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Importance of root development in autotransplantations: a retrospective study of 137 teeth with a follow-up period varying from 1 week to 14 years

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SUMMARY The aim of the present study was to perform a retrospective study of autotransplanted teeth with a variable but individually maximized follow-up period in order to provide information on the long-term clinical outcome. The sample was obtained from patients who were treated at the University Hospitals KU-Leuven, Belgium, during the period 1996–2010. Of the total of 109 subjects (137 teeth), 98 patients were invited for recall, of whom 68 patients (87 teeth) responded positively. Eleven out of the 109 patients were excluded due to loss of the transplanted tooth. Although 41 patients had no re-examination visit, clinical and radiological data from all 109 subjects were included in the sample. The follow-up period varied from 1 week of 14.8 years, with a mean of 4.9 years. Transplanted teeth receiving orthodontic treatment had a lower risk of ankylosis and were less likely to fail. The risk of root resorption was lower for teeth with stages one-half to three-quarters of root length at the time of transplantation. Molars were more susceptible to ankylosis. Almost all teeth showed partial or full obliteration of the pulp. Absence of further root development was higher in donor teeth with root length stage less than one-half. Trans-alveolar transplantation was less successful. Autotransplantation can be a valid alternative method in young adolescents for replacing missing teeth because of agenesis or trauma. The optimal time to transplant is when the root has reached two-thirds to three-quarters of the final root length.

Introduction

Treatment of children and adolescents with missing teeth is challenging. Growth and developmental changes in the oral region have to be taken into account. Treatment options include prosthetic replacement, orthodontic closure, and maintaining the deciduous tooth in case of agenesis. If a suitable donor tooth is available, autotransplantation is a viable option. In addition to congenitally missing or traumatized teeth that cannot be preserved, transplantation of impacted teeth to their normal position is another indication (trans-alveolar transplantation; Thomas *et al*., 1998; Tsukiboshi, 2002).

Autotransplantation refers to the transfer of a tooth from one region in the mouth to another in the same individual, into an extraction site, or surgically prepared socket. It is a well-established surgical treatment option to substitute missing teeth and offers a valuable and aesthetic solution at low cost. In contrast to osseo-integrated implants, the transplanted tooth can offer the benefit of capacity for functional adaptation, preservation of the alveolar ridge, and potential for continued alveolar bone induction in growing children (Paulsen and Andreasen, 1998; Czochrowska *et al*., 2002; Tsukiboshi, 2002; Zachrisson *et al*., 2004). After successful surgery, the transplanted tooth usually recovers its proprioceptive function and normal periodontal ligament (Aslan *et al*., 2010). Careful case selection (age, type of donor tooth, and root length), per-operative factors, such as surgical procedure, skill, and experience of the operator, and adequate immobilization influence the outcome of this procedure (Thomas *et al*., 1998; Kallu *et al*., 2005). The donor tooth should be expendable whereby no negative effects result from the change of its position in the arch or its potential future loss. A multidisciplinary approach and an accurate follow-up are essential for the survival of the tooth.

The purpose of the present retrospective study of autotransplanted teeth was to evaluate the effect of donor root development, donor tooth type, and orthodontic treatment on the overall success rates.

Materials and methods

The sample for this study comprised patients who were treated at the University Hospitals, KU-Leuven, Belgium. Kallu *et al*. (2005) documented part of this consecutive

sample collected during the period 1996–2003 (38 subjects and 47 teeth). Another sample of 88 subjects (110 teeth), transplantations performed during the period 2004–10, were added. In total, 17 subjects of this group were excluded because of their involvement in another ongoing study in which a surgical guide was used to accomplish the tooth transplantation (Table 1; Shahbazian *et al*., 2013). Of the total of 109 subjects (137 teeth), 98 patients were invited for recall, of which 68 patients (87 teeth) responded positively. Eleven out of the 109 patients were excluded due to loss of the transplanted tooth. Twelve patients could not be contacted and 18 patients did not attend their recall appointment for unknown reasons. Although 41 patients had no re-examination visit during the period 2010–11, all the information until the latest visit from all 109 subjects was included in the sample.

The baseline information such as gender, age, indication for transplantation, type of donor tooth, recipient site, and type of splint was registered from medical files. Out of the 109 subjects, 46 were women (55 teeth) and 63 were men (82 teeth; Table 1). The mean and median for the age at transplantation were 13 and 12 years respectively, with a minimum of 8 years and a maximum of 29 years. A total of 24 patients (31 teeth) had undergone trans-alveolar transplantation and 7 out of these 31 teeth were transplanted in the same individual. Out of 137 transplanted teeth, 9 were incisors, 11 were canines, 99 were premolars, and 18 were molars (Table 2).

