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A retrospective study of survival of 196 replanted permanent teeth in children

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Abstract

Background/Aim: The extra-alveolar period and storage medium are important for the survival of replanted teeth. The aim of this study was to evaluate factors affecting the survival of replanted teeth in children.

Material and Methods: Complete dental records of avulsed teeth including age, gender, extra-alveolar time, storage type and period, stage of root development, crown fracture, gingival laceration, alveolar fracture, antibiotics, and splint type and period were obtained. Kaplan-Meier, Cox regression and chi-square tests were used to analyse the risk factors affecting survival ($P < 0.05$).

Results: The study included 196 replanted teeth with a mean follow-up period of 4.0 years. Forty-two (21.4%), 45 (23.0%), and 109 teeth (55.6%) showed functional healing, inflammatory resorption and replacement resorption, respectively. The root resorption incidence of teeth with extra-alveolar time longer than 30 minutes was higher vs teeth with a time of less than 30 minutes ($P = 0.010$). Physiologically stored replanted teeth showed lower incidence of root resorption (19/31, 61.3%) than those stored in non-physiologic media (94/114, 82.5%) ($P = 0.025$). Root resorption incidence of teeth stored non-physiologically within 30 minutes and then transferred to physiologic media (25/33, 75.8%) was similar to that of teeth stored physiologically ($P = 0.127$). Teeth stored non-physiologically for longer than 30 minutes had a significantly higher root resorption incidence (99/113, 87.6%) than teeth stored non-physiologically within 30 minutes (55/83, 66.3%) (odds ratio = 1.726, $P = 0.001$). Pulp canal obliteration occurred in five of the 56 immature teeth (8.9%) but two of them were later extracted because of replacement resorption. The survival of mature teeth (111/140, 79.3%) was significantly higher than that of immature teeth (39/56, 69.6%) ($P = 0.007$).

Conclusions: This study suggested that non-physiologic storage within 30 minutes was critical for the periodontal healing of replanted teeth. Replanted immature teeth had lower survival rates than mature teeth.

KEYWORDS

extra-alveolar time, periodontal healing, pulp healing, stage of root development, storage medium, tooth replantation

1 | INTRODUCTION

Avulsion of permanent teeth is one of the most serious dental injuries, and 0.5%–3% of injuries to permanent teeth are avulsion.[1–3] Immediate replantation is the best treatment for avulsed teeth, but parents, teachers and even general dentists lack knowledge regarding appropriate emergency treatment after tooth avulsion.[4–6] This undoubtedly leads to delayed replantation and extensive desiccation of the tooth with subsequent necrosis of the periodontal ligament (PDL). These events contribute to external inflammatory resorption and replacement resorption, which are progressive processes that may lead to tooth loss.

The choice of treatment for a replanted tooth is related to the maturity of the root (open or closed apex). Immature teeth have an open apex and a thicker layer of PDL cells on the root surface. According to the International Association of Dental Traumatology's (IADT) latest guidelines,[7] pulp revascularization is possible for teeth with open apices that have been replanted immediately or kept in appropriate storage media prior to replantation. However, immature teeth have large dentin tubules and short roots, so once the teeth have inflammatory root resorption, it progresses very rapidly. The guidelines do not specify a particular time to initiate endodontic treatment for immature teeth, and there is still confusion about the survival of avulsed teeth with an open apex compared to a closed apex.

The extra-alveolar dry period affects the survival and repair of the damaged periodontium.[8] In 1981, Andreasen found a significant correlation among the frequency of root resorption,[9] extra-alveolar period and storage medium in a monkey model. An abrupt decrease in PDL survival was distinctly evident after 20 minutes of dry storage. Using a dog model, Barbizam demonstrated that 20 minutes of extra-oral dry time was as detrimental to the survival of the PDL as 60 minutes of extra-oral dry time.[8] However, the IADT currently sets the extra-alveolar dry time threshold at 60 minutes and outlines different treatment approaches for avulsion cases.[7] The inconsistency of experimental and clinical studies indicates a need for further research to confirm the actual threshold of the extra-alveolar dry time for the PDL.

