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Original Article

Autotransplantation in Pediatric Dentistry: Factors Affecting Treatment Outcomes

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Abstract

This research aimed to evaluate the outcomes of autotransplantation in both children and adolescents, with a focus on root growth, and determine the clinical and radiographic factors associated with the success rate. In this study, 73 teeth, autogenously transplanted in 63 patients, were examined over an observation period of 3.2 years on average. The mean age at the time of autotransplantation was 11.9 years. Based on the radiographic criteria, the success rate was 73.97% and the survival rate was 100%. Based on the radiographic criteria, the success rate was 73.97%, and the survival rate was 100%. A significant increase in root length was observed in the transplanted teeth with an open apex. An association was found between the success rate and use of bone graft and surgeon experience. In conclusion, greater clinical experience in autotransplantation (> 36 cases) and prohibiting the use of bone grafts may improve the prognosis of the transplanted teeth in children and adolescents. [J Korean Acad Pediatr Dent 2024;51(3):245-264]

Keywords

Autotransplantation, Impaction, Root development, Pediatric dentistry, Success rate

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Introduction

The management of teeth with poor prognosis is challenging in pediatric dentistry. Major causes of dilemma in both children and adolescents include tooth impactions in remote sites or ectopically positioned teeth that require immediate intervention and even teeth with severe traumatic injuries on the verge of exfoliation[1-5]. Because conventional prosthetic treatments involving osseointegrated implants are inappropriate for growing pediatric patients, autogenous transplantation is often adopted in pediatric dentistry[6]. It is a surgical technique of

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transferring teeth from one place to another in the same individual, offering remodeling and growth of the alveolar bone induced by periodontal membranes. It further allows the formation of natural marginal gingiva efficiently[7,8].

A wide range of success rates of autotransplantation, from 62% to 100%, had been reported in the systematic review by Almpani et al.[9]. Such large variations may be the result of differences in radiographic and clinical criteria, and characteristics of the study samples among literatures; for instance, age groups, donor tooth types and observation periods[9]. Previous findings were more focused on conventional autotransplantation in late adolescence and adulthood with indications of hypodontia or loss of tooth due to trauma and periodontal diseases[9-11]. Therefore, results from these previous reports have limited information for impaction cases, which are major causes of dilemma in children and adolescents. Moreover, past research has mostly involved multi-rooted molars as the donors. Donor teeth with a cone-shaped single root are known to be more favorable for autotransplantation because the furcation area is known to be more prone to an increase in pocket depth and the loss of alveolar bone[12,13]. Such uncontrolled variables were not considered in the previous studies. Furthermore, more than one dental surgeon participated in the majority of studies, conveying the possibility of human errors[11]. Finally, given that most of the study participants were based in Western countries, there seems to be a need for further research that evaluates the possible gaps that can arise from ethnic differences. For example, the direction of displacement of impacted maxillary canines differs between the Western and Asian populations in that a greater prevalence of buccally displaced canines is noted in the Asian population[14]. Such differences may influence the prognosis of transplanted teeth. These aforementioned limitations observed in the previously reported studies have yet to be discussed in depth. Ultimately, studies on the prognosis of autransplantation in Asian children and adolescents with indications of impactions, performed by the same surgeon, are still lacking. Evaluations on how previously known contributing factors such as the developmental stage before autotransplantation, surgical technique, and extraoral time of the donor teeth differ in Asian children and adolescents would provide new insights[11,15-17].

This study aimed to retrospectively evaluate the postoperative sequelae and root growth of single-rooted transplanted teeth and assess factors affecting the outcomes of autotransplantation performed by the same surgeon in Korean children and adolescents.

Materials and Methods

1. Study participants

The study consisted of patients aged 7 - 19, who had undergone autotransplantation at the Department of Pediatric Dentistry, Seoul National University Dental Hospital, between January 2010 and December 2022. Patients with both preoperative and postoperative radiographic data comprised standardized panoramic radiography, intraoral radiography, or cone-beam computed tomography (CBCT), which were included in this study. Preoperative CBCT was taken between 1 week and 2 months prior to the surgery.

Exclusions were made for individuals with syndromic tendencies or systematic diseases with multiple impactions. Patients who failed to attend monthly checkups in the first 6 months after autotransplantation were also excluded. The study was approved thoroughly by the Institutional Review Board of Seoul National University Dental Hospital (IRB No. ER123036).

2. Surgical procedures for autotransplantation

All surgical procedures were carried out by the same dental surgeon under general anesthesia. The first step involved gaining access to the donor teeth in the case of transalveolar autotransplantation. After making vertical and circular incisions along the gingival margins, a full-thickness flap was elevated. Cortical bone demarcations were carefully made with a bur under continuous saline irrigation to reveal the crown of the donor teeth.

Then, the donor teeth were luxated to free their bodies from the impaction sites, minimizing root surface damage. After extraction, the teeth were stored in the original impaction site to keep periodontal tissues on the root surface as vital as possible. For conventional autotransplantation, erupted donor teeth were stored in their extraction socket. Recipient site preparations were then performed using the Oneplant System Surgical Kit (Warantec, Seoul, Republic of Korea) under copious saline irrigation to accommodate the donor teeth with 1 mm of excess space around the root. Bio-Oss Bone Graft (Geistlich, Wolhusen, Switzerland), a widely used bone-regenerating xenograft material, was adopted in minor cases with severe dehiscence. Bone graft materials were soaked in saline, and carefully placed into the areas of dehiscence after transplantation. The donor teeth were transplanted to the designated sites without any premature occlusal contact and flexibly splinted to the adjacent teeth with composites and nickel-titanium (Ni-Ti), copper-nickel-titanium (Cu-Ni-Ti), or nylon wires. If an individual had been receiving orthodontic treatment before autotransplantation, the composites were directly splinted to the main archwire. The periosteal flap was then sutured for primary closure. Amoxicillin 250 mg was prescribed postoperatively to be taken three times orally daily for 7 days. Splinting wires were removed after varying periods (as described in the Materials and Methods section), followed by orthodontic treatment if required. Transplanted teeth were evaluated clinically and radiographically during routine checkups. The post-operative schedule for intraoral radiographs was planned as follows: 1-week, 2-week, 1-month, and 3-month intervals. If clinical symptoms such as spontaneous pain or discomfort upon percussion and palpation and radiographic signs of periapical rarefaction appeared, root canal treatment was initiated immediately, regardless of apex status. Panoramic radiographs were taken every 6 months for periodic evaluation.

3. Patient records

Information on the patient's sex, age at autotransplantation, indications, types, developmental stage and eruption status of the donor teeth, presence of predecessors, location of recipient sites, use of bone graft, splinting type, splinting period, timing of orthodontic treatment, surgeon experience in autotransplantation, and observation period were retrospectively procured from electronic dental records and radiographic data.

