Journal of Dental Sciences 20 (2025) 2273–2282

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Journal of Dental Sciences

Original Article

Assessing the impact of apicoectomy on autotransplantation success rates: A six-year retrospective cohort study in Taiwan

Kai-Yun Tso [a,b], Wei-Chih Chiu [a,b], Yu-Hsueh Wu [b,c*]

[a] *Division of Endodontics, Department of Stomatology, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan*
[b] *Department of Stomatology, National Cheng Kung University Hospital, College of Medicine, National Cheng Kung University, Tainan, Taiwan*
[c] *Institute of Oral Medicine, School of Dentistry, College of Medicine, National Cheng Kung University, Tainan, Taiwan*

Received 20 May 2025; Final revision received 26 May 2025
Available online 9 June 2025

KEYWORDS
Tooth autotransplantation;
Apicoectomy;
Endodontic intervention;
Survival rate

Abstract *Background/purpose:* Tooth autotransplantation is a viable surgical approach for rehabilitating edentulous areas. However, the influence of endodontic interventions, particularly apicoectomy, on outcomes of transplanting fully developed teeth remains incompletely understood. This study evaluated success and survival rates of autotransplantation in fully developed teeth and assessed the impact of various endodontic interventions on treatment outcomes in a Taiwanese population over a six-year period.

Materials and methods: A retrospective cohort study examined records of patients who underwent tooth autotransplantation at National Cheng Kung University Hospital, Taiwan, between 2018 and 2023. The study included 40 patients with 45 fully developed transplanted teeth. Three specialists evaluated radiographic images. Statistical analyses determined the influence of endodontic interventions on transplantation outcomes.

Results: The mean patient age at surgery was 35.1 $\pm$ 12.5 years and the mean follow-up period was 11.7 $\pm$ 9.9 months. Success rate at latest follow-up was 64.1 %, while survival rate reached 89.7 %. No statistically significant difference was observed between teeth that underwent apicoectomy or other endodontic interventions and those that did not (P-value >0.05).

Conclusion: Despite the modest success rate, possibly due to stringent evaluation criteria, the high survival rate confirms that autotransplantation of fully developed teeth is effective when following strict protocols. Current evidence suggests endodontic interventions do not significantly influence treatment outcomes.

* Corresponding author. Institute of Oral Medicine, School of Dentistry, College of Medicine, National Cheng Kung University, Tainan 701, Taiwan.
E-mail address: z10908025@ncku.edu.tw (Y.-H. Wu).

https://doi.org/10.1016/j.jds.2025.05.031

Introduction

Autotransplantation of teeth is a surgical procedure involving the transplantation of a tooth from one site to another within the same individual. It represents a viable treatment option for teeth that are not preservable due to trauma, infection, or other conditions. This approach originated in the 19th century, though with limited success rates. Significant advancements began in the mid-20th century, particularly with Andreasen's pioneering work on dental trauma in the 1950s, which expanded to autotransplantation research.[1–4]

Early studies established various indications for autotransplantation, including traumatized maxillary anterior teeth, ectopically positioned canines, and supernumerary teeth.[3] Research during this period identified critical factors affecting treatment outcomes, with particular emphasis on the impact of surgical time on extraoral duration. Multiple studies demonstrated that prolonged extraoral time negatively affects the periodontal ligament, potentially leading to ankylosis and root resorption.[4–6]

Despite these potential complications, autotransplantation has maintained high survival rates over decades of research. Contemporary studies confirm that it presents a favorable alternative to dental implants, allowing biological reconstruction of dentition without artificial materials.[7–13] Research in the 21st century has focused on refinements such as combining periodontal tissue regeneration techniques, analyzing pulp necrosis patterns, and characterizing root resorption phenomena.

Technological advancements in the past two decades, particularly computer-aided rapid prototyping (CARP) and 3D surgical guides, have significantly reduced extraoral time, minimizing periodontal ligament damage and surgical complexity.[13–16] This progress has maintained autotransplantation as a relevant treatment option even in the era of dental implant predominance.

With research showing no significant difference in success and survival rates between extraoral times of 18 and 15 min,[3,17,18] the timing of endodontic intervention has become an area of focus. Traditionally, root canal treatment protocols recommended pre-surgical intervention for accessible donor teeth, or post-surgical treatment two weeks after transplantation for impacted teeth or those not amenable to intraoral treatment.[19,20] However, the reduced extraoral time afforded by 3D-assisted techniques has enabled investigation of intraoperative endodontic interventions, including apicoectomy and revascularization procedures.[21–23]

Despite promising results from individual studies, most research on intraoperative endodontic interventions consists of single-dentist, single-institution reports. There remains a significant knowledge gap regarding the standardization of protocols across multiple practitioners within the same institution, particularly for teeth with fully developed roots. Furthermore, the specific impact of apicoectomy on autotransplantation outcomes has not been thoroughly investigated in the Taiwanese population, where treatment protocols may differ from those in Western countries.

This study aimed to evaluate the success and survival rates of autotransplantation in fully developed teeth in a Taiwanese population over six years. We also assessed the impact of endodontic interventions (particularly apicoectomy) on outcomes, analyzed different surgeons' results within our institution, and identified key variables affecting treatment success.

Materials and methods

This study was conducted and reported in accordance with the Preferred Reporting Items for Observational Studies in Endodontics (PROBE 2023) guidelines.[24]

Ethics and informed consent

This study was approved by the Institutional Review Board of National Cheng Kung University Hospital (approval numbers: B-ER-109-228 and B-ER-113-52). The requirement for informed consent was waived due to the retrospective nature of the study.

Study design and setting

A retrospective cohort study was conducted by examining medical records of patients who underwent tooth autotransplantation at the Department of Stomatology, National Cheng Kung University Hospital, Taiwan, from January 2018 to December 2023. The study focused on analyzing the influence of apicoectomy and other endodontic interventions on transplantation outcomes in teeth with fully developed roots.