The storage medium is a critical factor influencing the prognosis of replanted teeth. According to the IADT,[7] physiologic storage media include tissue culture medium and cell transport media. Examples of osmolality-balanced media are Hank's balanced salt solution (HBSS), saline and milk. Saliva can also be used. However, culture medium and HBSS are difficult to obtain in emergency and clinical situations. In some cases, the avulsed tooth may be kept dry or in a non-physiologic medium first and then transferred to a physiologic medium.

Few studies have discussed the effect of changes in storage media on the survival of avulsed teeth. Therefore, the aim of this study was to evaluate the factors associated with the prognosis of avulsed permanent teeth in children after a 1-year follow-up or longer, to assist clinicians and parents in the decision-making process associated with the management of avulsed teeth.

2 | MATERIAL AND METHODS

Approval of the study by the Ethics Committee of the Peking University School of Stomatology was obtained prior to the investigation (project number: PKUSSIRB-201626012). The dental records of patients with avulsed permanent teeth treated at the Department of Paediatric Dentistry, Peking University School and Hospital of Stomatology, from 1 January 2000 to 31 December 2016 were collected. Patients were included in the study if they fulfilled the following criteria: (a) the traumatized teeth were diagnosed with avulsion according to Andreasen's classification.[10] (b) The teeth were replanted and the follow-up period was at least 1 year, unless early complications lead to extraction before that time. (c) The dental records were complete, including the patient's gender and age, position of the avulsed tooth, diagnosis, stage of root development, total extra-alveolar time, storage media and time, crown fracture, gingival laceration, antibiotics, type and time of splint, time of performing pulp treatment and observation period. (d) The tooth had no previous trauma and no severe destruction of the crown caused by dental caries or restorations. The exclusion criteria were as follows: (a) the tooth could not be replanted. (b) The replanted tooth was under the influence of an ectopic erupting canine. (c) The patient had severe medical conditions (immunosuppression, severe cardiac conditions, epilepsy, etc.). (d) The replanted tooth suffered a second traumatic incident.

The following protocols were followed for all the teeth. The avulsed tooth was replanted with saline irrigating the socket and the root. After replantation, the tooth was fixed with a flexible splint (wire-composite splint or removable splint).[11] If a gingival laceration was present, it was sutured. The patient and parent were instructed about tetanus protection. Generally, the flexible splint was removed within 2 weeks after replantation. Pulpectomy was initiated before splint removal unless the potential for revascularization of the pulp space was being considered. For an immature replanted tooth, the possibility of pulp revascularization was assumed if the tooth had been stored in a physiologic medium (such as milk, saline or saliva) within 60 minutes. In this study, patients only had access to osmolality-balanced media including milk, saliva and saline. No avulsed tooth had been stored in physiologic media such as tissue culture and cell transport media.[7] Milk, saline and saliva were defined as physiologic media. The non-physiologic media included ice, tap water/water, homemade saline and dry storage. Following pulpectomy, a non-setting calcium hydroxide paste (OCO Präparate GmbH; Calxyl®) was placed in the root canal for at least 4 weeks. Then, root canal filling with gutta-percha and cement was performed for mature teeth. Vitapex (Neo Dental Chemical Products Co., Ltd.) was used in immature teeth for apexification. The patients had follow-up appointments weekly during the first month and then once every 3 months. Periapical radiographs were taken every 3 months during the first year and then every 6 months.

The stage of root development was determined by evaluation of radiographs using periapical bisecting angle exposures. Roots with an apical foramen <1 mm in diameter were designated as “mature,”

while those with an apical foramen >1 mm in diameter were designated as "immature."[12] The two researchers who evaluated the roots were calibrated by viewing 30 radiographs randomly selected from the replanted teeth radiograph database before the study. The Kappa coefficient was 0.867.

The following criteria for pulp healing described by Andreasen were used.[13] Pulp revascularization: positive sensibility reaction, normal tooth colour and normal periradicular condition including continued root formation and canal obliteration. Teeth with ingrowth of bone and PDL through the apex were also considered to be revascularized. Pulp necrosis: no reaction to electrical stimulation combined with periapical radiolucency and/or inflammatory resorption, and/or crown discoloration and/or tenderness to percussion and/or swelling.

