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Clinical and radiographic outcomes of replanted avulsed immature permanent teeth: a systematic review

Desfechos clínicos e radiográficos de dentes permanentes jovens avulsionados reimplantados: uma revisão sistemática

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ABSTRACT

Objective: The objective of this systematic review was to evaluate the survival, clinical and radiographic outcomes of replanting an avulsed immature permanent tooth in children. It was intended to address the complications on replanting an avulsed immature permanent tooth irrespective of outcomes. **Material and Methods:** A comprehensive search was performed using PubMed, Google Scholar, Lilacs and Cochrane databases on 2nd & 3rd November 2024. Titles and abstracts were screened followed by full-text articles from 2000 to 2024. Data extraction was then performed by using a self-designed sheet and risk of bias (ROB) assessment was done using Newcastle-Ottawa Scale. Prospective and retrospective observational studies were included. A total of 3026 articles were screened and eight articles were included in the review. The qualitative synthesis was performed on eight studies. **Results:** A total of 286 replanted immature avulsed teeth were evaluated. Clinical outcomes included pulpal healing in 31 teeth, pulpal necrosis in 139 teeth, periodontal healing in 50 teeth and apical periodontitis in 22 teeth. Radiographic outcomes included ankylosis-related resorption in 108 teeth, inflammatory-related resorption in 83 teeth, external root resorption in 12 teeth and pulp canal obliteration in 22 teeth. Overall, 97 teeth showed a successful outcome, while 56 teeth were extracted due to poor prognosis. Due to the heterogeneity of the studies, a meta-analysis was not attempted. **Conclusion:** Evidence suggests that although the survival rate for avulsed teeth was low, replanting immature permanent teeth is essential for future esthetic and functional reconstruction.

KEYWORDS

Avulsion; Dental trauma; Pulpal necrosis; Replantation; Tooth loss.

RESUMO

Objetivo: O objetivo desta revisão sistemática foi avaliar a sobrevida e os desfechos clínicos e radiográficos da reimplantação de dentes permanente jovens avulsionado em crianças. Propôs-se abordar as complicações da reimplantação de dentes permanentes jovens avulsionados, independentemente dos resultados. **Material e Métodos:** Uma busca abrangente foi realizada nas bases de dados PubMed, Google Acadêmico, Lilacs e Cochrane em 2 e 3 de novembro de 2024. A triagem se deu por leitura de título e resumo, seguido de leitura na íntegra dos artigos selecionados, publicados entre 2000 e 2024. A extração de dados foi então realizada utilizando uma planilha de autodesenvolvimento e a avaliação do risco de viés (ROB) foi feita utilizando a Escala de Newcastle-Ottawa. Estudos observacionais prospectivos e retrospectivos foram incluídos. Um total de 3.026 artigos foram selecionados e oito artigos foram incluídos na revisão. A síntese qualitativa foi realizada em oito estudos. **Resultados:** Um total de 286 dentes avulsionados jovens reimplantados foram avaliados. Os desfechos clínicos incluíram cicatrização pulpar em 31 dentes, necrose pulpar em 139 dentes, cicatrização periodontal em 50 dentes e periodontite apical em 22 dentes. Os desfechos radiográficos incluíram reabsorção relacionada à anquilose em 108 dentes, reabsorção relacionada à inflamação em 83 dentes, reabsorção radicular

externa em 12 dentes e obliteração do canal pulpar em 22 dentes. No total, 97 dentes apresentaram desfecho positivo, enquanto 56 dentes foram extraídos devido ao mau prognóstico. Devido à heterogeneidade dos estudos, não foi realizada uma meta-análise. **Conclusão:** As evidências sugerem que, embora a taxa de sobrevivência de dentes avulsionados tenha sido baixa, a reimplantação de dentes permanentes jovens é essencial para futuras reabilitações estéticas e funcionais.

PALAVRAS-CHAVE

Avulsão dentária; Traumatismo dentário; Necrose pulpar; Reimplante dentário; Perda dentária.

