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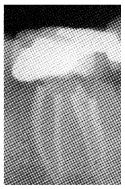

CLINICAL ARTICLE

Retrospective long-term evaluation of autotransplantation of premolars to the central incisor region

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Abstract

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Aim This retrospective case-series study aimed to examine the long-term outcomes of autogenously transplanted premolars.

Methodology Twelve patients in whom donor premolars were used to replace maxillary central incisors lost by trauma were clinically and radiologically monitored. Standardized clinical and radiographic records were systematically obtained during the follow-up period of 14 years, to determine the influence of specific clinical criteria on the overall success rate of transplantation.

Results The success rate of premolar autotransplantation in the maxillary central incisor area was 80% after 14 years follow-up. The highest success rate occurred in those teeth transplanted with two-thirds of full root development. Complete pulp obliteration was positively related to autotransplant viability, followed by root formation in the bony crypt.

Conclusions Autotransplantation of donor teeth, at the stage of ½ to ¾ of their expected root length, can provide a successful treatment solution for over 14 years.

Keywords: bicuspid/transplantation, incisor trauma, long-term follow-up, oral surgery, orthodontics, tooth autotransplant.

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Introduction

Autotransplantation has been shown to have a high level of success and is accepted as a viable method for replacing teeth lost due to trauma (Slagsvold & Bjercke 1974, 1978a,b, Andreasen 1981, Kristerson & Andreasen 1984, Kristerson 1985, Andreasen *et al.* 1988). It is also an option for treating agenesis of lateral incisors, particularly when the patient requires orthodontic treatment involving the extraction of immature premolars.

Our understanding of the progress and outcome at the pulp and periodontal levels, as well as the possibility of complications if the correct protocol is not followed, derives largely from the long-term studies of Andreasen (Andreasen *et al.* 1990a,b,c,d, Paulsen *et al.* 1995, Paulsen & Andreasen 1998). Success depends on the use of a standardized surgical technique under aseptic conditions that takes into account the tooth germ to be autotransplanted and its degree of root development, the region into which it is to be transplanted, preparation of the recipient alveolus, and the position to be occupied by the autotransplanted premolar within this alveolar crypt (Andreasen *et al.* 1990a). The pulp and periodontal healing of the autotransplanted premolar root must then be monitored over time.

The pre-autotransplantation examination should include intra-oral periapical radiographs, taken from an orthoradial position, of both the donor germ and the recipient area, as good bone support is needed to create the alveolar crypt, and the tooth to be transplanted should be assessed for its degree of root development (Andreasen *et al.* 1990a). Andreasen *et al.* (1990b) confirmed that the highest success rates were achieved with transplants performed at stages 3 and 4 of Moorrees' classification (Moorrees *et al.* 1963), where a root development of ½ to ¾ (between 7 and 9 mm long, with a wide open foramen) resulted in a success rate of 89.5% (Andreasen *et al.* 1990b).

Despite this, few studies have monitored pulp and periodontal healing in autotransplants for a follow-up observation period of more than 10 years. In addition, there are few reports correlating systematically pulp sensibility along with periodontal and pulp healing with donor tooth root development over long-term follow-up periods (over 14 years). Few previous studies have quantified normal autotransplant root development at the implant site over a long-term observation period. This 14-year retrospective clinical study on 12 tooth autotransplants in the maxillary central incisor region was undertaken to provide information on a number of key outcome measures.

Report

Study sample

This retrospective case series study involved 12 patients (seven girls and five boys), with 12 maxillary and mandibular premolars autotransplanted to the maxillary central incisor area following traumatic loss of a central incisor. Mean patient age at the time of surgery ranged from 9 to 13 years (Table 1). Patients were selected from 20 autotransplants if: (i) they had attended all check-up appointments during the long-term follow-up period of 10–14 years; (ii) there was no additional post-transplant trauma. Any patient who had not been fully monitored during this period was excluded from the study. Of the 20 patients, five had suffered post-transplant trauma and the remaining three were excluded because of change of residence. All transplantations and long-term radiological and clinical examinations were carried out by the same oral surgeon (A.M.M) in the Surgical Unit of the COINSOL Dental Hospital following an identical surgical protocol.