Post-operative periodontal healing was classified according to the description of Pohl et al,[14] as functional healing, inflammatory resorption and replacement resorption/ankylosis. Inflammatory resorption and replacement resorption/ankylosis were defined as PDL necrosis according to Andreasen.[15] The replanted tooth was classified as having replacement resorption/ankylosis if one or more of the following criteria were observed: high percussion tone, negative vertical mobility value, no mobility, progressive infraposition, radiographic loss of periodontal space or osseous replacement of the root substance. Inflammatory resorption was recorded when there were signs of radiolucencies indicating external resorption affecting the root surfaces and/or adjacent bone. Clinically such teeth were either symptomless or exhibited pain, mobility or infection-related swelling or a draining sinus.[16] Healing was classified as functional healing when infection-related complications and ankylosis/replacement resorption could be excluded by examination. The criteria were normal percussion tone, positive vertical mobility value, no reduced mobility, no infraposition, and no clinical and radiographic signs of infection.

Data were processed and analysed using the Statistical Package for the Social Sciences version 20.0 (IBM Corp.). The Kaplan-Meier method and chi-square test were used to analyse the data. Cox regression was used to examine the risk factors, with $P < 0.05$ accepted as demonstrating statistical significance. The non-physiologic storage period, total extra-alveolar time, storage media, gingival laceration, alveolar fracture, crown fracture, splint period and antibiotics were included as potential risk factors.

3 | RESULTS

The study included 403 cases of teeth diagnosed with avulsion. Overall, 76 avulsed teeth were not replanted; 122 teeth were lost to follow-up within 1 year; 4 maxillary lateral incisors and 1 maxillary central incisor had root resorption due to ectopic erupting canine and 4 teeth suffered from secondary trauma. Finally, 196 replanted teeth from 157 patients (94 boys and 63 girls with an average age of 9.9 years, range 6-16 years) were included in the statistical analysis. The mean follow-up period was 4.0 years with the longest observation period being 14.6 years. The maxillary central incisor was the most frequently avulsed tooth (150/196, 76.5%).

There were 56 immature teeth and 140 mature teeth. Five of the 56 (8.9%) replanted immature teeth developed pulp canal obliteration (PCO) and were classified as pulp revascularization. Two of the PCO teeth were extracted at 52 months after replantation because of replacement resorption. All pulp revascularization occurred in teeth that were stored in a non-physiologic medium within 30 minutes and the total extra-alveolar time was <1 hour and the roots were divergent or parallel with apices of width 2 mm or more. Among the other 51 immature teeth, 19 were diagnosed with pulp necrosis, 19 with apical radiolucency and 13 with inflammatory resorption waiting for pulp revascularization. Fifteen teeth were extracted because of uncontrollable inflammatory resorption or replacement resorption. The pulps of the mature teeth had been extirpated except one tooth because the patient missed his appointment after replantation. He returned 4 months later but half of the root had external replacement resorption. The tooth was left and just observed without endodontic treatment. Table 1 lists the treatment strategies for replanted teeth. The timing of endodontic intervention differed significantly between immature teeth (n = 51) and mature teeth (n = 139) ($P = 0.019$) with the median being 26 and 12 days, respectively. The survival rate of mature teeth (111/140, 79.3%) was greater than that of immature teeth (39/56, 69.6%) ($P = 0.007$; Figure 1).

TABLE 1 The survival of the replanted teeth according to the treatment strategies and the stage of root development

Stage of root development	No endodontic treatment		Endodontic treatment prior to replantation		Early endodontic treatment (within 14 d)		Delayed endodontic treatment (more than 14 d)		Total n (%)
	Survival	Loss of tooth	Survival	Loss of tooth	Survival	Loss of tooth	Survival	Loss of tooth	
Immature	3	2	—	1	5	7	31	7	56 (28.5)
Mature	1[a]	—	7	12	60	15	43	2	140 (71.5)
Total n (%)	4 (2.0)	2 (1.0)	7 (3.6)	13 (6.6)	65 (33.2)	22 (11.2)	74 (37.8)	9 (4.6)	196 (100.0)

Note: [a]The patient missed his appointment after replantation.

Four months later when he came back again, half of the root was observed to have replacement resorption. The tooth was left without endodontic treatment until data collection.