INTRODUCTION

Traumatic dental injuries often involve various forms of tooth damage, with avulsion being one of the most severe. Avulsion is the complete displacement of a tooth from its socket, severing the pulpal blood supply and exposing the periodontal ligament cells to the external environment [1]. This injury accounts for up to 16% of all traumatic injuries in permanent teeth, frequently affecting children aged 7-10 years. In this age group, the resilient alveolar bone offers minimal resistance to extrusive forces, often impacting the maxillary central incisors [2,3]. Although replantation is usually the preferred treatment, it cannot always be done immediately.

The International Association of Dental Traumatology (IADT) guidelines aim to maximize the probability of positive outcomes, though they do not guarantee them [4]. Proper emergency management and treatment planning are vital for a favorable prognosis. Several factors must be considered for treating an avulsed tooth including root development, extra- oral time, storage medium, the patient's age, medical status and the development of the dentition and face. The choice of treatment depends on the root's maturity (open or closed apex) and the condition of the periodontal ligament (PDL) cells [5,6].

Extra oral time play a crucial role in the outcome of an reimplanted avulsed tooth with open apex. An extra-oral time of less than 60 minutes aims to stabilize the tooth for 7-10 days, up to 2 weeks, to allow for possible revascularization of the pulp in children. However, severe complications like pulp necrosis, ankylosis, replacement resorption and infection-related inflammatory resorption are common. Progressive root resorption decreases the long-term survival probability of the replanted tooth, which may eventually be lost or require extraction [1,4].

Delayed replantation of immature permanent teeth causes significant pulp damage, leading to arrested root development and weak, vulnerable teeth. An ankylosed root may transform to bone during remodeling in growing patients, reducing the alveolar process height. Additionally, significant spontaneous tooth migration can occur if the avulsed tooth is lost, often causing undesirable midline deviation, which can impact social adaptation and psychological health [1]. Therefore, it is crucial to enhance knowledge about replantation and the survival rate of immature teeth and compare treatment options for complications during long-term follow-up.

Although some previous studies evaluated the outcomes of replanted avulsed immature permanent teeth, to date no systematic review has been performed reporting prospective and retrospective studies. Hence the present systematic review aims to evaluate the survival, clinical and radiographic outcomes of replanting an avulsed immature permanent tooth in children.

MATERIALS AND METHODS

Protocol and registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analysis (PRISMA) checklist [7]. The protocol was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the code CRD 42024488711.

Search strategy

A comprehensive search strategy was developed based upon the PIOST system: Population (P), children up to 18 years of age with avulsed immature permanent teeth; Intervention (I), replantation of avulsed immature permanent teeth; Outcomes (O), clinical and radiographic outcomes, tooth survival; Study design (S), Prospective and retrospective studies; Time period (T), 2000-2024. Individual search strategies

were performed for PubMed, Google Scholar, Lilacs and Cochrane Library databases using keywords and Medical Subject Headings (MeSH) term headings. Boolean phrases were included. Individual search strings were adapted for each database. To account for changes in replantation protocols, the evolution of revascularization as a regenerative procedure, the introduction of flexible splinting techniques and the recent availability of biomimetic materials the search has been carried out from January 1, 2000 to October 31,2024. Two authors [KP and PC] performed the literature search independently.

The following key search terms were used for the databases:

- Avulsed teeth AND open apex
- Tooth avulsion AND immature permanent teeth AND replantation
- Knocked out teeth AND replantation
- Tooth avulsion AND replantation
- Tooth avulsion AND replantation AND dental trauma

Inclusion and exclusion criteria

The inclusion criteria focused on children up to 18 years old with replanted avulsed immature permanent teeth, targeting studies that reported clinical and radiographic outcomes and were published between January 1, 2000 and October 31, 2024. Exclusion criteria ruled out animal studies, case reports/series, short communications, narrative and systematic reviews, unavailable full articles, other than published in English language and duplicate studies.

Study selection

Selection of studies was done initially by reading the title and abstract of the articles obtained from each database. Only those articles that were relevant to the review were collected and put for further evaluation. Articles reporting information based on dental trauma other than avulsion, articles which are not differentiating mature and immature teeth, primary teeth were excluded. Retrospective and prospective studies were assessed further for the review.

