and the Levene test proved equality of variances ($P > 0.05$), we conducted the Bonferroni *post hoc* test (BT) to compare the different adhesive point dimensions. When equality of variances was not proven (Levene test; $P < 0.05$), we used the Dunnett T3 *post hoc* test (DT3).

Results

We recorded a total of 4320 measurements: 1728 for both the WCS1 and the WCS2 and 864 for the WCS3. The three replicated pre- and post-splint measurements were averaged per dimension (horizontal and vertical), and tooth (12–22). All calculations and statistical comparisons were based on the resulting means.

Tooth mobility before splinting

Figure 4 shows the Periotest values before splinting for teeth 12, 11, 21, and 22 in the horizontal and vertical dimension. Tooth mobility was defined and adjusted with the horizontal Periotest values. Therefore, the variance was lower in the horizontal dimension compared with the vertical values. The injured teeth showed higher tooth mobility.

Factors that influenced splint rigidity

Adhesive point dimension

We first evaluated the influence of the APD on the splint effect, independent from other factors (Fig. 5). The data for the SpErel were not normally distributed; thus, we used non-parametric tests for comparisons. We found no significant differences (KWT; $P = 0.288$) among APDs on the SpErels. Therefore, no pair-wise comparison was performed.

Adhesive point dimension effects depended on tooth injury and splint type

Figure 6 shows the SpErel for WCS1 and WCS2, subdivided by tooth injury status as a function of adhesive point dimension.

Data were normally distributed for all groups (KST; $P > 0.05$). Therefore, parametric tests were used for comparison.

For the non-injured lateral incisors (teeth 12 and 22), the SpErel of WCS1 decreased slightly with increasing APD (Table 1, ANOVA; $P < 0.001$), but the SpErel of WCS2 showed no significant differences with different APDs (Table 1, ANOVA Welch test; $P = 0.095$).

For the injured central incisors (teeth 11 and 21), the SpErels of WCS1 were not affected by APD (Table 1, ANOVA Welch test; $P = 0.081$). The SpErels of WCS2 were significantly affected by APD (Table 1, ANOVA; $P < 0.001$). The *post hoc* test revealed statistically significant differences when comparing the adhesive point dimension in non-injured teeth splinted with WCS1 (Table 1, BT; $P < 0.05$), except for the comparison of 4 and 5 mm ADP (Table 1, BT; $P = 1.000$). For

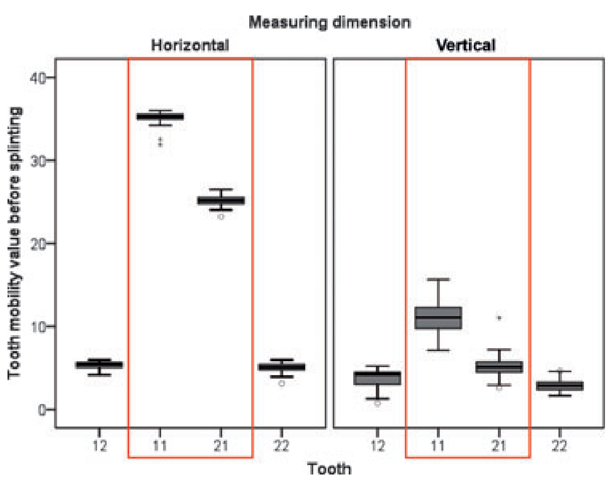

Fig. 4. Tooth mobility before splinting measured with the Periotest device [PTU] for the teeth 12, 11, 21, and 22 subdivided by the measuring direction. The values of the injured teeth 11 and 21 are marked with red frames*. PTU, Periotest unit. *The box (IQR, interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5 to three times of the IQR) and extreme values (asterisk; more than three times IQR).

