

In vitro comparison of the flexibility of different splint systems used in dental traumatology

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Abstract – Aim: The aim of the study was to evaluate the flexibility of five different splint systems [polyethylene fibre-reinforced splint (Ribbond® THM, Ribbond Inc., Seattle, WA, USA), resin splint (RS), wire-composite splint (WCS), button-bracket splint (BS) and titanium trauma splint (TTS)] commonly used in clinical practice for the treatment of dental traumatic injuries involving the periodontal supporting tissues. **Materials and methods:** For the experimental study, a resin cast of the upper arch was manufactured, where teeth 11, 12 and 21 (used for the stress analysis) were inserted in a non-rigid fashion so as to allow for replacement, whereas the other teeth were permanently fixed to the corresponding sockets. Two different test sessions were performed for each splint: (i) stress analysis with increasing intensity ranging between 0 and 50 N directed along the tooth's longitudinal axis; (ii) stress analysis with 45° of oblique force of increasing intensity ranging between 0 and 30 N. For each loading direction, five recordings were conducted without a splint, followed by five with the splint applied. The energy required to modify the position of the teeth was calculated for both the splinted and un-splinted teeth and the difference between the two values was determined. Energy variation was assessed for the testing of both axial (ΔE_a) and oblique force (ΔE_o). ΔE represents the rigidity index of the analysed contention devices: high ΔE values correspond to high rigidity materials. **Results:** The RS showed the highest ΔE value for the axial stress analysis, whereas the highest ΔE value at a 45° was recorded for the WCS and RS. For both tests, the lowest ΔE values were recorded for the TTS and Ribbond THM splints. **Conclusions:** The data show that the contention devices with the highest flexibility are the TTS and the Ribbond THM as they exhibit a lower energy variation needed for splint deformation compared with the other materials that were examined.

Epidemiological studies report that by the age of 16 years, 35% of the subjects have sustained dental trauma and that the percentage rises to 50% by the age of 18 (1, 2).

These traumas can involve both the primary and permanent dentition. Nevertheless, the former are mainly lesions of the supporting periodontal tissues (luxations and avulsion), whereas traumas involving the hard dental tissues (crown, crown-root and root fractures) are more frequently observed in the permanent dentition (1).

The frequent periodontal involvement observed in traumas of the primary teeth is due to the higher elasticity of the alveolar bone of the children, as at this age, there is more spongy than cortical bone (2, 3).

In any case, in daily practice clinicians often find themselves treating traumatic lesions involving the supporting tissues.

From a prognostic standpoint, traumas involving these structures have more unpredictable outcomes and *restitutio ad integrum* of the periodontal ligament is the crucial prerequisite for complete healing of the lesion.

To achieve this, a contention device or splint is employed, i.e. a 'rigid or flexible appliance for the fixation of mobile or dislocated parts' (4).

In dentistry, splinting consists of the connection of two or more teeth to each other to limit increased mobility because of acute periodontal lesions following trauma.

The splint reduces the load exerted on each tooth by distributing the masticatory and perioral muscle forces on multiple teeth and a broader surface.

Furthermore, the direction of the forces applied to the teeth is favourably modified, converting the lateral loads into vertical ones that are less harmful for the tooth-supporting apparatus (5), which can thus heal more easily by restoring bone integrity and rearranging the periodontal ligament fibres (6).

There are essentially two biomechanical factors regarded as the *conditio sine qua non* for successful treatment: mild loads applied to the healing tissues and controlled tooth movement (about 50 μm) within the traumatized socket (7).

Several splints are used in clinical practice but, independently of the type, passivity and flexibility are essential qualities for the physiological movement of the

traumatized tooth to promote healing of the periodontal fibres (8).

It has been observed that teeth stabilized with high-flexibility splints are less likely to undergo root resorption and show a better reorganization of the periodontal fibres compared with teeth splinted by means of rigid contention devices (7, 9, 10).