The root length at the time of transplantation was determined by means of the available radiographs (cone-beam computed tomography (CT), panoramic or apical radiograph) and varied from less than one-half (N = 12), one-half to three-quarters (N = 84), greater than three-quarters (N = 20) of the normal root length to apex closed (N = 21). This was defined as accurately as possible by two examiners, preferably by comparing with the contralateral tooth or the same tooth in the opposite jaw if the contralateral was missing. The cases were discussed and consensus was obtained.

Twenty-seven teeth were erupted and 110 teeth were unerupted before transplantation. The presence of a predecessor at the donor and recipient sites was noted. Stabilization after transplantation was performed in different ways. When initial stability was satisfactory, the tooth was immobilized by suturing with vicryl wire (N = 38). This process was called ‘suture on top’. Occasionally, a nylon wire (not disintegrating) was used as suturing material (N = 4). If there was doubt about the mobility, the tooth was strengthened with a splint, an orthodontic metal ligature wire (0.4 mm) attached with composite (N = 94). The duration of the splinting varied from 1 week to 2 months. Almost all the transplanted teeth were left in infra-occlusion. Only in one subject, a tooth was placed submucosally because of a very short root length.

During the recall visit clinical measurements, clinical pictures and standardized intraoral radiographs were taken. All information was collected in a standard post-transplantation template sheet. For some patients, a cone-beam CT was performed because these patients served as a control group for the study reported earlier (Shahbazian *et al*., 2012). In that case, a two-dimensional view was created and used for evaluation to exclude difference in assessment of the radiological parameters compared with that using an apical radiograph.

Clinical examination was performed by assessing tooth mobility, palpation, colour, presence of inflammation, percussion, probing pocket depth, gingivitis index, vitality, and occlusal contacts. It was recorded whether the patient underwent orthodontic treatment. Tooth mobility was scored on a scale from 0 to 3 (0: no mobility, ankylosis; 1:

Table 2 Donor and recipient tooth types.

	Molars	Premolars	Canines	Incisors
Donor tooth type, frequency/per cent	18/13.14%	99/72.26%	11/8.03%	9/6.57%
Recipient tooth type, frequency/per cent	12/8.76%	62/45.26	10/7.30%	53/38.69%
Trans-alveolar transplantation, frequency	4	7	11	9
Conventional transplantation, frequency	14	92	0	0

Table 1 Overview of patients (n = 109) and transplantations (N = 137).

	Women	Men	Conventional transplantation	Trans-alveolar transplantation	Recall	No recall (reason: no response)	No recall (reason: tooth extracted)
n (Patients)	46	63	85	24	68	31	11*
N (teeth)	55	82	106	31	87	38	12**

*One patient with two transplanted teeth responded positively for recall, but one of the transplants was already lost.
**Seven conventional transplanted teeth and five trans-alveolar transplanted teeth.

normal mobility; 2: horizontal mobility; and 3: teeth could be intruded). By comparing with the natural neighbouring teeth, colour was scored from 0 to 2 (0: normal colour; 1: minor discolouration; 2: major discolouration). Pocket probing was carried out with a calibrated periodontal probe (ASA Dental SPA, Bozzano Massarosa, Italy) at six sites of the transplanted tooth: mesiovestibular, vestibular, distovestibular, distolingual, lingual, and mesiolingual. A pocket depth exceeding 3 mm was prescribed as pathological. To measure the gingivitis index, the sulcus bleeding index proposed by Mühlemann and Son was used (Mühlemann and Son, 1971). Percussion was scored from 0 to 2 (0: no pain; 1: pain sensitivity; and 2: extreme pain sensitivity). Vitality was tested by means of a carbon dioxide stick (0: positive response; 1: no response; 2: delayed reaction; and 3: endodontic treatment).

Radiological evaluation included root resorption, lamina dura formation, ankylosis, apical closure, changes in the pulp chamber, root development, and crown-to-root ratio (anatomical crown in proportion to anatomical root). Resorption was categorized in surface (small and local area of damaged root), external (large area of resorption), inflammatory (pulp chamber infected), and internal resorption (resorption in pulp chamber). Further root growth was estimated by comparing with the contralateral tooth (to donor site) and classified as arrested, partial, or complete development. Teeth with initial closed apex were considered completely developed. Changes in the pulp chamber were qualified as increased in size (internal resorption), decreased in size (partial obliteration), constant (no changes), full obliteration, and endodontic treatment.

