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Clinical outcomes of 79 traumatically intruded permanent teeth in Chinese children and adolescents: A retrospective study

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Abstract

Background/Aim: Data on the clinical outcomes of traumatically intruded, young, permanent teeth in Chinese children and adolescents are absent. The aim of this study was to examine the probability of spontaneous re-eruption of injured teeth, to investigate the incidence of pulp necrosis with infection of the root canal system and replacement root resorption and to analyse possible factors related to healing complications after injury.

Materials and Methods: Clinical data from 6- to 18-year-old patients who sustained intrusive luxation from 2007 to 2016 were reviewed. Teeth were treated by awaiting re-eruption, orthodontic repositioning or surgical repositioning. The incidences of spontaneous re-eruption, pulp necrosis with infection, replacement resorption and marginal bone loss were calculated, and factors related to these complications were analysed using Cox regression and Kaplan-Meier analyses.

Results: Data from 79 teeth in 58 patients (mean age 9.19 ± 2.34 years) were examined over follow-up periods from 7 to 87 months (median 18 months). Of the 50 teeth awaiting re-eruption, the incidences of complete re-eruption and partial re-eruption were 40.0% and 34.0%, respectively. Teeth intruded <3 mm had a higher complete re-eruption rate (57.1%) than those with a 3-7 mm of intrusion (18.2%) (hazard ratio [HR] = 4.15). Of the 52 teeth observed for more than 12 months, pulp necrosis with infection, replacement resorption and marginal bone loss occurred in 57.4%, 15.4% and 61.5% of the teeth, respectively. Teeth with 3-7 mm (60.9%, HR = 2.97) or >7 mm (100%, HR = 6.44) of intrusion and teeth with uncomplicated crown fracture (85.7%, HR = 5.19) were more likely to develop pulp necrosis with infection. Teeth that received orthodontic or surgical repositioning showed higher incidences of replacement resorption (23.1%, HR = 5.72; 25.0%, HR = 11.68, respectively).

Conclusions: Spontaneous re-eruption of intruded teeth was significantly related to intrusion depth. Intrusion depth and crown fracture had strong relationships with pulp necrosis with infection, whereas the choice of treatment influenced the development of replacement resorption.

KEYWORDS
children and adolescents, complications, permanent teeth, spontaneous eruption, traumatically intrusion

1 | INTRODUCTION

Intrusive luxation refers to displacement of a tooth axially into the alveolar bone.[1] Traumatic intrusion of permanent teeth has a low incidence and has been reported to represent only 0.3%–2% of dental injuries in several studies.[2–6] Young permanent teeth have the potential to re-erupt. However, the prognosis of teeth with this injury is poor. Damage to the periodontium and pulp usually causes severe complications, including external inflammatory resorption, replacement resorption/ankylosis, pulp obliteration and pulp necrosis with infection of the root canal system (RCS). Replacement resorption is the worst complication for healing because there is no treatment that can arrest this type of resorption currently available.[7] The development of replacement resorption in a young patient may influence alveolar growth and the development of malocclusion.[8]

The low incidence of intrusive luxation may explain the paucity of knowledge concerning the treatment of these injuries. Treatment for this type of trauma involves observation for spontaneous re-eruption, orthodontic repositioning or surgical repositioning.[1] Treatment recommendations from the International Association of Dental Traumatology (IADT)[1] and the American Association of Endodontists (AAE)[9] indicate that teeth with incomplete root formation should first be allowed to re-erupt without intervention. If no movement occurs within a few weeks, then orthodontic repositioning can be initiated. If a tooth is intruded more than 7 mm, orthodontic or surgical repositioning should be performed immediately. However, based on a large number of clinical cases, Tsilingaridis et al[7] recommended that all teeth with incomplete root development should be managed by waiting for spontaneous re-eruption regardless of the degree of intrusion. On the other hand, teeth with complete root formation and intrusion of <3 mm should be allowed 2-4 weeks for re-eruption, followed by orthodontic or surgical repositioning if no movement is observed. If a tooth is intruded by more than 7 mm, then it should be repositioned surgically.[1] Studies on intrusive luxation have previously been published in Europe[2,7,8,10–13] and North America.[14] Several clinical studies have shown that injury-related or treatment-related factors may affect the pulp and periodontal prognosis of these teeth.[7,8,10–15] However, very little research on this topic has been conducted in China.

The aim of this retrospective study was to examine the probability of spontaneous re-eruption of injured teeth, to investigate the incidence of pulp necrosis with infection of the RCS and replacement root resorption and to analyse the possible factors related to healing complications after this injury.

2 | MATERIALS AND METHODS

This retrospective study examined patients with intrusive luxation treated at the Department of Paediatric Dentistry and the Emergency Department of Peking University School and Hospital of Stomatology during the period from 2007 to 2016. Clinical data were extracted from the records of patients who were 6 to 18 years old before 31 September 2017. Patients who had a second incident of dental trauma, had incomplete information, only had emergency treatment or had ≤6 months of follow up were excluded. The study was approved by the biomedical ethics committee at the Peking University School and Hospital of Stomatology (PKUSSIRB-201736084).

Clinical outcomes in this study included spontaneous re-eruption, pulp necrosis with infection of the RCS, replacement root resorption and marginal bone loss, as follows:

Spontaneous eruption

Complete re-eruption was registered when intruded teeth erupted to the same level as control teeth. Partial re-eruption was registered when teeth erupted but did not reach the control teeth.