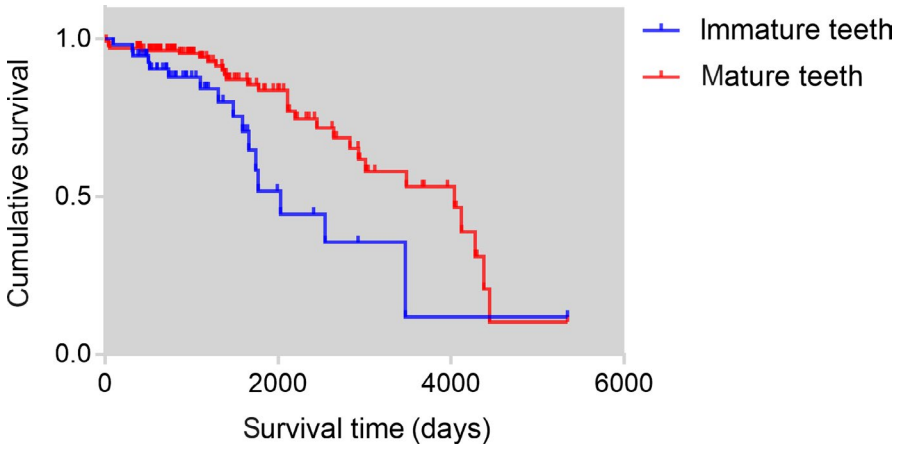

FIGURE 1 Kaplan-Meier survival curves for root development. Replanted immature teeth had a lower survival rate compared to mature teeth (P = 0.007)

Overall, 42 of the 196 replanted teeth (21.4%) had functional healing, 45 (23.0%) had inflammatory resorption, and 109 (55.6%) had replacement resorption. The time out of the tooth socket varied from 10 minutes to 144 hours. The incidence of root resorption in teeth with an extra-alveolar time longer than 30 minutes (140/172, 81.4%) was significantly higher than that of teeth replanted within 30 minutes (14/24, 58.3%) P = 0.010). Thirty-one replanted teeth were stored in a physiologic medium before replantation, 114 teeth were stored in a non-physiologic medium, and 33 teeth were stored in a non-physiologic medium for <30 minutes before being transferred to a physiologic medium. Eighteen teeth were stored in a non-physiologic medium for longer than 30 minutes before being transferred to a physiologic medium (Table 2). The incidence of PDL necrosis of replanted teeth stored in a physiologic medium was 61.3% (19/31), which was significantly lower than that of replanted teeth stored in a non-physiologic medium (94/114，82.5%) (P = 0.025). The incidence of PDL necrosis of replanted teeth stored in a non-physiologic medium for <30 minutes and then transferred to a physiologic medium (75.8%, 25/33) was similar to that of replanted teeth stored in a physiologic medium throughout (P = 0.127). The incidence of PDL necrosis of replanted teeth stored in a non-physiologic medium for <30 minutes (including being replanted or being transferred to a physiologic media within 30 minutes or stored in a physiologic medium all the time) was 66.3% (55/83), which was significantly lower than that of avulsed teeth stored in a non-physiologic medium for longer than 30 minutes (99/113, 87.6%) (P = 0.000). Figure 2 presents the survival data related to root resorption, with separate curves for cases with less or longer than 30 minutes of non-physiologic storage time. The survival pattern of replanted teeth with <30 minutes of non-physiologic storage time was better than that of other replanted teeth (P = 0.001).

Table 3 lists the independent relationships between the input factors and the outcome of root resorption. The best predictor of root resorption was non-physiologic time, followed closely by total extra-alveolar time and storage type. Other factors such as antibiotics, type and period of splint, alveolar fracture, crown fracture and gingival laceration had weak effects. After input variable interaction, the final Cox regression model indicated that the total non-physiologic time remained the strongest predictor of root resorption (OR = 1.726, P = 0.001; Table 4).

