Dental Traumatology 2008; **24**: 2–10; doi: 10.1111/j.1600-9657.2006.00480.x

An evidence-based appraisal of splinting luxated, avulsed and root-fractured teeth

Bill Kahler, Geoffrey S Heithersay

Discipline of Endodontics, School of Dentistry, The University of Adelaide, Australia

Abstract – The evidence-based methodology involves framing a well defined PICO (problem, intervention, comparison and outcome) question related to a clinical problem and then comprehensively searching for the evidence, which is evaluated to appraise the value of the treatment intervention. For this systematic review of splinting of teeth that have been luxated, avulsed or root-fractured, the clinical PICO question is (P) what are splinting intervention decisions for luxated, avulsed and root-fractured teeth (I) considering that the splinting intervention choice may include (i) no splinting, (ii) rigid or functional splinting for the different types of trauma and (iii) different durations of the splinting period (C) when comparing these splinting choices for the different types of trauma and their effect on (O) healing outcomes for the teeth.
A keyword search of PubMed was used. Reference lists from identified articles and dental traumatology texts were also appraised. The inclusion criterion for this review was either a multivariate analysis or controlled stratified analyses as many variables have the potential to confound the assessment and evaluation of healing outcomes for teeth that have been luxated, avulsed or root-fractured. A positive statistical test is not proof of a causal conclusion, as a positive statistical relationship can arise by chance, and so this review also appraises animal studies that reportedly explain biological mechanisms that relate to healing outcomes of splinted teeth. The clinical studies were ranked using the 'Centre of Evidence-based Medicine' categorization (levels 1–5). All 12 clinical studies selected were ranked as level 4. The studies generally indicate that the prognosis is determined by the type of injury rather than factors associated with splinting. The results indicate that the types of splint and the fixation period are generally not significant variables when related to healing outcomes. This appraisal identified difficulties in the design of animal experimentation to correctly simulate some dental injuries. Some of the studies employed rigid splinting techniques, which are not representative of current recommendations. Recommended splinting treatment protocols for teeth that have been luxated, avulsed or root-fractured teeth are formulated on the strength of research evidence. Despite the ranking of these studies in this appraisal as low levels of evidence, these recommendations should be considered 'best practice', a core philosophy of evidence-based dentistry.

Correspondence to: Bill Kahler, Endodontics, School of Dentistry, University of Adelaide, 5005, Australia
Tel.: 61 8 82672065
Fax: 61 8 83033444
e-mail: wyattkahler@bigpond.com

Accepted 6 December, 2005

An evidence-based philosophy

The evidence-based philosophy is defined as the 'conscientious, explicit and judicious use of current best evidence' which may be applied in clinical practice to provide optimal healing outcomes for patient care (1). The methodology of 'evidence-based dentistry' involves a search for current best evidence (e.g. electronic databases), a critical appraisal of the validity of the research, and the application of this information to clinical problems in the areas of diagnosis, treatment interventions and prognosis.

The Centre for Evidence-based Medicine ranking of articles for the quality of evidence ensure that treatment decisions are substantiated from high levels of evidence (2, 3). The complete table of the levels of evidence can be obtained by visiting http://cebm.jr2.ox.ac.uk/docs/levels.html and are summarized in Table 1. The philosophy is that the strength of the evidence should determine the requirement for treatment decisions and interventions which should then be provided to health care providers to limit delays between research and its clinical application (4).

Strength of the evidence is affected by bias, confounding issues or chance

The validity of a study is determined by the extent to which the design and conduct of the investigation are likely to prevent systematic errors or bias (2). Bias is due to defects in the design or execution of the study. A fundamental question in any research study is whether

Table 1. Evidence level stratification of relevant study designs

Level	Type of study
1	Randomized control trials Systematic reviews of randomized control trials
2	Low quality randomized control trials Cohort studies Systematic reviews of cohort studies
3	Case control studies Systematic reviews of case control studies
4	Poor quality cohort and case control studies Case series
5	Case reports Expert opinion without explicit critical appraisal Literature reviews

From Paik et al (51)

there is a true cause-effect relationship (causality) rather than just an association of the observations in the study. However, the evaluation of a causal relationship can be influenced by bias, confounding issues or chance (5).

The main types of bias relate to factors that involve inclusion in the study (selection bias) and how the interventions and outcomes are measured or collected (measurement bias). In medicine, selection bias can occur when people volunteer to participate in a study as this group may not be representative of the general population. Randomized clinical trials where the selection is blind to the specific hypothesis being investigated are less likely to be affected by selection bias. For ethical reasons, in medicine and dentistry, randomized trials need to be limited to interventions that are potentially beneficial. Because of these limitations, it may be necessary to include case-controlled studies where there is a retrospective analysis of patients that have received an intervention or treatment (5). The analysis may be further limited as it may not be possible for there to be adequate controls to assess the effect of no treatment.

Confounding issues are those where the real affect between the intervention/treatment and the outcome of treatment is biased by variables that are merely associated with the observed outcome. An assessment of confounding issues is important, as there may be other plausible explanations for the outcome of the intervention. Confounding issues can be controlled in the design of a study by random selection so that confounders may be distributed equally providing the sample size is sufficiently large. Alternatively, confounding issues can be controlled in the analysis by statistical modelling and stratification. By these means, the strength of the association can be measured separately in well-defined sub-groups. Sophisticated mathematical techniques can pool the results into strata (or classes) and adjust or control the effects of possible confounders (5). An investigation with multi-factorial aetiology has the difficulty that associations between the different factors can mask the pure effect of a single factor (6). A multivariate analysis allows the impact of one form of intervention to be measured while holding constant the influence of other variables (7). This has the effect of identifying associate relationships that may have been significant in a univariate analysis. A univariate analysis or frequency test can only provide a list of probable significant variables but will provide no insights into associations between the variables (8).