Full-text articles of the selected abstracts were then evaluated independently. The selection process involved two independent investigators (KP and PC) and a consensus decision was made to shortlist the articles that met all the criteria for systematic review. Any disagreement was resolved by consultation with a third reviewer (PR). Reference lists of the selected articles were also searched for additional data that may have been missed. There were no restrictions placed on the maximum follow-up period or sample size for the studies selected.

Data extraction

A data extraction sheet was designed after expert group discussion. The following data were extracted from the included articles: type of study; age; number of patients; number of immature teeth; follow up; clinical outcomes-pulp healing, pulp necrosis, periodontal healing, apical periodontitis; radiographic outcomes-ankylosis related resorption, inflammatory related resorption, external root resorption, pulp canal obliteration and number of teeth survived(success) /extracted(failure).

Methodological quality assessment

Two researchers (KP and PC) assessed the risk of bias in all selected studies using the Newcastle–Ottawa Scale (NOS) [8] to evaluate both prospective and retrospective studies. To ensure consistency, another reviewer [PR] had cross checked assessment. The NOS includes eight items with a potential total score of nine. It considers three main domains: patient selection, comparability of the study groups, and outcomes or results. Articles were classified as ‘high’, ‘moderate’ or ‘low quality,’ with high-quality articles scoring more than six points.

A Synthesis Without Meta-Analysis [9] was conducted on the included studies, due to heterogeneity of the population and outcome measures.

RESULTS

The search identified a total of 7099 articles from the PubMed, Google Scholar, Lilacs, and Cochrane Library databases. After the removal of duplicates, 3026 articles remained. Following the exclusion of case reports, case series, systematic reviews, literature reviews, animal studies and articles in other languages, 124 full-text articles are assessed for eligibility. After further review and excluding articles with incomplete data- no differentiation between mature and immature

permanent teeth, avulsion outcomes is not specified, combined with other injuries. Finally, after assessment, a total of eight studies were selected for qualitative synthesis. The search strategy followed the PRISMA guidelines and a checklist flowchart is provided (Figure 1).

Included studies

The included studies were from 2005 to 2020. Six [10-15] of them had a retrospective study design while two [16,17] were prospective studies. "Immature permanent teeth" were operationally defined based on radiographic evidence of an open apex and/or incomplete root development. Three studies [11,16,17] used Moorrees et al. [18], for classifying stages of root development and three studies [10,13,14] used radiographic method. Two studies [13,14] reported using Andreasen [19] diagnostic criteria for assessing the outcomes. Only two studies [10,11] received funding from Discipline Construction Fund of Beijing Stomatological Hospital and Brazilian agencies.

Study characteristics

All included studies were prospective and retrospective studies. Although the studies selected included patients aged 5-18 years, only permanent teeth with an open apex were included. The follow-up period ranged from 45 days to 13 years. A total of 286 immature avulsed permanent teeth were assessed. The characteristics of the included studies are shown in Table I, and the quality assessment of studies using the Newcastle-Ottawa Scale is shown in Table II and Table III for cohort and case-control studies, respectively. The diagnostic criteria differed among the included studies. As a result, the heterogeneity of the study results could not be statistically assessed, and a meta-analysis was not attempted.