4 | DISCUSSION

Several factors are involved in the process of pulp healing after avulsion with pulp canal obliteration—these are extra-oral time, storage conditions, apex width and root canal length.[17] Immature young permanent teeth have wide apices, and the blood supply is abundant, which is favourable for revascularization. Andreasen found that storage of avulsed teeth for more than 5 minutes decreased the chance of pulp revascularization.[18] Abd-Elmeguid found that PCO was the most common healing outcome of the pulp after avulsion, accounting for 96% of all healed teeth.[17] In the present study, five avulsed immature teeth (9.1%) had PCO, which presented as pulp revascularization, but two of them were extracted later because of replacement resorption. This indicated that pulp healing was hardly seen, although a few immature teeth showed signs of pulp revascularization.

The choice of treatment for replanted teeth was related to the stage of root development. The present study revealed that replanted immature teeth had a lower survival rate compared to mature teeth. This was consistent with the findings of Barrett, who reported that incisors replanted with open apices had a significantly decreased survival rate compared to teeth with mature apices.[19] Andersson et al[20] also found that the rate of root resorption was significantly higher in patients aged 8-16 years at the time of avulsion than in patients aged 17-39 years at the time of avulsion. The low survival rates of immature avulsed teeth might be due to the higher rate of bone remodelling in younger individuals. The short root length and low calcification of immature teeth suggest a reduced ability to resist inflammation and inflammation activated osteoclasts, resulting in progressive resorption being faster than in mature teeth.[20] Thus, the survival time was shorter than in mature teeth.

The appropriate timing of endodontic treatment for immature teeth has been difficult to judge for dentists. It is difficult to balance pulp revascularization against the possibility of pulp necrosis and infection. On one hand, the pulp needs time for revascularization while delayed pulpectomy may lead pulp necrosis and the initiation of root inflammatory resorption. It is a challenge to correctly evaluate

TABLE 2 The distribution of replanted teeth according to storage media and the time of periodontal healing

Dry storage time (min)	Additional physiologic storage		Periodontal healing		
	Medium	Time (min)	FH (%)	PDL Necrosis (%)	No. of teeth (%)
0	Saliva	0 ~ 30	0 (0.0)	1 (100.0)	1 (100.0)
		>30	4 (50.0)	4 (50.0)	8 (100.0)
	Saline	0 ~ 30	1 (100.0)	0 (0.0)	1 (100.0)
		>30	9 (75.0)	3 (25.0)	12 (100.0)
	Milk	0 ~ 30	1 (50.0)	1 (50.0)	2 (100.0)
		>30	3 (42.9)	4 (57.1)	7 (100.0)
0 ~ 30	—	—	8 (42.1)	11 ((57.9)	19 (100.0)
	Saliva	0 ~ 30	0 (0.0)	2 (100.0)	2 (100.0)
		>30	1 (14.3)	6 (85.7)	7 (100.0)
	Saline	0 ~ 30	0 (0.0)	2 (100.0)	2 (100.0)
		>30	5 (41.7)	7 (58.3)	12 (100.0)
	Milk	0 ~ 30	—	—	—
		>30	3 (30.0)	7 (70.0)	10 (100.0)
>30	—	—	12 (12.5)	84 (87.5)	96 (100.0)
	Saliva	0 ~ 30	—	—	—
		>30	—	—	—
	Saline	0 ~ 30	0 (0.0)	1 (100.0)	1 (100.0)
		>30	1 (10.0)	9 (90.0)	10 (100.0)
	Milk	0 ~ 30	1 (50.0)	1 (50.0)	2 (100.0)
		>30	0 (0.0)	5 (100.0)	5 (100.0)

Note: PDL necrosis included inflammatory resorption and replacement resorption.
Abbreviation(s): FH, functional healing.

