Best Splinting Methods in Case of Dental Injury–A Literature Review

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The objective of this manuscript was to review the literature on dental trauma splints and discuss materials used for splinting injured teeth in terms of their properties and conditions that are required for optimal stabilization.

A literature search was conducted in the PubMed database with the keywords: "trauma splints", "dental trauma" and "traumatic dental injuries". The search was limited to English language publications. 42 publications fulfilled the inclusion criteria and were in accordance with the current recommendations.

Optimal splinting of the teeth after trauma is one of the main predictors for pulpal and periodontal healing. The splints stabilize and protect the teeth, creating favorable conditions for the regeneration of the supporting tissues. Their application and removal should be easy and fast without any additional irritating of the surrounding tissues. The materials used to stabilize the injured teeth should keep the tooth in the original position, allowing for its physiological mobility.

Keywords: *children, splinting, dental trauma.*

INTRODUCTION

Dental injuries, next to caries and periodontal diseases, are one of the main causes of tooth loss in the pediatric population. Trauma can lead to tooth loss in a variety of ways, such as untreated avulsion, posttraumatic complications (e.g. root resorption and pulp necrosis) or extraction as a direct result of acute injury.

Appropriate treatment necessary for optimal healing of the pulp and periodontal ligament (PDL) of an injured tooth allows clinicians to preserve arch integrity and the development of the dentition in pediatric patients. Untreated dental injuries in children lead not only to functional limitations (e.g. difficulties in chewing) and developmental disturbances but also have a negative impact on children's wellbeing, social functioning, self-confidence and emotional balance. [1,2]

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Before starting the treatment, several factors, affecting the healing of injured tooth, should be considered. These factors can be divided into three groups:

1. Factors associated with the patient: age, stage of root development and the diameter of the apical foramen.
2. Factors associated with the trauma: type and extent of trauma, contamination of the root surface and extra-alveolar time (in case of avulsion), compression of the periodontal ligament, pulp and/or bone injury.
3. Factors associated with the treatment: optimal repositioning, use of flexible or rigid splinting, antibiotics and treatment delay. [3-5]

Splinting is considered to be one of the factors that can improve the prognosis of an injured tooth. A dental trauma splint is any kind of device used to stabilize the tooth in its natural position. An optimal splint should:

- be easily accessible,
- be applied directly intraorally, using materials available in the dental practice,
- ensure adequate fixation of a tooth, preventing its accidental ingestion or inhalation,
- protect from any further trauma during the healing period,
- be passive,
- allow for physiological tooth mobility to promote the healing of the PDL,

- not impair oral hygiene and speech,
- not traumatize oral soft tissues,
- not interfere with occlusal movements,
- be easy to remove, without causing permanent damage to the dental hard tissues,
- be comfortable and aesthetic. [5-7]

METHOD

To identify the relevant studies about the splinting of the injured teeth, a computerized literature search on Pubmed was performed during February 2018. An update was conducted in May 2019. The terms used in the search were: "trauma splints", "dental trauma" and "traumatic dental injuries". The literature search was performed according to the following inclusion criteria: 1) articles published in the English language, 2) papers about splints used after dental trauma and 3) studies that were in accordance with the current recommendations. The exclusion criteria were: 1) non–English articles, 2) case reports, personal opinions, letters, posters and conference reports, 3) full text not available, 4) papers about the prevalence and the dentists' knowledge of dental trauma, 5) studies on periodontal and sport splints and 6) studies on soft tissues and facial trauma. A total of 771 articles were found in the database in the initial search. All titles were then screened, and 69 papers were chosen. Of these, 27 were excluded after the review of their abstracts, leaving 42 selected articles. All these 42 articles were analyzed and included in the review.

RESULTS AND DISCUSSION

The topic with the largest number of articles was the rigidity of different splints (15 articles). In two articles, splint rigidity was evaluated *in vivo* in healthy and injured patients. In the remaining 13 articles, the rigidity was assessed *in vitro* using human cadaveric models (one article), animal models (one article) and artificial models (11 articles). The effect of splinting on injured teeth and surrounding structures was described in six articles. Four papers focused on the guidelines for the management of traumatic dental injuries, including the recommendation of splint type and splinting duration. Only two papers were found about splinting in the primary dentition.