Many studies have attributed the negative effect of the rigid contention to the periodontal neoangiogenesis deficit produced by excessive compression on the periodontal ligament, whereas the mechanical stimulus exerted by mild tooth movement would favour the revascularization process (11–14), prevent ankylosis and maintain the Hertwig's epithelial root sheath (15), which is vital in the event of the developing roots.

Complete immobilization, on the contrary, thwarts healing by interfering with fibroblast metabolism because of the lack of mechanical stimuli (7).

These considerations led several authors to conclude that a splint allowing mild tooth movement (1, 8, 15–20) for a limited period of time is actually more effective.

Materials technology is very prolific in proposing new contention systems that can satisfy the ideal requisites: appearance, user-friendliness and easy hygiene procedures, together with the ability to stabilize the traumatized tooth (8, 21–24) without employing an excessively rigid system.

This study compared the flexibility of five different splints commonly used in clinical practice through *in vitro* assessment of their degree of rigidity, expressed by the movement allowed to the splinted teeth.

Materials and methods

The examined splints were as follows:

- Polyethylene fibre-reinforced splint (Ribbond® THM)
- Wire-composite splint (WCS)
- Button-bracket splint (BS)
- Resin splint (RS)
- Titanium trauma splint (TTS)

Following the protocol proposed by Oikarinen (21), a resin cast of the upper arch was made and the stress analyses were performed on preformed resin teeth (Frasaco).

All teeth were fixed on the cast with the exception of the three front ones (11, 12, 20), which could be removed and replaced.

To simulate the form and characteristics of the periodontal ligament, polyvinyl siloxane (Gingifast Elastic-Zhermack, Ravigo, Italy) was placed at the apical level (thickness 3 mm to allow a small vertical movement (21, 25)) and around the root (thickness 0.3 mm) of 11, 12, and 21.

Therefore, after splinting, these three teeth had mild axial and bucco-lingual mobility and, being removable, they were replaced after each test.

The load was applied to 11, previously splinted to 12 and 21, as there are no benefits in extending the splinting (22, 23).

Before splint placement, the buccal aspect of the teeth was roughened with pumice powder and primer

agent (PermaQuick Primer and Bonding Resin/Ultradent) (24, 25).

We then proceeded with splint placement as follows.

Splint 1: Ribbond®

A fibre segment (Ribbond® THM) length of which corresponded to the teeth to be splinted was cut and then a thin layer of unloaded resin was placed on them (PermaQuick Bonding Resin, Ultradent Products Inc., South Jordan, UT, USA).

The buccal aspect of the teeth was covered with a thin layer of fluid composite (PermaFlow, Ultradent Products Inc., USA), avoiding the interproximal contact points.

The Ribbond® fibre, previously wetted with adhesive resin, was then applied at the middle third of the buccal surfaces of the teeth and light-cured for 40 s.

Splint 2: wire-composite splint

At the middle third of the teeth to be splinted, a wire made of two interwoven orthodontic steel wires (Aesculap Inc., Center Valley, PA, USA, $\varnothing = 0.016$) was passively adapted and fixed by means of a fluid composite (PermaFlow) and light-cured for 40 s.

Splint 3: button-bracket splint

Orthodontic brackets (Edgewise standard, slot = 0.022) were applied to the teeth to be splinted and a steel wire was passively adapted (Aesculap Inc., $\varnothing = 0.016$).

Splint 4: resin splint

The composite material (Enamel Plus) was applied at the middle third of the dental surfaces and light-cured for 40 s.

Splint 5: titanium trauma splint

The titanium wire (TTS, Medartis® Basel, Switzerland) was placed at the middle third of the dental surfaces. The TTS's rhomboidal holes were filled with fluid composite (PermaFlow) and light-cured for 40 s.

To assess the rigidity of the five splints, stress analyses were performed using a universal machine (Erichsen model 476, Fig. 1).

