Prognostic Factors for Clinical Outcomes in Autotransplantation of Teeth with Complete Root Formation: Survival Analysis for up to 12 Years

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Abstract

Introduction: Tooth autotransplantation is a treatment option that has the potential to restore masticatory function and esthetics to edentulous spaces resulting from extracted teeth. The purpose of this study was to investigate the prognostic factors and clinical outcomes for autotransplanted teeth with complete root formation. **Methods:** Patients who had received tooth autotransplantation in the Department of Conservative Dentistry, Yonsei University Dental Hospital, Seoul, Korea, from July 2001 to August 2010 were electronically searched, and a total of 105 cases of autotransplanted teeth met the inclusion criteria. Tooth survival, inflammatory root resorption (IRR), ankylosis, and related prognostic factors were assessed by using the survival analysis that was based on clinical and radiographic examination. **Results:** The cumulative tooth survival rate was 68.2% at 12 years after the tooth autotransplantation. According to the Cox proportional hazard regression analysis, patient age, donor position, and extraoral time were significantly associated with tooth survival (*P* < .05). Donor extraction type was significantly associated with IRR (*P* < .05), and transplantation timing and initial stability were significantly associated with ankylosis (*P* < .05) **Conclusions:** Patients less than 45 years of age, maxillary donor teeth, and an extraoral time of less than 15 minutes were associated with significantly higher tooth survival. Surgical extraction of the donor tooth was associated with a significantly higher incidence of IRR. Immediate transplantation after the extraction of the recipient site's tooth and low initial stability were associated with a significantly lower incidence of ankylosis (*J Endod 2016;42:198–205*)

Key Words

Autotransplantation, computer-aided rapid prototyping model, extraoral time, periodontal ligament, survival analysis

Tooth autotransplantation is a treatment option that has the potential to restore masticatory function and esthetics to edentulous spaces resulting from extracted teeth by repositioning the patient's own teeth to another recipient site in the same patient [1, 2]. By using the patient's own teeth, tooth autotransplantation exhibits a number of advantages compared with other treatment options (ie, dental implants or fixed partial prostheses), such as greater resistance to occlusal loading, maintenance of the periodontal ligament (PDL) and surrounding bone, and potential for better esthetics [1, 3, 4].

After its first reported clinical application in 1950 [2], the success rate of tooth autotransplantation has gradually increased because of advances in diagnostic and surgical techniques, such as computer-aided rapid prototyping (CARP) models. By applying preoperatively fabricated CARP models, the extraoral time is significantly reduced, and the suitability between the donor tooth and the recipient site is improved [5]. Consequently, recent clinical studies report high success rates with tooth autotransplantation [6, 7].

However, it should be noted that most studies have focused on autotransplantation using teeth with incomplete root formation [7–9], which restricts the application of tooth autotransplantation to patients in their early 20s and younger [10]. Therefore, to expand the potential therapeutic applicability of tooth autotransplantion, teeth with complete root formation could be considered for use as donor teeth. However, in the field of autotransplantation of teeth with complete root formation, there is currently a lack of clinical evidence regarding its clinical outcome and prognostic factors. One problem is that most studies use a relatively short follow-up period (ranging from 16.4–35.6 months on average) [7, 11, 12], which reduces the ability to assess the long-term predictability. When considering that the cumulative survival of tooth autotransplantation changes over time [11, 12], a longer follow-up period is required to properly assess the influence of related prognostic factors.

In addition, most studies analyzed the prognostic factors related only to tooth survival, but other clinical outcomes, such as inflammatory root resorption (IRR) and ankylosis, were not thoroughly analyzed [11–13] even though they are major

complications in tooth autotransplantation (14). Therefore, prognostic factors related to IRR and ankylosis should also be assessed.

The purpose of this study was to investigate the prognostic factors and clinical outcomes for autotransplanted teeth with complete root formation. To accomplish this goal, 105 cases of autotransplanted teeth were evaluated for up to 12 years, and clinical outcomes, including tooth survival, IRR, ankyloses, and other related prognostic factors, were assessed based on survival analysis.