Pulp necrosis with infection of the RCS

A lack of reaction to thermal or electric stimulation combined with periapical radiolucency and/or external infection-related (inflammatory) root resorption and/or crown discoloration[7] was considered a sign of pulp necrosis with an infected RCS.

Replacement resorption (ankylosis)

Loss of the periodontal ligament space, a high metallic percussion sound and decreased mobility constituted a diagnosis of replacement resorption.

Marginal bone loss

When the level of marginal bone was more than 2 mm lower than the cementoenamel junction during the follow up, marginal bone loss was recorded.

Patient histories including age at the time of the accident, gender and the cause of injury were acquired. Clinical examinations included tooth position, tooth number, adjacent tooth injury, the severity of intrusion, root development, other combined dental trauma (crown fracture and pulp exposure), the condition of the supporting tissues (alveolar bone fracture), examinations related to pulp condition (tooth colour, thermal and electric pulp testing, and pain to percussion) and examinations related to replacement resorption (tooth mobility and a metallic tone to percussion).

The standardized bisecting angle radiographic technique was used to assess the severity of intrusion. This was measured using the ImageJ software program (ImageJ 1.51j8, Wayne Rasband, USA) on radiographs as the difference in the levels of the cementoenamel junction of the intruded tooth and the corresponding contralateral tooth[2] (Figure 1A). In patients with more than one intruded incisor, dislocation and re-eruption were assessed from a combination of radiographs and patient records. The degree of intrusion was classified as mild (<3 mm), moderate (3-7 mm) or severe (>7 mm).[7]

Root development at the time of the accident was graded using six stages according to the system described by Andreasen et al[2]: 1,

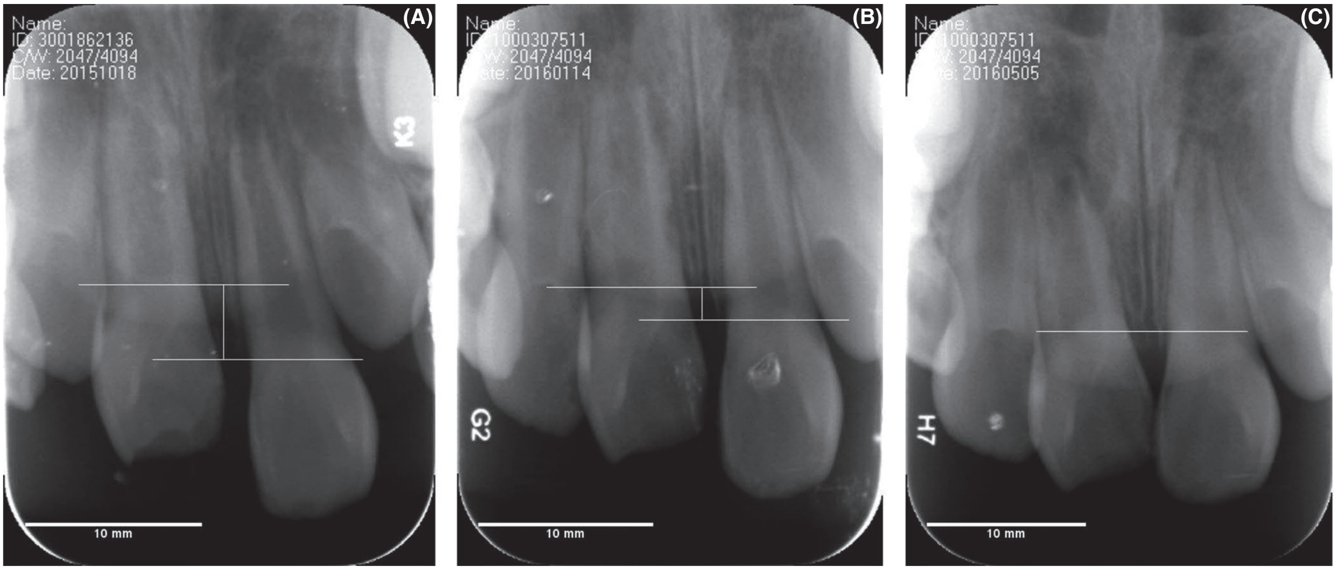

FIGURE 1 Intrusion and spontaneous re-eruption process of an immature upper right central incisor. A, Measurement of intrusion depth. The degree of intrusion was measured to the nearest millimetre on the radiograph as the difference in the level of the cementoenamel junction in the intruded tooth and the corresponding contralateral tooth. B, Three months later, the intruded tooth partially re-erupted to the level of the control. C, Six and a half months after injury, the intruded tooth had completely re-erupted to the level of the control. Periapical radiolucency and inflammatory resorption were apparent

one-quarter root formation; 2, one-half root formation; 3, three-quarters root formation; 4, full root formation, open apex; 5, full root formation, half-closed apex; 6, full root formation, apex closed. In the analysis, teeth were classified as immature (stages 1-4) or mature (stages 5 and 6).

Enamel or enamel-dentin crown fractures without pulp exposure in teeth were recorded as crown fractures.

Teeth with complicated crown fractures in which the pulp was exposed were registered as pulp exposure.

Contusion of the alveolar socket bone, fracture of the labial bone plate and fracture of the alveolar process were all registered as alveolar bone fractures.