The success criteria were adapted from the studies of Czochrowska *et al*. (2002) and Kallu *et al*. (2005). In this study, a successfully transplanted tooth was defined as a tooth with normal soft periodontal tissues, no progressive root resorption, no ankylosis (ankylosis is defined as absence of radiolucency between donor tooth root and alveolar bone), physiological mobility, no apical infection, and a crown-to-root ratio less than one to maintain tooth function (root length greater than one-half). Teeth not fulfilling all of the above criteria were classified as 'tentative'. Teeth that had been lost or were to be extracted were marked as a failure. Tentative and successful teeth were classified as 'survival' (Kallu *et al*., 2005). The overall success and survival rates were assessed as the number of teeth that were successfully transplanted or still present and functioning well at the moment of the examination visit, respectively, relative to the total number of transplanted teeth.

Clinical and radiological information from different consultations were used to fill in the post-transplantation templates. This template was also used for patients who did not attend the post-operative recall visit, although information in the medical files was sometimes limited. One patient had no consultation after surgery, and for six patients, there was no post-transplantation radiographic information available. These teeth were marked as 'tentative'. Subsequently, the retrospective data and the data from the recall visits were collected and grouped in the following way: 0–12 months, 1–5 years, 5–10 years, more than 10 years. The follow-up period varied from 1 week to 14 years 10 months, with a mean of 4 years 11 months. The observation period was minimum 5 years for 49 patients (63 teeth).

Data modifications for statistical analysis

Resorption and splinting type were recorded as 1. 'normal healing' and 'resorption' and 2. 'splint' and 'other', respectively. Outcome parameters of the irreversible type were analysed as time-to-event outcomes. The time period was defined as the interval between transplantation and the first recall at which the problem was detected. Prognosis is not an irreversible parameter: an uncertain prognosis can turn into success or failure. A change in parameter occurred in 6 out of 137 teeth. However, for the statistical analysis, we considered 'prognosis' as a time-to-event parameter.

Statistical methodology

Descriptive information of outcome parameter is provided in frequency tables, with a subdivision by last recall period. Table 3 shows an overview of the total number of teeth that could be evaluated for each outcome category. A Kaplan–Meier curve was created to describe the overall survival rate over time. Clinical and radiological variables were associated with a number of baseline parameters (Table 4). Logistic regression models were used for binary outcome parameters (resorption, lamina dura formation). The association between root development and orthodontic treatment was analysed by logistic regression with orthodontic treatment as a binary outcome variable. Proportional odds models were used for ordinal categorical outcome parameters (root development). A baseline-category logit model was used for analysis of mobility, with normal mobility used as the reference category. This model was also used in a secondary analysis of root development, with 'arrested (no further) development' as the reference category. To simplify the statistical analysis on vitality (as a four-category multinomial outcome without

Table 3 Total number of teeth radiologically or clinically examined for each outcome category.

Outcome parameter	*N*(teeth)
Resorption	130
Ankylosis	130
Lamina dura formation	130
Changes in the pulp chamber	130
Root development	122
Mobility	118
Vitality	114
Success/uncertain/failure	136
Orthodontic treatment	136

Table 4 Overview of statistical analyses between outcome and baseline parameters: *V* = statistically significant; *X* = statistically not significant; / = not examined.

	Resorption	Ankylosis	Lamina dura	Root development	Mobility	Vitality	Success	Failure
Donor tooth type	X	V	X	X	V	/	V	V
Stage of root length at transplantation	V	X	V	X	X	V	V	V
Indication for transplantation	V	V	/	/	/	/	/	V
Donor eruption stage	/	X	/	/	/	X	X	/
Recipient tooth site	/	V	/	/	/	/	V	V
Donor predecessor	/	/	/	/	/	/	V	/
Recipient predecessor	/	/	/	/	/	/	V	/
Trans-alveolar transplantation	/	/	/	/	/	/	/	V
Splinting type	X	X	/	/	/	/	/	/
Orthodontic treatment	X	V	/	X	/	/	/	V

clear reference), we considered models where the baseline parameter was considered the outcome parameter and vitality was the covariate. A proportional odds model was used for analysing the relationship with root length stage at transplantation and a logistic regression model was used for donor eruption stage. Time-to-event outcome parameters (ankylosis, success, and failure) were analysed using a proportional hazards Cox model. In all analyses, we took into account clustering of the observations as a result of repeated measurements over time and/or multiple teeth per patient.