Materials and Methods

Subject Materials

Patients who had received tooth autotransplantation in the Department of Conservative Dentistry, Yonsei University Dental Hospital, Seoul, Korea, from July 2001 to August 2010, as performed by a single operator (E.K.), were electronically searched for potential inclusion, and their eligibility for this retrospective study was further assessed based on the following inclusion and exclusion criteria.

Inclusion criteria were as follows: patients without severe systemic disease (American Society of Anesthesiologists classification 1 or 2) and permanent teeth with complete root formation (root development stage 5 and 6 by Moorrees et al [15]) as the donor teeth.

Exclusion criteria were the following: patients with severe systemic disease (American Society of Anesthesiologists classification 3 or more); primary teeth or permanent teeth with incomplete root formation (root development stage 14 [15]); and incomplete documentation on the pre-, intra-, and postoperative records.

Consequently, 105 teeth in 96 patients met the inclusion criteria, and their surgery record sheets and electronic and manual charts were reviewed.

Preoperative Preparation

On the first visit, the patient's medical history was reviewed, including underlying systemic disease such as chronic hypertension, diabetes mellitus, tuberculosis, and hepatitis B. A thorough dental history was recorded, and clinical examination of the donor tooth and recipient site was performed. This included mobility and percussion tests, periodontal probing, and pulp sensibility tests. Computed tomographic imaging (Highspeed Advantage and Denta Scan program; GE Medical Systems, Milwaukee, WI) was acquired on the donor tooth and the recipient site. Crown and root length and the cervical dimension of the donor tooth were measured and compared with the residual bone height and width of the recipient site, and anatomic relationships with the inferior alveolar nerve and maxillary sinus were also determined preoperatively. Written informed consent was obtained from each patient at this stage. In most cases, nonsurgical root canal treatment (RCT) of the donor tooth was completed preoperatively to reduce the extraoral time of the tooth, but in several cases in which the donor tooth was impacted and surgically extracted, RCT was performed extraorally during the surgery or conducted within 2 weeks after the surgery.

Surgery Simulation with CARP Model

Computed tomographic data (Digital Imaging and Communication in Medicine format) were 3-dimensionally reconstructed using a visualization program (V-works; Cybermed, Seoul, Korea), and actual-size CARP models of the donor tooth and the recipient site were fabricated using a rapid prototyping machine. Using these CARP models, model surgery was conducted preoperatively to confirm the suitability of the donor tooth in the recipient site and the postoperative interocclusal relationship.

Surgical Procedure

Amoxicillin 500 mg and ibuprofen 400 mg were prescribed 1 hour before the surgery. After local anesthetic injection, the recipient site's tooth was extracted with a mucoperiosteal flap elevation around the tooth. To reduce bone trauma, the tooth was sectioned with a #170 tapered fissure bur and then luxated passively with forceps. After the extraction, recipient bone preparation was conducted with a round implant bur (Center Punch Bur #3 mm; Degussa, Dusseldorf, Germany) under copious saline irrigation. After confirming the suitability of the model tooth in the recipient site, the donor tooth was extracted. To minimize trauma during the extraction, a #15 blade was initially introduced into the PDL space and tapped with a mallet. Then, the tooth was engaged and passively luxated with the forceps beak placed above the cementoenamel junction. The use of elevators was minimized to prevent any damage to the cementum and the PDL. When the donor tooth was impacted and surgically extracted, the same luxation protocol was used after the flap elevation and ostectomy around the donor tooth. The extracted donor tooth immediately received root-end resection, ultrasonic root-end preparation, and root-end filling under the operating microscope (OPMI PICO; Carl Zeiss, Göttingen, Germany) and was then transferred to the recipient site. ProRoot MTA (Dentsply, Tulsa, OK), Super EBA (Bosworth, Skokie, IL), or IRM (Caulk Dentsply, Milford, DE) was used as a root-end filling material. During the entire extraoral procedure, the donor tooth was handled by only engaging the crown portion by forceps, and the root surface was not touched manually. The tooth was frequently immersed in either saline or Hank's balanced salt solution (HBSS) to keep the root surface hydrated and to replenish nutrients for the cells of the PDL. In most cases, a simple periodontal pack was sufficient to stabilize the donor tooth, and a resin-wire splint was applied in several cases in which the donor tooth showed low stability. Amoxicillin 250 mg and ibuprofen 400 mg 3 times a day were prescribed for 1 week with 0.1% chlorhexidine rinse (Hexamedin; Bukwang Pharmaceutical, Ansan, Korea). The periodontal pack was removed 1 week postoperatively, and the resin-wire splint was maintained for 2 weeks.