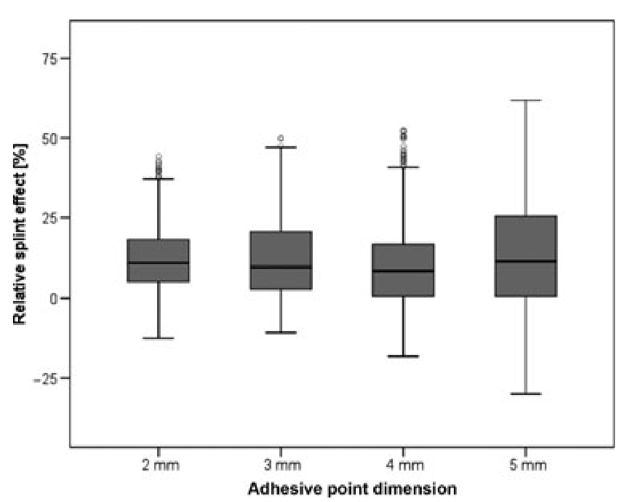

Fig. 5. Data from WCS1 and WCS2. Splint effect in percent for the four adhesive point dimensions, independent from the splint type, measuring dimension and tooth*. *The box (IQR, interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5 to three times of the IQR) and extreme values (asterisk; more than three times IQR).

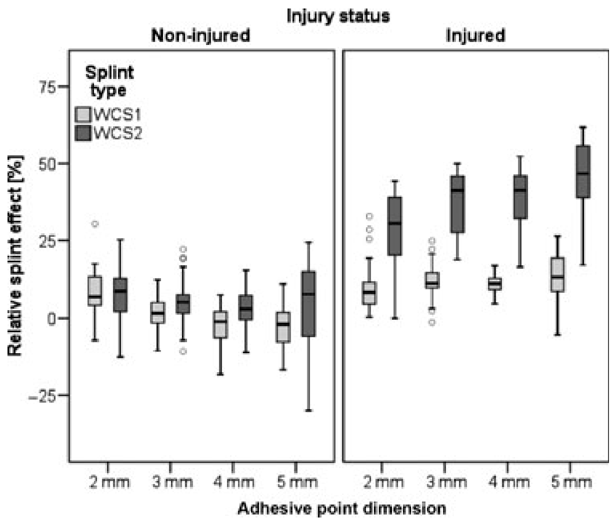

Fig. 6. Relative splint effect in percent, subdivided by tooth injury status and splint type*. WCS1, Wire-composite-splint 1 (Dentaflex 0.45 mm); WCS2, Wire-composite-splint 2 (Strengtheners 0. × 1.8 mm); Non-injured teeth, physiological tooth mobility (teeth 12 and 22); Injured teeth, pathological tooth mobility (teeth 11 and 21); *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 three times of the IQR) and extreme values (asterisk; more than three times IQR).

the WCS2, the SpErels for injured teeth increased significantly (Table 1, ANOVA; $P < 0.05$), except when comparing 3 and 4 mm APDs (Table 1, BT; $P = 1.000$).

Adhesive point dimension effects depended on measuring dimension and splint type

Figure 7 shows the SpErels for WCS1 and WCS2 as a function of the APD for each measuring dimension in non-injured and injured teeth. For WCS 1, in non-injured teeth, the SpErel decreased from positive to negative values with increasing APD in both, horizontal and vertical measurements. This implied a progressive loosening of the teeth as the adhesive points were enlarged. For WCS1, in injured teeth, the horizontal SpErel increased slightly in comparing 2 and 5 mm APDs, but not in comparing 3 and 4 mm APDs.

For WCS2, in non-injured teeth, the SpErels were not consistently distributed among the varying APDs. For injured teeth, the SpErel increased distinctly in both, horizontal and vertical dimensions, as the APDs were enlarged.

Different splint types effects on split rigidity at 5-mm adhesive point dimension

Figure 8 shows the SpErels at 5 mm APD for WCS1, WCS2, and WCS3. For both, injured and non-injured teeth, the SpErel increased in the order WCS1 < WCS2 < WCS3.