Analysis was performed by first checking the evidence for a general association between the baseline parameter and the outcome parameter. In cases where a statistically significant result ($P < 0.05$) was observed, all pairwise comparisons were tested. Bonferroni correction for multiple comparisons was then applied. Descriptive statistics and statistical analyses were performed using SAS software, version 9.2 of the SAS System for Windows (SAS Institute Inc., Cary, North Carolina, USA).

Results

Table 2 gives an overview of donor and recipient tooth types recorded in this study both related to conventional and trans-alveolar autotransplantations performed. Agenesis was the most frequent indication for transplantation (41.6%), followed by traumatic tooth loss due to avulsion, fracture, or luxation (28.5%). Sixty transplanted teeth underwent orthodontic movement. The period between the transplantation and the orthodontic treatment varied considerably. Seventy-three teeth were not involved in orthodontic treatment.

Resorption

Table 5 shows the incidence of the different types of resorption subcategorized by last recall period. No specific type of donor tooth seemed to be more susceptible to resorption. An association was found between resorption and stage of root length at transplantation. Teeth with a root length between one-half and three-quarters had smaller probability of resorption compared to teeth with a developmental stage greater than three-quarters or the apex-closed stage. Teeth transplanted because of agenesis of the predecessor were less likely to undergo resorption than trans-alveolarly transplanted teeth. There was no significant association between type of splinting and the presence of resorption or between orthodontic treatment and resorption.

Table 5 Outcome: resorption; ordered by last recall period.

Resorption, frequency (col pct)	Recall group				
	<1 year	1–5 years	5–10 years	>10 years	Total
Normal healing	16 (84.21)	41 (85.42)	34 (68.00)	11 (84.62)	102
Surface resorption	1 (2.26)	2 (4.17)	4 (8.00)	0 (0.00)	7
Inflammatory resorption	1 (5.26)	3 (6.25)	2 (4.00)	1 (7.69)	7
External resorption	0 (0.00)	2 (4.17)	9* (18.00)	1 (7.69)	12
Internal resorption	1 (5.26)	0 (0.00)	1 (2.00)	0 (0.00)	2
Total	19	48	50	13	130
Frequency missing = 7					

*One tooth shows external and internal resorption.
col pct, column percentage.

Ankylosis

Ankylosis was seen on the peri-apical radiographs of 14 teeth. Statistically, the risk of ankylosis was higher in the case of molars in comparison with premolars as donor teeth. An analogous association for recipient tooth site was found as well. A lower risk of ankylosis was observed in case of traumatic tooth loss in comparison with trans-alveolar transplantation. There was no association between ankylosis and stage of root length at transplantation, donor eruption stage, and splinting type. A decreased risk for ankylosis was found in combination with orthodontic treatment.

Lamina dura

Eighty-seven out of 130 teeth (66.9%) showed partial or full lamina dura formation on the apical radiograph taken at the final recall. There was strong evidence for a relationship with stage of root length at transplantation, the one-half to three-quarters category resulting in the highest probability for lamina dura formation.

Vitality and changes in the pulp chamber

Out of the 114 teeth that were tested with carbon dioxide for signs of vitality during the final consultation, 20 teeth responded positively, 32 teeth did not respond, 44 teeth gave a delayed reaction, and 18 teeth were endodontically treated, all in the absence of radiological signs of apical infection. Mostly, teeth with partial or fully obliterated roots gave delayed or no reaction. Higher levels of stage of root length at transplantation were statistically associated with 'endodontic treatment'.

Hundred and thirty teeth were radiologically evaluated for changes in the pulp chamber. Ninety teeth showed partial or full obliteration of the pulp chamber and 18 teeth showed root canal fillings (Table 6).

Root development

Table 7 shows that out of 122 evaluated teeth, root development continued in 68 teeth. Teeth with stage of root length less than one-half had a higher probability of having 'arrested growth' rather than 'complete development' compared with patients with root length stage greater than three-quarters. Furthermore, the relationship between root development and orthodontic treatment was analysed, but no association was found.

Mobility

Out of 118 teeth, 88 teeth had normal mobility, 13 teeth showed increased mobility in the horizontal plane, and only 2 teeth showed abnormal increased vertical mobility. A significant relationship with donor tooth type was observed. Molars had an increased probability, compared with premolars, of having 'no mobility/ankylosis' rather than 'normal mobility'.