Outcome Assessment

Patients were usually followed up at 1, 3, and 6 months and then every 6 months after the surgery. Subjective symptoms were recorded, and clinical and radiographic examinations were conducted, including mobility and percussion tests, periodontal probing, and bite tests. Periapical radiographs were acquired and evaluated by 2 blinded independent examiners. Based on these examinations, the following 3 types of outcomes were assessed: tooth survival, IRR, and ankylosis. The "event" in each outcome was defined as follows:

1. *Tooth survival:* Any signs and/or symptoms that severely impede normal masticatory function of the autotransplanted tooth, such as excessive mobility (horizontal movement exceeds 2 mm or any vertical movement) because of periodontal bone loss or IRR and persistent pain on mastication, were considered as treatment failure, and the tooth was planned for extraction. Radiographic findings that were not associated with the impairment of normal masticatory function, such as mild to moderate periodontal bone loss, limited root resorption, and ankylosis, were not considered as treatment failure (Fig. 1A–C). The date of the event corresponds to the date when treatment failure was diagnosed.
2. *IRR:* Progressive root resorption accompanying an adjacent radiolucency in the bone on a periapical radiograph was considered to represent IRR (16) (Fig. 1D–F). The date of the event corresponds to the date when IRR was diagnosed.

Figure 1. Case of tooth survival (first row): #16 was planned to be autotransplanted into the #14 site. (*A*) Postoperative periapical radiograph. (*B*) Eighteen months after tooth autotransplantation. (*C*) Ten years after tooth autotransplantation. The transplanted tooth was asymptomatic. Although the marginal bone level became slightly reduced, there was no tooth mobility. Case of IRR and subsequent treatment failure (second row): #16 was planned to be autotransplanted into the edentulous #19 site. (*D*) Postoperative periapical radiograph. (*E*) Six months after tooth autotransplantation. (*F*) Twenty-four months after tooth autotransplantation. IRR was diagnosed, but the tooth mobility was slight. Ten months later, treatment failure was diagnosed because of increased tooth mobility (horizontal movement exceeds 2 mm) and persistent pain on mastication. Case of ankylosis (third row): #32 was planned to be autotransplanted into the #14 site. (*G*) Postoperative periapical radiograph. (*H*) Twenty-four months after tooth autotransplantation. Ankylosis was diagnosed from the radiographic findings and a metallic sound upon the percussion test. (*I*) Nine years after tooth autotransplantation. The transplanted tooth was asymptomatic and maintained normal masticatory function.

3. *Ankylosis:* Ankylosis was diagnosed when a metallic sound was detected on the percussion test and the disappearance of the PDL space and lamina dura, bone replacement of the root dentin, but no adjacent radiolucency was observed on a periapical radiograph (16) (Fig. 1*G–I*). The date of the event corresponds to the date when ankylosis was diagnosed.

These 3 outcomes were regarded to be separate from each other. In other words, the findings of IRR or ankylosis did not necessarily cause the labeling of treatment failure, and the findings of treatment failure did not cause the labeling of IRR or ankylosis. Cases without an event during the entire follow-up period were classified as "censored," and survival time was defined as the period between the date of surgery and the date of the censor or event. A total of 15 pre- and intraoperative clinical variables were recorded including sex, age, donor position, donor tooth type, recipient position, recipient tooth type, relationships between the donor and recipient position, preoperative donor occlusion, donor root anatomy, donor extraction type, transplantation timing, retrofilling material, extraoral time, and initial stability; their effects on these 3 out-

comes were analyzed. IRR and ankylosis were also included as postoperative clinical variables, and the associations between IRR and tooth survival, ankylosis and tooth survival, and ankylosis and IRR were analyzed. Regarding donor extraction type, when the donor tooth extraction required flap elevation and ostectomy, the case was classified as "surgical extraction," and other cases were classified as "simple extraction." Regarding transplantation timing, when the recipient extraction and tooth autotransplantation were conducted within the same day, the case was classified as "immediate surgery," and when they were conducted on different days, the case was classified as "delayed surgery." Regarding initial stability, when the autotransplanted tooth showed horizontal mobility less than 2 mm postoperatively without additional splinting, the case was classified as having "good initial stability," and other cases were classified as having "poor initial stability."