Sample size and patient selection

No formal sample size calculation was performed for this exploratory retrospective study. All eligible cases within the study period were included to maximize the available data for analysis.

Inclusion criteria consisted of patients who underwent autotransplantation of molars with fully developed roots (Moorrees stage 13),[25] and complete pre-operative and post-operative records with radiographic follow-up. Exclusion criteria included single-rooted transplanted teeth, teeth with incomplete root development, intentional replantation cases, and intra-alveolar autotransplantation according to Tsukiboshi standards.[26] These criteria were established to highlight outcomes of traditional tooth autotransplantation with complete root formation.

Outcome measures

Treatment outcomes were categorized as success, survival, or failure. Success was defined as tooth presence without root resorption or ankylosis, with normal mobility (Supplementary Fig. 1). Survival was defined as functional tooth presence despite potential root resorption or ankylosis (Supplementary Fig. 2). Failure was defined as tooth extraction, non-functionality, or scheduled extraction due to poor prognosis. Secondary outcomes included biological complications such as infection, inflammation, and pain (Supplementary Fig. 3).

Data collection and assessment

Clinical data were extracted from the hospital Healthcare Information System using standardized case report forms to ensure consistency. Parameters recorded included percussion pain, palpation pain, sinus tract presence, swelling, probing depth, tooth mobility, and metallic sound. Surgery time, extraoral time, and intraoperative conditions were systematically documented.

Radiographic images from the hospital Picture Archiving and Communication System (PACS) were evaluated, with periapical radiographs using parallel technique preferred. Panoramic radiographs were used when periapical images were unavailable. To minimize assessment bias, radiographs were de-identified and independently evaluated by three endodontic specialists to determine root resorption and ankylosis, with consensus reached for final diagnosis. Cases with incomplete clinical or radiographic records were excluded. For analyses involving extraoral time, the 9 cases where this parameter was not documented were excluded from only those specific analyses.

Treatment protocol

The treatment protocol followed three distinct phases, was illustrated in Fig. 1.

Pre-operative phase

Patients were comprehensively assessed by an interdisciplinary team including oral and maxillofacial surgeons (evaluating donor tooth extraction and recipient site characteristics), endodontists (assessing endodontic treatment options), and prosthodontists (evaluating prosthetic rehabilitation possibilities). Cone-beam computed tomography (CBCT) (Planmeca Oy, Helsinki, Finland) was employed for detailed anatomical assessment and treatment planning. CBCT data were processed using Exoplan and Exocad software (exocad GmbH, Darmstadt, Germany) for surgical simulation and model design. When indicated, computer-aided rapid prototyping (CARP) technology was planned to facilitate the procedure. Tooth models were fabricated using a 3D printer with NextDent C&B MFH resin (NextDent B.V., Soesterberg, The Netherlands).

Intraoperative phase

Prophylactic amoxicillin 2 g was administered 30 min presurgery when indicated. All procedures were performed under local anesthesia with 2 % lidocaine. The recipient site was prepared using a high-speed handpiece with diamond burs, with CARP models used for trial fitting when available.

Donor tooth extraction was performed with careful attention to minimizing damage to the root and periodontal ligament, using dental forceps applied only to the crown. Extraoral time measurement began immediately upon extraction. The tooth was maintained in 0.9 % sterile saline-soaked gauze throughout the procedure.

Endodontic intervention (Fig. 2) was performed while the tooth remained in moist condition. This included access cavity preparation and canal location if possible, followed by temporary sealing with cotton pellets and Caviton (GC Corporation, Tokyo, Japan). When canal location was unsuccessful, apicoectomy was performed. Following endodontic treatment, the tooth was returned to the surgeon for placement in the prepared socket, at which point extraoral time measurement ended.

Final adjustments included enameloplasty when necessary, followed by fixation using non-absorbable sutures and/or steel wire with light-cured resin to stabilize the transplanted tooth.

Post-operative phase

Patients underwent 1—3 follow-up examinations. Sutures were removed after 5—7 days and fixation wires after 2—4 weeks. Root canal treatment was completed within 2—4 weeks post-surgery. Regular monitoring at 1—3 months intervals assessed clinical condition and radiographic findings, along with prosthetic rehabilitation when indicated.

Statistical methods

Statistical analysis was performed using SPSS version 17.0 (SPSS Inc., Chicago, IL, USA). Descriptive statistics were used to characterize the sample population and treatment outcomes. For comparative analyses, chi-square tests were employed for categorical variables, with Fisher's exact test used when sample sizes were small. The significance level was set at 0.05, with P-values less than 0.05 considered statistically significant.

Initial single-factor analyses were conducted to evaluate the influence of individual variables on treatment outcomes. These were followed by adjusted analyses to examine potential interactions between variables and their combined effect on treatment success and survival rates.