The role of chance can be assessed with statistical significance tests that measure the level of confidence (5). However, statistical relevance is dependent on the size of the sample with 20–30 cases considered a minimum (7). Indeed, a reported frequency of complications of 50% will in 40 cases have a 95% confidence limit of $\pm 16\%$, whereas 400 cases will have a 95% confidence of $\pm 5\%$ (9). Case reports dominate much of the medical and dental literature where the sample size is small and it is not possible for there to be a meaningful statistical analysis.

It is an important consideration that a positive statistical analysis is not proof of a causal conclusion. Most studies are affected somewhat by bias, confounding issues and chance. A multivariate analysis tests an extensive number of associations, which allows for significant relationships to arise by chance alone without any biological explanation. Consequently, the results of a statistical analysis should be evaluated with caution and statistical correlations should be supported by a biological process or explanation (10).

The evidence-based approach

The evidence-based methodology involves framing a well defined PICO (problem, intervention, comparison, and outcome) question related to a clinical problem, and then a comprehensively searching the literature for the evidence, which is evaluated to appraise the value of the treatment intervention (11). A well-defined clinical question allows for an inclusion/exclusion criterion for studies to be selected so that the level of evidence is high and relevant to the problem under review. The criteria should be specific so as to limit bias (12). The studies are then critically appraised and can be assigned a level of evidence, which aims to reduce the subjectivity of the review. This systematic review may allow for a statistical summary of the data; a meta-analysis which quantitatively structures the results of all the selected studies to a defined standardization criterion to allow an evaluation of the observation or effect of the treatment intervention. Where the results of the selected studies cannot be statistically analysed, the review is considered to be a qualitative systematic review (12). Both approaches provide a rigorous evaluation to minimize bias, confounding issues and chance to select the evidence to answer the clinical question.

Splinting decisions for luxated, avulsed and root-fractured teeth

Dentists are required to decide on treatment decisions and interventions for unscheduled emergency patients when they present with oro-facial or dento-alveolar trauma. As these are infrequent in general practice, the clinician may refer to published guidelines for the management of dento-alveolar trauma (see Table 2).

Table 2. Current splinting recommendations for permanent teeth

Injury	Splinting recommendation
Luxation injuries	Concussion and subluxation: a flexible splint is optional for 7–10 days Extrusion: stabilize tooth with a splint for 3 weeks Lateral luxation: Stabilize tooth with a splint for 3 weeks. In instances of marginal bone breakdown after 3 weeks, add 3–4 weeks extra splinting time
Avulsion	Apply a flexible splint for 1–2 weeks When extra-oral time >60 min apply a flexible splint for 4–6 weeks
Root fracture	Stabilize the tooth with a splint for 3–4 weeks
Alveolar fracture	Stabilize the fragment with a splint for 3–4 weeks

Adapted from IADT Guidelines (15) http://www.iadt-dentaltrauma.org/Trauma/dental_trauma.htm and from the 'Recommended Guidelines' of the American Association of Endodontists (AAE) (16) for the treatment of traumatic dental injuries at http://www.aae.org/dentalpro/guidelines.htm

However, few of the current protocols have been tested by prospective longitudinal outcome studies in humans (13). Significantly, Andreasen and Andreasen state that 'the efficacy of splinting on the healing outcome is considered questionable on the strength of experimental and clinical data' (14).

It is generally accepted and recommended that teeth subjected to trauma should be splinted after repositioning of the tooth to prevent displacement and further injury to the pulp or the periodontal ligament during the healing phase (14, 17). A splint is defined as a 'rigid or flexible device or compound used to support, protect, or immobilize teeth that have been loosened, replanted, fractured, or subjected to certain endodontic procedures' (18). Historically, splinting of teeth utilized the principles of jawbone fracture with rigid, long-term immobilization for a few months (17). However, the use of long-term rigid splinting was questioned when experimental evidence demonstrated rigid immobilization increased the risk of pulpal necrosis (19) and external root resorption (19–21). In an experimental study using rhesus monkeys, less ankylosis was observed for one tooth that had lost its rigid splint after its initial application following extraction and replantation (22). In another study teeth splinted for just 1 week were found to be clinically firm (23). Animal experimentation has also shown that normal masticatory stimulation can partially prevent the development of ankylosis in teeth following extraction and replantation (24), which suggests that splints should allow for a degree of movement.

Current guidelines advise that avulsed teeth require a functional splint for 7–10 days so as to allow for functional or physiological movement of the root. A functional splint retains the tooth in the socket but is flexible enough to allow functional stimulation of the periodontium. The results of recent studies have challenged the current guidelines for the management of avulsed teeth, with evidence that the type of splint and duration of the splinting period are not significant variables in pulpal or periodontal healing (25–27).