Statistical Analysis

Cumulative survival rates were calculated based on the Kaplan-Meier method. According to the 3 clinical outcomes, clinical

variables were initially analyzed by the log-rank test as a univariate analysis, and variables identified to be significant were then submitted to multivariate Cox proportional hazard regression analysis. All statistical analysis was conducted in SPSS version 20 (SPSS Inc, Chicago, IL) (α = 0.05).

Results

Tooth Survival

Overall, the cumulative survival rate was 88.1% at 3 years and 68.2% at 12 years after tooth autotransplantation (Fig. 2A). Of the

clinical variables evaluated, patient age, donor position, extraoral time, and IRR were significant when comparing the cumulative tooth survival with the log-rank test ($P < .05$) (Table 1; Fig. 2B–D). The Cox proportional hazard regression model was constructed by including the pre- and intraoperative variables found to be significant upon univariate analysis. Consequently, patient age, donor position, and extraoral time were revealed to be significant according to the Cox proportional hazard regression analysis ($P < .05$) (Table 2). In other words, patients less than 45 years of age, maxillary donor teeth, and an extraoral time of less than 15 minutes were associated
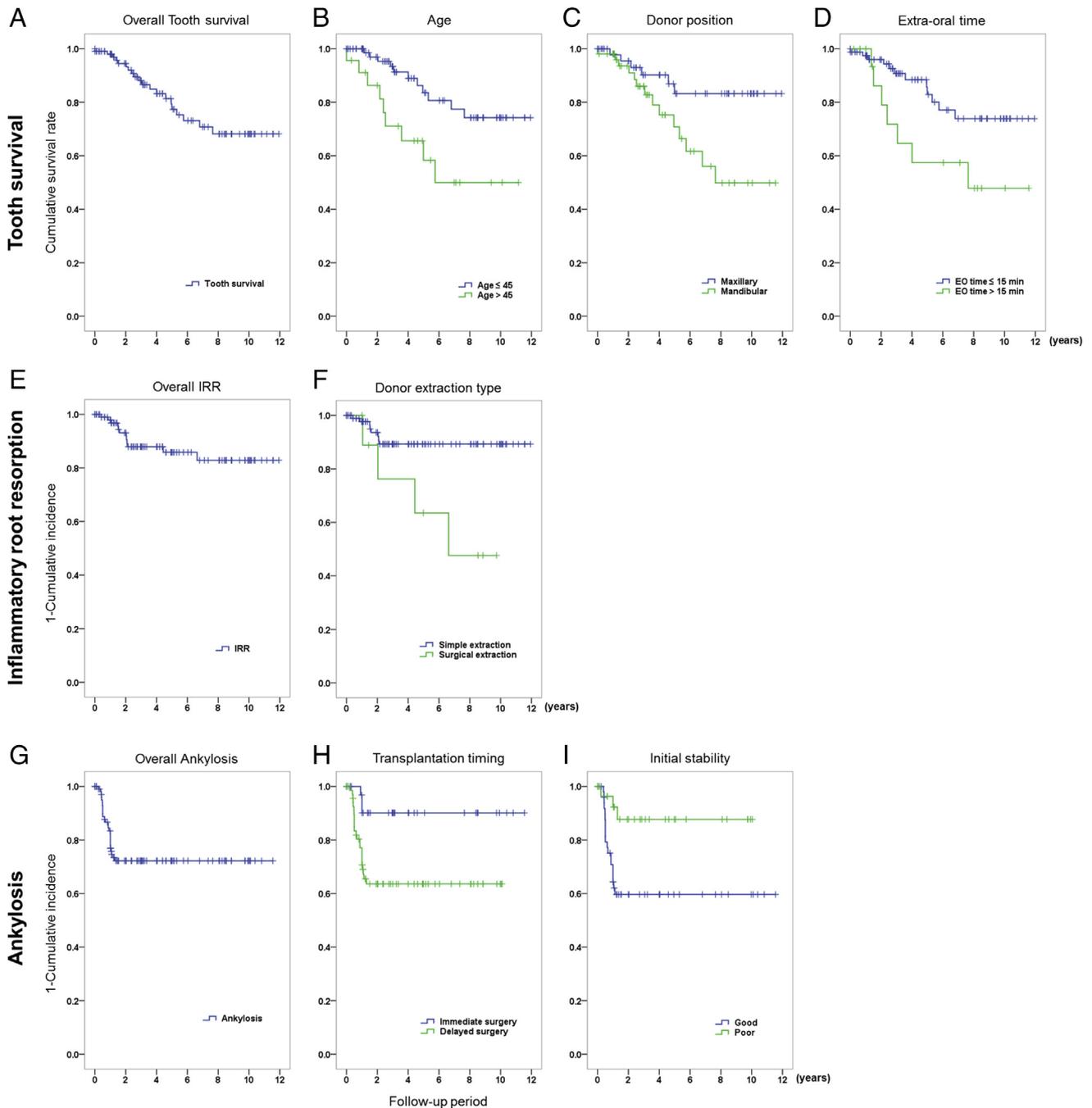
Figure 2. First row: Kaplan-Meier survival curves of tooth survival arranged according to (A) overall outcome, (B) age, (C) donor position, and (D) extraoral time. Second row: Kaplan-Meier survival curves of IRR arranged according to (E) overall outcome and (F) donor extraction type. Third row: Kaplan-Meier survival curves of ankylosis arranged according to (G) overall outcome, (H) transplantation timing, and (I) initial stability.