Success and failure

Out of 136 teeth, 18 transplanted teeth failed, 29 were marked as tentative, and 89 were successful at their last consultation (Table 8). The survival and success rates for the total number of transplanted teeth in the sample were 86.8 and 65.4%, respectively, with a mean observation time of 4 years 11 months. The Kaplan–Meier curve in Figure 1 describes the survival rate in another way. In this curve, the dropouts indicate tooth loss or no further follow-up. A 5 year survival of 93.1% and a 10 year survival of 72.2% were obtained (Figure 1). Premolars were found to be more successful compared with molars, and teeth with root lengths of one-half to three-quarters were found to be more successful compared with the three other stages of development. An association was observed between success and recipient predecessor. Cases with a deciduous tooth present were more successful than those without a deciduous tooth. Trans-alveolar transplantation showed a high risk of failure (Table 4). A remarkable association, however, was observed between failure and absence of orthodontic treatment. Teeth that received orthodontic treatment were less likely to fail than those without treatment.

Discussion

Autologous transplantation of teeth is influenced by a number of pre-, per-, and post-operative factors such as donor tooth type, stage of root length at transplantation, recipient

Table 6 Changes in the pulp chamber after transplantation.

Changes pulp chamber, frequency (col pct)	Recall group				
	<1 year	1–5 years	5–10 years	>10 years	Total
Increased in size (internal resorption)	1 (5.56)	0 (0.00)	2 (4.00)	0 (0.00)	3
Decreased in size (pulp obliteration started)	4 (22.22)	22 (44.90)	15 (30.00)	4 (30.77)	45
Constant (no pulp obliteration)	9 (50.00)	3 (6.12)	3 (6.00)	0 (0.00)	15
Full obliteration of the pulp chamber	2 (11.11)	18 (36.73)	21 (42.00)	8 (61.54)	49
Endodontic treatment is done (root canal filled)	2 (11.11)	6 (12.24)	9 (18.00)	1 (7.69)	18
Total	18	49	50	13	130
Frequency missing = 7					

col pct, column percentage.

Table 7 Root development after transplantation. Teeth with root length at the apex closed stage at transplantation were taken out of the group 'complete root length'.

Root development, frequency (col pct)	Recall group				
	<1 year	1–5 years	5–10 years	>10 years	Total
Arrested (no further root growth)	9 (50.00)	6 (14.29)	16 (32.65)	3 (23.08)	34
Partial root growth	1 (5.56)	20 (47.62)	15 (30.61)	8 (61.54)	44
Complete root length	1 (5.56)	10 (23.81)	11 (22.45)	2 (15.38)	24
Normal root length: 'apex closed' at transplantation	7 (38.89)	6 (14.29)	7 (14.29)	0 (0.00)	20
Total	18	42	49	13	122
Frequency missing = 15					

col pct, column percentage.

tooth site, trans-alveolar transplantation, surgical trauma, and orthodontic treatment subsequent to transplantation.

Periodontal healing

Successful periodontal healing is usually completed after 8 weeks when the root periphery is surrounded by a newly formed periodontal space, marked by the absence of root resorption and the presence of a lamina dura (Thomas *et al*., 1998; Mendes and Rocha, 2004; Aslan *et al*., 2010). This study observed a higher probability for lamina dura formation in teeth with one-half to three-quarters of root formation at surgery in comparison with the three other stages of root length. Besides, the risk of root resorption was lower in the one-half to three-quarters category compared with teeth at stages greater than three-quarters or apex-closed ones. Previous reports confirm this finding and describe that periodontal healing without root resorption is closely related to the stage of root development and decreases with increasing root development (Andreasen *et al*., 1990).

Serious complications such as replacement resorption and ankylosis are correlated with mechanical or biochemical damage to the periodontal ligament (cementum injury) during surgery (Tsukiboshi, 2002; Diaz *et al*., 2008). An atraumatic surgical technique preserves bone and periodontal support and protects the Hertwig's root sheath and pulpal tissue (Thomas *et al*., 1998; Mendes and Rocha, 2004). Ankylosis could be related to stage of root length at transplantation (Andreasen *et al*., 1990; Diaz *et al*., 2008), but in our study, this relationship was not found to be statistically significant. However, an association with molars as type of donor tooth was observed. The explanation could be that molars are more difficult to remove atraumatically, causing a higher risk for ankylosis (Figure 2).

Table 8 Prognosis of the transplanted teeth.