The treatment choices were classified as spontaneous re-eruption, orthodontic repositioning or surgical repositioning based on intrusion depth and root development according to the IADT Guidelines.[1] Orthodontic repositioning and surgical repositioning were also called active positioning. In this study, for immature teeth with <3-and 3-7-mm intrusion depths, spontaneous re-eruption was allowed. For teeth that failed to re-erupt spontaneously or those with severe intrusion, orthodontic appliances were used to force the teeth to reach their normal levels. For mature teeth with <3 mm of intrusion, re-eruption was used, followed by orthodontic or surgical repositioning. Teeth with severe intrusion and complete root formation were surgically repositioned using forceps and splinted with a flexible splint for 2-4 weeks. Pulp treatment was performed according to the pulp condition and root formation. A positive response to pulp testing, normal tooth colour, a normal periradicular condition and pulp canal obliteration was considered evidence of a normal pulp. Teeth without crown fracture were monitored closely for changes in the pulp status. Indirect pulp therapy and pulpotomy were performed in immature teeth with uncomplicated and complicated crown fractures without signs of pulp necrosis, and the pulp status was monitored closely. Regenerative endodontic therapy or apexification was applied for immature teeth with pulp necrosis and infection of the RCS. Root canal therapy using a temporary filling with calcium hydroxide was considered when the pulp became necrotic and infected in teeth with complete root formation.

Patients were followed up at 2 weeks, 1 month, 3 months, and 6 months and then routinely every 6 months after the injury. During the follow-up period, clinical examinations including tooth colour assessment, thermal and electric pulp testing, pain to percussion, tooth mobility and a metallic tone to percussion were performed. Radiographic examinations were routinely performed at 1, 3, and 6 months and at any other time when needed. Re-eruption was measured from a combination of radiographs and clinical records. The incidence and timing of tooth re-eruption, pulp necrosis with infection, replacement resorption and marginal bone loss were recorded.

All data were analysed using SPSS software (16.0; SPSS Inc). The mean ± SD, the median and frequency were used to describe variables. The chi-square test and Fisher's exact test were used to analyse differences in frequency. To illustrate the effects of variables significantly related to the outcome, Cox regression analysis and Kaplan-Meier survival analysis were conducted and compared. A significance level of $P < .05$ was used in all analyses.

3 | RESULTS

Information on 116 patients was extracted from the records. Based on the inclusion and exclusion criteria, 58 patients with 79 teeth were finally included in this study (Figure 2). Of the 58 patients (mean age 9.19 ± 2.34 years), 32 were male and 26 were female.

Observation times ranged from 7 to 87 months with a mean of 25.4 months and a median of 18 months. Fifty-two teeth in 36 patients were followed up for more than 12 months. Of the 52 teeth in 36 patients, the mean observation time was 33.6 ± 22.4 months with a median of 25.5 months (range 13-87 months).

In this study, the main reason for tooth injury was falling while running/jumping/playing (44.8%), followed by outdoor sports (19.0%) and traffic accidents (13.8%) (Table 1).

Thirty-nine patients had intrusion of one tooth, 14 patients had two intruded teeth, and five patients had at least three intruded teeth. All intruded teeth were maxillary anterior teeth and mostly central incisors (83.6%) followed by lateral incisors (12.6%) (Table 2). Forty-three intruded teeth had crown fractures, 13 of which also had a pulp exposure. In 91.1% of the intruded teeth, an adjacent tooth was also injured, and alveolar bone fractures occurred in 22 teeth (27.8%) (Table 2).

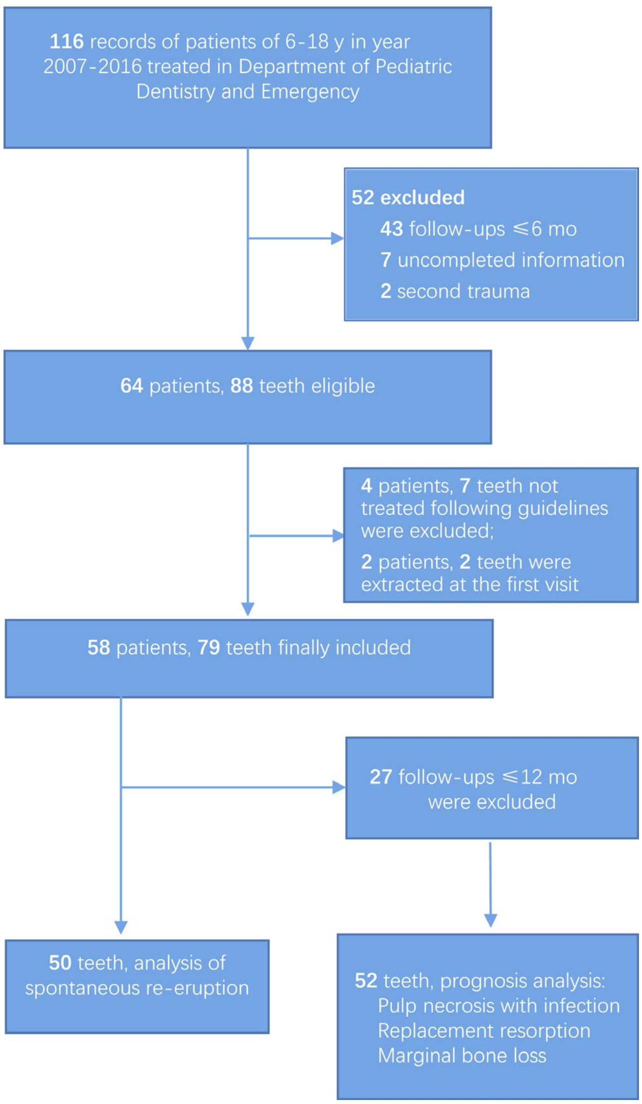

FIGURE 2 Flow chart of the sampling procedure and materials

After the first visit, 50 teeth were assigned to re-erupt spontaneously. Thirteen teeth failed to re-erupt spontaneously and were then treated by orthodontic repositioning. In addition, one tooth with partial re-eruption and four teeth with 3-7 mm of intrusion at the first visit were treated by orthodontic movement. During orthodontic treatment, six teeth were repositioned to a normal level within 3 months, four reached a normal level in the following 3-6 months, and another six required 6-14 months to reach a normal level. Three teeth exhibited replacement resorption, and treatment was stopped. For one of these teeth, treatment was changed to surgical repositioning. Twenty-five teeth received surgical repositioning after the first visit because of severe intrusion depth. The final numbers of teeth that received orthodontic and surgical repositioning according to root development and intrusion depth are shown in Table 3.