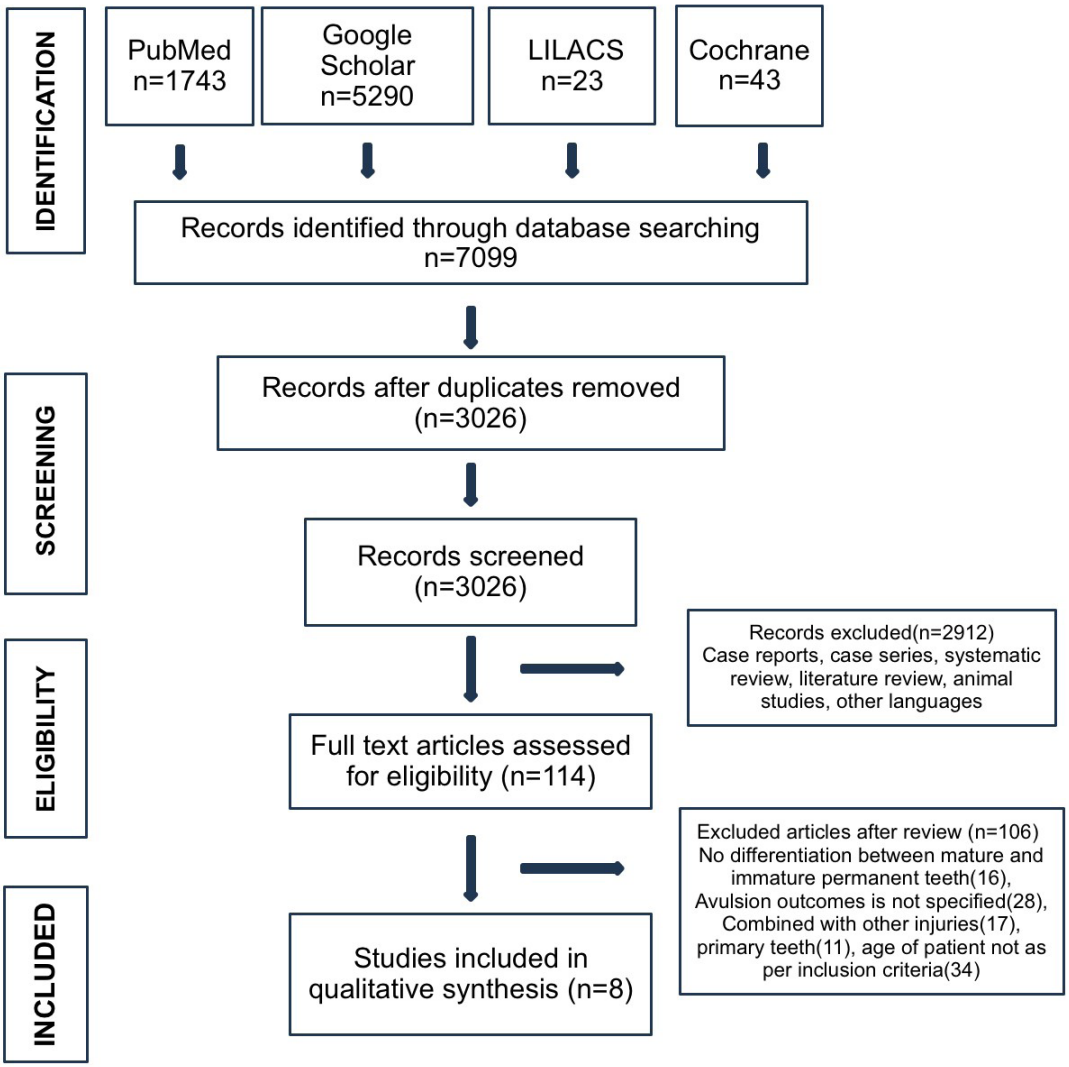

Figure 1 - PRISMA flow diagram for the study selection.

Table 1 - Study characteristics

S.No	Author, Year	Type of study	Age (Years)	No. of patients	No. of immature teeth	Follow up	OUTCOMES									
							CLINICAL				RADIOGRAPHIC				TEETH SURVIVAL	
							Pulp healing	PN	PH	AP	ARR	IRR	ERR	PCO	Success	Failure
1	Zhang et al, 2020[6]	Retrospective study (cohort study)	07/nov	34	40	1.5-10Y	4	-	19	-	12	9	-	-	28	12
2	Amaro et al, 2020[7]	Retrospective study (cohort study)	5.1-14	117	133	45D-13.9Y	17	104	19	-	70	38	12	17	-	-
3	Demir et al, 2020[8]	Retrospective study (case- control study)	08/dez	9	4	2-3Y	2	-	-	-	2	-	-	-	2	2
4	Wang et al, 2019[9]	Retrospective study	jun/16	157	56	1-14.6Y	5	19	12	19	-	15	-	5	39	17
5	Tsilingaridis et al, 2015[10]	Retrospective study (case- control study)	jun/18	50	10	7M-13.4Y	-	3	-		5	-	-	-	8	2
6	Hecova et al, 2010[11]	Retrospective study (cohort study)	07/out	-	17	5Y	-	13	-	3	9	8	-	-	6	11
7	Petrovic et al, 2010[12]	Prospective study (cohort study)	07/set	-	13	5Y	-	-	-		1	12	-	-	7	6
8	Pohl Y et al,2005[13]	Prospective study (cohort study)	jul/17	24	13	2.6Y	3	-	-		9	1	-	-	7	6