Prognosis, frequency (col pct)	Recall group				
	<1 year	1–5 years	5–10 years	>10 years	Total
Failure	5 (20.83)	3 (6.12)	9 (18.00)	1 (7.69)	18
Success	14 (58.33)	36 (73.47)	28 (56.00)	11 (84.62)	89
Tentative	5 (20.83)	10 (20.41)	13 (26.00)	1 (7.69)	29
Total	24	49	50	13	136
Frequency missing = 1					

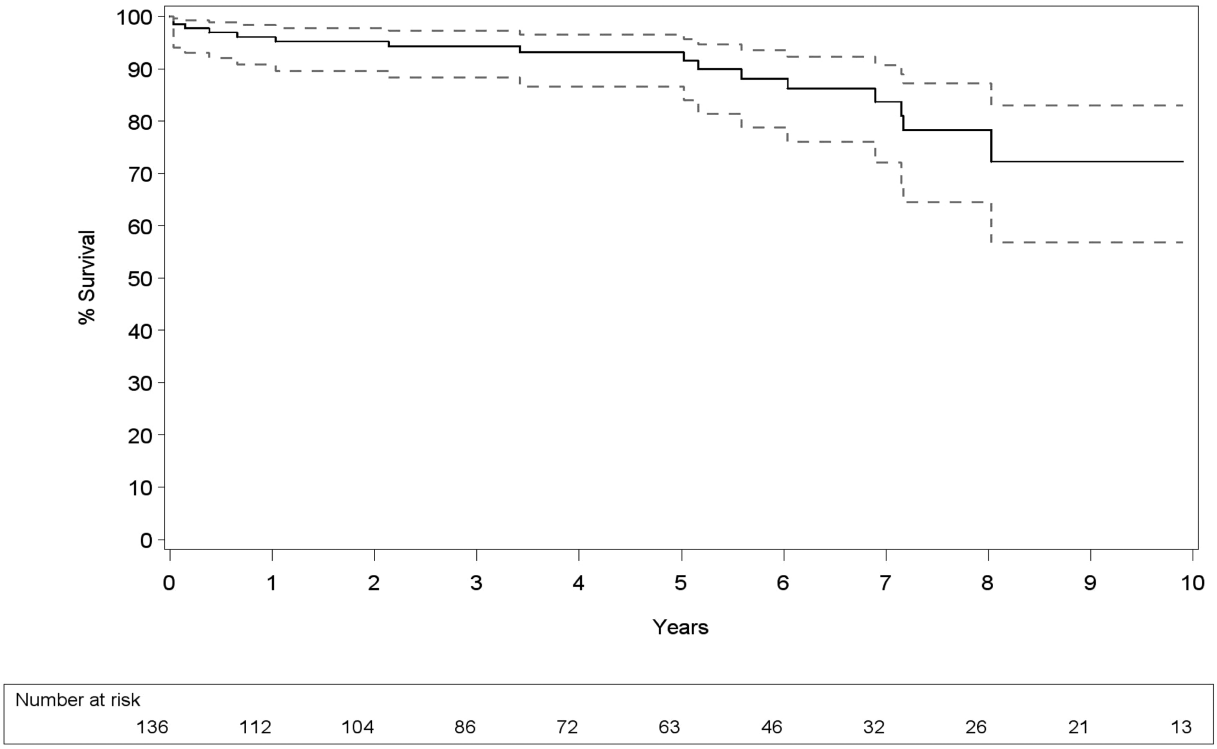
col pct, column percentage.

Pulp healing

Varying degrees of pulp obliteration were seen in almost all teeth of the sample in this investigation. This did not differ from that found in previous reports. Obliteration of the pulp chamber and canal appears to be an early and normal physiologic sign of pulp healing. Radiographic signs of obliteration are usually observed within 6 months after surgery (Andreasen *et al*., 1990; Paulsen *et al*., 1995; Jonsson and Sigurdsson, 2004). This healing is related to ingrowths of connective tissue from the periodontal ligament into the pulp canal and chamber. This tissue, histologically different from normal pulp tissue, stimulates formation of tertiary dentin, which slowly obliterates the root canal. It is vital and will not induce pathological changes (Paulsen and Andreasen, 1998; Jonsson and Sigurdsson, 2004; Figure 3).

Vitality was tested with carbon dioxide. CO_2, electric pulp test (EPT), and laser Doppler flowmetry (LDF) are reliable and accurate tests, but CO_2 and EPT were less repeatable yet less time-consuming than LDF (Chen and Abbott, 2011).