Other recent reports have challenged previously accepted splinting regimes for the treatment of root fractured teeth where the established practice consisted of re-positioning the coronal segment if displaced and then placing a rigid splint for 2–3 months (14). Re-positioning and extended immobilization was considered necessary for hard tissue bridging between the fragments (14, 28–30). However, a number of reports have indicated that healing can occur without splinting (31–35). Even a study of cervical root fractures, where longer periods of immobilization have been recommended because of the high location of the fracture and mobility of the coronal segment, failed to establish benefits on healing in relation to the type and duration of splinting (or no splinting) (36). New recommendations now suggest that best practice for treatment of teeth with root fractures is functional stabilization for a few weeks where treatment is similar to that provided for luxation injuries (37–39).

The splinting decisions in the guidelines for treatment of traumatic injuries by the International Association for Dental Trauma (IADT) and the AAE clearly indicate a functional splint for luxation and avulsion injuries but the recommendation for root-fractures and alveolar fractures is less clear. Teeth with the latter injuries are described as requiring stabilization with a splint. The degree of rigidity is not clarified. It would therefore be timely for a systematic review to appraise the studies that determine the evidence for the recommended protocols for splinting luxated, avulsed and root-fractured teeth.

Methodology

This review addresses the following clinical PICO question; (P) what is the evidence to determine splinting intervention decisions for luxated, avulsed and root-fractured teeth (I) considering that the splinting intervention choice may include (i) no splinting, (ii) rigid or functional splinting for the different types of trauma and (iii) different durations of the splinting period (C) when comparing these splinting choices across the different types of trauma and their effect on (O) healing outcomes for the teeth.

A comprehensive search was undertaken to identify studies published in English from 1966 to early 2005 which related splinting of traumatized teeth to healing outcomes. Initially, a PubMed search was performed using key words (tooth, teeth, splinting, trauma, concussion, subluxation, luxation, root-fractures, avulsion and alveolar bone fracture). The article for each reference was located, photocopied and evaluated. The references of each article were examined to identify other articles that related to splinting of traumatized teeth. References from a key text (14) were also examined for additional articles.

After the initial survey it was clear that many factors other than splinting could affect healing outcomes and have the potential to be confounders. Variables include the sex and age of the patient, stage of root development, severity of the trauma and degree of dislocation. If the tooth was avulsed, what was the length of time before replantation, was a suitable storage media utilized and was further repositioning of the tooth required? Other issues include the type and rigidity of splints and the length of time the teeth have been immobilized. All of these issues are variables that have the potential to confound any assessment and evaluation of healing outcomes for traumatized teeth. Accordingly, multivariate analysis is clearly the most appropriate test of the significance of these factors on healing outcomes.

The inclusion criteria for articles were

1 Clinical studies where the research design included a multivariate analysis or controlled stratified analyses.
2 Animal studies that examined biological mechanisms associated with splinting of teeth related to healing outcomes of teeth.

Healing and non-healing outcomes analysed as independent variables by the majority of the multivariate tests were pulp survival, pulp canal obliteration, pulp necrosis and resorption of the root.

In addition, for root-fractured teeth, the healing categories analysed were

1 Healing with interposition (union) of hard tissue,
2 Healing with interposition of fibrous-connective tissue,
3 Healing with interposition of bone and fibrous connective tissue and
4 No healing with interposition of granulation tissue (30).

All selected articles were ranked according to the level of evidence according to the guidelines in Table 1. Statistical advice was sought when evaluating the research methods of the selected papers to determine the nature of the test and the strength of the statistical evidence. A review of the literature then examined whether research evidence is being implemented in the 'Recommended Guidelines' of the 'IADT' (15) and the 'AAE' (16).

Results

Based on the inclusion criteria 12 studies analysed the data with a multivariate test or controlled stratified analysis and nine studies were selected from the literature that related to biological processes involved with healing outcomes of splinted teeth (Tables 3 and 4). The 'level of evidence' for the selected clinical studies was rated level 4, being case series with no control group.

The majority of studies related to biological processes involved animal experimentation and were therefore not assigned a level of evidence. The monkey studies were cross-sectional rather than longitudinal in design where any two teeth compared were only representative of a particular healing period, without being part of the same reparative process (20). A further limitation of these studies was that the animals were often sacrificed at 8 weeks so the observation period was short. Surface and inflammatory resorption was first noted at 1 week and replacement resorption noted at 2 weeks although the extent and frequency of the resorptive areas slightly increased for the 8-week observation period (19, 22, 23, 40–42).

Discussion

The level of evidence

The centre of Evidence-based Medicine ranks randomized clinical trials and systematic reviews and meta-analysis of randomized clinical trials as the highest level of evidence (level 1). As discussed earlier, in the interest of the patient, it is often not ethical practice to randomly assign treatment interventions. For example, dental organizations such as the AAE and the IADT recommend splinting treatment protocols for teeth that have been luxated, avulsed or root-fractured teeth on the strength of the research evidence. The majority of the studies were ranked as case series without controls as the experimental design did not include a control group. It was also not possible to submit the data of the selected studies to a meta-analysis. In many instances, the statistical tests were obscure and not standardized or fully described. The variation in the type of splint complicated the data sets as in one study the type of splint was not reported (43), in another study *P*-values were averaged for the five different types of splints (8) and in another the splint type was not included in the logistic model (26). Some of the studies did not report estimates (e.g. odds ratio, relative risk etc), standard deviation or *P*-values required for a meta-analysis. In a multivariate analysis, the inclusion of the variables for further analysis is based on the significance (*P*-values) of the univariate analysis. As splint type and/or fixation period was not generally a significant variable, these relationships were not reported and therefore not available for meta-analysis. However, the studies listed in Table 3 were considered to have satisfied the inclusion criteria for this review as the authors stated that all variables had been tested in the multivariate analysis although the results may not have been reported.