Duration of splinting

Since the research revealed that long-term splinting could lead to adverse outcomes, such as replacement resorption and ankyloses, [8-10] it is recommended that the duration of splinting should be as short as possible. The current International Association of Dental Traumatology (IADT) [11,12] and the American Association of Endodontists guidelines [13] for splinting times are shown in Table 1. The American Academy of Paediatric Dentistry (AAPD) has endorsed the IADT recommendations.

However, evidence-based appraisal of injured teeth concluded that the splinting duration was not a significant factor when related to healing outcomes. [14] Similar findings were reached in another study, which suggested that the fixation period does not affect the likelihood of successful periodontal healing after the replantation of avulsed teeth. [15] In light of the fact that the evidence for the association between short-term splinting and an acceptable healing outcome appears inconclusive, [15] further research is necessary. For now, the dentist is advised to use the currently recommended splinting protocols.

Types of splints

Most of modern teeth splinting methods require an acid etch technique. The devices are usually bonded to the labial surface of the teeth. The splints, which are one of the most widely used in dental practice, are **wire-composite** splints (Fig. 1). The wires made from stainless steel suitable for this kind of splint are, for example, a rectangular orthodontic wire (0.41 mm x 0.41 mm), a multi-stranded flexible orthodontic wire or a ligature round wire with less than 0.4 mm in diameter. Nickel-titanium wires are also used. [4]

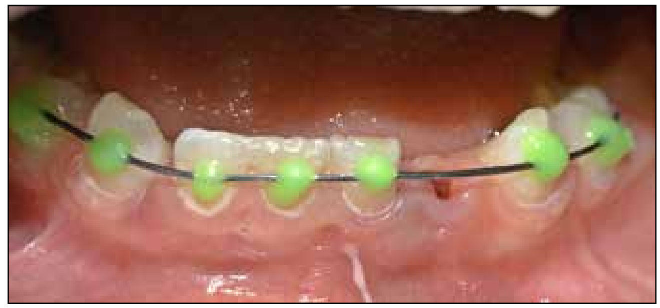

Figure 1: The wire-composite splint. Colored flowable composite was used to facilitate the removal of residual material from the enamel.

Composite resin splints are composed of composite alone that is applied interdentally to the labial surface of the teeth. Although they are easily available in every dental practice, they are not recommended. However, multiphase resin materials (e.g. Luxatemp ® DMG, Hamburg, Germany; Protemp ® 3M ESPE, St. Paul, USA), which are commonly used for direct prosthetic temporary restorations, may be used as trauma splints, especially as an emergency treatment. The advantage of this kind of stabilization is the possibility of applying the material in stages, which is useful in the case of multi injured teeth. [4] These splints require the crowns to have fully erupted with appropriate interproximal contacts; they are not suitable in case of missing teeth.

Fiber-reinforced composite splints are another device used to stabilize teeth after trauma. For these kinds of splints, different materials are commercially available:

- polyethylene fibers (e.g. Ribbond®-THM, Ribbond Inc., Seattle, USA)
- glass fibers in the form of the band (e.g. Fiber-Splint® Polydentia SA, Mezzovico-Vira, Switzerland), the rope, the woven or the unidirectional fiber (e.g. Quartz Splint, RTD, Saint-Egrève, France)
- Kevlar® fibers, made of the aromatic polyamide (e.g. B-W Dental, Frederiksberg, Denmark)

The titanium trauma splint (TTS, Medartis AG, Basel, Switzerland) (Fig. 2) are specially designed to stabilize the teeth after repositioning or replantation. TTS, with its unique rhomboid mesh structure, is only 0.2 mm thick. Thanks to its design, TTS is easily adaptable to the dental arch, and rhomboid opening facilitates its application. [16]

Figure 2: The Titanium Trauma Splint in patient suffered from subluxation of teeth 12, 11 and 21. The lower teeth were splinted with more rigid splint (double twisted wire) because of the fracture of the alveolar bone.

Orthodontic splints (Fig. 3) need special materials, like wires and brackets, that are not always available in the dental practice. These kinds of devices involve fixed orthodontic appliances or button brackets which are bonded to the teeth and connected by twisting flexible wire around the buttons. [17] The major concern regarding these splints is their ability to exert forces on the teeth that can interfere with healing. A study evaluating splints constructed with orthodontic materials revealed that they always generate some force; however, the amount of force exerted can be modified by parameters like the type of ligature, the form of the arch wire (straight or performed) and the cross-section of the wire. [18] That is why it is recommended that only an experienced clinician should use such materials to stabilize dislocated teeth. There are several clinical situations when the use of fixed orthodontic appliances for splinting is advisable:

Figure 3: A splint in a patient that suffered from severe teeth 11 and 21 intrusion and avulsion of 12. Laceback passive ligature was made using orthodontic appliance that the patient was treated with.