Pulp regeneration and revascularization are expected when the apical foramen displays at least a diameter of 1 mm radiographically (Andreasen *et al*., 1990; Tsukiboshi, 2002; Mendes and Rocha, 2004). Regeneration of the pulp of completely mature teeth cannot occur, making endodontic treatment necessary (Tsukiboshi, 2002; Bae *et al*., 2010). If the donor tooth is accessible, the endodontic treatment should be done before transplantation. When the transplanted tooth is unerupted, it is advisable to perform the root filling 1–2 weeks after surgery (Tsukiboshi, 2002 'When the transplanted tooth is unerupted'; Mendes and



		95% confidence interval	
Years	Survival	Lower Limit	Upper Limit
5	93.14	86.94	96.46
10	72.23	59.37	81.63

Figure 1 Kaplan–Meier curve for survival (with 95% confidence interval), along with 5 and 10 year survival rates.

Rocha, 2004). Frequently, it still seemed necessary to endodontically treat donor teeth with a root length more than three-quarters because of pulpal necrosis leading to inflammatory resorption.

Development of the root

Full development of the root can be expected when surgery is performed under ideal circumstances and Hertwig's epithelial sheet is preserved; moreover, it depends on the root length at the moment of transplantation (Andreasen *et al*., 1990; Paulsen *et al*., 1995; Diaz *et al*., 2008). According to Andreasen *et al*. (1990), teeth in early stages of root development show less post-transplantation root growth than those with more mature roots but incompletely formed apices. However, the amount of further root growth is difficult to predict based on the stage of root development of the donor tooth (Andreasen *et al*., 1990). In the present study, teeth with root length around one-half were found to be at higher risk for arrested root development rather than reaching their full length compared with teeth of root length greater than three-quarters at transplantation. Because arrested root growth is a possibility, it is advised that the tooth to be transplanted should ideally have reached root development of more than one-half root formation to maintain good oral function afterwards.

Orthodontic treatment

In the study of Jonsson and Sigurdsson (2004), 87.5% of the transplanted teeth were orthodontically moved and this did not appear to influence the long-term prognosis of the teeth. The present study describes two striking associations for transplanted teeth receiving orthodontic treatment. The

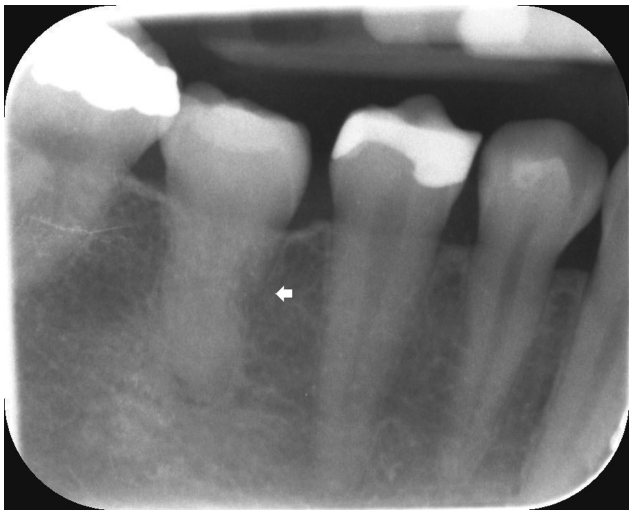


Figure 2 Apical radiograph of a transplanted molar showing ankylosis and replacement resorption.

Figure 3 Apical radiograph of a transplanted premolar showing further root development with pulp obliteration of that part of the root formed before transplantation.

latter have a lower risk for ankylosis and are less likely to fail. This finding is not cited in other studies. Andreasen *et al*. (1990) reported a slight increase in the frequency of both surface and inflammatory root resorption subsequent to orthodontic movement of transplanted teeth with complete root development. According to Paulsen *et al*. (1995), orthodontic rotation induced slight surface resorption and shortening of the root in premolars transplanted at the three-quarters stage and end-stage of root development with open apex. Orthodontic rotation might reduce apical blood flow when the apical foramen is located eccentrically, especially in late stages of pulp obliteration (Paulsen *et al*., 1995). However, the association with root resorption was not found to be significant in our study and orthodontic forces seemed not to affect root development. The possibility to move autotransplants orthodontically without negatively affecting prognosis appears a major advantage of autotransplantation. Some authors advise to wait with orthodontic treatment for 3–6 months after transplantation, i.e. after periodontal healing but before total pulp obliteration (Andreasen *et al*., 1990; Paulsen *et al*., 1995; Josefsson *et al*., 1999).