Autotransplantation indications were categorized into the following subgroups suggested by Lundberg and Isaksson[10] and Kvint et al.[18] with minor modifications more suitable for children and adolescents: impactions, root malformations, traumatic injuries, and other cases that did not fit into the aforementioned categories. The developmental stages of the donor teeth were evaluated using the classification system designed by Demirjian and Goldstein[19], from stage 0 (without calcification) to stage H (complete closure of the apex). CBCT (Somatom Sensation 10, Siemens AG, Erlangen, Germany), which was taken approximately 2 months prior to the surgery, was used for the evaluation of the Demirjian stage. Eruption status was categorized as unerupted, partially erupted, and fully erupted. Tooth eruption is divided into preeruptive intraosseous stage, mucosal penetrance, and posteruptive (preocclusal and postocclusal) stage. Based on this method of division, a partially erupted state was defined as teeth at the moment of mucosal penetrance, with only cusps and tips shown intraorally. A fully erupted state was defined as teeth at the posteruptive stage[20]. This judgment was made based on electronic dental records and radiographic data. The presence of predecessors of the donor teeth at autotransplantation and the location of the recipient sites (maxilla or mandible) were also recorded. Types of splinting were categorized into no splinting, splinting with nylon, CuNiTi or NiTi wire. In addition, the length of the splinting period was divided into five categories: no splinting, direct orthodontic engagement without splinting, and 0 - 4, 4 - 8, and ≥ 8 weeks of splinting, as presented by Kokai et al.[21] who emphasized splint removal and engagement of orthodontic treatment between 4 and 8 weeks. The timing of orthodontic treatment was divided into three groups: no orthodontic treatment, preoperational, or postoperational orthodontic treatment. Operator experience in autotransplantation was defined as the first half of the cases (less experienced) and the latter half of the cases (more experienced). The period between the operation date and the most recent checkup date with both panoramic and periapical radiographic data was recorded as the observation period.

4. Records of treatment outcomes

1) Radiographic criteria for success

Success rate was evaluated based on the radiographic criteria presented by Czochrowska et al.[22] and Kallu et al.[11]. Samples fulfilling the following criteria were marked as successful: (1) no exhibition of root resorption, (2) absence of ankylosis, and (3) crown-to-root ratio < 1 for proper tooth function. The radiographic evaluation of root resorption was defined by resorption cavities present within the root or its surface, as stated in Andreasen's definitions[23]. Radiographically, ankylosis was defined as the absence of a radiolucent band between the alveolar bone and the root of the transplanted tooth[24]. Standardized intraoral radiographs taken using the parallel technique were used for both criteria. The root and crown lengths of the transplanted and contralateral control teeth were measured from the panoramic radiograph on the root apex and incisal tip to the coronal level of the alveolar bone using ImageJ (version 1.53e, Wayne Rasband, National Institutes of Health, MD, USA) [25].

2) Radiographic evaluation of the pulp condition

Further radiographic evaluation was performed on changes in the size of the pulp canal. The donor teeth, which had undergone root canal treatments, were noted and defined as nonvital. For vital teeth, changes in the size of the pulp canal were assessed by the following categories, based on the studies of Denys et al.[16]: constant (no changes in size), decreased (partial canal obliteration), and full canal obliteration. These changes were listed according to the recall period.

3) Radiographic evaluation of root development

Panoramic radiographs were used for the measurement of the crown-to-root ratio of the donor teeth and that of the contralateral control teeth[26]. Only the subgroup with control teeth was evaluated to examine if any differences exist between the ratio of the transplanted and control teeth[27]. The mean achievement in root growth, with the control teeth as a reference, was also determined according to the developmental stage[16]. Finally, changes in the root length grouped according to the tooth developmental stage was evaluated. The initial length of the root before autotransplantation was measured using CBCT. The final length of the root was measured using panoramic radiographs because CBCT was not taken after autotransplantation. Using the linear conversion ratio derived from a reference tooth (an untransplanted incisor), root length changes were calculated.

5. Statistical analysis

The baseline characteristics of study participants listed according to the donor tooth types were summarized using descriptive statistics, with means of Fisher's exact test of independence. The observation periods were assessed using the Kruskal-Wallis test, followed by Bonferroni's correction to analyze the between-group comparisons for the observation period. Changes in the pulp condition according to the recall period were examined using Fisher's exact test of independence. The crown-to-root ratios of the transplanted teeth, which were nonparametrically distributed, were compared with those of the contralateral nontransplanted control teeth using the Wilcoxon signed rank test. The mean achievement of the expected tooth length was evaluated among non-endodontically treated teeth using the one-way analysis of variance to test for significant associations, followed by Bonferroni's correction. The changes in the root length categorized according to the tooth developmental stage were analyzed using a one-way analysis of variance. Tukey's HSD was used as the post-hoc analysis. Associations among the candidate factors and radiographic treatment outcomes were determined using Fisher's exact test of independence. Finally, parameters showing significance with success rate using Fisher's exact test of independence were entered into the univariate binomial logistic regression model through the enter method, as highlighted by Andreasen et al.[28] and Gonnissen et al.[29]. Postoperative radiographic assessments of each transplanted tooth were performed by the same examiner and repeated twice within 4 weeks. The intraobserver agreement was high, with weighted Cohen's kappa values of 0.971 for root resorption, 0.955 for ankylosis, and 0.988 for the crown-to-root ratio, which indicate the reliability of the radiographic evaluation. Statistical analysis was performed using IBM SPSS Statistics for Windows version 26 (IBM Corp., Armonk, NY, USA).

Results

1. Distribution and baseline characteristics of the study participants

In total, 63 patients (male, n = 27; female, n = 36) with 73 autogenously transplanted teeth were included. The mean age of the patients at autotransplantation was 11.90 ± 1.38 (range, 7.76 - 15.82) years. Preoperative CBCT was taken at 35.71 ± 11.42 (range, 5.00 - 54.00) days on average before the surgery. The mean observation period was 38.88 ± 27.62 (range, 6.50 - 124.87) months. The major indication for autotransplantation was tooth impaction (97.26%). One case (1.37%) involved the transposition of the lateral incisor and canine, whereby both teeth were transplanted simultaneously to their ideal positions.

The success rate was 73.97%, with higher rates for transalveolar canine transplantation (84.48%). The distribution of the donor teeth and recipient sites with the respective success rates is summarized in Table 1. Cases involving transalveolar transplantations of canines and premolars are described in Fig. 1 and Fig. 2, respectively.

The baseline characteristics are summarized in Table 2. Statistically significant associations were found between the donor tooth type and age groups (p = 0.001) where expected frequencies for incisors, canines, and premolars were high for the groups aged 7 - 9, 11 - 13, and ≥ 13 years, respectively. Similar associations were revealed regarding the tooth developmental stage. A high percentage of incisor donors was at Demirjian stage F, whereas both canine and premolar donors were mostly at Demirjian stage G (p = 0.044). One partially erupted case (1.3%) was noted for transposition of the maxillary canine and the first premolar where the canine tip was observed buccally at high position between the first and second premolars. Furthermore, predecessors were more likely present for the canine and premolar donors than for incisor donors (p = 0.010). The percentage of transplantation to the maxilla was greater for incisor and canine donors, whereas that to the mandible was greater for premolar donors (p = 0.002). Moreover, no orthodontic treatment was provided after autotransplantation in most cases for premolars. In contrast, incisor and canine donors received orthodontic treatment more often (p = 0.008). Finally, the observation time for the canine donors was significantly greater than that for incisor donors; however, no associations were found among the rest (p = 0.041).