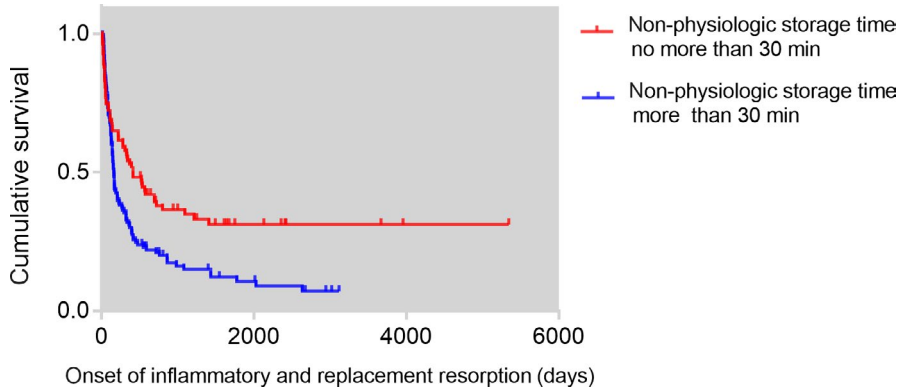

FIGURE 2 Kaplan-Meier survival curves according to non-physiologic storage time. Replanted teeth were more likely to be free of inflammatory and replacement resorption with a non-physiologic storage time of no more than 30 min vs more than 30 min. The onset of inflammatory and replacement resorption for teeth with a non-physiologic storage time no more than 30 min was later than that of the others ($P = 0.001$)

the pulp state of immature teeth and to predict whether pulp revascularization will occur. In this retrospective study, it was noted that endodontic treatment was performed when immature teeth (31/50, 62%) were found to have developed a draining sinus, gingival swelling or apical radiolucency. This meant that the endodontic treatment was delayed. To avoid uncontrollable resorption, patients should be carefully reviewed. In addition, laser Doppler flowmetry might be helpful to assess the pulp state of immature teeth awaiting revascularization.[21–24]

In agreement with previous studies, the present study observed a diminished likelihood of PDL healing with longer extra-alveolar periods.[15,16] Additionally, prolonged non-physiologic storage time of the teeth was more important to prognosis than the total extra-alveolar period. Trope reported that survival of the root PDL cells was unlikely

TABLE 3 Clinical factors related to periodontal healing of replanted teeth

Clinical factors	FH (%)	PDL necrosis (%)	Probability (Chi-square)
Crown fracture			
No	40 (22.6)	137 (77.4)	0.223
Yes	2 (10.5)	17 (89.5)	
Alveolar fracture			
No	35 (21.2)	130 (78.8)	0.865
Yes	7 (22.6)	24 (77.4)	
Gingival laceration			
No	33 (22.9)	111 (77.1)	0.398
Yes	9 (17.3)	43 (82.7)	
Stage of root development			
Immature	12 (21.4)	44 (78.6)	1.000
Mature	30 (21.4)	110 (78.6)	
Total extra-alveolar time			
≤30 min	10 (41.7)	14 (58.3)	0.010
>30 min	32 (18.6)	140 (81.4)	
Storage type			
Physiologic media	12 (38.7)	19 (61.3)	0.050
Non-physiologic media	20 (17.5)	94 (82.5)	
Non-physiologic (≤30 min) changed to physiologic media	8 (24.2)	25 (75.8)	
Non-physiologic (>30 min) changed to physiologic media	2 (11.1)	16 (88.9)	
Non-physiologic storage period			
≤30 min	28 (33.7)	55 (66.3)	0.000
>30 min	14 (12.4)	99 (87.6)	
Type of splint			
Wire-composite splint	29 (21.5)	106 (78.5)	0.189
Removable splint	1 (5.9)	16 (94.1)	
Both	12 (27.3)	32 (72.7)	
Splinting period			
≤14 d	16 (22.2)	56 (77.8)	0.889
>14 d	26 (21.0)	98 (79.0)	
Antibiotics			
No	17 (17.2)	82 (82.8)	0.142
Yes	25 (25.8)	72 (74.2)	

Note: PDL necrosis included inflammatory resorption and replacement resorption.
Abbreviation(s): FH: functional healing.

TABLE 4 Cox regression model showing the factors related to periodontal healing

Variables	*B*	SE	*df*	Sig.	Exp(*B*)	95% CI
Non-physiologic period						
≤30 min	Ref. group					
>30 min	0.546	0.170	1	0.001	1.726	1.237-2.408

with a dry time of more than 60 minutes.[25] Boyd found that a total extra-alveolar time of more than 30 minutes was an important risk factor for the onset of resorption in replanted avulsed teeth in children.[16] The present study investigated two types of timing as critical time limits for periodontal functional healing: 30 and 60 minutes (Table 5). The results revealed that avulsed teeth with a non-physiologic storage period of <30 minutes had a significantly higher incidence of functional healing. This finding suggests that a non-physiologic storage period of