Evaluation of success and survival

A large variation of success and survival rates has been reported in the literature. Reasons for this observation could be the difference in sample size/type, variations in post-operative periods, and the different definitions of success. Only few articles give success and survival rates of transplanted teeth with uniform follow-up periods (Josefsson *et al*., 1999). In the study of Diaz *et al*. (2008), a survival rate of 100% is described, but only for 10 transplanted teeth with a follow-up period varying from 5 to 27 months. Czochrowska *et al*. (2002) reported survival and success rates of 90 and 79%, respectively, for 33 transplanted teeth, with a mean follow-up period of 26.4 years. Jonsson and Sigurdsson (2004) published a study of 40 transplanted premolars with a survival rate of 97.5% and success rate of 92.5%, with a mean follow-up period of 10 years 4 months. In this study, the success criteria were based on the absence of inflammatory pulpal changes and progressive root resorption, the presence of normal peri-apical healing (no ankylosis), and a root length more than half of the final root length. Transient root resorption was not considered unsuccessful. When resorption becomes stable, the tooth may still be retained for a long time (Tsukiboshi, 2002). In the study of Kallu *et al*. (2005), further root development was included in the success criteria, and they reported overall success and survival rates of 68 and 88%, respectively. The findings of our study describe a similar result of 65% success rate and 87% survival rate (5 and 10 year survival of 93% and 72%, respectively).

Success and survival rates are affected by several factors such as type of donor tooth and stage of root development at transplantation. Molars as donor teeth were less successful than premolars in the present study. This was consistent with the finding in the study by Kallu *et al*. (2005), where premolars had a higher success rate. Several studies have shown a well-documented higher success for teeth with root length one-half to three-quarters at time of transplantation (Czochrowska *et al*., 2000; Kallu *et al*., 2005). The above-described associations in the present study support these earlier reports. Transplanted teeth with immature root formation and open apex are favourable for the healing process, with increased probability of pulp revascularization and vitality (Diaz *et al*., 2008), although teeth in early stages of root development have a greater chance for arrested root growth than those with more mature roots but incompletely formed apices (Andreasen *et al*., 1990). Autotransplantation of teeth with fully formed roots reduces the success rates (Czochrowska *et al*., 2000). When a root shows one-quarter of its length, the mean time to reach one-half root length is 1.7 years for premolars; for canines, it is 2.3 years for men and 1.8 years for women. The

time interval from one-half to three-quarters of root length ranged from 1.1 to 1.6 years (Moorrees *et al*., 1963).

In the present study, trans-alveolar transplantations had a high risk of failure and were more susceptible to ankylosis and root resorption. The accessibility of impacted teeth during surgery is lower, whereby the risk of damaging the root surface while extracting the tooth is higher, and ankylosis or root resorption is strongly correlated with damage to the root surface during surgery (Czochrowska *et al*., 2000). Furthermore, the periodontal ligament of impacted teeth is thinner than that of teeth that are functioning normally (Gonissen *et al*., 2010). In case of trans-alveolar transplantation, there is a chance that there is no preformed alveolus to position the donor tooth. According to Tsukiboshi (2002), transplantation is more successful if the recipient socket is an extraction site with periodontal ligament attachment still present. Success rates of teeth autotransplanted into artificially formed sockets are lower than those of teeth transplanted into extracted sockets (Tsukiboshi, 2002; Gonissen *et al*., 2010). In addition, this explains the finding of our study that when a deciduous tooth was present at the recipient site, the transplantation was more successful.

Conclusion

Autotransplantation is a biological method that preserves the periodontal ligament and favours the growth of the alveolar ridge (Czochrowska *et al*., 2002; Tsukiboshi, 2002; Zachrisson *et al*., 2004). A well-established protocol for transplantation of teeth is essential for successful transplantations.

The best outcome was recorded when the donor tooth root development reached two-thirds to three-quarters of the final root length. Orthodontic treatment did not affect the prognosis of the transplanted teeth. It is suggested to postpone orthodontic treatment till pulpal and periodontal healing has taken place but to start treatment before full pulp obliteration, i.e. 3 to 9 months after transplantation.

This study reiterates that autotransplanted teeth can have a favourable long-term prognosis in children and adolescents where implants are not yet an option to replace a missing or lost tooth. However, longer-term follow-up periods are needed to demonstrate the use of autotransplantation as a lifelong treatment modality in children and adolescents with missing teeth.

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