Table 1. The distribution of donor teeth and recipient sites that meet the success criteria

Donor tooth type	Recipient site	Transplanted teeth n (%)	Success rate n (%)
Incisor	Incisor	4 (5.48)	2 (50.00)
Canine	Canine	58 (79.45)	49 (84.48)
	Premolar	2 (2.74)	1 (50.00)
Premolar	Incisor	1 (1.37)	0 (0.00)
	Premolar	8 (10.96)	5 (62.50)
Total		73 (100.00)	54 (73.97)

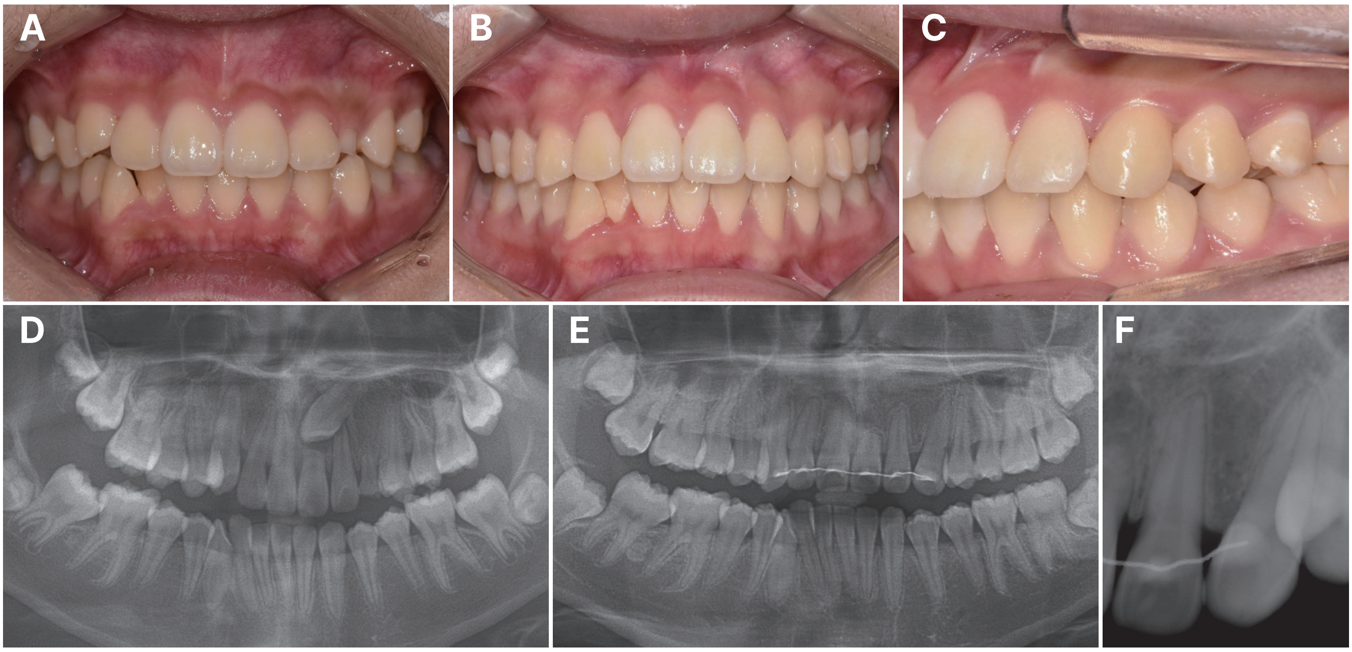

Fig. 1. Clinical photographs, panoramic, and periapical radiographs of an 11-year-old female with the left maxillary canine in the ectopic eruption pathway were taken before and after the treatment. In (A) and (D), hyperplastic follicles of the canine and root resorption of the left central incisor were clearly evident. Orthodontic treatment was engaged following autotransplantation to align and close interdental spaces. In (B), (C), and (E), clinical photographs and radiographs taken 4 years after autotransplantation. In (F), radiographic healing without any signs of ankylosis or resorption is evident.

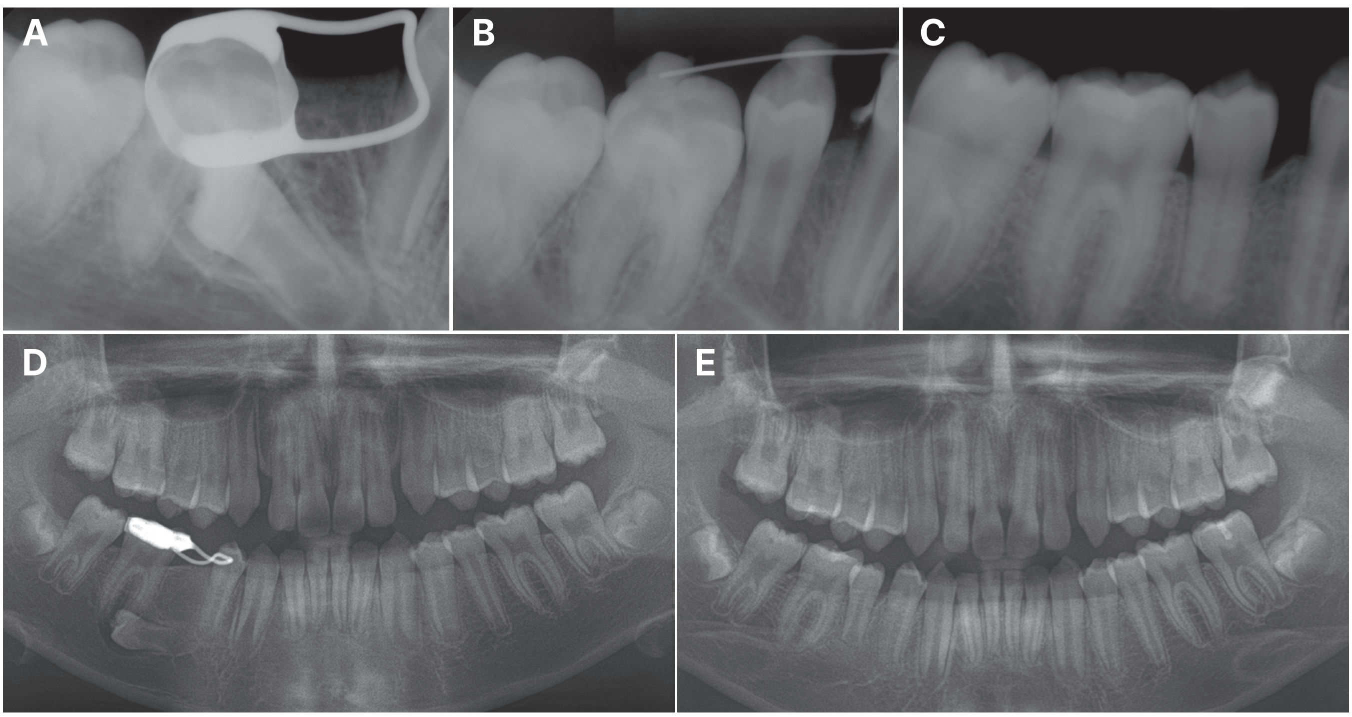

Fig. 2. Panoramic and periapical radiographs of an 11-year-old male with the right mandibular second premolar in the ectopic eruption pathway were taken before and after the treatment. In (A) and (D), a spontaneous eruption of the premolar failed to occur despite the efforts of the space maintainer. In (B), flexible wire splinting was performed with Ni-Ti wire subsequent to autotransplantation. In (C) and (E), panoramic and periapical radiographs were taken 1.5 years after autotransplantation.