TABLE 5 Clinical factors that did not have a significant association with periodontal healing of replanted teeth

Clinical factors	FH (%)	PDL necrosis (%)	Probability (chi-square)
Total extra-alveolar time			
≤60 min	21 (27.6)	55 (72.4)	0.092
>60 min	21 (17.5)	99 (82.5)	
Non-physiologic storage period			
≤60 min	33 (25.4)	97 (74.6)	0.058
>60 min	9 (13.6)	57 (86.4)	

Note: PDL necrosis included inflammatory resorption and replacement resorption.
Abbreviation(s): FH, functional healing.

TABLE 6 The relationship between replanted teeth stored for the entire time in saliva, saline or milk with periodontal healing ($P = 0.743$)

	Periodontal healing			
Storage medium	FH (%)	PDL necrosis (%)	No. of teeth	Probability
Saliva	4 (44.4)	5 (55.6)	9 (100.0)	0.743
Saline	10 (76.9)	3 (23.1)	13 (100.0)	
Milk	4 (44.4)	5 (55.6)	8 (100.0)	

Note: PDL necrosis included inflammatory resorption and replacement resorption.
Abbreviation(s): FH, functional healing.

TABLE 7 The relationship between replanted teeth stored for the entire time in saliva or dry storage time with periodontal healing ($P = 0.032$)

	Periodontal healing			
Storage medium	FH (%)	PDL necrosis (%)	No. of teeth (%)	Probability
Saliva	4 (44.4)	5 (55.6)	9 (100.0)	0.032
Dry	20 (17.5)	94 (82.5)	114 (100.0)	

Note: PDL necrosis included inflammatory resorption and replacement resorption.
Abbreviation(s): FH, functional healing.

30 minutes might be a critical time limit for periodontal ligament cell viability. It is also consistent with experimental results indicating that 20 minutes is the threshold of PDL cell viability.[8,26]

The medium in which the avulsed tooth is stored influenced the periodontal healing and pulp healing.[15,18,25] The IADT recommends special storage or transport media (eg, tissue culture/transport medium, HBSS).[7] Adnan found that milk was the most recommended storage medium, based not only on PDL cell viability, but also practical considerations.[27] However, this process is progressive and inevitable, and even appropriate storage is limited to short periods.[28,29] In the present study, there was no significant influence on periodontal healing between the milk, saline and saliva (Table 6) while a difference between saliva and dry storage was noted (Table 7). Considering the sample of each medium was small, plus since milk, saline and saliva are still listed as acceptable physiologic media in the guideline of the IADT,[7] milk, saline and saliva were considered to be physiologic media and were analysed as a whole. The results revealed that if a tooth was stored in a non-physiologic medium for <30 minutes and then transferred to a physiologic medium, the periodontal healing was similar to that of a tooth stored in the physiologic medium the entire time. If a tooth was stored in a non-physiologic medium for longer than 30 minutes and then transferred to a physiologic medium, the periodontal healing prognosis did not improve.

With regard to the limitations of this study, given its retrospective design, selection bias was likely. A small number of immature teeth were included (55 teeth), and the stage of root development could not be differentiated. In addition, because of delayed endodontic treatment and the small sample size, the optimal time of endodontic treatment for immature teeth could not be determined, although the median time until initiation of endodontic treatment was 26 days for immature teeth. Another limitation of this retrospective study was that the non-viable soft tissue attached to the root surface was not removed prior to replantation in delayed replanted cases. For this reason, an immune-inflammatory reaction might occur and result in the onset of replacement resorption.

In summary, the main finding of this study was that a non-physiologic period of <30 minutes was critical for PDL cell viability. Teeth stored in a non-physiologic medium for <30 minutes and then transferred to a physiologic medium had a similar prognosis to that of teeth stored in a physiologic medium. Immature avulsed teeth had lower survival rates than mature teeth. Pulp revascularization was rarely seen in immature avulsed teeth, and PCO was the common outcome of pulp healing. Immature avulsed teeth with PCO were also at potential risk of subsequent replacement resorption.

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CONFLICT OF INTEREST

The authors confirm that they have no conflict of interest.

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