- When the teeth are severely malpositioned, and it is not possible to design adequate wire-composite splint
- When traumatized teeth need repositioning, e.g. intruded teeth
- When the least traumatic technique of repositioning is desirable. [19]

The nylon (fishing line) splint (Fig. 4) is an alternative for wires and was first presented as a device which is easy to apply and remove, atraumatic, relatively aesthetic, hygienic, durable and comfortable. [20]

Table 1: Duration of splinting according to IADT and AAE

Type of injury	Splinting time/flexibility	
	IADT	AAE
Subluxation	2 weeks (if necessary)/flexible	2 weeks (if necessary)/flexible
Extrusion/extrusive luxation	2 weeks/flexible	2 weeks/flexible
Lateral luxation	4 weeks/flexible	2 weeks (if displacement is extensive 4 weeks)/flexible
Avulsion Closed apex: - tooth replanted before the patient's arrival to the dentist - tooth kept in in an adequate storage media - tooth kept dry less than 60 minutes	2 weeks/flexible	1–2 weeks/flexible
Closed apex: - tooth stored dry more than 60 minutes	2 weeks/flexible	1–2 weeks/flexible
Open apex: - tooth replanted before the patient's arrival to the dentist - tooth kept in in an adequate storage media - tooth kept dry less than 60 minutes	2 weeks/flexible	2 weeks/flexible
Open apex: - tooth stored dry more than 60 minutes	4 weeks/flexible	4 weeks/flexible
Root fracture (middle third)	4 weeks/flexible	4 weeks/flexible
Root fracture (cervical third)	4 months/flexible	4 months/flexible
Alveolar fracture	4 weeks/undefined	4 weeks/flexible

Figure 4: The nylon (fishing line) splint.

Recently, **the power chain** (Fig. 5), which is an elastic material used in orthodontics to close spaces, has been proposed for teeth splinting. The power chain needs further research as a material for the stabilization of injured teeth, especially in clinical situations. However, the evaluation of its parameters carried out so far has provided promising results. [21]

Figure 5: The power chain splint in patient with mixed dentition.

Removable splints. Stabilization of a child's injured teeth with acid-etched retained splints can be challenging as a result of missing teeth during the transitional dentition period, mobile primary teeth due to physiological root resorption, not fully erupted permanent successors or malocclusion. A good alternative in such cases are removable splints made of polycarboxylate, polyacrylic or Ethylene-Vinyl Acetate (EVA) copolymer. These splints are effective in eliminating the early contact in the anterior teeth area. It can be suspected that a removable splint, by allowing slight movement of the tooth, encourages more rapid periodontal reorganization and reattachment.[22]

Splint rigidity (Table 2)

One of the requirements necessary for optimal splinting is that the device used for teeth fixation should be versatile in achieving varying levels of stiffness (rigid, semi-rigid or flexible).[4] However, there is still no precise term that could actually define what is considered rigid versus flexible. [23] That gives the clinicians a wide range of materials they can use for splinting. The classification of the rigidity of the splints, based on the comparison between tooth mobility after fixation and physiological mobility, assumes that the flexible splints allow for more mobility than a non-injured tooth, semi-rigid ones for equal to normal tooth mobility and rigid ones for less than normal tooth mobility. [4,24]

According to the existing guidelines, traumatized teeth are recommended to be stabilized with flexible splints (Table 2). Allowing controlled, mild movement of the tooth during healing is considered as an indispensable condition for successful treatment. [25] Complete, rigid immobilization, on the contrary, has a negative effect not only on the pulpal and periodontal healing but also on root development in immature teeth, especially the ones at earlier developmental stages. Nutritional deficit of Hertwig's epithelial root sheath (HERS) caused by the rigid splinting may result in an additional restriction of the potential root growth. It has been proven also that prolonged rigid fixation may impair revascularization [26]

Several studies have focused on the influence of the reinforcement material on splint rigidity.