TABLE 1. Univariate Analysis of Potential Prognostic Factors for Tooth Survival, Inflammatory Root Resorption (IRR), and Ankylosis by Log-rank Test

	Tooth survival			Inflammatory root resorption			Ankylosis		
	Censored (n)	Failed (n)	P value	Censored (n)	Failed (n)	P value	Censored (N)	Failed (n)	P value
Preoperative factors									
Sex			.802			.364			.927
Male	41/51	10/51		44/51	7/51		39/51	12/51	
Female	44/54	10/54		49/54	5/54		40/54	14/54	
Age			.012*			.763			.180
≤45	71/82	11/82		73/82	9/82		64/82	18/82	
>45	14/23	9/23		20/23	3/23		15/23	8/23	
Donor position			.023*			.899			.975
Maxillary	46/52	6/52		46/52	6/52		40/52	12/52	
Mandibular	39/53	14/53		47/53	6/53		39/53	14/53	
Donor tooth type			.056			.909			.080
Third molar	71/91	20/91		81/91	10/91		66/91	25/91	
Others	14/14	0/14		12/14	2/14		13/14	1/14	
Recipient position			.074			.357			.174
Maxillary	32/34	2/34		32/34	2/34		29/34	5/34	
Mandibular	53/71	18/71		61/71	10/71		50/71	21/71	
Recipient tooth type			.297			.708			.118
Molar	74/93	19/93		83/93	10/93		68/93	25/93	
Premolar and Incisor	11/12	1/12		10/12	2/12		11/12	1/12	
Donor and recipient, 1			.487			.326			.244
Same jaw	57/71	14/71		65/71	6/71		56/71	15/71	
Different jaw	28/34	6/34		28/34	6/34		23/34	11/34	
Donor and recipient, 2			.456			.701			.677
Same quadrant	41/52	11/52		47/52	5/52		40/52	12/52	
Different quadrant	44/53	9/53		46/53	7/53		39/53	14/53	
Preoperative donor occlusion			.432			.957			.882
Occluded	53/66	13/66		59/66	7/66		49/66	17/66	
Nonoccluded	32/39	7/39		34/39	5/39		30/39	9/39	
Donor root anatomy			.237			.776			.440
Single root	27/30	3/30		27/30	3/30		24/30	6/30	
Multiple roots	58/75	17/75		66/75	9/75		55/75	20/75	
Donor extraction type			.694			.008*			.056
Simple extraction	78/95	17/95		87/95	8/95		69/95	26/95	
Surgical extraction	7/10	3/10		6/10	4/10		10/10	0/10	
Transplantation timing			.472			.582			.008*
Immediate surgery	30/35	5/35		32/35	3/35		32/35	3/35	
Delayed surgery	55/70	15/70		61/70	9/70		47/70	23/70	
Intraoperative factors									
Retrofilling material			.158			.675			.813
Mineral trioxide aggregate	14/20	6/20		17/20	3/20		15/20	5/20	
Others	71/85	14/85		76/85	9/85		64/85	21/85	
Extraoral time			.044*			.523			.121
≤15 min	70/82	12/82		73/82	9/82		58/82	24/82	
>15 min	11/18	7/18		15/18	3/18		16/18	2/18	
Initial stability			0.447			0.313			0.012*
Good	38/52	14/52		44/52	8/52		33/52	19/52	
Poor	24/29	5/29		27/29	2/29		26/29	3/29	
Postoperative factors									
IRR			.001*			NM			.234
Absent	80/93	13/93		NM			72/93	21/93	
Present	5/12	7/12					7/12	5/12	
Ankylosis			0.315			0.345			NM
Absent	63/79	16/79		72/79	7/79		NM		
Present	22/26	4/26		21/26	5/26				