The data per injury status for each splint, applied at an APD of 5 mm, were normally distributed (KST, $P > 0.05$). For non-injured and injured teeth, the selection of the splint type significantly influenced the SpErel (Table 2, ANOVA Welch test; $P < 0.001$). A pair-wise comparison revealed significant differences between WCS1 and WCS2 or WCS3 (Table 2, DT3; $P < 0.05$), except for the comparison of WCS2 and WCS3 in non-injured teeth (Table 2, DT3; $P = 0.353$).

Splint type effects depended on tooth injury status and measuring dimension

Figure 9 shows the relative splint effects when applied at a 5-mm adhesive point dimension, measured in two measuring dimensions on non-injured and injured teeth. For non-injured teeth, the splint type influenced the horizontal SpErel only marginally, but it significantly influenced the vertical SpErel in the order WCS1 < < WCS2 < WCS3. For injured teeth, WCS2 and WCS3 showed distinctly higher SpErels compared with WCS1, in both dimensions.

Discussion

Methodological factors

Dental splint rigidity should be adapted to the type of dento-alveolar trauma (3, 6, 8, 9, 11). Previous studies found that splint rigidity was influenced by the selec-

Table 1. P-values for the general test for differences and the pair-wise comparison of the relative splint effect for the four adhesive point dimensions, subdivided by tooth injury status and splint type

Tooth Status		Non-injured			Injured		
Splint Type		WCS1		WCS2	WCS1	WCS2	
General Test for differences		ANOVA $P < 0.001$		ANOVA (Welch test) $P = 0.095$	ANOVA (Welch test) $P = 0.081$	ANOVA $P < 0.001$	
Levene Statistic		$P = 0.542$		$P < 0.001$	$P < 0.001$	$P = 0.513$	
Post hoc tests APD	2 mm/3 mm	$P < 0.001$	Bonferroni			$P < 0.05$	Bonferroni
	2 mm/4 mm	$P < 0.001$				$P < 0.001$	
	2 mm/5 mm	$P < 0.001$				$P < 0.001$	
	3 mm/4 mm	$P < 0.05$				$P = 1.000$	
	3 mm/5 mm	$P < 0.05$				$P < 0.001$	
	4 mm/5 mm	$P = 1.000$				$P < 0.05$	

APD, Adhesive point dimension; WCS1, Wire-composite-splint 1 (Dentaflex 0.45 mm); Non-injured teeth, physiological tooth mobility (teeth 12 and 22); Injured teeth, pathological tooth mobility (teeth 11 and 21); ANOVA, Analysis of variance.

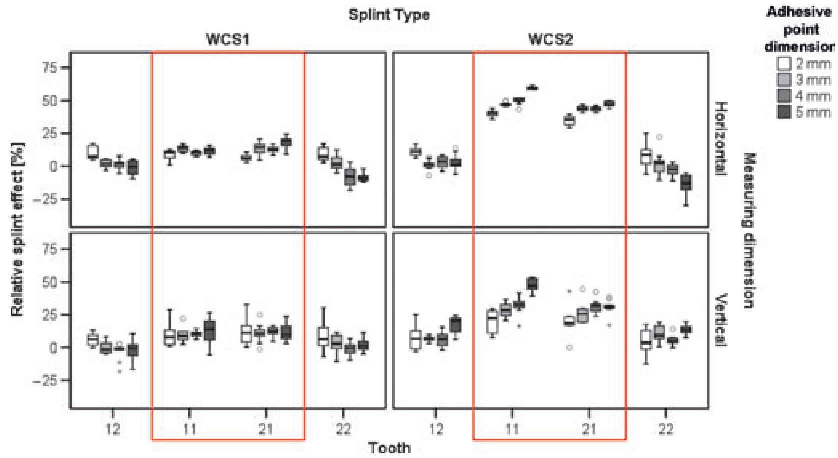

Fig. 7. Relative splint effect in percent for the WCS1 and WCS2, subdivided by the measuring dimension, as a function of the adhesive point dimension for non-injured teeth 12 and 22 an injured teeth 11 and 21 (red frames)*. *The box (IQR, interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5 to three times of the IQR) and extreme values (asterisk; more than three times IQR).