Among the commonly used trauma splint devices, wire-composite splints with a wire diameter of up to 0.4 mm, [6,23,24,27-31] Titanium Trauma Splints, [6,21,27,32,33] and a nylon fishing line [21,23] are considered to be flexible. A power chain, which has so far only been evaluated under experimental conditions, is also classified as flexible splint due to its low stiffness affording sufficient tooth mobility. [21]

Different factors, such as splint extension, abutment tooth position or adhesive point dimension, were investigated for their effect on splint rigidity. As far the composite adhesive points are concerned, studies have shown that increasing their dimensions does not predictably influence the rigidity of splints, specifically when it concerns flexible reinforcement materials. [29] However, in the case of more rigid materials**, the rigidity increases with the enlargement of the adhesive point dimension.** [29,34]

The wire length influences the rigidity. [24] While using an elastic material, the splint extension influences the splint rigidity of the injured tooth only in the horizontal dimension. That means that the vertical dimension is not affected, and the transmission of functional forces is preserved. In order to ensure adequate stabilization of the injured tooth, simultaneously allowing for its physiological movements, the splint should include only one uninjured tooth bilaterally. [24,35]

In children with mixed dentition, when some of the teeth are missing or not fully erupted yet, the splint application may be challenging. In addition to problems with the splint design, the other consideration is whether the lack of a neighboring tooth and the need to apply the material to the tooth, proximal to the gap, will change the parameters of the splint. As for the splint rigidity, it turns out that it is not significantly dependent on the position of abutment and if adjacent teeth are missing, it is possible to fix the splint to adjacent teeth near the gap. [34]

Biomechanical aspects of splints

The aim of splinting is to stabilize injured teeth and to create a safe environment that promotes the healing of damaged structures. There are two biomechanical factors that are necessary for optimal tissue healing: 1) low-magnitude strains induction to the healing tissues and 2) a controlled micro movement of the tooth in the traumatized socket (approximately 50 µm). [25,32] The study that assessed the biomechanical effect of splints on the traumatized tooth revealed that the splint that had a higher intrinsic rigidity protected the tooth better from stresses. [25] Therefore, according to the authors, it could be assumed that the more rigid the splint, the less stress is exerted and, consequently, the better healing of the injured support periodontal structures might occur. [25] However, as a result, a wrongful

Table 2. A summary of studies evaluating rigidity of dental trauma splints.

Paper	Splints tested	Material	Evaluation	Results
[30] Oikarinen, 1988	- wire – composite splints (WCS) with stainless steel wires of various diameters: 0.3, 0.4, 0.5 mm - the Schuchardt splint - the arch bar splint	commercial artificial model	test by producing compressive forces between 15-95 N	0.3 mm WCS can be regarded as a functional fixation and it should be recommended for teeth splinting
[31] Oikarinen et al. 1992	- Fermit splint - flexible wire-composite splint - Kevlar splint - fiber splint - Protemp splint - rigid wire-composite splint - Triad Gel splint	animal models	Mühlemann periodontometer , Periotest (Siemens, BRD)	rigid splints: Fermit, rigid wire-composite, Triad Gel; flexible splints: Protemp, flexible wire-composite
[35] Ebeleseder et al. 1995	- 0.017 x 0.025″ orthodontic steel wire– composite splint (WCS)	human, injured teeth	Periotest (Siemens)	there is no benefit from extending the splint to more than one adjacent firm tooth;
[27] von Arx et al. 2001	- Titanium Traum Splint (TTS) - wire (0.160″x0.22″) – composite splint - bracket splint - resin splint (Ptoremp)	human, healthy teeth	Periotest (Gulden, Bensheim, Germany)	all tested splints maintain physiologic vertical and horizontal tooth mobility
[33] Stellini et al. 2005	- Titanium Trauma Splint (TTS) - resin splint (RS) - button-bracket splint - wire- composite splint	commercial artificial model	tests under application of a defined load	with the exception of RS as to rigidity, the other three splints were practically the same in response
[6] Berthold et al. 2009	- four composite splint: 1) Protemp®, 2) Tetric® flow, 3) Luxatemp®, 4) Rely X Unicem® - wire -composite splints (WCS): 1) 0.45 mm (WCS1), 2) rectangular 0.4 x 0.4-m (WCS2), 3) 0.8 mm x 1.8 mm strengtheners (WCS3) - Titanium Ring Splint (TRS) - Titanium Trauma Splint (TTS) - bracket splint - Schuchardt splints: 1) with only wire ligatures applied, 2) wire ligatures covered with composite	commercial artificial model	Periotest (Gulden, Bensheim, Germany)	rigid splints: composite splints, TRS, WCS3; flexible splints: TTS, WCS1, WCS2
[32] Mazzoleni et al., 2010	- polyethylene fibre-reinforced splint (Ribbond® THM) - wire-composite splint (WCS) - button-bracket splint (BS) - resin splint (RS) - Titanium trauma splint (TTS)	commercial artificial model	test under application of a defined load	TTS and Ribbond THM had the highest flexibility compared with other materials examined
[24] Berthold et al. 2011	wire-composite splints (WCS): Dentaflex 0.45 mm (WCS1), Strengthens 0.8 x 1.8 mm (WCS2)	custom-made artificial model	Periotest (Gulden, Bensheim, Germany), Zwicki 1120 (Zwick, Ulm, Germany)	WCS1 is flexible compared with more rigid WCS2; the wire length influences the rigidity
[28] Berthold et al. 2012	- wire-composite splints (WCS): Dentaflex 0.45 mm (WCS1), Strengthens 0.8 x 1.8 mm (WCS2) - quartz-fiber splints (QS): UD 1.5 mm (QS1) Rope 1.5 mm (QS2) Woven 2.5 mm (QS3) Dry fibers 667 tex (QS4)	custom-made artificial model	Periotest (Gulden, Bensheim, Germany), Zwicki 1120 (Zwick, Ulm, Germany)	WCS1 is flexible; QS1 and QS2 can be classified as rigid; QS3 and QS4 are semi-rigid in the horizontal dimension