Table 2. The baseline characteristics of study subjects according to their tooth type

Characteristics	Tooth type Incisor n (%)	Canine n (%)	Premolar n (%)	*p* value	Total n (%)
Age (year)†					
7 - 9	2 (50.0)	0 (0.0)	0 (0.0)	0.001	2 (2.7)
9 - 11	1 (25.0)	17 (28.3)	0 (0.0)		18 (24.7)
11 - 13	1 (25.0)	32 (53.3)	4 (44.4)		37 (50.7)
≥ 13	0 (0.0)	11 (18.4)	5 (55.6)		16 (21.9)
Gender†					
Male	2 (50.0)	23 (38.3)	5 (55.6)	0.565	30(41.1)
Female	2 (50.0)	37 (61.7)	4 (44.4)		43(58.9)
Tooth developmental stage (Demirjian stage) †					
F	2 (50.0)	3 (5.0)	2 (22.2)	0.044	7 (9.6)
G	1 (25.0)	37 (61.7)	5 (55.6)		43 (58.9)
H	1 (25.0)	20 (33.3)	2 (22.2)		23 (31.5)
Eruption status†					
Unerupted	3 (75.0)	57 (95.0)	8 (88.9)	0.240	68 (93.2)
Partially erupted	0 (0.0)	1 (1.7)	0 (0.0)		1 (1.3)
Erupted	1 (25.0)	2 (3.3)	1 (11.1)		4 (5.5)
Presence of predecessors†					
No	4 (100.0)	16 (26.7)	2 (22.2)	0.010	22 (30.1)
Yes	0 (0.0)	44 (73.3)	7 (77.8)		51 (69.9)
Recipient site†					
Maxilla	4 (100.0)	53 (88.3)	3 (33.3)	0.002	60 (82.2)
Mandible	0 (0.0)	7 (11.7)	6 (66.7)		13 (17.8)
Use of Bone graft†					
No	4 (100.0)	56 (93.3)	8 (88.9)	0.636	68 (93.2)
Yes	0 (0.0)	4 (6.7)	1 (11.1)		5 (6.8)
Types of splinting†					
No splinting	0 (0.0)	1 (1.7)	0 (0.0)	0.815	1 (1.4)
Nylon wire	0 (0.0)	6 (10.0)	2 (22.2)		8 (11.0)
Cu-NiTi wire	4 (100.0)	35 (76.7)	6 (66.7)		56 (76.7)
NiTi wire	0 (100.0)	7 (11.7)	1 (11.1)		8 (11.0)
Splinting period†					
No splinting	0 (0.0)	1 (1.7)	0 (0.0)	0.920	1 (1.4)
Direct loading without splinting	0 (0.0)	7 (11.7)	0 (0.0)		7 (9.6)
0 - 4 weeks	1 (25.0)	23 (38.3)	4 (44.4)		28 (38.4)
4 - 8 weeks	3 (75.0)	21 (35.0)	4 (44.4)		28 (38.4)
≥ 8 weeks	0 (0.0)	8 (13.3)	1 (11.2)		9 (12.2)
Timing of orthodontic treatment†					
None	1 (25.0)	12 (20.0)	7 (77.8)	0.008	20 (27.4)
Pre-operational	1 (25.0)	23 (38.3)	1 (11.1)		25 (34.2)
Post-operational	2 (50.0)	25 (41.7)	1 (11.1)		28 (38.4)
Surgeon's experience†					
First half	2 (50.0)	28 (46.7)	6 (66.7)	0.532	36 (49.3)
Later half	2 (50.0)	32 (53.3)	3 (33.3)		37 (50.7)
Total	4	60	9		73
Observation period (Mean ± SD, month)‡	$13.7 \pm 6.2_a$	$41.1 \pm 28.2_b$	$35.6 \pm 25.0_{ab}$	0.041	38.9 ± 27.6

† : Fisher's exact test; ‡ : Kruskal-Wallis test; Cu-NiTi: Copper-Nickel-Titanium; NiTi: Nickel-Titanium.
Note: Means not sharing subscripts differ significantly at α = .01 as indicated by Bonferroni's correction.

2. Treatment outcomes

Overall, 14 (19.2%) and 4 (5.5%) transplanted teeth had no signs of root resorption and ankylosis, respectively. In addition, 7 (9.59%) teeth had a crown-to-root ratio of ≥ 1, and 16 (21.92%) teeth had received root canal treatment after autotransplantation (Table 3). Table 4 shows changes in the pulp condition of the transplanted teeth grouped according to the recall period. Moreover, 16 (21.9%) transplanted teeth had received root canal treatment, with the majority performed between 1 and 5 years of the recall period. The size of most of the pulp remained constant in the first year. However, over time, a greater percentage of the pulp canal narrowed and eventually became fully obliterated ($p = 0.003$).

Table 3. Summary of the radiographic outcomes of the transplanted teeth

Resorption n (%)	Ankylosis n (%)	Crown-to-root ratio ≥ 1 n (%)	Success rate n (%)
14 (19.18)	4 (5.48)	7 (9.59)	54 (73.97)

In this study, 54 transplanted teeth with available contralateral teeth were screened to evaluate differences between the crown-to-root ratios of the transplanted and control teeth. Fig. 3 shows the relationship between the root and the crown length to determine the distribution of the transplanted and the control. Only 6 samples among the transplanted teeth had a crown-to-root ratio of ≥ 1. The mean crown-to-root ratio of the transplanted teeth was 0.77 and that of the control teeth was 0.62 ($p < 0.0001$, Fig. 4). None of the transplants reached the

Table 4. Changes in the size of the pulp subsequent to autotransplantation, ordered by the last recall period

Pulp status	Recall period (years), n (%)				
	≤ 1 year	1 - 5 years	> 5 years	Total	*p* value
Constant	5 (62.5)	9 (16.4)	0 (0.0)	14 (19.2)	0.003
Decrease in size	3 (37.5)	14 (25.5)	3 (30.0)	20 (27.4)	
Full obliteration	0 (0.0)	21 (38.2)	2 (20.0)	23 (31.5)	
Endodontic treatment	0 (0.0)	11 (20.0)	5 (50.0)	16 (21.9)	
Total	8	55	10	73	

p value from Fisher's exact test of independence.

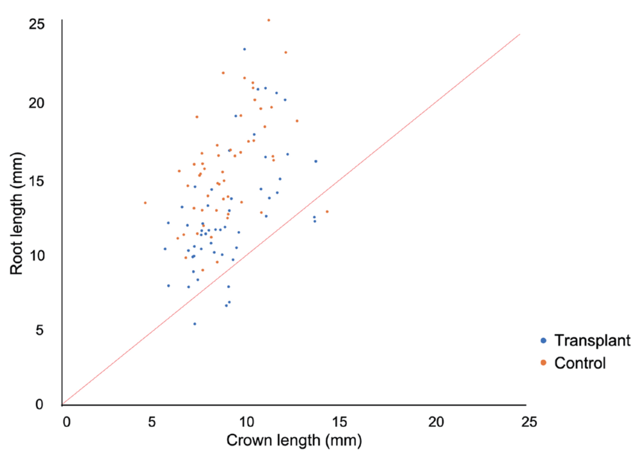

Fig. 3. Scatterplot of the root (y-axis) and crown lengths (x-axis) for 54 autogenously transplanted teeth and for the contralateral natural tooth (control) in the same patients. 19 transplanted teeth without the control tooth were excluded. The red diagonal line refers to the crown-to-root ratio of 1.