Of the 50 teeth observed for spontaneous re-eruption without intervention, 20 (40.0%) completely re-erupted within 0.5-18 months (mean 5.3 months, median 3.5 months). Seventeen teeth (34.0%) partially re-erupted within 0.5-12 months (mean 3.7 months, median

TABLE 1 Causes of traumatic intrusion (n = 58)

Causes	Number	Percentage (%)
Falling while running/ jumping/playing	26	44.8
Sports	11	19.0
Traffic accident	8	13.8
Jumping from a height	6	10.3
Impact	1	1.7
Unknown	6	10.3
Total	58	100

TABLE 2 Characteristics of intruded teeth, adjacent tooth injury and alveolar bone fracture (n = 79)

	Number	Percentage (%)
Position of intruded tooth		
Central incisor	66	83.6
Lateral incisor	10	12.6
Canine	3	3.8
Severity of intrusion (mm)		
<3 mm	29	36.7
3-7 mm	37	46.8
>7 mm	13	16.5
Stage of tooth development		
Mature	43	54.4
Immature	36	45.6
Crown fracture	43	54.4
Pulp exposure	13	16.5
Adjacent tooth injury	72	91.1
Alveolar fracture	22	27.8
Total teeth	79	100

TABLE 3 Choice of treatment related to root development and intrusion depth (n = 79)

	Root development	Intrusion depth <3 mm	3-7 mm	>7 mm	Total
Spontaneous re-eruption	Immature	15	14	0	29
	Mature	13	8	0	21
	Total	28	22	0	50
Orthodontic repositioning	Immature	2	8	0	10
	Mature	3	5	0	8
	Total	5	13	0	18
Surgical repositioning	Immature	0	3	2	5
	Mature	1	9	11	21
	Total	1	12	13	26

2.0 months). Cox regression analysis indicated that the severity of intrusion was a significant factor for spontaneous re-eruption (hazard ratio [HR] = 4.15, *P* = .005). For complete re-eruption, teeth intruded <3 mm had a higher re-eruption rate (57.1%) than those with 3-7 mm of intrusion (18.2%) (*P* = .013, Table 4; *P* = .004, Figure 3). The mean complete re-eruption time was 4.3 months (median 3.0 months) for teeth intruded <3 mm and 9.5 months (median 10.0 months) for teeth with 3-7 mm of intrusion. Patients with intruded teeth that completely re-erupted were younger (mean age 7.75 ± 1.07 years) than those whose teeth did not re-erupt (9.08 ± 1.80 years) or partially re-erupted (9.47 ± 2.48 years) (*P* = .017, Table 4). No significant relationships were found between complete tooth re-eruption and crown fracture, pulp status or alveolar bone fracture.

Of the 52 teeth followed up for more than 12 months, five mature teeth with necrotic and infected pulps received root canal treatment using a temporary calcium hydroxide filling at the first visit. Six teeth (12.8%, 6/47) developed pulp canal obliteration. Twenty-seven teeth (57.4%, 27/47) developed pulp necrosis and infection within 0.5-18 months (mean 3.8 months, median 2.0 months). Cox regression analysis showed that the severity of intrusion (HR = 6.44 for

TABLE 4 Rate of spontaneous re-eruption related to age, severity of intrusion, root development, crown fracture, pulp exposure and alveolar bone fracture (n = 50)

	Spontaneously re-erupted teeth, n (%) Complete re-eruption	Partial re-eruption	No re-eruption	Total
Age	7.75 ± 1.07	9.47 ± 2.48	9.08 ± 1.8	8.68 ± 1.96
P-value	.017			
Severity of intrusion				
<3 mm	16 (57.1)	8 (28.6)	4 (14.3)	28
3-7 mm	4 (18.2)	9 (40.9)	9 (40.9)	22
P-value	.013			
Root development				
Immature	13 (44.8)	9 (31.0)	7 (24.1)	29
Mature	7 (33.3)	8 (38.1)	6 (28.6)	21
P-value	.764			
Crown fracture				
Yes	12 (48.0)	8 (32.0)	5 (20.0)	25
No	8 (32.0)	9 (36.0)	8 (32.0)	25
P-value	.456			
Pulp exposure				
Yes	0	6 (100.0)	0	6
No	20 (45.4)	11 (25.0)	13 (29.5)	44
P-value	.001			
Alveolar bone fracture				
Normal	19 (41.3)	14 (30.4)	13 (28.3)	46
Fracture	1 (25.0)	3 (75.0)	0	4
P-value	.224			
Total	20 (40.0)	17 (34.0)	13 (26.0)	50