The machine, by means of a cylindrical punch, applies an increasing linear force measured in Newtons (N) at the incisal margin of tooth 11 (Fig. 2).

Using programmable logic controller (PLC) software, for each test, the machine is able to elaborate a force-movement graphic that makes it possible to evaluate the movement of the teeth when the applied load is increased.

- Four analyses were performed to evaluate each splint:
- 1 Test 1: test without splint, with axial load (the application point was the incisal margin of 11), and linear increasing intensity ranging from 0 to 50 N (Fig. 3);
 - 2 Test 2: test with splint, with axial load (the application point was the incisal margin of 11), and linear increasing intensity ranging from 0 to 50 N;



Fig. 1. Universal machine (Erichsen 476).

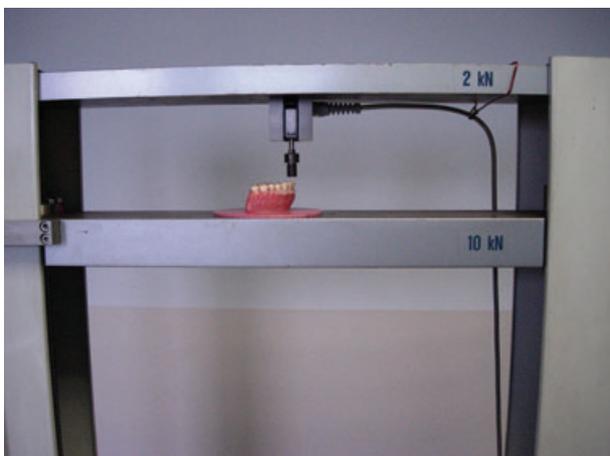


Fig. 2. Linear force applied at the incisal margin of the 11.

3 Test 3: test without splint, with oblique 45° force (the application point was the incisal margin of 11), and linear increasing intensity ranging from 0 to 30 N (Fig. 4);

4 Test 4: test with splint, with oblique 45° force (the application point was the incisal margin of 11), and linear increasing intensity ranging from 0 to 30 N.

The four tests were repeated five times for each splint for a total of 20 experiments.

The increasing load of 0–50 N was chosen because these values fall into the physiological range of the masticatory forces, which amount to 10–20 N for soft foods and reach 100 N for harder ones (26).

For the 45° tests, the maximum applied load was lower to compensate for the broader movement caused by the oblique force.

The values obtained for the tests 1 and 3 represent the reference parameter for tests 2 and 4.

After each set of tests, with and without splints, the teeth (and their supporting polyvinyl siloxane) were always exchanged with identical new elements, and their position was replicated by means of a polyether template (Impregum F; Espe Dental AG, Seefeld, Germany)



Fig. 3. Axial load and linear increasing intensity ranging from 0 to 50 N.



Fig. 4. Oblique 45° force and linear increasing intensity ranging from 0 to 30 N.

prepared when the cast was made. Therefore, for each test, the initial position was replicated so as to minimize any bias due to wear of the materials.

Results

Each splint underwent testing under both axial and 45° loads, with respect to the longitudinal tooth axis (respectively, tests 1 and 2; tests 3 and 4), recording the movements of the teeth at the increasing applied forces, with and without the splint.

For each splint, at the end of the two sets of 5 tests, the mean of the movements recorded at 50 N was calculated. (Table 1)

For the RS splint, it was impossible to calculate the relative movement at 50 N because it constantly fractured with smaller loads, with a maximum allowed movement of 0.25 mm in the 5 tests, corresponding to 42 N.

Similarly, the mean of the movements at 30 N of the different splints during the 45° tests was recorded (Table 2).

During this test as well, the RS always fractured, allowing for a maximum movement of 0.85 mm at 17.6 N.

To assess the rigidity of the examined splints, the deformation energy (E) was calculated both for the stress and movement analyses.