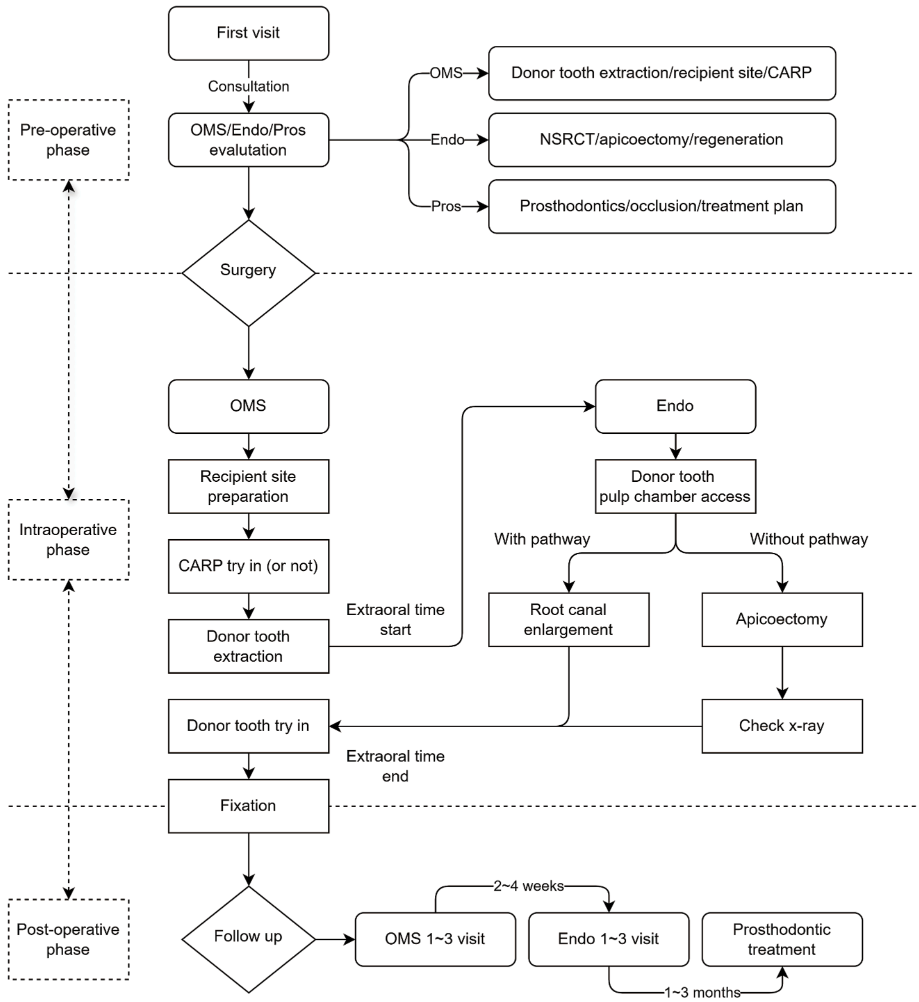

Figure 1 Flow chart of the current study protocol
This diagram illustrates the treatment workflow including all practitioner procedures and decision points, representing the current protocol implemented at the Department of Stomatology. The process is divided into three main phases: pre-operative assessment, intraoperative treatment, and post-operative follow-up and treatment. The intraoperative phase is further subdivided into oral and maxillofacial surgeon operating time and endodontist operating time.
Abbreviations: CARP, computer-aided rapid prototyping; Endo, endodontist; NSRCT, non-surgical root canal treatment; OMS, oral and maxillofacial surgeon; Prostho, prosthodontist.

Results

Participants

During the study period from 2018 to 2023, 45 teeth from 40 patients were initially considered for autotransplantation. Five teeth from four patients were excluded due to being single-rooted teeth or intentional replantation, leaving 40 teeth from 36 patients included in the study (Table 1). One patient (T01) was excluded from the analysis due to not undergoing endodontic treatment, resulting in a final analysis of 39 teeth from 35 patients.

Of the 35 patients analyzed, 19 were male (54.3 %) and 16 female (45.7 %), with an average age at surgery of 35.1 ± 12.5 years (range: 20–74 years). Twelve patients (34.3 %) had systemic diseases, while 23 (65.7 %) had no reported systemic conditions.

Treatment characteristics

Regarding transplantation sites, wisdom teeth were used as donor teeth in 38 cases (97.4 %), with only one case using a maxillary second molar. The recipient sites included maxillary first molars (5 teeth, 12.8 %), maxillary second molars (9 teeth, 23.0 %), mandibular first molars (7 teeth, 18.0 %), and mandibular second molars (18 teeth, 46.2 %). Most recipient sites were mandibular molars (25 teeth, 64.2 %), while most donor teeth were maxillary molars (26 teeth, 66.7 %).

Endodontic treatment interventions were categorized into eight groups based on timing and type of intervention (Fig. 2). In our sample, Group 1 was excluded from analysis, and no cases fell into Group 2. The distribution of interventions was as follows: Group 7 was the most common (19 teeth, 48.7 %), followed by Groups 3 and 6 (7 teeth