A common problem in all the studies was a lack of statistical descriptive information. Information normally included in a 'Statistical Table' such as mean, median, standard deviation, skewness, kurtosis and a correlation matrix were not provided. These characteristics of the data and statistical properties are important to understand biases that will impact on the validity of the statistical analyses (7). If evidence-based practice is to be a dominant consideration, then more detailed information will need to be reported as is the norm in some other disciplines (e.g. economics). While there are constraints on the scientific method in dental studies, further research would benefit from a template for the minimum level of rigour in research design and statistical validity.

Potential for bias

The inclusion criteria for this review identified studies that tested for confounding variables and associated relationships. However, many of these studies are retrospective in nature and the possibility for bias exists. Indeed a standardized clinical trauma study is difficult to design because of the many patient, trauma and treatment variables. The rarity of these injuries hinders the collection of sizeable data sets for analysis. The

Table 3. Studies included in this evidence-based appraisal

Study	LOE	Teeth	Type of splint	Fixation period	Result
Alveolar fractures					
Andreasen (1970a) (6)	4	71 teeth with alveolar fractures	Arch bar 43 teeth Cap splint 25 teeth No splint three teeth	1–35 days (11 teeth) 36–42 days (20 teeth) >43 days (34 teeth)	ToS and FP not a S/V for development of PN and PCO
Luxation injuries					
Andreasen (1970b) (47)	4	189 luxated permanent incisor teeth	Ligature wiring 40 teeth Arch bars 83 teeth Cap splint 31 teeth No splint 35 teeth	1–35 days (52 teeth) 36–42 days (54 teeth) >43 days (62 teeth)	ToS and FP not a S/V for healing outcomes
Andreasen and Vestergaard-Pedersen (1985) (8)	4	Prospective study of 637 luxated permanent teeth	CONCISE® 16 teeth SCUTAN® 11 teeth Cap or acrylic 11 teeth Ortho bands 111 teeth Suture/no splint 360 teeth Unknown 2 teeth	≤3 weeks (83 teeth) 3–4 weeks (43 teeth) 4–6 weeks (61 teeth) >6 weeks (93 teeth) None (354 teeth) Unknown three teeth	ToS and FP not a S/V for development of PN
Andreasen et al. (1987) (45)	4	As above	As above	As above	Ortho band/resin splints is a S/V for PCO Acid–etch resin similar to no splints
Luxation and avulsion injuries					
Oikarinen et al. (1987) (44)	4	172 periodontally injured teeth: Luxation and avulsion injuries	Rigid splint: bent metal bar fixed to teeth by wires ± acrylic	Mean duration was 52 days	ToS and FP not a S/V for PN or resorption FP was a S/V for loss of alveolar bone
Avulsion injuries					
Andreasen et al. (1995a) (26)	4	Prospective study of 400 avulsed and replanted incisor teeth 66 teeth with PN	Acid-etch comp 25 teeth Cap splint 8 teeth Ortho bands 20 teeth	0–21 days (20 teeth) 21–40 days (19 teeth) >40 days (26 teeth)	ToS and FP not a S/V for PN
Andreasen et al. (1995b) (27)	4	As above although 272 teeth related to periodontal ligament healing	Acid-etch comp 132 teeth Cap splint 29 teeth Ortho bands 111 teeth	0–21 days (135 teeth) 21–40 days (39 teeth) >40 days (93 teeth)	ToS or FP not a S/V for periodontal healing
Kinirons et al. (2000) (43)	4	128 replanted permanent incisors	Not disclosed	Median 15 days Range 4–52 days	FP not a S/V for resorption
Root-fracture injuries					
Andreasen et al. (1989) (31)	4	Prospective study of 95 root-fractured incisor teeth	Acid-etch/no splinting 69 teeth Ortho bands 26 teeth	3 months	ToS not a S/V for HT or CT healing ToS (ortho bands) was a S/V for GT healing
Cvek et al. 2001 (37)	4	Retrospective study of 208 root-fractured incisors	Cap splints 142 teeth Ortho bands 26 teeth No splinting 40 teeth	28–60 days (44 teeth) 60–90 days 58 teeth 91–357 days 66 teeth	ToS and FP not a S/V for pulpal healing or hard tissue healing
Welbury et al. 2002 (46)	4	Retrospective study of 84 root-fractured incisors	Composite + 0.7 mm arch wire	2–3 months	ToS and FP not a S/V to pulpal healing or hard tissue healing
Andreasen et al. 2004 (38)	4	Retrospective study of 400 root-fractured permanent incisors inclusive of teeth in Cvek (2001) 208 teeth from 1959–1973 and 192 teeth from 1977–1995	Ortho bands 26 teeth Cap splint 236 teeth Composite 10 teeth Comp + arch bar 28 teeth Kevlar®/fibre 44 teeth No splinting 56 teeth	<28 days (18 teeth) 29–42 days (25 teeth) 43–56 days (57 teeth) 71–98 days (98 teeth) >99 days 77 teeth	ToS is a S/V for healing outcomes. Cap splints lowest frequency and Kevlar® highest. No difference between splinted and non-splinted for non-displaced teeth FP not a S/V

LOE, level of evidence (refer Table 1); ToS, type of splint; FP, fixation period; PN, pulp necrosis; PS, pulp survival; HT, hard tissue healing; CT, connective tissue healing; GT, granulation tissue non-healing; S/V, significant variable.