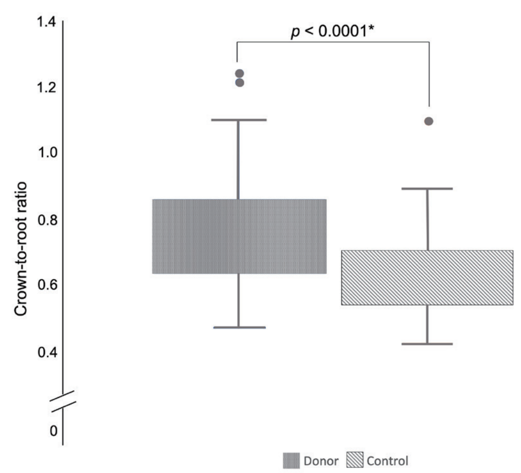

Fig. 4. Boxplot of crown-to-root ratios of the transplanted and contralateral control teeth. The values denoted in the box plot refer to the mean crown-to-root ratio. *p* value was derived from Wilcoxon signed rank test.

final root length, with control teeth as the reference (mean achievement in root length = 82.27%, Table 5). No significant associations were observed regarding the mean achievement in root length and tooth developmental stages (p = 0.895). The changes in root length were grouped according to the tooth developmental stages (Table 6). A greater and more significant increase in root length was observed between the transplanted teeth at Demirjian stages F and G when compared to stage H (p = 0.000). However, no significant differences were noted between Demirjian Stages F and G.

3. Factors affecting the treatment outcomes

The association between each of the parameters and radiographic outcomes including signs of resorption, ankylosis, and crown-to-root ratios ≥ 1 was thoroughly determined. Two parameters were significantly associated with root resorption (Table 7). More frequent resorptions were observed when using bone grafts during autotransplantation (odds ratio (OR) = 23.20, p = 0.004). Significant associations with the operator's experience were evident (OR = 0.201, p = 0.019). Parameters showing no signifi-

Table 5. The achievement of the expected tooth length, or residual, listed according to the tooth's developmental stage

Tooth developmental stage (Demirjian stage)	n (%)	Achievement of expected tooth length (%)	
		Mean ± SD	p value
F	5 (9.26)	84.81 ± 12.17	
G	32 (59.26)	82.02 ± 12.63	0.895
H	17 (31.48)	81.99 ± 12.74	
Total	54 (100.00)	82.27 ± 12.41	

p value from one-way analysis of variance.

Table 6. Post-operative root growth, according to the Demirjian stage at the time of autotransplantation

Tooth developmental stage (Stage)	Changes in root growth after autotransplantation (mm)			
	n (%)	Mean ± SD	F	p value
F	7 (9.59)	$4.33 \pm 3.14_a$		
G	43 (58.90)	$3.82 \pm 2.50_a$	13.448	0.000
H	23 (31.51)	$0.11 \pm 0.81_b$		

p value from one-way analysis of variance.
F: the ratio of the two sample variances.
Note: Means not sharing subscripts differ significantly at α = .01 as indicated by Tukey's HSD.

Table 7. Associations between candidate prognostic factors and root resorption

Variables	OR	95% CI	p value
Age	-	-	0.698
Gender	1.094	0.336 - 3.556	1.000
Donor tooth type	-	-	0.468
Tooth developmental stage	-	-	0.399
Eruption status	-	-	1.000
Presence of predecessors	1.742	0.434 - 6.982	0.531
Recipient site	0.45	0.116 - 1.752	0.258
Use of bone graft	23.2	2.345 - 229.504	0.004
Splinting period	-	-	0.111
Timing of orthodontic treatment	-	-	0.318
Surgeon's experience	0.201	0.051 - 0.795	0.019

p value from Fisher's exact test of independence.
OR: odds ratio; CI: confidence interval.

cant associations were age (*p* = 0.698), sex (*p* = 1.000), donor tooth type (*p* = 0.468), tooth developmental stage (*p* = 0.399), apical status (*p* = 0.347), eruption status (*p* = 1.000), presence of predecessors (*p* = 0.531), recipient site (*p* = 0.258), splinting period (*p* = 0.111), and timing of orthodontic treatment (p = 0.318). Similarly, the use of bone grafts was significantly associated with ankylosis (OR = 22.000, *p* = 0.022, Table 8). The following parameters did not show any significant associations: age (*p* = 0.695), sex (*p* = 1.000), donor tooth type (*p* = 0.552), tooth developmental stage (*p* = 0.203), eruption status (*p* = 0.252), presence of predecessors (*p* = 0.579), recipient site (0.552), splinting period (*p* = 0.125), timing of orthodontic treatment (*p* = 0.370), and surgeon experience (*p* = 0.054). Donor tooth type (OR = 0.311, *p* = 0.011) displayed statistical significance to the crown-to-root ratio of the transplanted teeth (Table 9). Age (*p* = 0.094), sex (*p* = 0.692), tooth developmental stage (p = 0.487), apical status (*p* = 0.671), eruption status (*p* = 0.405), presence of predecessors (*p* = 0.424), recipient site (*p* = 1.000), splinting period (*p* = 0.799), orthodontic treatment (*p* = 0.275), use of a bone graft (*p* = 0.405), and operator experience (*p* = 0.228) were not significantly associated with the postoperative crown-to-root ratio of the transplanted tooth.

Table 8. Associations between candidate prognostic factors and ankylosis

Variables	OR	95% CI	*p* value
Age	-	-	0.695
Gender	1.464	0.195 - 11.016	1.000
Donor tooth type	-	-	0.552
Tooth developmental stage	-	-	0.203
Eruption status	-	-	0.252
Presence of predecessors	0.408	0.054 - 3.101	0.579
Recipient site	0.632	0.060 - 6.604	0.552
Use of bone graft	22.000	2.259 - 214.227	0.022
Splinting period	-	-	0.125
Timing of orthodontic treatment	-	-	0.370
Surgeon's experience	0.889	0.792 - 0.998	0.054

p value from Fisher's exact test of independence.
OR: odds ratio; CI: confidence interval.

Table 9. Associations between candidate prognostic factors and crown-to-root ratios

Variables	OR	95% CI	*p* value
Age	-	-	0.094
Gender	1.842	0.333 - 10.194	0.692
Donor tooth type	0.311	0.312 - 7.964	0.011
Tooth developmental stage	-	-	0.487
Eruption status	-	-	0.405
Presence of predecessors	1.855	0.379 - 9.088	0.424
Recipient site	0.750	0.082 - 6.820	1.000
Use of bone graft	0.387	0.037 - 4.043	0.405
Splinting period	-	-	0.799
Timing of orthodontic treatment	-	-	0.275
Surgeon's experience	2.823	0.511 - 15.600	0.261

p value from Fisher's exact test of independence.
OR: odds ratio; CI: confidence interval.

Finally, the multivariate analysis on identifying key prognostic factors affecting success rates was performed (Table 10). The splinting type was excluded from the multivariate analysis as it showed multicollinearity with the splinting period. The use of a bone graft (unstandardized regression weight (β) = -3.852, OR = 0.021, 95% confidence interval (CI) = 0.001-0.816, p = 0.039) and operator experience (β = 1.553, OR = 4.724, 95% CI = 1.041 - 21.432, p = 0.044) were significantly associated with success rates. Despite significance with means of Fisher's exact test of independence, the patient's age at autotransplantation, splinting period, and timing of orthodontic treatment were considered less critical in the final regression model.