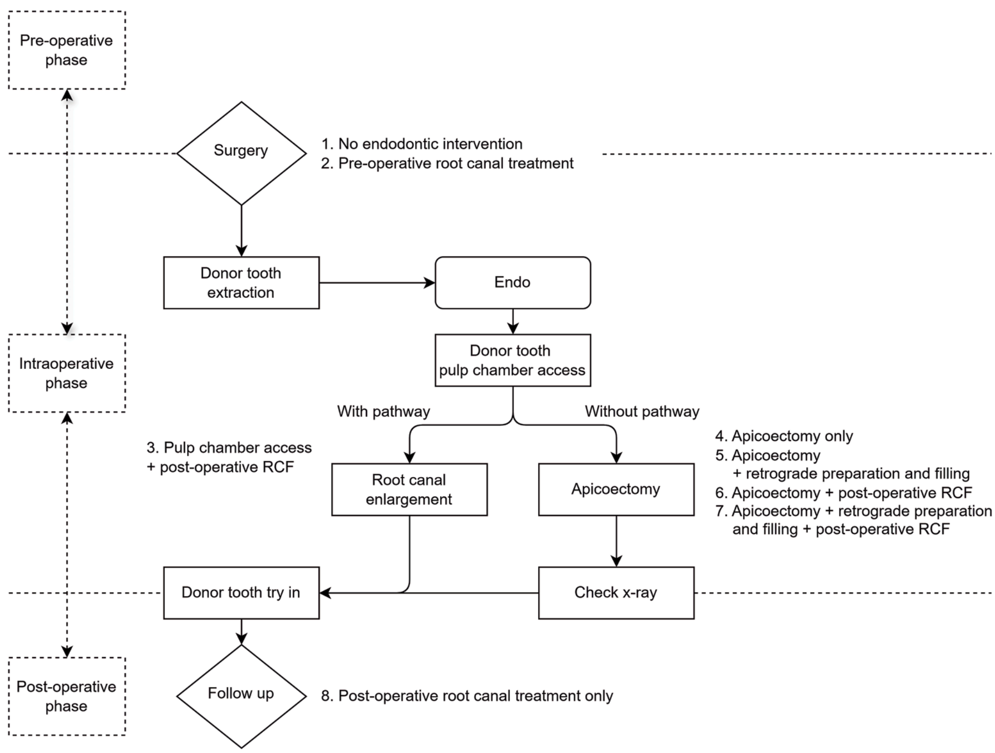

Figure 2 Endodontic intervention options during autotransplantation
This figure depicts the eight categories of endodontic interventions across three timeframes: pre-operative, intraoperative, and post-operative phases. Pre-operative options include: group 1) no endodontic intervention (excluded from analysis), and group 2) pre-operative root canal treatment (no cases in this study). Intraoperative interventions, determined by the endodontist based on tooth condition, include: group 3) intraoperative pulp chamber access with post-operative root canal filling (when canal pathways are successfully located), or if canal location is challenging: group 4) intraoperative apicoectomy alone, group 5) intraoperative apicoectomy with retrograde preparation and filling, group 6) intraoperative apicoectomy without filling but with post-operative root canal filling, and group 7) intraoperative apicoectomy with retrograde preparation and filling plus post-operative root canal filling. The post-operative option is: group 8) post-operative root canal treatment only.
Abbreviations: Endo, endodontist; RCF, root canal filling.

each, 17.9 %). Group 8 accounted for 4 teeth (10.3 %), while Groups 4 and 5 were used in one tooth each (2.6 %).

Computer-aided rapid prototyping (CARP) was used in 24 cases (61.5 %). Various fixation methods were utilized, with most teeth (29 teeth, 74.4 %) fixed using a combination of sutures and wires. Other fixation methods included sutures only (7 teeth, 17.9 %), wires only (2 teeth, 5.1 %), and no fixation (1 tooth, 2.6 %). Extraoral time was documented in 30 cases, with 13 teeth (43.3 %) having an extraoral time $\leq$15 min and 17 teeth (56.7 %) $>$15 min.

Treatment outcomes

The mean follow-up period was 11.7 $\pm$ 9.9 months (range: 1—44 months). Analysis revealed 25 successful cases (64.1 %), 10 survival cases (25.6 %), and 4 failures (10.3 %), resulting in a success rate of 64.1 % and a survival rate of 89.7 %.

Root resorption was observed in 14 teeth (35.9 %), while ankylosis was noted in 9 teeth (23.1 %). Of the failed cases, one tooth had been extracted, while three teeth were scheduled for extraction but remained in place due to treatment planning or scheduling considerations. Regarding prosthetic treatment, 4 teeth (10.3 %) retained temporary crowns, 9 teeth (23.1 %) had permanent crowns, and 26 teeth (66.7 %) either did not require prosthetic restoration or maintained resin fillings.

Factors influencing treatment outcomes

Kaplan—Meier survival analysis demonstrated that all treatment failures occurred within the first 12 months post-surgery (specifically at 1, 5, 9, and 11 months). All teeth with follow-up periods exceeding 12 months remained viable (Fig. 3).

Univariate analysis was conducted to identify factors potentially influencing treatment outcomes (Table 2). None of the examined variables significantly affected success or survival rates (all *P*-values $>$0.05). These variables included patient-related factors (age, sex, presence of systemic disease), procedural factors (fixation method, use of CARP, extraoral time), and treatment-related factors (presence of apicoectomy, surgeon and endodontist experience).

Further analysis of age as a potential factor, using either 30 or 40 years as cutoff points, showed no significant differences in success rates, survival rates, root resorption, or

Table 1 Clinical characteristics and treatment outcomes of autotransplanted teeth.

ID	Age	Sex	Systemic disease	Extraoral time (min)	Endodontic intervention	Fixation	Prothesis	Follow-up (months)	Root resorption	Ankylosis	Outcome
T01	19	F	O	No record	1	Wire	No	3	O	O	Survival
T02	56	M	O	No record	3	Suture + wire	Crown	44	X	O	Survival
T03	31	F	X	No record	3	Suture + wire	Crown	16	X	X	Success
T04	32	F	X	No record	3	Wire	Crown	7	X	X	Success
T05	33	F	O	No record	8	Suture	Crown	5	X	X	Success
T06	39	M	X	18	7	Suture + wire	No	3	X	X	Success
T07	23	M	O	No record	7	Suture + wire	Temp crown	8	X	O	Survival
T08	21	M	O	20	3	Suture + wire	No	10	X	X	Success
T08	21	M	O	20	7	Suture + wire	No	9	O	X	Success
T09	36	F	X	15	4	No fixation	No	11	X	X	Success
T09	36	F	X	12	6	Suture + wire	No	8	X	X	Success
T10	20	F	X	No record	8	Suture + wire	Extraction[a]	5	X	X	Failure[a]
T11	39	F	X	No record	7	Suture + wire	No	14	X	X	Success
T12	35	F	X	No record	8	Suture + wire	No	16	X	X	Success
T13	42	F	O	18	7	Suture + wire	Extraction[a]	1	O	X	Failure[a]
T14	40	M	O	22	7	Suture + wire	Crown	7	X	X	Success
T15	48	F	X	17	6	Suture + wire	Crown	5	O	O	Survival
T16	43	F	X	16.5	7	Suture	Crown	1	X	X	Success
T17	31	F	X	11	7	Suture + wire	Crown	17	O	O	Survival
T18	24	M	X	21.5	6	Suture	Temp crown	39	O	O	Survival
T19	26	M	X	9	3	Suture + wire	Crown	30	O	X	Success
T20	74	M	O	12	7	Suture + wire	Crown	27	O	O	Survival
T20	75	M	O	10	6	Suture + wire	No	22	X	X	Success
T21	31	F	X	10	6	Suture + wire	Crown	18	O	X	Success
T22	38	M	O	22	7	Suture + wire	Temp crown	7	X	X	Success
T23	40	M	X	10	6	Suture + wire	Temp crown	10	O	X	Survival
T24	29	M	X	7	3	Suture + wire	Extraction	9	O	X	Failure
T25	29	M	O	No record	8	Suture	Extraction[a]	11	O	X	Failure[a]
T25	27	M	O	15	7	Suture	No	3	X	X	Success
T26	21	M	X	15	7	Suture + wire	No	1	O	X	Success
T27	26	F	X	18	7	Suture + wire	No	4	O	O	Survival
T28	31	M	X	14	6	Wire	No	14	X	X	Success
T29	53	F	X	13	7	Suture + wire	No	21	X	X	Success
T30	34	F	X	6	5	Suture	No	15	O	O	Survival
T31	31	M	X	20	3	Suture	No	14	X	X	Success
T32	25	M	O	11.5	7	Suture + wire	No	5	X	O	Survival
T33	20	F	X	17	7	Suture + wire	Crown	8	X	X	Success
T34	66	M	O	15	7	Suture + wire	No	5	X	X	Success
T35	36	M	O	14	7	Suture + wire	Temp crown	6	X	X	Success
T36	24	M	X	15	7	Suture + wire	No	1	X	X	Success