Table 2. A summary of studies evaluating rigidity of dental trauma splints (continued).

Paper	Splints tested	Material	Evaluation	Results
[23] Kwan et al. 2012	- wire-composite splints using stainless steel (SS) and nickel titanium (NT) wires: 1) 0.3 mm 2) 0.4 mm 3) 0.5 mm - nylon fishing line - composite splint	human cadaveric models	Periotest M (Medizintechnik Gulden, Germany)	composite splint and wire-composite splints made with wires > 0.4 mm are not flexible; nylon fishing line splint is flexible
[29] Franz et al., 2013	wire-composites splints: 1) Dentaflex 0.45 mm 2) Strengtheners 0.8 x 1.8 mm 3) Dentaflex 0.45 mm completely covered with flowable composite	custom-made artificial model	Periotest (Gulden, Modautal, Germany)	WCS1 is flexible; WCS2 and 3 are rigid; splint rigidity was influenced by adhesive point dimension only when splinting with WCS2 (rigid splint)
[34] Zhu et al., 2016	wire-composite splint (WCS) 0.8 mm	commercial artificial model	universal testing machine (Z020, Zwick/Roell, Ulm, Germany)	attaching injured teeth to one uninjured tooth bilaterally, using a stainless steel WCS (≤0.8 mm), can be regarded as flexible splinting; increase in size of the adhesive splinting point decreased horizontal but not vertical mobility
[21] Ben Hassan et al., 2016	- composite twistflex wire splint (TF) - titanium trauma splint (TTS) - fiberglass roving resin splint double layers (DFG) - fiberglass roving resin splint single layer (SFG) - nylon (fishing) line composite splint (FL) - power chain composite splint (PC)	commercial artificial model	test under application of a defined load	TTS, FL and PC are recommended as being the most flexible; DFG should be avoided as it was significantly stiffer; TF and SFG may be considered acceptable alternatives
[46] Shirako et al., 2017	- composite splint, width 1.5mm (CS1) - composite splint, width 2.5mm (CS2) - wire-composite splint, rectangular orthodontic wire 0.533×0.635 mm (WCS1) - wire-composite splint, cobalt-chromium alloy wire 0.9 mm (WCS2)	custom-made artificial model	Periotest Classic (Medizintechnik Gulden)	WCS1 and WCS2 can be categorized as flexible splints for injured teeth with moderate degree of mobility (simulated as extrusive or lateral luxation); CS1 and CS2 can be categorized as flexible splint for injured teeth with a high degree of mobility - out of range of Periotest values (simulated as avulsion or cervical area of root fracture)
[45] Shirako et al., 2017	four resin materials: 1) light-cured composite resin MI Flow II (MI; GC Corporation) 2) light-cured resin for splinting teeth G-FIX (GF; GC Corporation) 3) adhesive resin cement Super-Bond CB (SB; Sun Medical Co. Ltd.) 4) self-cured methyl-methacrylate resin Unifast III (UF; GC Corporation)	the specimens were made out of each tested material	flexural strength test using a universal machine (AG-X plus5 kN; Shimadzu, Kyoto, Japan)	GF may be more flexible than a composite splint (a rigid splint) and is a suitable material for use as dental trauma splint