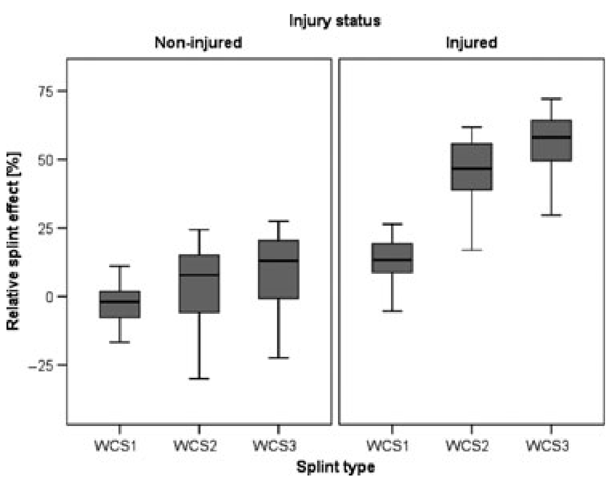

Fig. 8. Relative splint effect in percent for 5-mm adhesive point dimension, subdivided by tooth injury status as a function of the splint type*. WCS1, Wire-composite-splint 1 (Dentaflex 0.45 mm); WCS2, Wire-composite-splint 2 (Strengtheners 0.8 × 1.8 mm); WCS3, Wire-composite-splint 3 (Dentaflex 0.45 mm covered with resin composite); Non-injured teeth, physiological tooth mobility (teeth 12 and 22); Injured teeth, pathological tooth mobility (teeth 11 and 21); *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 three times of the IQR) and extreme values (asterisk; more than three times IQR).

Table 2. P-values for the general test for differences (ANOVA) and the pair-wise comparison (Dunnett T3 *post hoc* test) of the relative splint effect for the three wire-composite splints (5-mm adhesive point dimension), subdivided by tooth injury status

Tooth Status		Non-injured		Injured	
General Test for differences		ANOVA (Welch test) $P < 0.001$		ANOVA (Welch test) $P < 0.001$	
Levene Statistics		$P < 0.001$		$P = 0.011$	
PHT WCS	WCS1/WCS2	$P < 0.05$	DT3	$P < 0.001$	DT3
	WCS1/WCS3	$P < 0.001$		$P < 0.001$	
	WCS2/WCS3	$P = 0.353$		$P < 0.05$	

WCS, Wire-composite-splint; WCS1, Wire-composite-splint 1 (Dentaflex 0.45 mm); WCS2, Wire-composite-splint 2 (Strengtheners 0.8 × 1.8 mm); WCS3, Wire-composite-splint 3 (Dentaflex 0.45 mm covered with resin composite); Non-injured teeth, physiological tooth mobility (teeth 12 and 22); Injured teeth, pathological tooth mobility (teeth 11 and 21); ANOVA, Analysis of variance; PHT, *post hoc* test; DT3, Dunnett T3 test.

tion of reinforcement material (3, 10, 13, 16–19), by the splint extension (4, 20), and, for orthodontic retainers, by the APD (28). In this study, we examined the influence of the APD on the rigidity of dental trauma splints. In contrast to adhesively attached, long-term, periodontal splinting or orthodontic retainers, which are predominantly located on the lingual surface, dental trauma splints are typically bonded to the vestibular tooth surface for only a short period of time. Attaching the splints to the vestibular tooth surface simplifies the insertion and removal procedures and allows, when necessary, endodontic access from the lingual tooth surface. Splint removal, including the composite adhesive points, runs the risk of damaging the enamel (20, 29). Therefore, it is theoretically desirable to limit the APD with the objective of minimizing the affected area.