Abbreviations: F, female; M, male; O, present; X, absent.
"Endodontic intervention 1, no endodontic intervention; 2, pre-operative root canal treatment; 3, intraoperative pulp chamber access with post-operative root canal filling; 4, intraoperative apicoectomy only; 5, intraoperative apicoectomy with retrograde preparation and filling; 6, intraoperative apicoectomy without filling with post-operative root canal filling; 7, intraoperative apicoectomy with retrograde preparation and filling plus post-operative root canal filling; 8, post-operative root canal treatment only."
[a] T10, T13, and T25 were scheduled for extraction but remained in place at the time of analysis.

ankylosis (Table 3). Similarly, root resorption and ankylosis were not significantly associated with extraoral time or any other examined variables (Table 4).

Discussion

This study investigated the outcomes of tooth autotransplantation with fully developed roots and the impact of various endodontic interventions, particularly apicoectomy. The overall success rate was 64.1 % and survival rate 89.7 % after a mean follow-up of 11.7 months. No significant associations were found between treatment outcomes and various clinical variables, including endodontic intervention methods.

Tooth autotransplantation has evolved as an effective treatment option for tooth loss over decades. Long-term follow-up studies have demonstrated high success rates for

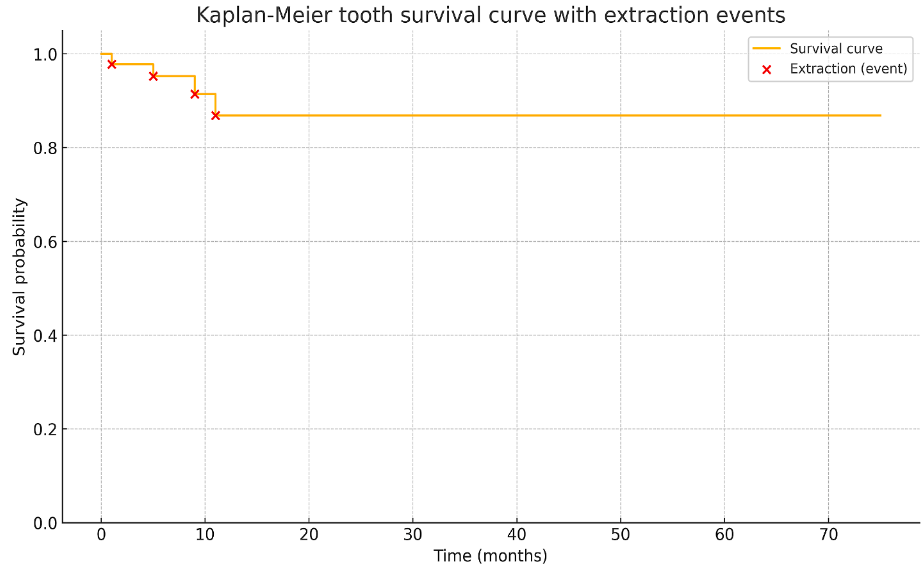

Figure 3 Kaplan—Meier tooth survival curve with extraction events
Survival curve showing the cumulative survival probability over time. The Y-axis represents survival probability, with 1.0 indicating 100 % survival. The follow-up period ranged from 1 to 74 months. Failures occurred at 1, 5, 9, and 11 months, with the survival rate stabilizing at 87.2 % after 12 months. All teeth with follow-up periods exceeding 12 months maintained survival.

Table 2 Univariate analysis of clinical variables affecting success and survival rates.