NM, not measurable.

*Statistical significance was identified at α = 0.05.

IRR

Overall, the cumulative incidence of IRR was 12.1% at 3 years and 17.1% at 12 years after tooth autotransplantation (Fig. 2E). Of the clinical variables evaluated, the donor extraction type was significant when comparing the cumulative incidence of IRR using the log-rank test (P < .05) (Table 1; Fig. 2F). The Cox proportional hazard regression model was constructed by using the pre- and intraoperative variables found to be significant upon univariate analysis, including the donor extraction type along with 2 more variables that had an effect on tooth survival, including the patient's age and extraoral time. Consequently, donor extraction type was revealed to be significant according to the Cox proportional hazard regression analysis (P < .05) (Table 2). In

TABLE 2. Multivariate Cox Proportional Hazard Regression Analysis of Selected Prognostic Factors for Tooth Survival, Inflammatory Root Resorption, and Ankylosis

	OR	95% CI	P value
Tooth survival			
Age			.004*
≤45	1	Reference	
>45	4.05	1.58–10.36	
Donor position			.017*
Maxillary	1	Reference	
Mandibular	3.52	1.25–9.90	
Extraoral time			.017*
≤15 min	1	Reference	
>15 min	3.26	1.24–8.60	
Inflammatory root resorption			
Age			.584
≤45	1	Reference	
>45	1.450	0.38–5.50	
Donor extraction type			.020*
Simple extraction	1	Reference	
Surgical extraction	4.260	1.26–14.42	
Extraoral time			.593
≤15 min	1	Reference	
>15 min	1.440	0.38–5.38	
Ankylosis			
Age			.937
≤45	1	Reference	
>45	1.04	0.40–2.69	
Transplantation timing			.033*
Immediate surgery	1	Reference	
Delayed surgery	9.07	1.20–68.73	
Extraoral time			.216
≤15 min	1	Reference	
>15 min	0.4	0.09–1.72	
Initial stability			.017*
Good	1	Reference	
Poor	0.23	0.07–0.77	

CI, confidence interval; OR, odds ratio.

*Statistical significance was identified at $\alpha = 0.05$.

other words, surgical extraction of the donor tooth was associated with a significantly higher incidence of IRR compared with the simple extraction of the donor tooth.

Ankylosis

Overall, the cumulative incidence of ankylosis was 27.8% at 2 years, and it remained the same until 12 years after tooth autotransplantation (Fig. 2G). Of the clinical variables evaluated, transplantation timing and initial stability were significant when comparing the cumulative incidence of ankylosis using the log-rank test ($P < .05$) (Table 1; Fig. 2H and I). A Cox proportional hazard regression model was constructed by using the pre- and intraoperative variables found to be significant on univariate analysis, including transplantation timing and initial stability along with 2 more variables that had an effect on the tooth survival, including the patient's age and extraoral time. Consequently, transplantation timing and initial stability were revealed to be significant according to the Cox proportional hazard regression analysis ($P < .05$) (Table 2). In other words, immediate transplantation after the extraction of the recipient site's tooth and low initial stability were associated with a significantly lower incidence of ankylosis compared with delayed transplantation and high initial stability.