Y - Years, D - Days, M - Months, PN - Pulp Necrosis, PH - Periodontal Healing, AP - Apical Periodontitis, ARR - Ankylosis Related Resorption, IRR - Inflammatory Related Resorption, ERR - External Root Resorption, PCO - Pulp Canal Obliteration.

Table II - Quality assessment template for cohort study based on Newcastle-Ottawa-Scale

			Selection Bias Assessment				Comparability	Outcome				
Study No.	Author	Year	Representativeness of exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not of study		Assessment of the outcome	Was follow-up long enough for outcome to occur	Adequacy of follow up	Total	Methodological Quality
01	Zhang et al[6]	2020	*	*	*	*	**	*	*	*	9	High
02	Amaro et al[7]	2020	*	NA	*	*	NA	*	*	*	6	Moderate
04	Wang et al[9]	2019	*	NA	*	*	NA	*	*	*	6	Moderate
06	Hecova et al[11]	2010	*	NA	*	*	NA	*	*	*	6	Moderate
07	Petrovic et al[12]	2010	*	NA	*	*	NA	*	*	*	6	Moderate
08	Pohl Y et al[13]	2005	*	*	*	*	**	*	*	*	9	High

NA - Not Applicable.

Table III - Quality assessment template for case-control study based on Newcastle-Ottawa-Scale

			Selection Bias Assessment				Comparability	Outcome				
Study No.	Author	Year	Is the case definition adequate	Representativeness of cases	Selection of controls	Definition of controls	Comparability of cases and controls on the basis of design or analysis	Assessment of the exposure	Same method of ascertainment of cases and controls	No response	Total Score	Methodological Quality
03	Demir et al[8]	2020	*	*	NA	*	NA	*	*	*	6	Moderate
05	Tsilingarids et al[10]	2015	*	*	NA	*	NA	*	*	*	6	Moderate

NA - Not Applicable.

Assessment of risk of bias

Out of the eight studies, six [10,11,13,15-17] are cohort studies and two [12,14] are case-control studies. The NOS was used for the quality assessment. Two out of the five cohort studies were identified as having high methodological quality (a score of 9), while the remaining three studies had moderate methodological quality (a score of 6). Both case-control studies were identified as having moderate methodological quality (a score of 6).

Analysis of outcomes

A total of 286 replanted immature avulsed teeth were evaluated. Clinical outcomes included pulpal healing in 31 teeth, pulpal necrosis in 139 teeth, periodontal healing in 50 teeth and apical periodontitis in 22 teeth. Radiographic outcomes included ankylosis-related resorption in 108 teeth, inflammatory-related resorption in 83 teeth, external root resorption in 12 teeth and pulp canal obliteration in 22 teeth. Overall, 97 teeth showed a successful outcome, while 56 teeth were extracted due to poor prognosis.

DISCUSSION

Since avulsions are a common form of dental trauma, making evidence-based treatment decisions is crucial for managing and predicting the outcomes of injured teeth. Dental trauma is frequent among young patients, and their teeth often have incomplete root development. The primary goal of replanting a traumatized immature tooth is to preserve it as long as possible.

Clinical outcomes

In this review, 286 immature avulsed replanted teeth from eight studies were analyzed. Five studies [10-13,17] encompassing 31 teeth, reported pulpal healing, while four studies [11,13-15] reported pulpal necrosis in 139 teeth. The lack of clear signs of pulp necrosis with infection shortly after replantation might indicate ongoing healing. Pulpal healing is significantly influenced by the length of time the tooth remains out of the socket. According to Kling et al. [20] and Andreasen et al. [21] storage conditions do not impact pulp outcomes, as pulp tissue is relatively protected by the root walls, with only the apical structures exposed to the external environment. However, pulpal healing depends on the connection at the pulp- periodontium interface, so the duration out of the socket, regardless of storage conditions is crucial. Tsilingaridis et al. [14] found that root development is closely linked to pulp necrosis following avulsion.