Discussion

Autotransplantation is a versatile surgical technique with high potential that can be used to solve problems such as aplasia, impaction, tooth loss due to traumatic injuries, periodontal diseases, or other unfortunate events in all age groups. On many occasions, autotransplantation is performed to replace the missing tooth in the case of aplasia in adults. According to Lundberg's study on 278 autotransplanted teeth[10], the majority of the indications for autotransplantation was aplasia (60.43%), followed by caries and associated diseases (23.38%), impaction (8.27%), and trauma (3.24%). Similarly, in the studies by Kvint et al.[18], autotransplantation indicators were mainly aplasia (48.84%), displacement (21.86%), and caries-associated diseases (12.56%). Conversely, in this study, the major indication was tooth impaction. The overall frequency of individual-based permanent tooth eruption disturbances is reported to be approximately 20%[30]. Specifically, the maxillary canine is the second most prevalent tooth in terms of ectopic eruption, af-

Table 10. Factors affecting the success rate after autotransplantation

Factors	β	Standard error	OR	95% CI	p value
Age					
≥ 13	1				
11 - 13	-1.615	1.816	0.199	0.006 - 6.984	0.374
9 - 11	0.448	1.152	1.565	0.164 - 14.977	0.697
7 - 9	-1.872	1.063	0.154	0.019 - 1.235	0.078
Use of bone graft					
No	1				
Yes	-3.852	1.862	0.021	0.001 - 0.816	0.039
Splinting period					
≥ 8 weeks	1				
4 - 8 weeks	-2.345	1.553	0.096	0.005 - 2.012	0.131
0 - 4 weeks	-0.997	1.401	0.369	0.024 - 5.750	0.477
Direct loading without splinting	19.531	14232.241	303499716.0	0.000	0.999
No splinting	18.533	40192.969	111831791.8	0.000	1.000
Timing of orthodontic treatment					
None	1				
Pre-operational	-0.557	1.164	0.573	0.059 - 5.606	0.632
Post-operational	1.290	1.010	3.633	0.502 - 26.286	0.201
Surgeon's experience					
First half	1				
Later half	1.553	0.772	4.724	1.041 - 21.432	0.044

p value from binomial logistic regression analysis.
β: unstandardized regression weight; OR: odds ratio; CI: confidence interval.

fecting approximately 2% of the population[31,32]. This explains why transalveolar transplantation of the canine had the highest percentage among other types of donor teeth (79.45%, Table 1). These data provide a glimpse of the clinical potential of autotransplantation in tooth impactions in children and adolescents. In a rare case, conventional transplantation of an erupted premolar to the incisor site (1.37%) was performed to replace central incisors with congenital root malformations. The reliability of such conventional transplantation was demonstrated by Czochrowska et al.[25] who successfully used premolars as a donor to replace central incisors lost from trauma. Similar to studies by Plakwicz et al.[27], we included transplanted teeth with an observation time of at least 6 months to determine legitimate and reliable results.

All of the transplanted teeth, even premolars, were single-rooted in our study. This coherence regarding root morphology is significant since the furcation area of multi-rooted teeth may be more susceptible to inflammation[12,13]. In fact, from the age above 30 years, at least 1 furcation involvement was observed in 50% of molars[33]. Differences in the degree of healing in single-rooted and multi-rooted teeth should be controlled so that the weight of other prognostic factors can be accurately determined. In this manner, our study opted out the candidate factor related to furcations, increasing the reliability of our results.

Large variations in the success rates of the transplanted teeth exist, as confirmed in various articles[9]. This variation may be due to the differences in the radiographic or clinical criteria, sample size, age groups, tooth types, and observation periods. In this study, the success criteria involved the absence of both root resorption and ankylosis and teeth with a crown-to-root ratio of < 1 based on well-established criteria. Kokai et al.[21] reported a success rate of 71% with 5.8-year follow-up for 100 teeth with closed apex. Czochrowska et al.[22] examined 33 teeth with a success rate of 79%, with 26.4-year follow-up. Similarly, Kallu et al.[11] revealed a success rate of 68%, with an observation period of 3.8 years for 273 teeth. In the present study, the success rate was 73.97% for 73 teeth, with a mean observation period of 3.2 years, falling in the range reported previously (Table 2). The lower success rate was noted for incisors (50%) and premolars (55.6%) as the donor teeth. Because 93.2% of the donor teeth were impacted, surgical maneuvers to proclaim the teeth from the impaction site were inevitable in our studies. Possible damage on the root surface of the donor teeth might have affected the prognosis. Conversely, a greater success rate was noted for canine autotransplantation (83.3%) compared with the results of Kallu et al.[11] (51%). Possible explanations for these differences lie in the anteroposterior position of the canines. Palatally displaced canines are approximately two times more frequently observed, except in Asian populations where more buccally displaced canines are seen[14,34-37]. Palatal impactions make surgical accessibility more challenging[38]. In general, buccally displaced canines are easier to access in terms of surgical exposure, minimizing root surface damage.

The orthodontic traction of deeply impacted teeth or teeth with unfavorable orientations has a poor prognosis. In this case, the extraction of the impacted teeth may be the only option apart from transalveolar autotransplantation, which is considered the last resort[39]. Even in the presence of postoperative sequelae such as resorption and ankylosis after surgery, transplanted teeth are likely to survive without exfoliation in children and adolescents[40]. Therefore, 26.03% of “failed” cases do not literally refer to failures in our study.

The eruption timing of incisors, canines, and premolars ranged from 7 - 8, 11 -12, and 10 - 12 years, respectively[41]. Deviation from this range would make parents question the “missing” teeth, and they would seek treatment if necessary. Although some patients may coincidentally notice the impaction during a routine checkup at a dental clinic, the parents are highly likely curious about the reason for its absence. This partly explains why the high percentage of transplantations of incisors, canines, and premolars were performed at the ages of 7 - 9, 11 - 13, and ≥ 13 years, respectively ($p = 0.001$).

The tooth developmental stage of the donor teeth is an important factor that must be first considered because it influences the prognosis of the transplant. Specifically, when the root formation of two-thirds to three-quarters is achieved, it is adequate for optimal autotransplantation[16,42-44]. Thus, in this study, the tooth developmental stage at the time of operation was mostly Demirjian stage G for canines and premolars. Conversely, approximately half of the transplanted incisors were at stage F (p = 0.044). This may be because the impacted incisors with their crown facing the nasal floor usually accompany root underdevelopment and dilacerations[45].

Prolonged retention of primary predecessors is usually associated with the presence of local factors such as the supernumerary teeth and the ectopic eruption of the impacted teeth. Henklein et al.[46] noted a higher incidence of primary predecessors for impacted canines and premolars, whereas none were present for the incisors. In accordance with these previous studies, the presence of predecessors at the time of autotransplantation was significantly associated with the canines and premolars but not with the incisor site (p = 0.01). Prolonged retention of primary incisors may be rarely observed because the neighboring permanent central or lateral incisors, which are approximately 1.3 times wider in the mesiodistal width, take up the available space, leading to premature exfoliation[47]. The primary predecessors of canines and premolars are usually retained well without root resorption unless pulp treatment or restorative treatments are performed beforehand[46].