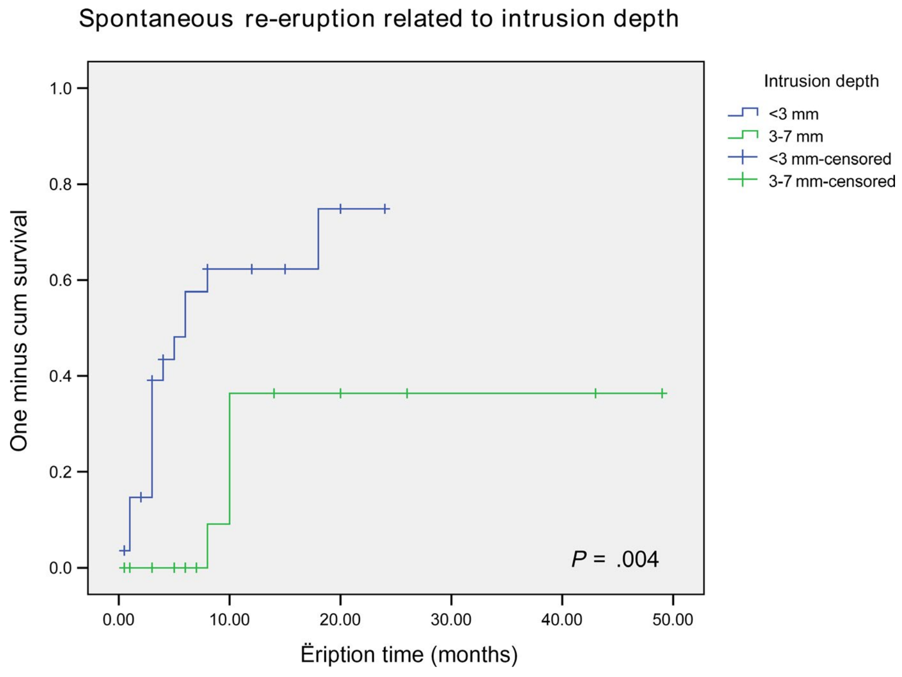

FIGURE 3 Kaplan-Meier analysis of spontaneous re-eruption in relation to intrusion depth. A significantly higher distribution of complete spontaneous re-eruption was observed in teeth with <3 mm of intrusion (*P* = .004)

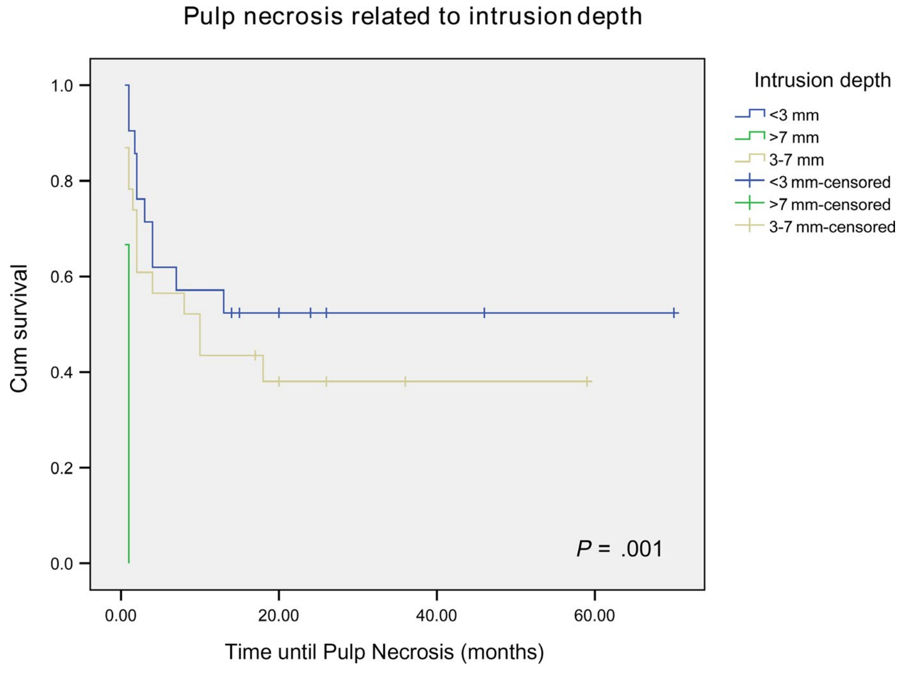

FIGURE 4 Kaplan-Meier analysis of pulp necrosis and infection in relation to intrusion depth. Significantly more teeth with pulp necrosis and infection were observed in teeth with 3-7 mm and >7 mm of intrusion (*P* = .001)

>7 mm, $P = .012$; HR = 2.97 for 3-7 mm, $P = .018$) and crown fracture (HR = 5.19, $P < .001$) were significant factors related to pulp necrosis and infection. Pulp survival in teeth with <3 mm of intrusion (52.4%, 11/21) was significantly higher than in teeth with 3-7 mm (39.1%, 9/23) and >7 mm (0, 0/3) of intrusion ($P = .001$, Figure 4). Teeth with uncomplicated crown fractures (85.7%, 18/21) had a higher incidence of pulp necrosis and infection than those without crown fracture (34.6%, 9/26) ($P < .001$, Figure 5, Table 5). In teeth with crown fracture, the incidence of pulp necrosis and infection was higher with moderate (3-7 mm) or severe (>7 mm) intrusion (100%, $P = .363$), though the difference was not statistically significant. In non-fractured teeth, pulp necrosis and infection occurred more often in mature teeth (44.4%, 4/9, $P = .667$) or in teeth with >3 mm of intrusion (43.8%, 7/16, $P = .399$), though the differences were not statistically significant (Tables 6 and 7). Kaplan-Meier estimates of the mean time for pulp necrosis and infection based on different factors are shown in Table 8.