This energy (in mJ) can be defined as the work needed by the machine to move the teeth by a predefined dS value, and it is expressed by the formula (1)

$$E = L = \int_0^{S_{\max}} F(S)ds \quad (1)$$

As the applied load increases linearly over time during this type of experiment, the deformation energy can be simplified by the formula (2), where L represents work, S_{\max} is the maximum movement and F_{\max} is the load linked to maximum movement

$$E = L = \frac{1}{2} F_{\max} S_{\max} \quad (2)$$

The S_{\max} value the allowed tooth movement before irreversible deformation of the splint occurs was adopted as a reference parameter to compare the flexibility of the tested materials. This corresponds to

Table 1. Movements recorded at 50 N

Splint at 50 N	Mean movement (mm)	
	Without splint	With splint
Ribbon	0.43	0.41
TTS	0.6	0.56
WCS	0.38	0.36
RS	0.61	N/A
BS	0.59	0.47

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.

Table 2. Movements recorded at 30 N

Splint at 30 N	Mean movement (mm)	
	Without splint	With splint
Ribbon	1.5	1.1
TTS	1.33	1
WCS	1.64	1.3
RS	1.43	N/A
BS	1.47	1.23

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.

Table 3. E_1 , E_2 mean values and difference between the means of energy deformation for tests 1 and 2 ($n = 5$)

	E_1 means \pm SD	E_2 means \pm SD	$\Delta E_a \pm$ SD
Ribbon	1.802000 \pm 0.158177	2.000000 \pm 0.164469	0.198000 \pm 0.289948
TTS	1.598000 \pm 0.170939	1.702000 \pm 0.158177	0.104000 \pm 0.016733
WCS	2.770000 \pm 0.138564	2.992000 \pm 0.120499	0.222000 \pm 0.258302
BS	1.535000 \pm 0.537192	2.394000 \pm 0.555050	0.859000 \pm 1.091.664
RS	1.600000 \pm 0.636396	5.250000 \pm 0.777817	3.650000 \pm 1.414.214

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.

the movement allowed by the RS, which – unlike all the other splints – fractured before 50 and 30 N were reached.

With this procedure, the deformation energy was calculated for each splint as follows:

- 1 E_1 = deformation energy of test 1;
- 2 E_2 = deformation energy of test 2;
- 3 E_3 = deformation energy of test 3;
- 4 E_4 = deformation energy of test 4.

The difference between the deformation energies of each type of splint was calculated every time as:

$$-\Delta E_a = E_2 - E_1 \quad -\Delta E_o = E_4 - E_3$$

where ΔE_a corresponds to the variation of deformation energy for each test performed along the longitudinal axis and ΔE_o indicates the change in deformation energy for each oblique force test. The mean values of the deformation energy obtained in the five sessions of the tests 1 and 2 were then assessed (Table 3).

ΔE_a indicates the difference between the mean deformation energy obtained from the five tests performed with and without splint (Table 3).

The mean values of the deformation energy tests were also calculated for tests 3 and 4 (Table 4).

In this case, ΔE_o represents the difference between the mean deformation energy obtained from the five tests performed with and without the splint (Table 4).

Statistics

To compare the mean values of E_1 and E_2 and E_3 and E_4 , a series of Student’s t -tests for independent variables were performed, one for each type of splint (Tables 5 and 6).

The reliability of the Student’s t -test was confirmed by the F -test for equal variances, employed to verify if the standard deviations of the compared groups differed significantly.

The F -test was not statistically significant in any of the cases, as the P -value was always > 0.05 .

Discussion

This study provides experimental data on the flexibility of different splint systems commonly used in clinical practice to allow a certain degree of mobility to traumatized teeth to promote optimal healing of the periodontal tissues.