Discussion

This study aimed to determine the effects of significant prognostic factors on the long-term outcome of tooth autotransplantation. Prognostic factors provide the clinician with guidelines for future clinical

outcomes of individual cases, assisting the clinician to make better treatment planning decisions. Several studies have analyzed the prognostic factors of tooth autotransplantation; however, they mainly focused on the overall treatment success as the clinical outcome (11–13, 17). Therefore, in this study, the association between the prognostic factors and supplementary clinical outcomes, such as IRR and ankylosis, were also analyzed to provide more detailed information on the prognosis of tooth autotransplantation.

Tooth Survival

Patient age is the factor that has been consistently highlighted to be significant in the success of tooth autotransplantation (11, 12, 17, 18). Elderly patients exhibit several factors that could be disadvantageous in tooth autotransplantation compared with young patients. Zhang et al (19) reported that the regenerative potential of PDL cells is reduced with aging, which might interfere with the normal adaptation of the donor tooth on the recipient site. In addition, when considering that the mineralization density of the mandible is increased with aging (20), surgical trauma during donor extraction could be increased in elderly patients.

In relation to the donor tooth position, maxillary teeth showed significantly higher cumulative survival compared with mandibular teeth. A possible explanation is that surgical trauma during extraction could be relatively high in mandibular teeth compared with maxillary teeth because of the difference in the mineralization density between the maxilla and the mandible (21, 22). Devlin et al (21) reported that the mean bone mineralization density of the mandible (1.11 g/cm) was twice that of the anterior maxilla (0.55 g/cm) and more than 3 times greater than that of the posterior maxilla (0.31 g/cm). Therefore, additional considerations are required to reduce the surgical trauma during extraction of the donor tooth, especially for mandibular molars, in order to improve tooth survival after tooth autotransplantation (7, 23).

Extraoral time less than 15 minutes was also associated with a positive effect on tooth survival, which is consistent with the results of previous studies on intentional replantation (16, 24). Fundamentally, the viability of PDL cells is 1 of the most critical factors for successful adaptation of the donor tooth on the recipient site (25), and at the same time, excessive extraoral time has been reported to have a detrimental effect on the survival of PDL cells (26); therefore, it is important to reduce the extraoral time of the donor tooth to improve the prognosis of tooth autotransplantation. In this regard, the application of the CARP model is recommended to minimize the extraoral time in tooth autotransplantation (5, 6, 27, 28). Lee et al (5) achieved 7.4 minutes of average extraoral time using CARP models in 22 cases of tooth autotransplantation and suggested that the CARP model is effective in reducing the extraoral time of the donor tooth because it enables the clinician to finish the bone preparation of the recipient site before the extraction of the donor tooth.

Inflammatory Root Resorption

Trope et al (29) suggested that IRR after tooth replantation is associated with 2 major factors: damage to the PDL and cementum from surgical trauma and bacterial contamination within the root canal and dentinal tubules. In this regard, surgical extraction of the donor tooth revealed several risk factors regarding the occurrence of IRR compared with simple extraction. One factor is that surgical trauma during extraction could be greater in cases of impacted teeth compared with the extraction of fully erupted teeth, which might cause more damage to the PDL and cementum of the tooth. Another factor is that preoperative RCT is not possible in cases of surgical extraction, which requires

additional extraoral RCT during the surgery or postoperative RCT. However, it should be noted that the extraoral RCT necessarily increases the extraoral time of the donor tooth (28), which might result in an increased chance of PDL cell necrosis and bacterial contamination in the dentinal tubules. Postoperative RCT prevents such possibilities; however, the necrotic pulp chamber and dentinal tubules remain vulnerable to postoperative bacterial contamination before the completion of RCT (30). In the same line, Chung et al (31) reported that the incidence of IRR was 2 times higher in studies that initiated RCT beyond 2 weeks compared RCT initiated within 2 weeks after tooth autotransplantation. Therefore, it appears that an impacted tooth with complete root formation might not be an appropriate donor in tooth autotransplantation. When using such a tooth as a donor, efforts should be paid to minimizing surgical trauma during extraction, and RCT of the donor tooth should be initiated as soon as possible after the surgery.