Replacement resorption occurred in eight teeth (15.4%) (Table 5). The mean time to replacement resorption was 12.6 months (median: 10.5 months). Cox regression analysis showed that the significant factor in replacement resorption was the treatment method (HR = 5.72 for orthodontic repositioning, $P = .132$; HR = 11.68 for

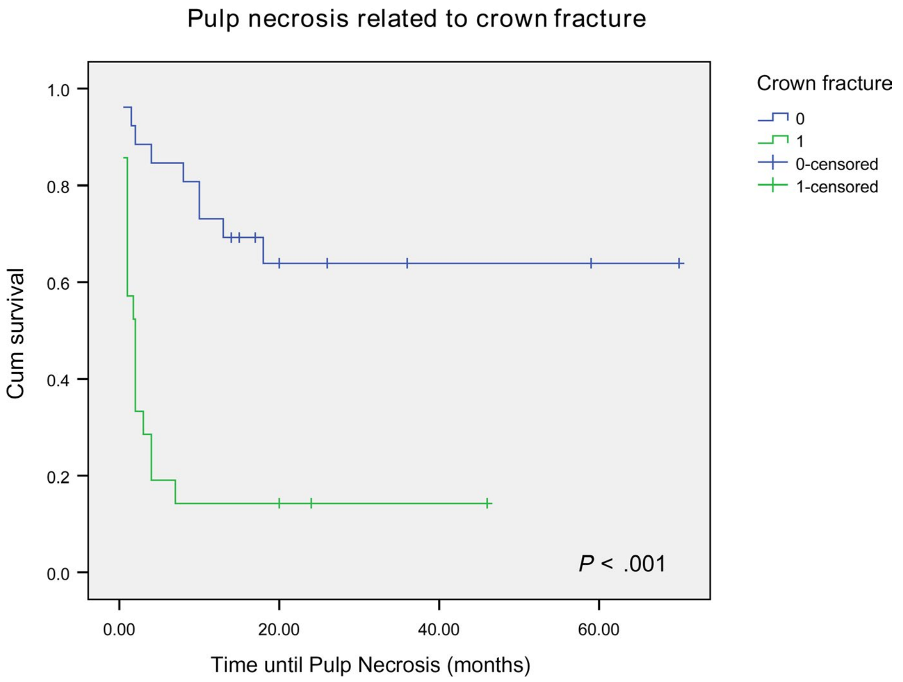

FIGURE 5 Kaplan-Meier analysis of pulp necrosis and infection in relation to crown fracture. Significantly more teeth with pulp necrosis and infection were observed in teeth with crown fracture and intrusion ($P < .001$). 0 = without crown fracture, 1 = with crown fracture

surgical repositioning, $P = .033$). Teeth that received orthodontic or surgical repositioning had a higher incidence of replacement resorption (23.1%, 25.0%, $P = .048$, Table 5; $P = .037$, Figure 6). Teeth with 3-7 mm or >7 mm of intrusion and teeth without crown fracture had higher incidences of replacement resorption (22.2%, 25.0%, $P = .022$; 22.2%, $P = .021$, respectively) (Table 5). When including crown fracture in the stratified analysis, teeth with crown fracture had a higher incidence of replacement resorption among mature teeth (11.8%, 2/17, $P = .212$) or teeth with >7 mm of intrusion (25%, 1/4, $P = .110$) (Table 6) even though the differences were not statistically significant. Kaplan-Meier estimates for the mean time to replacement resorption based on different factors are shown in Table 8.

Marginal bone loss was noted in 32 teeth (61.5%) (Table 5). The mean time to bone loss was 9.9 months (median: 4.0 months) after injury. No statistically significant differences were found for any related factors.

4 | DISCUSSION

In this retrospective study, the incidence of, and the factors related to, spontaneous re-eruption and complications of intruded permanent teeth in 6- to 18-year-old patients were analysed. The mean age in this study was 9.19 ± 2.34 years, which is similar to those reported in other studies.[8,11,14] The main cause for the dental trauma was falling (44.8%), as also reported by Andreasen et al (40.8%).[2]

The severity of intrusion and the extent of eruption and marginal bone loss were measured on radiographs following the method described by Andreasen et al.[2] The bisecting angle radiographic technique was not an optimal method for measuring the extent of intrusion or bone loss, reflecting a limitation of this retrospective study. However, the ImageJ program was used to measure those variables to reduce errors. In addition, the severity of intrusion was recorded as mild (<3 mm), moderate (3-7 mm) or severe (>7 mm).[7] Re-eruption was divided into complete re-eruption, partial re-eruption and no re-eruption, and bone loss was divided into two groups (yes or no) when performing analysis to reduce possible errors in the statistical analysis.

The incidence of spontaneous re-eruption (74.0%) in this study was lower than that in previous studies (88.2% and 94.6%),[8,10] and the mean time to complete re-eruption (0.5-18 months, mean 5.3 months) was similar to that in the study by Wigen et al[10] (3-12 months, mean 5.6 months), but the time range was wider. The mean age (7.75 ± 1.07) of patients with complete re-eruption was younger than that of patients with partial or no re-eruption, indicating that age is a factor influencing completely spontaneous re-eruption of intruded teeth. However, because of the small sample size in this study, no relationship between root development and spontaneous re-eruption was found. Cox regression and Kaplan-Meier analyses showed that teeth with <3 mm of intrusion had a higher re-eruption rate than those with 3-7 mm of intrusion (Figure 3), indicating that the severity of intrusion was another key factor in re-eruption.