The transalveolar transplantation of maxillary canines, the second most prevalent tooth for impaction, was predominant in our study[32]. This explains the finding that most of the recipient sites were in the maxilla (p = 0.002). Premolars usually have sufficient space for eruption owing to the presence of a leeway space[48]. Thus, pre-orthodontic treatment for space acquisition was relatively less likely to be needed for premolars. The need for space acquisition and esthetic alignment of the anterior teeth might increase the need for orthodontic treatment (p = 0.008). Finally, the observation period of canine and premolar transplantations was longer than that of incisor transplantation (p = 0.041). Incisors as donors only take up a small percentage of 73 cases (5.48%); therefore, the statistical significance observed among the donor teeth regarding the follow-up periods may not be clinically meaningful.

The resorption rate (19.18%) was relatively higher than those reported in previous studies by Lundberg and Isaksson[10] (7.91%), Kallu et al.[11] (21.3%), and Kokai et al.[21] (10%). The preservation of periodontal tissues on the root surface of the donor teeth is paramount. Because the accessibility of the deeply impacted donor teeth is usually limited, root surface damage upon extraction might be inevitable[38]. However, this statement cannot explain the reason why the percentage of teeth with signs of ankylosis (5.48%) was lower than that in previous studies: Kallu et al.[11] reported 13.6%, and Kokai et al.[21] revealed 15%. Long-term rigid splinting and the lack of occlusal stimuli increase the incidence of ankylosis[49,50]. As a postoperative intervention to minimize the risk of ankylosis, the orthodontic loading after the healing period has shown positive effects[51,52]. In the present study, orthodontic biologic loading was employed in over two-thirds of cases (72.6%). This may partly explain the comparably lower incidence of ankylosis.

Pulp healing in the form of varying degrees of calcification was observed. In our study, 62.5% of the transplanted teeth falling into the category of $\leq$ 1-year recall period showed no changes in the size of the pulp canal. This shows that signs of canal calcification within a year were only evident in about one-third of cases. This result was in agreement with the previous findings that signs of canal calcification were evident 6 months after autotransplantation, and such phenomena are not considered pathological sequelae[16,28]. Between 1 and 5 years of recall period, 63.7% of teeth revealed radiographic signs of obliteration. The connective tissue originating from the local periodontal ligaments may be incorporated into the pulp canal, which is responsible for this repair. Despite being unidentical histologically from the pulp tissue, it induces the formation of reactive or reparative dentin, leading to gradual canal obliteration[53]. The transplanted teeth with a closed apex usually undergo root canal treatment within 2 weeks after surgery[21]. In this study, the percentage of teeth with a closed apex was 31.5%, whereas the percentage of teeth that have undergone endodontic treatment was 21.92%. Clearly, not every fully developed tooth received root canal treatment after autotransplantation. Only teeth showing clinical symptoms to percussion and palpation were endodontically treated. This implies that teeth with a closed apex may not necessarily need root canal treatment in children and adolescents, suggesting some differences in healing potential compared with adults. The transplanted teeth evaluated at > 5-year recall period had conveyed that some of the transplanted teeth had received root canal treatment at some point during the observation period. Not every transplanted tooth with an open apex sustained pulp vitality throughout the observation period. According to Denys et al.[16], it is advisable to perform root canal treatment on teeth with an open apex even in the absence of clinical symptoms due to the plausibility of pulpal necrosis and inflammatory resorption at any time. Ten teeth (20%) among the transplanted teeth with open apex had undergone root canal treatments since radiographic signs of periapical rarefaction appeared. This emphasizes the importance of periodic examination of the transplanted teeth. Based on our results, transplanted teeth with an open apex are not advised to be endodontically treated until clinical or radiographic signs appear.

The percentage of the transplanted teeth with a crown-to-root ratio of ≥ 1 was similar to those reported by Kallu et al.[11] (5.5%) and Czochrowska et al.[22] (6.06%). However, none of the transplanted teeth reached the final root length (contralateral control teeth as a reference), similar to the results reported by Andreasen et al.[42]. Certain reductions in root length may be due to damage on Hertwig's epithelial root sheath. Furthermore, the lag period before the full vascularization at the root apex of the donor teeth might lead to a delay in nutrition supply. The ectopic positioning of the donor teeth to the recipient sites to ensure infraocclusion may also influence revascularization[42]. Moreover, similar to studies by Westerveld et al.[26], no significant results were revealed among the developmental stage and the mean achievement in the final tooth length (Table 6). Determining the stage of tooth development with the Demirjian stage is difficult when the root formation lies in between two discrete stages; therefore, it is considered only an estimate. Further information such as the width of the root apex would be a more reliable indicator in the determination of the stage of tooth development[26]. The transplanted teeth with a wider apical width and root development > 50% of the final length have a longer final root length[26,42]. Thus, root development stages must always be considered before autotransplantation.

Clinically, the amount of root growth after autotransplantation must be determined. These findings aim to reveal if the amount of root development differs among the transplanted teeth at different Demirjian stages. The transplanted teeth with an open apex (Demirjian stages F and G) both showed a significant increase in root length when compared to the teeth with a closed apex (Demirjian stage H), as depicted in Table 6. All transplanted teeth with an open apex showed root development (none of them ceased to grow). This result from our study was in agreement with the results published by Lucas-Taulé et al.[54], who reported that over 84.1% of teeth with open apex showed root formation. Data on Demirjian stage H was evaluated to take into account of the possible errors in measurements because it represents teeth with complete root development with a closed apex. The mean root growth of 0.11 ± 0.81 mm was set as a reference for ceased development. No significant differences in the amount of root growth were observed between the transplanted teeth at Demirjian stages F and G. These findings were in accordance with studies reported by Andreasen et al.[42] and Slagsvold and Bjercke[43] that an increase in root length was observed when autotransplantation was performed between one-half and three-quarters of the expected root length. No significant differences were observed within this length. It can be concluded that significant root growth can be expected in teeth with open apex.

Similar to previous studies[27], the crown-to-root ratio of the transplanted teeth was greater than that of the control teeth (Fig. 4, $p < 0.0001$). Only 6 transplanted teeth had a crown-to-root ratio of ≥ 1 (Fig. 3). According to Plakwicz et al.[27], as the difference only represents roots that are 1 - 1.25 mm shorter for transplanted teeth, it may not be clinically significant.

Bone grafts are widely used to promote the healing of intrabony defects via periodontal regeneration. In the case of implantation of titanium fixtures in regions with large defects, bone grafts can act as pillars for primary stability[55]. In such cases, bone grafts are crucial since titanium fixtures do not possess periodontal ligament cells, whereby bone-tissue regenerating potential is absent. Conversely, autogenously transplanted teeth have periodontal ligament cells on the surface of the root capable of inducing bone formation. These differences had given rise to a controversial issue regarding the necessity for the use of bone graft upon autotransplantation. According to Suwanapong et al.[56], even in the case of excess bone removal during recipient site preparation, complete trabeculation of alveolar bones was seen within 12 months without any signs of inflammation. The healing of transplanted teeth was not dependent on the amount of remaining bone at the recipient site. Since trauma to the donor root surface due to insufficient recipient site preparation acted as greater threat, extensive bone removal was recommended. Moreover, the use of bone grafts did not significantly improve healing in terms of bone regeneration, as highlighted by Bauss et al.[57] and Miura et al.[58]. Instead, bone grafts disturbed the stability of the transplant. In autotransplantation where immediate revascularization is paramount, the presence of bone grafts might hinder the supply of nutrients to the transplanted donor teeth. This explains the higher rates of root resorption, ankylosis, and a lower success rate with the use of bone grafts. Intriguingly, the rate of bone formation was faster in the patients under 18 years, relative to older patients[56]. These results further emphasized the lack of need for bone grafts upon autotransplantation in children and adolescents. Thus, the criteria for the use of a bone graft are still unclear. In our study, a bone graft was utilized in the case of severe dehiscence, approximately 3 to 4 times greater than the width of the crown of the donor teeth. Such dehiscence was often observed in impacted canines with hyperplastic follicles. Based on the results from our study, bone grafts should not be used even in the presence of large bony defects. Preservation of periodontal ligament cells is more crucial without exerting trauma upon transplantation, followed by flexible splinting at infraoccluded state.