	Success rate			Survival rate		
	Success	Non-success	*P*-value	Survival	Non-survival	*P*-value
Age			0.11			0.106
≤30 years	5/12 (41.7 %)	7/12 (58.3 %)		9/12 (75.0 %)	3/12 (25.0 %)	
>30 years	16/23 (69.6 %)	7/23 (30.4 %)		22/23 (95.7 %)	1/23 (4.3 %)	
Gender			0.782			0.999
Male	11/19 (57.9 %)	8/19 (42.1 %)		17/19 (89.5 %)	2/19 (10.5 %)	
Female	10/16 (62.5 %)	6/16 (37.5 %)		14/16 (87.5 %)	2/16 (12.5 %)	
Systemic disease			0.383			0.594
Present	6/12 (50.0 %)	6/12 (50.0 %)		10/12 (83.3 %)	2/12 (16.7 %)	
Absent	15/23 (65.2 %)	8/23 (34.8 %)		21/23 (91.3 %)	2/23 (8.7 %)	
Fixation method		0.598			0.926	
No fixation	1/1 (100 %)	0/1 (0 %)		1/1 (100 %)	0/1 (0 %)	
Suture only	4/7 (57.1 %)	3/7 (42.9 %)		6/7 (85.7 %)	1/7 (14.3 %)	
Wire only	2/2 (100 %)	0/2 (0 %)		2/2 (100 %)	0/2 (0 %)	
Combined	18/29 (62.1 %)	11/29 (37.9 %)		26/29 (89.7 %)	3/29 (10.3 %)	
CARP			0.673			0.631
Yes	16/24 (66.7 %)	8/24 (33.3 %)		22/24 (91.7 %)	2/24 (8.3 %)	
No	9/15 (60.0 %)	6/15 (40.0 %)		13/15 (86.7 %)	2/15 (13.3 %)	
Donor tooth			0.686			0.999
With apicoectomy	19/31 (61.3 %)	12/31 (38.7 %)		28/31 (90.3 %)	3/31 (9.7 %)	
Without apicoectomy	6/8 (75.0 %)	2/8 (25.0 %)		7/8 (87.5 %)	1/8 (12.5 %)	
Oral surgeon			0.686			0.999
Attending	21/32 (65.6 %)	11/32 (34.4 %)		28/32 (87.5 %)	4/32 (12.5 %)	
Resident	4/7 (57.1 %)	3/7 (42.9 %)		7/7 (100 %)	0/7 (0 %)	
Endodontist			0.999			0.267
Attending	19/29 (65.5 %)	10/29 (34.5 %)		27/29 (93.1 %)	2/29 (6.9 %)	
Resident	6/10 (60.0 %)	4/10 (40.0 %)		8/10 (80.0 %)	2/10 (20.0 %)	
Extraoral time			0.255			0.999
≤15 min	7/13 (53.8 %)	6/13 (46.2 %)		12/13 (92.3 %)	1/13 (7.7 %)	
>15 min	13/17 (76.5 %)	4/17 (23.5 %)		16/17 (94.1 %)	1/17 (5.9 %)	

Abbreviations: CARP, computer-aided rapid prototyping.
P-values were calculated using chi-square test or Fisher's exact test where appropriate.

Table 3 Influence of age on treatment outcomes.

	Age ≤30 years	Age >30 years	*P*-value	Age ≤40 years	Age >40 years	*P*-value
Success rate			0.11			0.401
Success	5/21 (23.8 %)	16/21 (76.2 %)		18/21 (85.7 %)	3/21 (14.3 %)	
Non-success	7/14 (50.0 %)	7/14 (50.0 %)		10/14 (71.4 %)	4/14 (28.6 %)	
Survival rate			0.106			0.999
Survival	9/31 (29.0 %)	22/31 (71.0 %)		25/31 (80.6 %)	6/31 (19.4 %)	
Non-survival	3/4 (75.0 %)	1/4 (25.0 %)		3/4 (75.0 %)	1/4 (25.0 %)	
Root resorption			0.256			0.999
Present	6/13 (46.2 %)	7/13 (53.8 %)		10/13 (76.9 %)	3/13 (23.1 %)	
Absent	6/22 (27.3 %)	16/22 (72.7 %)		18/22 (81.8 %)	4/22 (18.2 %)	
Ankylosis			0.456			0.34
Present	4/9 (44.4 %)	5/9 (55.6 %)		6/9 (66.7 %)	3/9 (33.3 %)	
Absent	8/26 (30.8 %)	18/26 (69.2 %)		22/26 (84.6 %)	4/26 (15.4 %)	

P-values were calculated using chi-square test or Fisher's exact test where appropriate.

Table 4 Association between root resorption, ankylosis and other variables.

	Root resorption			Ankylosis		
	Yes	No	*P*-value	Yes	No	*P*-value
CARP use			0.342			0.674
Yes	10/24 (41.7 %)	14/24 (58.3 %)		5/24 (20.8 %)	19/24 (79.2 %)	
No	4/15 (26.7 %)	11/15 (73.3 %)		4/15 (26.7 %)	11/15 (73.3 %)	
Extraoral time			0.31			0.666
≤15 min	7/13 (53.8 %)	6/13 (46.2 %)		4/13 (30.8 %)	9/13 (69.2 %)	
>15 min	6/17 (35.3 %)	11/17 (64.7 %)		3/17 (17.6 %)	14/17 (82.4 %)	
Apicoectomy			0.686			0.653
Present	12/31 (38.7 %)	19/31 (61.3 %)		8/31 (25.8 %)	23/31 (74.2 %)	
Absent	2/8 (25.0 %)	6/8 (75.0 %)		1/8 (12.5 %)	7/8 (87.5 %)	
Follow-up period			0.498			0.238
≤12 months	8/25 (32.0 %)	17/25 (68.0 %)		4/25 (16.0 %)	21/25 (84.0 %)	
>12 months	6/14 (42.9 %)	8/14 (57.1 %)		5/14 (35.7 %)	9/14 (64.3 %)	

Abbreviations: CARP, computer-aided rapid prototyping.
P-values were calculated using chi-square test or Fisher's exact test where appropriate.

this technique,[7,10,14] while providing advantages of preserving natural teeth and alveolar bone. These benefits contribute to long-term oral health and overall dental aesthetics.[9]

The technique is particularly valuable for adolescents and young adults, as it helps maintain natural tooth function and aesthetics while avoiding self-consciousness issues potentially caused by tooth loss.[7] Indications include traumatic tooth loss, congenitally missing teeth, and replacement of teeth with poor prognosis.[21] An important advantage is the preservation of the periodontal ligament, allowing transplanted teeth to be orthodontically moved if needed.[27,28]