One of the study limitations is represented by the consideration that the structural and physical properties of the resin cast used for the experiments is

Table 4. E_3 , E_4 mean values and difference between the means of energy deformation for tests 3 and 4 ($n = 5$)

	E_3 means \pm SD	E_4 means \pm SD	$\Delta E_0 \pm$ SD
Ribbon	0.742000 \pm 0.078230	0.852000 \pm 0.078867	0.110000 \pm 0.157003
TTS	0.749000 \pm 0.066370	0.840400 \pm 0.075702	0.091400 \pm 0.141774
WCS	0.513200 \pm 0.114853	0.739380 \pm 0.103023	0.226180 \pm 0.217427
BS	0.477800 \pm 0.095547	0.624600 \pm 0.098238	0.146800 \pm 0.193771
RS	0.434600 \pm 0.052923	0.657600 \pm 0.045703	0.223000 \pm 0.090526

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.

Table 5. Student's t -test for the mean values of E_1 and E_2 ($P = 0.05$)

Treatment	E_1	E_2	Significance
Ribbon	1.802 \pm 0.158	2.000 \pm 0.164	NS
TTS	1.598 \pm 0.171	1.702 \pm 0.158	NS
WCS	2.770 \pm 0.139	2.992 \pm 0.120	$P = 0.0269^*$
BS	1.535 \pm 0.537	2.394 \pm 0.555	$P = 0.0377^*$
RS	1.600 \pm 0.636	5.250 \pm 0.778	$P = 0.00004^{****}$

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.
The increasing number of * states the major relevance of the statistical significance.

Table 6. Student's t -test for the mean values of E_3 and E_4 ($P = 0.05$)

Treatment	E_3	E_4	Significance
Ribbon	0.742 \pm 0.078	0.852 \pm 0.079	NS
TTS	0.749 \pm 0.066	0.840 \pm 0.075	NS
WCS	0.513 \pm 0.115	0.739 \pm 0.103	$P = 0.0112^{**}$
BS	0.478 \pm 0.096	0.625 \pm 0.098	$P = 0.0435^*$
RS	0.435 \pm 0.053	0.658 \pm 0.046	$P = 0.00001^{****}$

TTS, titanium trauma splint; WCS, wire-composite splint; RS, resin splint; BS, button-bracket splint.
The increasing number of * states the major relevance of the statistical significance.

not representative of the more complex structure of the biological dental tissues, alveolar bone and periodontium.

The reported data nevertheless describe the physical characteristics of the examined splints and thus represent an indication of their respective behaviour in the oral cavity.

In general, the change observed in the deformation energy represents the energy absorbed by the splint.

A different force is needed to arrive at the same degree of deformation of two different materials, a rigid one and a flexible one; in particular, ΔE will be higher for the rigid one.

The parameter that allows the comparison of different splints is therefore the value of the deformation energy of the tested materials.

The differences in mean movements of teeth without splinting (Tables 1 and 2) may be explained from the substitution of the teeth and their supporting polyvinyl siloxane with new materials at the end of each series of tests. The extent of shift of the tooth without splint was, in fact, carried out each time just to evaluate the

flexibility of the different splinting techniques taking into account the inevitable small differences in thickness in the supporting material from one test to another. The analyses were performed with two different force application angles to replicate the forces applied on the teeth in physiological conditions as precisely as possible.

In both tests, the RS splint – unlike the other devices – fractured after minimal deformation and with stresses of < 50 and 30 N.

The RS was the most rigid splint, exhibiting a very high ΔE_a (Table 3) and showing a statistically significant difference ($P = 0.00004$) between the means of deformation energy with and without the splint (Table 5).

In tests 1 and 2, the BS and WCS splints also showed statistically significant differences between the means of deformation energy with and without the splint (respectively, $P = 0.0377$ and $P = 0.0269$; Table 5), with ΔE_a values (Table 3) much lower than those recorded for RS.

These results suggest that while the BS and WCS splints showed flexibility, they may not give the traumatized tooth the mobility (7) it needs for optimal healing.

Even if tooth mobility is a prerequisite, Cengiz et al. observed that the WCS seems to protect the traumatized teeth from stresses in the apical and cervical regions more than the other splint types because of the higher intrinsic rigidity of the orthodontic wire fixed on the tooth surface (7).