Ankylosis

Tooth autotransplantation inevitably induces interruption of the vascular supply to the root surface, which could be detrimental to the survival of PDL cells. Meanwhile, tooth ankylosis is initiated from the destruction of PDL and subsequent infiltration of the osteoblasts and osteoclasts into the root dentin (32). Therefore, rapid revascularization of the PDL would be significant in preventing ankylosis of the autotransplanted tooth. Cardaropoli et al (33) reported that the fresh extraction socket and the surgically produced bone defect exhibited different healing because of the presence and absence of the PDL cell remnants in the socket. In a fresh extraction socket, PDL fibroblasts remaining in the socket wall actively proliferate and migrate into the coagulum, promoting the reconstruction of the connective tissue and the bone (34), which implies more rapid revascularization to the donor root surface. Skoglund and Hasselgren (35) also found that tissue ingrowth to the immature autotransplanted tooth was considerably slower in the surgically created socket compared with the natural socket and suggested that the trauma during the surgical preparation of the socket wall results in delayed revascularization to the autotransplanted tooth. Therefore, in terms of the cell survival of the PDL, the fresh extraction socket appears to provide a better environment compared with the surgically created socket, which resulted in a low incidence of ankylosis.

Interestingly, autotransplanted teeth with low initial stability are associated with a less likely occurrence of ankylosis compared with those with high initial stability, which is in line with previous studies that reported that cases without rigid fixation were associated with better healing in tooth autotransplantation (36, 37). Kristerson and Andreasen (36) suggested that periodontal revascularization after tooth autotransplantation is enhanced by physiological micromovements of the autotransplanted tooth, which implies delayed vascularization on the autotransplanted tooth with high initial stability. Oortgiesen et al (38) also reported that PDL cells proliferated more actively under mechanical stimulation. Another factor is that the donor tooth usually does not 3-dimensionally fit within the prepared bone socket, and high initial stability might be a result of the impingement of the autotransplanted tooth in the socket. In this case, mechanical stress could be concentrated on several impingement points between the socket wall and the donor root surface at the initial healing stage, which might cause localized apoptosis of PDL cells (39) and subsequent initiation of ankylosis.

In this study, either saline or HBSS was used as a storage medium during the extraoral procedure. Saline provides physiologic pH and osmolality, but it lacks glucose, calcium, and magnesium ions, which are required to sustain metabolic activity of PDL cells. In this respect, HBSS has been regarded as an effective medium for long-term storage of the tooth because it contains nutrients that are essential to maintain cell metabolism (40, 41). However, it should also be noted that in a short-term storage less than 60 minutes similar results regarding PDL cell viability were reported between the 2 solutions (42–44). Therefore, it would be significant to compare these 2 solutions in a surgical environment in which the extraoral time is controlled within 15 minutes in most cases (5). For this reason, we attempted to add extraoral storage medium (saline vs HBSS) as a clinical variable, but for now the number of cases treated with HBSS were not sufficient to be processed statistically. We expect this issue to be specified in follow-up studies.

In this study, the cumulative survival of tooth autotransplantation for up to 12 years was 68.2%, which is still not sufficient to completely replace the single implant placement (45). However, recent clinical studies and case reports show that tooth autotransplantation provides obvious clinical benefits when used in cases with adequate indications (4, 23, 27, 46–49). Therefore, prognostic factors for tooth autotransplantation need to be further investigated to facilitate proper case selection at the treatment planning stage. Furthermore, the pre- and intraoperative procedures could also be improved based on knowledge of the prognostic factors, such as the introduction of the CARP model, orthodontic forces, and piezosurgery (5, 7, 23, 28). Further biologic research and clinical trials are required to improve our understanding of the mechanism of PDL healing and the clinical outcomes of tooth autotransplantation.

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