conclusion could be drawn that the higher rigidity of the splinting material, the more favorable healing of the tissues. [32] Partly contradictory results were obtained by the authors of another study in which a greater stress concentration was observed in the alveolus of the injured tooth when a rigid splint was stimulated. [36] Moreover, the study showed that even the rigid wire, which was larger than the ones usually used for splinting, displayed some amount of flexibility. [36]

Splint placement and removal

One of the requirements for optimal splinting assumes that the device should be easily fixed and removed without damaging the enamel. The easiness of applying and removing the splint is determined by the time needed to perform these procedures. According to the study made, the shortest working times were recorded for the TTS. [27] The longest time was needed for the application of the bracket splint and for the removal of the wire composite splint. [27]

Different techniques are used to remove the remaining adhesives from the enamel surface in the case where the splinting material is fixed with composite resin. These techniques include hand instruments, like pliers and scalers, various burs, abrasive discs or rubber wheels and cusps.

The major concern about the mechanical removal of the splint is that it can cause iatrogenic, irreversible damage to the enamel. Based on the results obtained in the experimental study, which investigated the surface roughness of the enamel after different splint removal methods, Soflex discs and a 16-blade tungsten carbide bur are recommended as those instruments that cause the least damage to the enamel. [37]

Comfort of use

Although trauma splints are temporary devices, the comfort of their use is very important. From the patient's perspective, the splint should be comfortable, and should not interfere with speaking, eating and oral hygiene.

Optimal oral hygiene is essential to promote healing. Injured periodontal structures require a proper oral hygiene protocol to help tissues recovery. [38] The accumulation of plaque and debris must be avoided throughout the healing period. A clinical study, evaluating the periodontal parameters (plaque and bleeding on probing indices) in volunteers with TTS, resin, wire-composite and bracket splints applied, showed that proper oral hygiene is possible to maintain when using all of these devices. [27] Moreover, based on their own subjective feelings, volunteers assessed that all these splints, except for the resin one, did not cause the impairment of oral hygiene. [27]

Discomfort associated with splint usage is most noticeable during the initial period of splinting, especially for bracket splint, which causes more mechanical irritations and leads to the higher sensitiveness of the lips and impairment of speech in comparison with the other devices. [27]

Splinting in primary dentition

According to the IADT guidelines, splinting of injured primary teeth is recommended only for alveolar bone fractures and possibly for intra-alveolar root fractures. [39] Luxation injuries, even after repositioning, do not require splinting. However, one of the studies showed that the success rate of treating luxated primary teeth with splinting was 58.9%. [40] The highest rate of success was observed in teeth with subluxation while repositioning and splinting of lateral luxation had the lowest rate of success. On the other hand, another study demonstrated that there was no statistically significant difference in the prognosis among primary teeth with lateral and extrusive luxation that were treated using semi-rigid splints and the teeth that were not splinted. [41] However, a better prognosis was observed in the root fracture group in which primary teeth were stabilized with splints. [41]

Splinting as an emergency treatment

It often occurs that patients with dental trauma that accompany other organ injuries are first managed by paramedics at the scene of the accident or in the emergency departments. Teeth injuries in multi-injured patients, who are treated in emergency care services or operating rooms are usually ignored or managed inadequately. Emergency rooms are not equipped with dental instruments and paramedics' knowledge and skills about posttraumatic teeth injuries are often unsatisfactory. [42,43] The easy-to-perform fixation with suturing is a good alternative for temporary splinting that can be carried out by medical staff in emergency departments. This method of suturing can be done with a 2/0 dental suture penetrating from the palatal to the vestibular soft tissues incorporating the tooth in a "criss-cross" manner, with a horizontal locking mattress to hold a tooth in place. [44]

CONCLUSION

Materials that are currently recommended and used for stabilization of injured teeth fulfil most of the requirements for optimal splinting. Nevertheless, the researchers persevere in trying to find some other alternatives, offering new materials and splinting protocols.

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