multivariate analyses in the selected studies revealed that the treatment interventions (types of splint and fixation period) are not generally significant variables when related to the healing outcome. The studies generally indicated that prognosis is determined by the type of injury rather than the treatment interventions associated with the application of splints. However, the fact that splints are employed as a specific treatment strategy according to established guidelines could introduce bias and skew this observation (8). Randomized prospective

Table 4. Studies that explain biological processes on the effect of splinting on healing outcomes

Studies	Method	Results
Hurst (1972) (22)	Histological study of replanted teeth in monkeys Extra-alveolar tine of 20 min Orthodontic ligature wire/acrylic rigid splint Fixation period 2 or 6 weeks All teeth root treated before replantation	Collagen fibres failed to regain density of control May be related to decreased functional stimulation with splinting as less ankylosis and better collagen in the tooth where the splint had detached
Andreasen (1975a) (21)	Histological study of replanted teeth in monkeys Extra-alveolar time of 18 min Orthodontic band/acrylic rigid splint vs no splint Fixation period 2 or 6 weeks All teeth root treated before replantation	The frequency and extent of replacement resorption was significantly lower in non-splinted teeth compared with the splinted teeth. Splinting appeared to exert a harmful effect
Andreasen (1975b) (23)	Test clinical findings vs healing outcomes Orthodontic band-acrylic splint usually for 1–2 weeks for human teeth	Teeth splinted for 1 week tended to reach normal level of mobility 3 weeks after replantation
Morley et al (1978) (40)	Histological study of replanted teeth in monkeys Extra-alveolar time not reported Rigid vs semi-rigid fixation Fixation period was 8 weeks	Ankylosis was consistently found with rigid fixation. Greater frequency of oxytalin and collagen fibres noted with functional splint.
Andreasen (1980) (41)	Histometric study of replanted teeth in monkeys Extra-alveolar tine of 0 or 18 min No splinting	Surface and inflammatory resorption noted at 1 week. Replacement resorption at 2 weeks. Gingival fibres unite at 1 week to support tooth
Nasjleti et al (1982) (20)	Histological study of replanted teeth in monkeys Extra-alveolar time of 30 min maximum Interproximal acid-etch rigid splint Fixation period of 7 or 30 days All teeth root treated before replantation	Resorption was far more predominant in teeth that were splinted for 30 days than in teeth splinted for 7 days
Kristerson and Andreasen (1983) (19)	Histological study of autotransplanted teeth in monkeys Extra-alveolar time of 18 min Acrylic splint vs no splint Fixation period 2 or 6 weeks	Splinting increased the extent of pulp necrosis and inflammatory root resorption Splinting appeared to exert a harmful effect
Andersson et al 1985 (24)	Histological study of replanted teeth in monkeys Monkeys fed either a soft or hard diet Air-dried for 60 min All teeth root treated before replantation No splinting	Monkeys on the hard diet had significantly less ankylosis and a larger area of the root surrounded by normal periodontal membrane
Berude et al (1988) (25)	Histological study of replanted teeth in monkeys Extra-alveolar time of 30 min Physiological vs Rigid vs no splint Fixation period of 10 days	No significant differences were found in the periodontal healing pattern for the physiologically splinted, rigidly splinted or non-splinted teeth.
Mandel and Viidik (1989) (42)	Mechanical and histological study for extruded teeth in monkeys Rigid splint (0.15 mm wire + comp) vs no splint Fixation period 2 weeks	No significant differences in the mechanical properties and histological assessments between the splinted and non-splinted teeth

clinical trials would be needed to address issues of bias although the ethical dilemma would be denying recommended treatment.

The retrospective nature of many of the studies can introduce error in the analysis. For instance, in some of the studies, the type of splint and duration of the fixation period was not recorded. Andreasen and Vestergaard Pedersen noted in a retrospective analysis that lateral luxation injuries may have been misclassified for other luxation injury categories (8).

There were other opportunities for bias as in some studies relationships could not be tested because of insufficient sample size (38). There was the possibility for selection bias. The selection of patients for re-examination may have been biased as significant differences were noted between patients examined and those that failed the follow-up appointments (6, 44). A further limitation of many of the studies is that only maxillary incisor teeth were investigated and so the results are only inferred for other teeth.

Splinting decision choice

The broader question of whether splinting is beneficial needs to be asked as studies of root-fractured teeth have reported no difference in the frequency of healing between splinted and non-splinted teeth (37, 38). This result should be interpreted with caution, as this relationship was only true when there was no dislocation of the coronal fragment. The prognosis for the healing outcome is more dependent on the type of injury rather than the effect of the splinting. For example, in teeth where the coronal fragment had been displaced, the splinted teeth had a significantly lower frequency of healing than non-splinted teeth with no displacement. It is likely therefore, that the lower rate of frequency of healing is a consequence of more severe trauma that produced the displacement rather than the splinting technique. This hypothesis could not be tested as there were not enough displaced teeth to provide an analysis on the effect of splinting (vs no splinting) (38). Further evidence on the severity of trauma affecting treatment outcomes was demonstrated when pulp canal obliteration was more frequently associated with extrusion, lateral luxation and intrusion injuries than with concussion and subluxation (45).

The types of splints and splinting duration were generally not significant variables when related to healing outcomes [see Table 3]. However, the use of cap splints and orthodontic bands were associated with a greater frequency of pulp necrosis (31, 38) and pulp canal obliteration (45) when compared with acid etch resin splints and no splinting. It could be argued that the adverse healing outcome may be caused by the splinting technique where forceful placement of the cap splint or orthodontic band altered the balance between healing and non-healing by providing additional trauma to an already injured pulp. These splinting techniques were used prior to the development of a passively applied acid-etch resin technique and are no longer recommended (14).