Only three studies [10,11,13] reported periodontal healing in 50 teeth and 22 teeth showed apical periodontitis reported in two studies [13,15]. Hinckfuss et al. [22] found that the success of periodontal healing after replantation was not affected by the duration of splinting. The vitality of periodontal ligament cells, influenced by extraoral time and storage conditions has a greater impact on healing than the splinting period. Andreasen et al. [21] identified several key factors for PDL healing, including root development stage, length of dry storage out of the socket, immediate replantation and length of wet storage recommending immediate replantation when possible. A late diagnosis of post-traumatic pulp necrosis can result in complications such as apical periodontitis, fistulas or inflammatory root resorption.

Mobility after tooth replantation is common due to PDL damage and root resorption. Immediate replantation with short-term flexible splinting supports healing and minimizes long-term mobility. In contrast, delays and rigid splinting increase risks of resorption, ankylosis and persistent mobility [23].

Orthodontic retention may be indicated after replantation to maintain tooth position and minimize mobility, particularly in young patients or those with reduced periodontal support [24]. Methods such as bonded lingual or removable retainers, new materials and customization provide effective stabilization without increasing trauma risk [25]. However, orthodontic forces must be applied cautiously, using light, controlled forces and incorporating rest intervals to minimize the risk of root resorption and ankylosis [26]. Proper timing generally 3–4 months for mild trauma and 6–12 months for avulsions along with close monitoring and interdisciplinary planning, is essential to ensure long-term functional and periodontal stability [27].

Radiographic outcomes

Reimplanted avulsed tooth has low healing rate and high prevalence of root resorption.

Resorption is categorized into replacement resorption/ankylosis, external resorption and inflammatory resorption. Replacement root resorption being most common, followed by inflammatory and surface root resorption. Ankylosis occurs when the periodontal ligament and pre-cementum are lost, causing the root surface to contact the alveolar bone directly, leading to tooth resorption and replacement by bone.

In this review, 108 teeth showed ankylosis-related resorption, 83 had inflammatory-related resorption and 12 had external root resorption.22 teeth showed pulp canal obliteration. Trauma, especially avulsion, often causes minimal injury to the periodontal ligament, leading to at least surface resorption. Andersson et al. [28] reported that teeth replanted with viable PDL cells prevented cementum resorption, leading to a better prognosis. Initial cemental resorptions open communication between the periodontal membrane and pulp through dentinal tubules, which can cause pulp infection and maintain inflammatory root resorption [29-31].

Andreasen et al. [21] reported that ankylosis related resorption is most frequent complication and predominant which is seen in this review. The consequences of ankylosis- related resorption are more severe in growing individuals. The condition is progressive and if the tooth is left in situ, infraposition will occur and growth of the surrounding alveolar bone will be arrested [32,33]. Tsilingaridis et al. [14] demonstrate that only extra-oral time and storage medium were significant correlated to the development of ankylosis-related resorption. Based on animal and human studies, it has been concluded that teeth stored dry prior to replantation show significantly more ankylosis-related resorption than teeth replanted immediately after avulsion.

Most instances of ankylosis and infection-related resorption were detected in teeth brought to the hospital in dry conditions [34]. The medium in which the tooth was stored influences root resorption and pulp healing. Thus, it is important that the teeth should be stored in a medium capable of maintaining periodontal ligament cell viability [35-37].

Inflammatory resorption occurs if the pulp is infected and toxic elements spread from the pulp canal to the resorption cavity, damaging the periodontal ligament. Early endodontic treatment might prevent the extraction of the infected tooth and halt absorption [38].