Because the same oral surgeon performed the surgical operation with identical protocol, determining how one's experience in autotransplantation influences the prognosis of the transplanted teeth is possible. Schwartz et al.[17] reported higher success rates as the operator gained more experience. However, Jakobsen et al.[59] assured that surgeon experience is not a critical factor. Autotransplantation performed by two senior surgeons and six unexperienced junior surgeons did not significantly affect the survival rate of the transplanted donor teeth. The survival rate differs from the success rate because the transplanted teeth showing any signs of postoperative sequelae such as signs of resorption or ankylosis are all considered "survived" as long as these teeth are not extracted. In the present study, 37 teeth transplanted in the latter half of the total cases (50.7%) showed a significantly higher success rate and a lower incidence of root resorption. Because every transplantation was performed by the same surgeon, our results are more persuasive in terms of experience.

The splinting period was not a significant factor that influenced success rates in our study. Preoperative orthodontic treatment allows for the acquisition of sufficient space at the recipient site. Transplantation of the donor teeth at the vertically and mesiodistally ideal position allowed bracket positioning at which passive ligation of the archwire was possible. Consequently, direct orthodontic loading without splinting was engaged in 7 cases. However, not every case with preoperational orthodontic treatment led to direct loading. Sometimes, in the case where the transplanted teeth were positioned either too submerged or buccally faced to avoid occlusion, direct orthodontic engagement would exert excessive force. Such active force may lead to root resorption or alveolar bone loss and direct loading is discouraged[60]. Despite the recommended composite-wire splinting period between

4 and 8 weeks for the transplanted teeth with a closed apex reported by Kokai et al.[21], 9 cases were splinted for more than 8 weeks. In the areas of severe dehiscence, especially for canines in our study, primary stability was delayed and therefore removal of splints was postponed accordingly. According to Kim et al.[61], radiographic infrabony dehiscence observed right after extraction of mandibular third molars recovered to a normal range after 6 months. Similarly, the increase in bone density subsequent to mandibular cyst enucleation was reported to be 37% within 6 months and 42.27% after 12 months[62]. The rate of spontaneous bone healing may be greater in the first few months, but individual differences in the healing potential should be taken into account[61]. The longest splinting period of approximately 9.7 weeks, an outlier, was recorded in our study. The rest of the cases falling into the category of ≥ 8 weeks of splinting period were within 9 weeks. This clearly demonstrated that alveolar bone formation in areas of large dehiscence to achieve optimum stability takes at most 10 weeks. However, there was insufficient evidence to support associations among the splinting periods and the success rates in our study. This highlights the possibility that as long as initial stability with signs of radiographic bone formation and physiologic mobility is achieved, splints can be removed at any time, from a 1-week postoperative stitch out to 10 weeks. This statement was supported by Lundberg and Isaksson[10] and Kokai et al.[21] who carried out fixation for varying periods of 1 to 3 weeks and 4 to 8 weeks, respectively. Due to the fact that prolonged fixation may result in ankylosis, it would be advisable to stop splinting as soon as the primary stability of the transplanted teeth is achieved[52].

The skewed distribution in age groups and donor tooth types was noted in this retrospective study. Moreover, limitations such as patients' and parents' demands, which might have influenced the overall treatment plan, were not controlled. Thus, a predesigned prospective study with more evenly distributed age groups and tooth types is warranted.

In this study, the majority of indications were tooth impactions. The location and depth of the impaction may influence the difficulty of donor tooth extraction. For instance, palatally displaced maxillary canines are more challenging to extract than buccally displaced canines[38]. Complications may be encountered during surgery, and technically challenging extraction may damage periodontal tissues, which are strongly associated with root resorption or ankylosis [18,63]. Three-dimensional information on the mesiodistal angulation and buccolingual position of the ectopically positioned teeth can be acquired in further studies to reflect the possible adversity of surgical procedures.

Perioperative factors such as the tooth extraoral time and storage media may affect the overall treatment outcome[15]. Although such information was limited in this study, variations in these perioperative factors were partly controlled and minimized. The same surgeon performed all surgical procedures, and the extraoral time was minimized by placing the donor teeth into the impaction site for the preservation of periodontal tissues on the root surface.

The influence of types of splinting on success rates was opted out of this study due to the matter of multicollinearity. It is known that flexible splinting is crucial in the case of splinting traumatically avulsed teeth. A wire with a diameter of 0.4 mm, or 0.014 inches, and nylon wire are known to be ideal flexible splints[64]. In this study, all forms of splinting involved nylon or wire splints such as Cu-NiTi and NiTi of 0.014-inch diameter. Since all these types of splints fall into the category of flexible splinting, the weight of their significance on the success rates may be low. Prospective studies on comparing rigid and flexible splinting, or suture and wire splinting may be required in the future.

Linear measurements using ImageJ software on panoramic radiographs have some limitations. The patient's head position may cause changes in the occlusal plane, leading to deviations from the actual measurements. According to Stramotas et al.[65], linear vertical measurements and calculations of the ratio of the same patient at different times revealed consistent accuracy. Absolute measurements from panoramic radiographs by themselves may be different from the actual measurements.

Calculating differences in vertical lengths at two time points or ratios has been confirmed to be both reliable and accurate. In the future, using post-operative CBCT to measure root length would be more accurate.

This study only involved radiographic treatment outcomes to evaluate the success criteria. As mentioned in previous studies, clinical treatment outcomes such as color, mobility, and pocket depth can provide further information required for proper evaluations of autotransplantation outcomes[11,21,22]. A discrepancy in radiographic and clinical outcomes may be observed, conveying the possibility of localized inflammation within the pulp or on periodontal membranes. Further studies with more standardized clinical and radiographic criteria are recommended.

Conclusion

In this study, 54 (73.97%) of 73 transplanted teeth met the success criteria, with 100% survival during the observation period. In addition, 16 (21.9%) of 73 transplanted teeth had received root canal treatment. For vital teeth, pulp healing in the form of canal calcification (58.9%) was observed. A significant increase in root growth was noted for transplanted teeth with an open apex, and none of the root growth ceased clinically. These results highlight the predictability and clinical potential of autotransplantation in children and adolescents, particularly for tooth impactions.

The root developmental stage of the donor teeth was not a critical factor in the success of autotransplantation. Instead, being technically more experienced on the surgical procedures and prohibiting the use of bone grafts may lower the probability of root resorption, ankylosis, or root development for proper tooth function. Even in the presence of the aforementioned postoperative sequelae, the transplanted teeth can be functionally and esthetically pleasing without exfoliation in children and adolescents.

Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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