Pulp necrosis and infection of the RCS is a common complication after intrusive luxation. In the present study, 57.4% of teeth developed pulp necrosis and infection, which is consistent with other studies (45.2%–75.0%).[7,10,11,13,14] Tsilingaridis et al[7] and Wigen et al[10] reported that 20.4%–35.3% of intruded teeth developed pulp canal obliteration during the follow-up period, but only 12.8% of teeth were found to have pulp canal obliteration in this study. Long-term follow up is needed in future studies to analyse pulp canal obliteration following intrusion. The risk of pulp necrosis and infection was higher in teeth with moderate or severe intrusion, indicating

TABLE 5 Pulp necrosis with infection, replacement resorption and marginal bone loss related to severity of intrusion, root development, crown fracture, pulp exposure, alveolar bone fracture and choice of treatment in teeth with more than 12 months follow up (n = 52)

	Pulp and periodontal complications, n (%)					
	Pulp necrosis with infection		Replacement resorption		Marginal bone loss	
		P-value		*P*-value		*P*-value
Severity of intrusion						
<3 mm	10 (47.6)	.293	1 (4.8)	.022	13 (61.9)	.883
3-7 mm	14 (60.9)		6 (22.2)		17 (63.0)	
>7 mm	3 (100.0)		1 (25.0)		2 (50.0)	
Root development						
Immature	11 (45.8)	.100	3 (12.0)	.153	13 (52.0)	.174
Mature	16 (69.6)		5 (18.5)		19 (70.4)	
Crown fracture						
Yes	18 (85.7)	<.001	2 (8.0)	.021	15 (60.0)	.826
No	9 (34.6)		6 (22.2)		17 (63.0)	
Pulp exposure						
Yes	3 (100)	.251	0	1.00	3 (75.0)	.565
No	24 (54.5)		8 (16.7)		29 (60.4)	
Alveolar bone fracture						
Normal	23 (62.2)	.209	6 (15.4)	.559	25 (64.1)	.510
Fracture	4 (40.0)		2 (15.4)		7 (53.8)	
Treatment						
Spontaneous re-eruption	13 (59.1)	.953	1 (4.3)	.048	11 (47.8)	.176
Orthodontic reposition	7 (53.8)		3 (23.1)		10 (76.9)	
Surgical reposition	7 (58.3)		4 (25.0)		11 (68.8)	
Total	27 (57.4)		8 (15.4)		32 (61.5)	52

TABLE 6 Root development and intrusion depth of teeth with crown fracture related to pulp necrosis with infection and replacement resorption (n = 25)

		Root development, n (%)			Intrusion depth, n (%)				
	N	Immature	Mature	*P*-value	<3 mm	3-7 mm	>7 mm	*P*-value	Total
Pulp necrosis with infection	21	6 (85.7)	12 (85.7)	1.000	8 (72.7)	7 (100.0)	3 (100.0)	.363	18 (85.7)
Replacement resorption	25	0	2 (11.8)	.212	1 (9.1)	0	1 (25.0)	.110	2 (8.0)

TABLE 7 Root development and intrusion depth of teeth with no crown fracture related to pulp necrosis with infection and replacement resorption (n = 27)

		Root development, n (%)			Intrusion depth, n (%)			
	N	Immature	Mature	*P*-value	<3 mm	3-7 mm	*P*-value	Total
Pulp necrosis with infection	26	5 (29.4)	4 (44.4)	.667	2 (20.0)	7 (43.8)	.399	9 (34.6)
Replacement resorption	27	3 (17.6)	3 (30.0)	.830	0	6 (35.3)	.110	6 (22.2)

TABLE 8 Kaplan-Meier estimated mean time of diagnosis of pulp necrosis with infection, replacement resorption and marginal bone loss (n = 52)

	Estimated mean survival time, months					
	Pulp necrosis with infection (n = 27)		Replacement resorption (n = 14)		Marginal bone loss (n = 32)	
Variables	Mean	95% CI	Mean	95% CI	Mean	95% CI
Severity of intrusion						
<3 mm	38.5	24.4, 52.7	66.3	59.3, 73.3	32.9	20.0, 45.7
3-7 mm	25.3	14.2, 36.4	50.0	36.4, 63.6	32.6	17.8, 47.3
>7 mm	0.8	0.5, 1.2	19.0	19.0, 19.0	44.8	3.3, 86.2
P-value	.001			.181	.810	
Root development						
Immature	39.2	25.8, 52.6	60.9	51.3, 70.4	44.8	29.9, 46.7
Mature	19.8	9.1, 30.4	43.7	32.3, 55.1	28.8	14.8, 42.9
P-value	.038			.474	.179	
Crown fracture						
Yes	8.3	1.6, 14.9	49.31	36.8, 61.8	35.8	19.6, 52.0
No	47.6	35.7, 59.5	52.93	40.8, 65.1	31.9	20.2, 43.7
P-value	<.001			.504	.922	
Pulp exposure						
Yes	1.8	0, 4.0		No statistics[a]	24.5	0, 59.9
No	33.7	23.8, 43.5			36.5	25.2, 47.8
P-value	.014				.617	
Alveolar bone fracture						
Normal	28.7	18.3, 39.1	56.3	46.3, 66.3	35.4	23.3, 47.6
Fracture	16.4	9.0, 23.7	23.1	19.3, 26.8	41.1	18.6, 63.6
P-value	.309			.835	.722	
Treatment						
Spontaneous eruption	36.3	25.2, 47.5		No statistics[a]	32.0	21.5, 42.5
Orthodontic movement	1.7	1.0, 2.3			58.7	16.5, 100.8
Surgical repositioning	22.1	5.6, 38.5			35.9	10.4, 48.5
P-value	.045				.448	