As a result, one could draw the wrongful conclusion that the higher the splint rigidity, the better the chances of healing because of the lower stress exerted on the injured periodontal tissues.

Nevertheless, there is evidence that tooth immobilization is unnecessary for healing of the traumatized periodontium. In contrast, the tooth requires a certain degree of controlled mobility (7), which would favour the production and maturation of collagen and protocollagen, given that the load is not excessive and the movement limited to a maximum range of 150 μ m (7).

According to Weisman (26), the characteristics of the ideal splint include passivity and flexibility to guarantee both contention and physiological dental mobility, without exerting any displacing force on the traumatized tooth (16).

Passivity varies according to the different properties of the materials and the technique employed for their placement. When using brackets and orthodontic wires, as required by the BS, it is difficult to prevent undesired forces from affecting the healing process (26, 27).

Splint flexibility is considered one of the main factors in post-traumatic healing which, according to clinical data, is related to the degree of allowed movement and

should resemble physiological conditions as closely as possible (7, 8).

The best semi-physiological mobility can be obtained by means of flexible splints. In this study, the Ribbond THM and the TTS showed the highest flexibility, with a significant difference between the mean values of the deformation energy with and without splinting ($P > 0.05$) (Table 5), and ΔE_a showed significantly lower values compared with the other examined samples (Table 3).

The higher flexibility of the Ribbond THM and the TTS was also confirmed by the results of the analysis performed at a 45° (Tables 4 and 6).

In the same oblique test, however, the WCS and RS showed greater rigidity, with similar ΔE_o values (Table 4).

Despite the fact that the RS was the most rigid splint, during tests 3 and 4, it showed far more flexibility compared with tests 1 and 2, as was the case with the BS.

For the RS, this difference is because of the wider composite surface of force distribution at 45°, whereas for the BS, it is because of the mechanical nature of the system, which is composed of brackets and wire that better withstand excursions on the horizontal and vertical planes (7, 27).

Overall, we can conclude that the TTS and the Ribbond THM have the highest elasticity, demonstrated by their low deformation energy.

In fact, independently from the loading direction, the deformation energy recorded with and without splint was not significant, contrary to what was observed for the other tested materials (Tables 5 and 6).

The highly overlapping results of the two systems are ascribable to their similar elasticity module and their strong resemblance in shape and size.

On the other hand, the RS was the most rigid splint and was thus subjected to fracture with even minimal deformations that were instead endured by more pliable materials, which were initially deformed and did not break until later. Consequently, for clinical application, the RS does not appear to be able to allow in all situations the necessary tooth mobility for the healing of the periodontal ligament (7, 10) and, in addition, the fracture of the splint may occur when it is subjected to forces of low extent (25). This implies excessive rigidity of the splint, which also demonstrates low stress tolerance to progressive weakening, continuing to serve its purpose for a given period of time. Moreover, RS provides less comfort to the patients compared with other splinting techniques (10, 16).

Consequently, the post-traumatic rigid splints used in the past, which once reflected the principles of immobilizing bone fractures (16), are no longer employed to treat periodontal traumatic injuries, as prolonged immobilization increases the risk of root resorption (6).

Mandel and Viidik have shown that the post-traumatic healing obtained by means of passive and flexible semi-rigid splints is similar to what a traumatized tooth would undergo without a splint (28–31), whereas Andreasen et al. (8) reported that the splinting does not modify the healing process of non-displaced teeth.

Even if the use of semi-rigid splint systems does not seem to affect the healing processes significantly provided that any mechanical stress exceeding the physiological tolerance range is avoided (7), based on the data obtained from this study and in accordance with the literature (25), we can state that among the examined splint systems, the TTS and the Ribbond THM are the materials with the passivity and flexibility features that are best suited for the treatment of traumatic lesions involving the supporting tissue of the tooth.

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