We used a practical, reproducible, reliable measurement method, the dynamic Periotest method (2, 26, 30, 31). The Periotest provided information about the damping characteristics of the periodontal and indirect information about tooth mobility (2, 26, 32–34).

For this study, we used an individually manufactured metal model that included bovine tooth facets (1, 13, 14, 20). This artificial model provided the combined advantages of simulating physiological or increased mobility and obtaining reproducible results with low to moderate inter-individual variability (1, 14). *In vivo*, the PDL of sound human teeth consists of a fibrous struc-

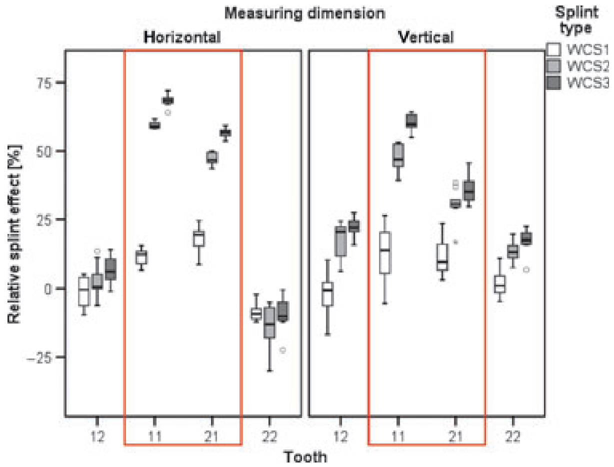

Fig. 9. Relative splint effect in percent for 5-mm adhesive point dimension, subdivided by the measuring dimension as a function of the splint type for non-injured teeth 12 and 22 an injured teeth 11 and 21 (red frames)*. *The box (IQR, interquartile range) represents the 25th to 75th percentile, the whiskers show the minimum and maximum, except for outliers (dots; 1.5 to three times of the IQR) and extreme values (asterisk; more than three times IQR).

ture that functions to suspend the tooth in the alveolar socket. The fibers of the PDL are aligned, predominantly, to absorb compression forces, but also to withstand limited pulling forces. In our *in vitro* study, the simulated PDL was made of silicon. The silicon layer, located between the tooth and the alveolar socket surface, was designed to simulate the elastic properties of the natural fiber structure and to function as a buffer for compression forces. When applying pulling forces, the retention force of the simulated PDL was a function of the static friction between the silicon and the metal surfaces of the tooth and the alveolar socket. The retention force of the simulated PDL was lower in the model compared with the fiber structure in sound human teeth. Therefore, the model teeth were additionally anchored in their alveolar socket with apical adjusting screws. In teeth that sustain dislocation injuries, the fibers are partially or completely ruptured, and the periodontal gap may be filled with a blood clot. To mimic the clinical *in vivo* situation, we fabricated the PDL of injured teeth with silicon (apical third) and rubber foam (middle and cervical parts) (1, 13, 14, 20). The apical adjusting screws were only slightly tightened. Compared with human volunteers, the model offered the advantage of conducting measurements and splint insertions as often as necessary. The enamel surface of the bovine tooth facets allowed the use of the acid-etch technique for adhesively bonding reinforcement materials with resin composite to the tooth surface. For this study, the mesio-distal APD was based on the width of the tooth facets.

For evaluating the influence of the APD on splint rigidity, we compared the flexible WCS1 to the rigid WCS2 (2, 3, 13, 14, 20). We hypothesized that increasing the APD in the mesio-distal dimension or covering the wire with flowable composite (WCS3) would increase the splint rigidity of WCS1 and render it similar to the WCS2. The majority of dental trauma cases require flexible splinting. Only alveolar process fractures and cervical infra-alveolar root fractures should be rigidly splinted. Therefore, if no rigid splint material is available in a dental office, the flexible WCS1 could be modified by covering the wire to receive a rigid splint variant.