Our survival rate of 89.7 % with a mean follow-up of 11.7 months aligns with previous studies. However, our success rate of 64.1 % is somewhat lower than other reports, which have shown success rates between 70 and 100 %.[29] This discrepancy may be attributed to our strict definition of success based on Boschini's criteria requiring the absence of both root resorption and ankylosis.[21]

Our diagnostic approach, involving three endodontic specialists evaluating anonymized radiographic images, may have resulted in higher detection rates of root resorption (35.9 %) and ankylosis (23.1 %). This approach, though less commonly used in retrospective studies of tooth autotransplantation, is supported by diagnostic radiology research suggesting greater accuracy with multiple evaluators.[30,31]

The wide range of success rates (approximately 30—100 %) reported in various meta-analyses and literature reviews reflects the lack of standardized success criteria across studies.[19] Previous research has similarly noted that stringent clinical and radiological success criteria may result in lower overall success rates.[32]

Traditional approaches to endodontic management recommend pre-surgical treatment when feasible or post-surgical intervention within two weeks.[20,26] Some researchers have advised against intraoperative endodontic treatment due to concerns about increased extraoral time and potential root surface damage.[17]

However, with the advent of CARP technology effectively reducing extraoral time,[16,33] recent research has begun exploring intraoperative endodontic interventions including apicoectomy with retrograde filling. Our finding that apicoectomy did not significantly influence treatment outcomes aligns with emerging evidence showing promising results for intraoperative endodontic procedures.[23]

While the most common intervention in our study was apicoectomy with retrograde preparation and filling plus post-operative root canal filling (48.7 % of cases), no significant differences in outcomes were found between different endodontic approaches. This suggests clinicians may have flexibility in selecting the most appropriate endodontic intervention based on individual case requirements.

Extraoral time has traditionally been considered a critical factor affecting periodontal ligament viability.[4,13] Our finding that extraoral time ($\leq$15 min versus >15 min) did not significantly affect treatment outcomes supports Andreasen's earlier research suggesting periodontal ligament can recover normally within 18 min.[3]

Similarly, we found no significant association between extraoral time and complications such as root resorption or ankylosis, consistent with findings from previous studies.[17] This may be attributed to careful handling of donor teeth and maintenance in moist conditions throughout the procedure, highlighting the importance of proper surgical technique regardless of total extraoral duration.

A major strength of this study is its comprehensive assessment of endodontic interventions in autotransplantation, an area that has received limited attention in previous research. The use of multiple independent evaluators for radiographic assessment enhances the reliability of our findings.[31] Additionally, our study represents real-world clinical practice involving multiple practitioners within a single institution, providing insights into the applicability of autotransplantation protocols across different clinicians.

The rigorous definition of success used in this study, while yielding lower success rates, provides a more stringent evaluation of treatment outcomes that may better guide clinical expectations and decision-making. Additionally, our study adheres to the PROBE 2023 guidelines for reporting observational studies in endodontics, which enhances the transparency and methodological rigor of our research.

This study has several limitations. The sample size is relatively small, though comparable to recent similar studies. The median follow-up time was 9 months (mean 11.7 months), which may be insufficient to observe long-term outcomes. Recent studies have similarly limited sample sizes, reflecting the declining frequency of this procedure at single institutions.[22,23,34]

The retrospective design limits our ability to control for confounding variables and standardize treatment protocols. Additionally, the accuracy of detecting root resorption may be suboptimal without cone-beam computed tomography.[22] The generalizability of our findings may be limited to similar tertiary care settings with experienced surgical teams.

Future research should consider multi-center collaboration to increase sample size and diversity of treatment approaches. Longer follow-up periods would provide more comprehensive data on long-term outcomes. Further investigation into different endodontic intervention methods is warranted, particularly regarding pulp canal calcification and obliteration, which has received little attention in existing literature.

In conclusion, this study demonstrates favorable outcomes for tooth autotransplantation with fully developed roots (89.7 % survival rate, 64.1 % success rate) when performed according to strict protocols. Our findings indicate that intraoperative endodontic procedures, including apicoectomy, do not adversely affect treatment outcomes, which is particularly relevant in the era of CARP technology. Clinicians can therefore consider various endodontic intervention options based on individual case requirements without compromising treatment success. Autotransplantation remains a valuable biological solution for tooth replacement, though future standardized multicenter studies with longer follow-up periods would enhance our understanding of factors influencing outcomes.

Declaration of competing interests

The authors have no conflicts of interest relevant to this article.

Acknowledgements

The present study was supported by a grant from National Cheng Kung University Hospital (NCKUH-2021075 and NCKUH-20250194).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jds.2025.05.031.

References

1. Andreasen JO, Paulsen HU, Yu Z, Ahlquist R, Bayer T, Schwartz O. A long-term study of 370 autotransplanted premolars part I surgical procedures and standardized techniques for monitoring healing. *Eur J Orthod* 1990;12:3—13.
2. Andreasen JO, Paulsen HU, Yu Z, Bayer T. A long-term study of 370 autotransplanted premolars part IV root development subsequent to transplantation. *Eur J Orthod* 1990;12:38—50.
3. Andreasen JO, Paulsen HU, Yu Z, Bayer T, Schwartz O. A long-term study of 370 autotransplanted premolars part II tooth survival and pulp healing subsequent to transplantation. *Eur J Orthod* 1990;12:14—24.
4. Andreasen JO, Paulsen HU, Yu Z, Schwartz O. A long-term study of 370 autotransplanted premolars. part III. periodontal healing subsequent to transplantation. *Eur J Orthod* 1990;12:25—37.
5. Smith JJ, Wayman BE. Successful autotransplantation. *J Endod* 1987;13:77—80.
6. Paulsen HU, Andreasen JO, Schwartz O. Pulp and periodontal healing, root development and root resorption subsequent to transplantation and orthodontic rotation: a long-term study of autotransplanted premolars. *Am J Orthod Dentofacial Orthop* 1995;108:630—40.
7. Amos MJ, Day P, Littlewood SJ. Autotransplantation of teeth: an overview. *Dent Update* 2009;36:102—4. 07-10, 13.
8. Chung WC, Tu YK, Lin YH, Lu HK. Outcomes of autotransplanted teeth with complete root formation: a systematic review and meta-analysis. *J Clin Periodontol* 2014;41:412—23.