[a]No statistics are computed because all cases are censored during Kaplan-Meier analysis.

that these teeth should be repositioned orthodontically as soon as possible or they can be subjected to gingivectomy[10] to gain access to the root canal for treatment. Crown fracture was significantly related to pulp necrosis and infection in this study, which was also supported by Andreasen et al[15] This finding may be explained by the increased likelihood of bacterial invasion into the ischaemic pulp through the exposed dentinal tubules.[7,15] This association suggests that indirect pulp capping and dentin coverage, such as with resin restoration, should be performed as soon as possible to prevent bacterial invasion in such cases. When including crown fracture in the stratified analysis, pulp necrosis and infection was more likely to occur in mature teeth or teeth with moderate or severe intrusion which suggested that major factors related to complications are still root development and the severity of intrusion. Root development was found to be a significant factor in pulp necrosis and infection in several studies.[7,10,11,15] However, in this study, mature teeth had a higher rate of pulp necrosis and infection (69.6%) than immature teeth (45.8%), but the difference was not significant. A larger sample size is needed in the future to analyse this difference.

Replacement resorption occurred in 15.4% of all intruded teeth followed up for more than 12 months. A similar phenomenon was observed in other studies (12%–22%).[7,10,13,14] In research carried out by Andreasen et al,[15,16] replacement root resorption was significantly related to a >3-mm intrusion depth and orthodontic or surgical repositioning. Tsilingaridis et al[7] and Wigen et al[10] also showed that significantly fewer teeth were diagnosed with replacement resorption after awaiting re-eruption compared with orthodontic or surgical repositioning. In the present study, teeth with orthodontic or surgical repositioning and 3-7 mm or >7 mm of intrusion had significantly higher rates of replacement resorption,

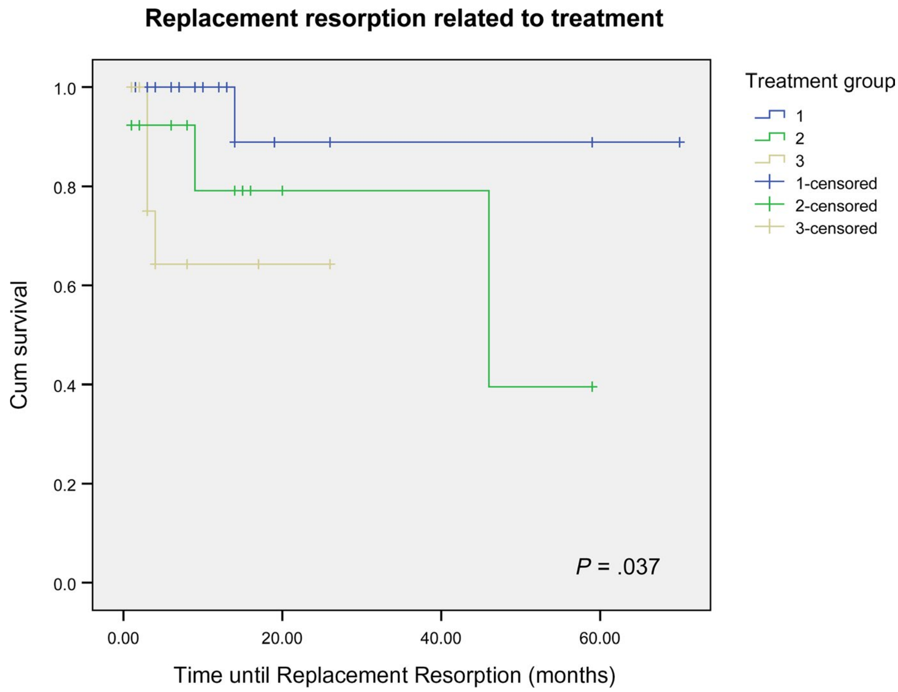

FIGURE 6 Kaplan-Meier analysis of replacement resorption in relation to treatment. Significantly more teeth with replacement resorption were observed with orthodontic or surgical repositioning ($P < .001$). 1 = awaiting spontaneous re-eruption, 2 = orthodontic repositioning, 3 = surgical repositioning

which supports previous studies. In addition, teeth with uncomplicated crown fractures developed less replacement resorption in this study, which may be explained by the force of destruction to the periodontium being reduced by the crown fracture. Similar to pulp necrosis, in teeth with crown fracture, the incidence of replacement resorption was higher in mature teeth or teeth with >7 mm of intrusion, again highlighting the two significant factors (root development and the severity of intrusion) in replacement resorption.

Marginal bone loss is another complication of tooth intrusion. Andreasen et al[15,16] suggested that this complication is significantly related to mature teeth, gingival laceration, orthodontic or surgical repositioning and splint type. In this study, teeth with mature roots or active repositioning had higher rates of marginal bone loss, but the differences were not significant.

The present study had certain limitations. First, the sample size was small and the follow-up period was short. Second, other significant variables related to replacement resorption and marginal bone loss, such as gingival laceration, splint type and antibiotic use, were not included in the study as they were not accurately recorded. Therefore, further studies with standardized, complete and detailed records, a large sample size and a long-term observation period are needed in the future.

5 | CONCLUSIONS

Intrusion depth was significantly related to complete spontaneous re-eruption. The severity of intrusion and crown fracture had strong relationships with the development of pulp necrosis and infection, whereas the choice of treatment influenced the development of replacement resorption.

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