The splint rigidity can be expressed as splint effect, a function of the initial tooth mobility and the mobility after splint insertion (3, 10, 16–18). Previous studies observed that the initial tooth mobility could influence (3, 4, 16–18, 21) or was positively correlated with (4) the splint effect. Therefore, in this study, we aimed to reduce the influencing effect of initial mobility values by evaluating the relative splint effect, or the percent change (1, 13, 14, 20).

Study outcome

Influence of adhesive point dimension

The aim of this study was to evaluate the influence of the composite APDs and the splint type on the rigidity of different dental wire-composite splints. When evaluating the influence of the APD without considering other factors (splint type, measuring dimension, and tooth injury status), we found no significant differences among APDs (Fig. 5). However, the standard deviation of the SpErel increased in parallel with the APD (Fig. 5). This could be explained by considering the influence of the volumetric shrinkage (9.0 ± 0.29%) of the flowable composite (Grandio flow) during polymerization (35). The shrinkage during polymerization of the flowable composite that surrounded the wires probably caused a deformation of the passively fit wire, followed by slight tooth dislodgement. In a simplified model, the shape of the adhesive points can be described as a flattened hemisphere. Therefore, the volumes of the linearly increasing adhesive point sizes (2, 3, 4, and 5 mm) would increase exponentially. The macro-mechanical surface design of the Dentaflex wire (WCS1) and the Strengtheners (WCS2) ensured improved retention of the composite by filling the intervening spaces. However, this could lead to amplifying the effect of the polymerization shrinkage on the SpErel.

The influence of the APD was then assessed according to tooth injury status and splint type (Fig. 6, Table 1). For the rigid WCS2, APD had no statistically significant influence on sound, non-injured teeth; however, increases in APD significantly increased the SpErel on loose, injured teeth. In contrast, for the thin, flexible WCS1, increasing the APD caused decreasing SpErels on sound, non-injured teeth, but changes in APD had almost no effect on SpErel on loose, injured teeth. These findings supported the notion that polymerization shrinkage of flowable composite may have influenced the SpErel, and the shrinkage may have counteracted the desired effect of increasing the SpErel with increasing APDs. This was particularly applicable to the thin, flexible WCS1.

These results suggested that splint rigidity could not be predictably increased by enlarging the APD, particularly for flexible wires. Instead, we recommend controlling splint rigidity by varying the stiffness of the wires.

Influence of splint type

We had hypothesized that covering the flexible Dentaflex wire with composite (WCS3) would increase splint rigidity compared with WCS1. However, the connection between the wire and the flowable composite was mechanical, and increased movement of injured, splinted teeth could fracture the composite material under force application. To counteract the fracture risk, it was necessary to increase the thickness of the resin composite that covered the wire. However, a thicker composite covering might increase the negative effect of the polymerization shrinkage. Nevertheless, one advantage of this method would be an improved esthetic outcome.

The influence of the splint type was evaluated for WCS1, WCS2, and WCS3 with an APD of 5 mm. Smaller APDs were not feasible when applying WCS3, because it was not technically possible to avoid accidental resin composite displacement. The influence of the splint type on the SpErel was statistically significant (Fig. 8, Table 2). Interestingly, covering the flexible Dentaflex resulted in higher rigidity than achieved with the rigid Strengtheners. This was consistent with findings in previous studies, when resin composite was used for interdental splinting or in fiber-reinforced resin splints (3, 13).

Conclusions

Despite the limitations of this *in vitro* study, we could draw the following conclusions: (1) increasing the size of the APD did not predictably increase the rigidity of WCS1 (Dentaflex, 0.45 mm), (2) increasing the size of the APD increased the rigidity of WCS2 (Strengtheners 0.8 × 1.8 mm), (3) covering the flexible Dentaflex with flowable composite (WCS3) distinctly increased splint rigidity, (4) WCS1 can be defined as flexible and WCS2 and WCS3 as rigid splint variants, (5) for controlling splint rigidity, we recommend using reinforcement materials with different stiffness properties, (6) APD should be as small as possible to reduce the risk of damaging tooth enamel during the splint removal procedure.

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