A number of studies of root-fractured incisor teeth reported that rigid splinting did not favour pulpal survival or hard tissue healing and recommended that rigid splinting of root-fractured teeth be discontinued (37, 38, 46). Therefore, short term splinting may be sufficient for healing to occur. Recently, Andreasen et al in a retrospective study of 400 root-fractured permanent incisors reported that the type of splint had an influence on the healing outcome (38). This study included the material from Cvek et al with patients treated from 1959 to 1973 (37). A further 192 root-fractured incisor teeth treated from 1977 to 1995 were included. This period coincided with the introduction of adhesive splinting techniques. This study reported on three new splinting types that allowed varying degrees of flexibility. Cap splints again resulted in the lowest frequency of healing while Kevlar® splints and no splinting provided the highest frequency of healing. Interestingly, hard tissue healing was significantly more frequent in teeth that were not splinted (37) although it would be likely that the majority of these teeth had not been displaced. This study does suggest that hard tissue healing can occur when teeth are subjected to a functional stress. Andreasen et al. (38) reported that splinting for periods greater than 4 weeks appeared to provide no beneficial healing outcome for root-fractured teeth, thereby providing evidence in support of the current guidelines recommending a splint period of 3–4 weeks.

A functional splint for 7–10 days is currently recommended for avulsed and replanted teeth (14). Although univariate analyses had indicated that the type of splint and the length of the splinting period were significant variables it was therefore surprising that the multivariate analyses by Andreasen et al. (26) in prospective studies of 400 avulsed and replanted teeth reported no significant relationship for these variables for pulpal or periodontal healing (27). This result differed from experimental studies with histological examination of replanted teeth that showed a slight reduction in the frequency of ankylosis when splinting techniques were for a short period and allowed some degree of mobility (21, 22, 40). Reasons for these discrepancies were attributed to the issue of reliability of experimental models and will be discussed in the next section.

An extended period of splinting may be required to stabilize a tooth where there has been extensive loss of marginal bone. For example, in a study of luxated teeth, loss of marginal bone was significantly related to the type of luxation, the time interval between injury and treatment, fracture of supporting bone and the number of injured teeth (47). In these instances, the majority of the selected studies suggested that an extended fixation period is not an indicator for a poor healing outcome. However, Oikarinen et al. (44) reported that an extended fixation period was related to loss of marginal alveolar bone. An alternative explanation may be that long periods of immobilization resulted in bone loss from periodontitis associated with oral hygiene difficulties (48).

Studies that explain the biological process of the effect of splinting on healing outcomes

Several studies in monkeys have shown that rigid splinting of extracted and auto-transplanted teeth results in an increase in the frequency of pulp necrosis (19) and replacement resorption (19–21). Andreasen (21) suggested that functional forces were beneficial as the frequency and extent of replacement resorption was significantly lower in the non-splinted teeth compared with the rigidly splinted teeth. This finding was confirmed in a later experimental study (40). Functional stimulation has been reported to prevent and remove small areas of replacement resorption (23), probably because of rapid repopulation of necrotic zones in the periodontal ligament with blood vessels and fibroblasts (24). Extended fixation periods appeared to increase the frequency and extent of root resorption and dentoalveolar ankylosis which was far more predominant in teeth that were splinted for 30 days than in teeth splinted for 7 days (20).

The above studies are frequently cited in the literature to justify the use of a functional splint for 7–10 days for the treatment of avulsed teeth. However, some of the above studies do not conform to that protocol as rigid splinting techniques were used (19–23, 40). The one study that compared rigid and functional splinting and reported a beneficial effect when a functional splint was utilized was published as an Abstract (40). In three of the studies, the extracted tooth was endodontically treated extra-orally before replantation (20, 21, 24), which was later shown to significantly increase the incidence of surface and replacement resorption (49). Therefore, the evidence supporting the protocol for functional splints is based on assumption from animal studies where teeth were rigidly splinted and clinical studies where only a univariate analysis had indicated a significant relationship.

The significance of a functional splint has been questioned. Berude et al. (25) demonstrated that the choice of either a rigid or a functional splint did not alter the periodontal healing response of replanted avulsed teeth in monkeys. No significant difference was found in the periodontal healing pattern (ankylosis, active and arrested resorption and periodontal ligament healing) for the physiologically splinted, rigidly splinted or non-splinted replanted teeth. That no difference occurred between the rigidly splinted and functionally splinted groups is clinically important. In a recent report the type of splint (rigid vs functional) was not a significant variable for the development of resorption in 400 replanted human teeth (27).

The above finding of Berude et al. (25) must be regarded with caution as a major limitation of all monkey experiments of replanted and luxated teeth is that extraction of these teeth does not simulate the injury being tested. High bone density, extreme curvature of the roots and hypercementosis of some root apices contributed to long luxation/extraction periods. Berude et al. reported the time required for tooth extraction ranged from 3–21 min while Andreasen (21) reported a range of 36–260 s. Protracted luxation during tooth extraction probably damaged cells in the periodontal ligament. Indeed, resorption is predominantly located at the facial and palatal or lingual aspects of replanted teeth in experimental studies (20, 25, 41). This pattern of damage may not occur from a traumatic avulsion injury. It must be considered questionable whether animal experimentation provides a satisfactory model to evaluate healing outcomes in some trauma studies.