Pulp canal obliteration is considered the mechanism by which the pulp heals after replantation of avulsed immature permanent teeth. Teeth with intracanal bone-like tissue were considered together with teeth that had hard tissue deposition on the dentinal walls followed by narrowing of the pulp lumen, and all of them were classified as pulp canal obliteration (Kling et al. [20], Andreasen et al. [21], and Abd-Elmeguid et al. [39]). Abd Elmeguid et al. [39] stated that PCO can be recognized radiographically during the first year from the onset of trauma.

Teeth survival

According to reported findings, 97 teeth had shown success rate and 56 teeth had been extracted due to poor prognosis. Wang et al. [40] stated that long-term success and survival rate enhancement of intentional replantation are likely dependent upon short extraoral time, reductions in pocket depth, type of tooth and type of root-end material filling. Coste et al. [41] stated that survival function was an objective measure defined as the interval that a replanted tooth remained functional without any signs of infection or local arrest of alveolar bone growth. Such criteria are supported by the concept that keeping a replanted tooth, even if periodontal healing patterns have not been ideal, can be considered successful replantation provided it does not compromise bone maintenance for future definitive rehabilitation in growing patients. The overall survival rate after replantation of permanent teeth was 50% after 5.5 years. Advanced stages of root development, together with the increase in the patient's age at the moment of trauma, up to the limit of 16 years, were good prognostic factors for tooth survival [29]. Previous recommendations involved a procedure that promotes crown removal and leaves root below CEJ submerged in order to avoid collapse of socket as it is slowly replaced by bone- Decoronation [42]. Decoronation helps in prolonging the time period of avulsed tooth before extracting till the replacement of tooth [43,44].

Successful healing of replanted avulsed teeth depends not only on appropriate emergency and clinical management but also on strict patient compliance. Maintaining optimal oral hygiene,

adhering to dietary and functional restrictions, attending scheduled follow-ups and completing necessary endodontic treatment significantly enhance periodontal healing and reduce the risk of complications such as infection, inflammatory resorption and ankylosis. Consequently, patient cooperation is a critical factor in ensuring the long-term survival and functional stability of the replanted tooth [5,45,46].

The variability in results is likely due to heterogeneity among the studies, caused by differences in participants, interventions, outcomes, measurement tools and risk of bias. The absence of RCTs on replanted teeth limited this study, as it relied on studies not providing the highest level of evidence. Prospective RCTs on interventions are complex due to uncontrollable variables, and ethical approval for such studies is unlikely. Instead, prospective cohort studies could offer the highest level of evidence for replantation studies, though their inclusion in meta-analyses is debated. Confounders in one cohort study might appear across several studies, potentially associating increased risk with the confounder rather than the intervention, invalidating the meta-analysis.

A meta-analysis was not conducted because the included studies lacked a comparison group and there was significant heterogeneity in methodologies such as differences in replantation time, storage media, follow-up periods and outcome measures. These factors limited the feasibility of producing valid pooled estimates.

Retrospective audits from institutions with established trauma assessment forms and standardized management protocols would offer stronger evidence than those without such protocols. Standardized data collection forms and trauma protocols have been used prospectively to study factors that should be recorded initially. Meta-analyses were not possible due to the small sample sizes and the significant differences in study design, methodology and observation periods

CONCLUSION

Based on the evidence available to assess the outcomes of replanted avulsed immature teeth through clinical and radiographic evaluation, it is fair to conclude that although the survival rate of avulsed teeth is low, replantation of immature permanent teeth is necessary. For future esthetic and functional reconstruction, treatment should progress based on the complications encountered.

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Author's Contributions

KSSP, PC, PA, CV, PR: Conceptualization. KSSP, PC, PA, CV, PR: Methodology. KSSP, PC, CV, DA: Validation. KSSP, PC, DA: Formal Analysis. KSSP, PC, PR, DA: Investigation. KSSP: Resources. KSSP, PC: Data Curation. KSSP: Writing – Original Draft Preparation. KSSP, PC, PA, CV, PR: Writing – Review & Editing. KSSP: Funding Acquisition. PC: Software. PC, CV, PR, DA: Visualization. PC, PA, CV, PR, DA: Supervision. PC, CV: Project Administration.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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