9. Almpani K, Papageorgiou SN, Papadopoulos MA. Autotransplantation of teeth in humans: a systematic review and meta-analysis. *Clin Oral Invest* 2015;19:1157—79.
10. Armstrong L, O'Reilly C, Ahmed B. Autotransplantation of third molars: a literature review and preliminary protocols. *Br Dent J* 2020;228:247—51.
11. Dioguardi M, Quarta C, Sovereto D, et al. Autotransplantation of the third molar: a therapeutic alternative to the rehabilitation of a missing tooth: a scoping review. *Bioengineering* 2021;8:120.
12. Pecci Lloret MP, Martínez EP, Rodríguez Lozano FJ, et al. Influencing factors in autotransplantation of teeth with open apex: a review of the literature. *Appl Sci* 2021;11:4037.
13. Plotino G, Abella Sans F, Duggal MS, et al. Present status and future directions: surgical extrusion, intentional replantation and tooth autotransplantation. *Int Endod J* 2022;55:827—42.
14. Machado LA, do Nascimento RR, Ferreira DM, Mattos CT, Vilella OV. Long-term prognosis of tooth autotransplantation: a systematic review and meta-analysis. *Int J Oral Maxillofac Surg* 2016;45:610—7.
15. Ong D, Itskovich Y, Dance G. Autotransplantation: a viable treatment option for adolescent patients with significantly compromised teeth. *Aust Dent J* 2016;61:396—407.
16. Verweij JP, Jongkees FA, Anssari Moin D, Wismeijer D, van Merkesteyn JPR. Autotransplantation of teeth using computer-aided rapid prototyping of a three-dimensional replica of the donor tooth: a systematic literature review. *Int J Oral Maxillofac Surg* 2017;46:1466—74.
17. Kim E, Jung JY, Cha IH, Kum KY, Lee SJ. Evaluation of the prognosis and causes of failure in 182 cases of autogenous tooth transplantation. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2005;100:112—9.
18. Jang Y, Choi YJ, Lee SJ, Roh BD, Park SH, Kim E. Prognostic factors for clinical outcomes in autotransplantation of teeth with complete root formation: survival analysis for up to 12 years. *J Endod* 2016;42:198—205.
19. Tan BL, Tong HJ, Narashimhan S, Banihani A, Nazzal H, Duggal MS. Tooth autotransplantation: an umbrella review. *Dent Traumatol* 2023;39(Suppl 1):2—29.
20. Tsukiboshi M, Tsukiboshi C, Levin L. A step-by step guide for autotransplantation of teeth. *Dent Traumatol* 2023;39(Suppl 1):70—80.
21. Boschini L, Melillo M, Berton F. Long term survival of mature autotransplanted teeth: a retrospective single center analysis. *J Dent* 2020;98:103371.
22. Raabe C, Bornstein MM, Ducommun J, Sendi P, von Arx T, Janner SFM. A retrospective analysis of autotransplanted teeth including an evaluation of a novel surgical technique. *Clin Oral Invest* 2021;25:3513—25.
23. Liao F, Wang H, Zhao J, Zhang B, Zhong H. Effectiveness evaluation of autotransplanted teeth after performing extraoral endodontic surgery instead of conventional root canal therapy. *BMC Oral Health* 2023;23:1005.
24. Nagendrababu V, Duncan HF, Fouad AF, et al. PROBE 2023 guidelines for reporting observational studies in endodontics: explanation and elaboration. *Int Endod J* 2023;56:652—85.
25. Moorrees CFA, Fanning EA, Hunt EE. Age variation of formation stages for ten permanent teeth. *J Dent Res* 1963;42:1490—502.
26. Tsukiboshi M. Autotransplantation of teeth: requirements for predictable success. *Dent Traumatol* 2002;18:157—80.
27. Bae JH, Choi YH, Cho BH, Kim YK, Kim SG. Autotransplantation of teeth with complete root formation: a case series. *J Endod* 2010;36:1422—6.
28. Plotino G, Abella Sans F, Duggal MS, et al. Clinical procedures and outcome of surgical extrusion, intentional replantation and tooth autotransplantation - a narrative review. *Int Endod J* 2020;53:1636—52.
29. Akhlef Y, Schwartz O, Andreasen JO, Jensen SS. Autotransplantation of teeth to the anterior maxilla: a systematic review of survival and success, aesthetic presentation and patient-reported outcome. *Dent Traumatol* 2018;34:20—7.
30. Kumar A, Bhadauria HS, Singh A. Descriptive analysis of dental X-ray images using various practical me thods: a review. *PeerJ Comput Sci* 2021;7:e620.
31. Meusburger T, Wülk A, Kessler A, et al. The detection of dental pathologies on periapical radiographs—Results from a reliability study. *J Clin Med* 2023;12:2224.
32. Gonnissen H, Politis C, Schepers S, et al. Long-term success and survival rates of autogenously transplanted canines. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2010;110:570—8.
33. Tsukiboshi M, Yamauchi N, Tsukiboshi Y. Long-term outcomes of autotransplantation of teeth: a case series. *Dent Traumatol* 2019;35:358—67.
34. Hwang LA, Chang CY, Su WC, Chang CW, Huang CY. Rapid prototyping-assisted tooth autotransplantation is associated with a reduced root canal treatment rate: a retrospective cohort study. *BMC Oral Health* 2022;22:25.