Splinting has not been shown to improve the mechanical properties of the periodontal ligament in the treatment of extrusion injuries in monkeys (42). However, animal (41) and human (23) studies have demonstrated that strong gingival attachment to support the tooth in the socket is attained after 1 week for splinted and non-splinted teeth. These findings support the trend for shorter fixation periods.

Evidence in support of the current recommendations

The current trend for functional splints is supported in recently published reviews (13, 39, 50). The guidelines for treatment of traumatic injuries by the IADT and the AAE specify a functional splint for luxation and avulsion injuries, but the wording for root-fractures and alveolar fractures is less clear. Teeth with the latter injuries are described as requiring stabilization with a splint but the degree of rigidity is not specified.

There is support for the principle of treating root-fractures in a similar fashion to luxation injuries utilizing a functional splint for 3–4 weeks (36, 37, 46). Despite evidence from multivariate analyses that the type of splint and fixation period are not significant variables on healing outcomes (26, 27), a functional splint for 7–10 days is advisable for avulsion injuries. A week is required for attachment of the damaged periodontal ligament (41) and medico-legal considerations justify splinting for at least that period, so that the tooth is not accidentally dislodged or subjected to further trauma.

Conclusions

All 12 clinical studies selected in this evidence-based appraisal of the splinting guidelines were ranked using the Centre of Evidence-based Medicine categorization as level 4. The studies generally indicated that the prognosis is determined by the type of injury rather than factors associated with splinting as multivariate analyses indicated that the type of splint and the fixation period were generally not significant variables when related to healing outcomes. Indeed, many of the clinical studies and animal experimentation employed rigid fixation techniques so the results of these investigations are not representative of the current protocols. Presently, flexible splinting is only assumed to assist periodontal healing and further research is warranted.

The current protocols recommend splinting treatment protocols for teeth that have been luxated, avulsed or root-fractured teeth on the strength of the research evidence. There are difficulties in the design of trauma studies so the evidence should not be just judged by a strict adherence to an evidence-based ranking but rather assessed by studies that demonstrated, in some instances, 40 years of clinical evaluations in dental traumatology. Despite the ranking of these studies as low levels of evidence, these protocols should be considered 'best practice', a core philosophy of evidence-based dentistry.

Acknowledgements

The authors wish to thank Associate Professor Nicholas Chandler for reviewing this article and Drs Anne Wyatt, David Brennan and Mrs Emmae Ramsey for statistical advice.

References

1. Lawrence A. Welcome to evidence-based dentistry. Evid Based Dent 1998;1:2–3.
2. Richards D, Lawrence A. Evidence based dentistry. Evid Based Dent 1998;1:7–10.
3. Richards D. Not all evidence is created equal-so what is good evidence? Evid Based Dent 2003;4:17–8.
4. Greenhalg T. How to read a paper: papers that summarise other papers (systematic reviews and meta-analyses). Br Med J 1997b;315:672–5.
5. Moles DR, dos Santos Silva I. Causes, associations and evaluating evidence; can we trust what we read. Evid Based Dent 2001;2:75–8.
6. Andreasen JO. Fractures of the alveolar process of the jaw. Scand J Dent Res 1970a;78:263–72.
7. Studenmund AH. Using econometrics. A practical guide, 4th edn. Addison Wesley Longman: Boston; 2001.
8. Andreasen FM, Vestergaard-Pedersen B. Prognosis of luxated permanent teeth- the development of pulp necrosis. Endod Dent Traumatol 1985;1:207–20.
9. Andreasen JO, Andreasen FM, Mejàre I, Cveck M. Healing of 400 intra-alveolar root fractures. 1. Effect of pre-injury and injury factors such as sex, age, stage of root development, fracture type, location of fracture and severity of location. Dent Traumatol 2004;20:192–202.
10. Greenhalgh T. How to read a paper: Statistics for the non-statistician 11. "Significant relations and their pitfalls". Br Med J 1997a;315:422–5.
11. http://www.cebm.net/levels_of_evidence.asp.
12. Torabinejad M, Bahjri K. Essential elements of evidence-based endodontics: Steps involved in conducting clinical research. J Endod 2005;31:563–9.
13. Barrett EJ, Kenny DJ. Avulsed permanent teeth: a review of the literature and treatment guidelines. Endod Dent Traumatol 1997;13:153–63.

14. Andreasen JO, Andreasen FM. Textbook and color atlas of traumatic injuries to the teeth, 3rd edn. Mosby: Munksgaard; 1994.
15. http://www.iadt-dentaltrauma.org/Trauma/dental_trauma.htm.
16. http://www.aae.org/dentalpro/guidelines.htm.
17. Kehoe JC. Splinting and replantation after traumatic avulsion. J Am Dent Assoc 1986;112:224–30.
18. American Association of Endodontists. An annotated glossary of terms used in endodontics, 7th edn. Chicago: American Association of Endodontists; 2003, 15.
19. Kristerson L, Andreasen JO. The effect of splinting upon periodontal and pulpal healing after autotransplantation of mature and immature permanent incisors in monkeys. Int J Oral Surg 1983;12:239–49.
20. Nasjleti CE, Castelli WA, Caffesse RG. The effects of different splinting times on replantation of teeth in monkeys. Oral Surg Oral Path Oral Med 1982;53:557–66.
21. Andreasen JO. The effect of splinting upon periodontal healing after replantation of permanent incisors in monkeys. Acta Odontol Scand 1975a;33:313–23.
22. Hurst RV. Regeneration of periodontal and transseptal fibres after autografts in rhesus monkeys: a qualitative approach. J Dent Res 1972;51:1183–92.
23. Andreasen JO. Periodontal healing after replantation of traumatically avulsed human teeth. Assessment by mobility testing and radiography. Acta Odontol Scand 1975b;35:325–35.
24. Andersson L, Lindskog S, Blomlöf L, Hedström K-G, Hammarström L. Effect of masticatory stimulation on dentoalveolar ankylosis after experimental tooth replantation. Endod Dent Traumatol 1985;1:13–6.
25. Berude JA, Lamar Hicks M, Sauber JJ, Shou-Hua L. Resorption after physiological and rigid splinting of replanted permanent incisors in monkeys. J Endod 1988;14:592–600.
26. Andreasen JO, Borum MK, Jacobsen MK, Andreasen FM. Replantation of 400 avulsed permanent incisors. 2. Factors related to pulpal healing. Endod Dent Traumatol 1995a;11:59–68.
27. Andreasen JO, Borum MK, Jacobsen MK, Andreasen FM. Replantation of 400 avulsed permanent incisors. 4. Factors related to periodontal ligament healing. Endod Dent Traumatol 1995b;11:76–89.
28. Michanowicz AE, Michanowicz JP, Abou-Rass M. Cementogenic repair of root fractures. J Am Dent Assoc 1971;82:569–79.
29. Zachrisson BV, Jacobsen I. Long term prognosis of 66 permanent anterior teeth with root fracture. Scand J Dent Res 1975;83:345–54.
30. Andreasen JO, Hjørting-Hansen E. Intra-alveolar root fractures: radiographic and histologic study of 50 cases. J Oral Surg 1967;25:414–26.
31. Andreasen FM, Andreasen JO, Bayer T. Prognosis of root-fractured incisors: prediction of healing modalities. Endod Dent Traumatol 1989;5:11–21.
32. Chang SP, Walker RT. Root fractures: a case of dental non-intervention. Endod Dent Traumatol 1988;4:186–8.
33. Yates JA. Root fractures in permanent teeth: a clinical review. Int Endod J 1992;25:150–7.
34. Tziafas D, Margelos I. Repair of untreated root fracture: a case report. Endod Dent Traumatol 1993;9:40–3.
35. Caliscan MK, Pehlivan Y. Prognosis of root-fractured permanent incisors. Endod Dent Traumatol 1996;12:129–36.
36. Cvek M, Mejàre I, Andreasen JO. Healing and prognosis of teeth with intra-alveolar fractures involving the cervical part of the root. Dent Traumatol 2002;18:57–65.
37. Cvek M, Andreasen JO, Borum MK. Healing of 208 intraalveolar root fractures in patients aged 7–17 years. Dent Traumatol 2002;17:53–62.
38. Andreasen JO, Andreasen FM, Mejàre I, Cveck M. Healing of 400 intra-alveolar root fractures. 2. Effect of treatment factors such as treatment delay, repositioning, splinting type and period and antibiotics. Dent Traumatol 2004;20:203–11.
39. Bakland LF, Andreasen JO. Dental traumatology: essential diagnosis and treatment planning. Endo Topics 2004;7:10–24.
40. Morley RS, Malloy RB, Hurst RVV, James R. Analysis of functional splinting upon autologously replanted teeth. J Dent Res 1978; 57IADR abstract no.593.
41. Andreasen JO. A time-related study of periodontal healing and root resorption activity after replantation of mature permanent incisors in monkeys. Swed Dent J 1980;4:101–10.
42. Mandel U, Viidik A. Effect of splinting on the mechanical and histological properties of the healing periodontal ligament after experimental extrusive luxation in the monkey. Arch Oral Biol 1989;34:209–17.
43. Kinirons MJ, Gregg TA, Welbury RR, Cole BOI. Variations in the presenting and treatment features in replanted permanent incisors in children and their effect on the prevalence of root resorption. Br Dent J 2000;189:263–6.
44. Oikarinen K, Gundlach KKH, Pfeifer G. Late complications of luxation injuries to teeth. Endod Dent Traumatol 1987;3:296–302.
45. Andreasen FM, Yu Z, Thomsen BL, Andersen PK. Occurrence of pulp canal obliteration after luxation injuries in the permanent dentition. Endod Dent Traumatol 1987;3:103–15.
46. Welbury RR, Kinirons MJ, Day P, Humphreys K, Gregg TA. Outcomes for root-fractured permanent incisors: a retrospective study. Pediatr Dent 2002;24:98–102.
47. Andreasen JO. Luxation of permanent teeth due to trauma. A clinical and radiographic follow-up study of 189 injured teeth. Scand J Dent Res 1970b;78:273–86.
48. Ngassapa DN, Friehofer H-PM, Maltha JC. The reaction of the periodontium to different type of splints. 1. Clinical aspects. J Oral Maxillofac Surg 1986;51:240–9.
49. Andreasen JO. The effect of pulp extirpation or root canal treatment on periodontal healing after replantation of permanent incisors in monkeys. J Endod 1981;7:245–52.
50. Trope M. Clinical management of the avulsed tooth: Present strategies and future directions. Dent Traumatol 2002;18:1–11.
51. Paik S, Sechrist C, Torabinejad M. Levels of evidence for the outcome of endodontic retreatment. J Endod 2004;30:745–50.