Table 1 Autotransplant root development, pulp and periodontal healing follow-up

Patient No (ys)	Root stage	Pulp sensibility (+−)/Periodontal healing (+−)/Root development (mm)				
		Initial	6 mth	1 ys	10 ys	14 ys
1 (11 ys)	1/2 R	$+^{a}/+^{b}/15.5^{c}$	$+^{a}/+^{b}/16.7^{c}$	$+^{a}/+^{b}/17.2^{c}$	$-^{a}/+^{b}/21^{c}$	–
2 (11 ys)	3/4 R	$-^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/19.5^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/21.5^{c}$	$-^{a}/+^{b}/21.5^{c}$
3 (10 ys)	3/4 R	$-^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/19.5^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/20.5^{c}$	–
4 (11 ys)	3/4 R	$-^{a}/+^{b}/19.5^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/20.5^{c}$	–	–
5 (11 ys)	3/4 R	$-^{a}/+^{b}/18.5^{c}$	$-^{a}/+^{b}/19.3^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/22^{c}$	$-^{a}/+^{b}/22^{c}$
6 (13 ys)	R c	$-^{a}/+^{b}/20^{c}$	$-^{a}/SR^{b}/20.5^{c}$	$-^{a}/+^{b}/20.5^{c}$	$-^{a}/+^{b}/21^{c}$	$-^{a}/+^{b}/21^{c}$
7 (9 ys)	1/2 R	$-^{a}/+^{b}/18.5^{c}$	$+^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/21.5^{c}$	$-^{a}/+^{b}/21.5^{c}$
8 (10 ys)	3/4 R	$-^{a}/+^{b}/19^{c}$	$+^{a}/+^{b}/20^{c}$	$-^{a}/+^{b}/21^{c}$	$-^{a}/+^{b}/22^{c}$	$-^{a}/+^{b}/22^{c}$
9 (9 ys)	1/2 R	$-^{a}/+^{b}/18^{c}$	$-^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/19.6^{c}$	$-^{a}/+^{b}/21.5^{c}$	$-^{a}/+^{b}/21.5^{c}$
10 (10 ys)	3/4 R	$-^{a}/+^{b}/18.5^{c}$	$-^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/19.5^{c}$	$-^{a}/+^{b}/20.5^{c}$	$-^{a}/+^{b}/20.5^{c}$
11 (10 ys)	3/4 R	$-^{a}/+^{b}/19^{c}$	$-^{a}/+^{b}/19.5^{c}$	$-^{a}/+^{b}/20^{c}$	$-^{a}/IR^{b}/21^{c}$	–
12 (10 ys)	1/2 R	$-^{a}/+^{b}/18^{c}$	$+^{a}/+^{b}/18.5^{c}$	$-^{a}/+^{b}/19.8^{c}$	$-^{a}/+^{b}/22.5^{c}$	–

[a]: autotransplant pulp sensibility *(+−)*; [b]: adequate (+) *or* inadequate (−) autotransplant periodontal healing; [c]: autotransplant root development *(mm);* wk, weeks; mth, months; ys, years; Rc, root length complete and open apex; 3/4 R, root length %; 1/2 R, root length V2; SR, surface resorption; IR, inflammatory resorption and extraction.

The donor premolar root-development stages (Moorrees *et al.* 1963) were stages 3 (½ root length), 4 (¾ root length) and 5 (complete root length) for four, seven and one autotransplant patient, respectively (Table 1; Fig. 1a–c).

Surgical protocol

All transplantations were performed under sedation (Andreasen *et al.* 1990a) using Dormicum® at a dose of 0.2 mg kg^{-1} body weight and local anaesthesia, supplemented with nitrous oxide analgesia. The autotransplants were also performed under antibiotic cover, consisting of penicillin (5 000 000 units) for 4 days, the first dose being administered by the intramuscular route 1 h before the intervention.

All autotransplants were performed in the first 15 days following loss of maxillary incisors after trauma, without loss at the buccal bone plate. A mucoperiosteal flap was raised in the area to expose the alveolar bone, and an alveolar bed for the autologous tooth was prepared using a contra-angle handpiece at 1000–10 000 rpm, with a bone drill and under saline irrigation (Fig. 2a,b). The alveolar bed for the recipient autologous tooth was prepared 2 mm deeper, as determined by the periapical radiograph, and 1 mm wider than the erupted or semi-erupted donor premolar. Once the crypt was prepared, it was plugged with gauze to prevent contamination with saliva or clot formation before insertion of the transplanted premolar.

Donor tooth extraction was performed by incision around the tooth before luxating it with diamond forceps, using mainly rotatory movements. Once extracted, the donor

Figure 1 Typical clinical appearance of recipient alveolar bed of the autologous tooth area (a), donor premolar eruption (b) and donor tooth root formation (c).

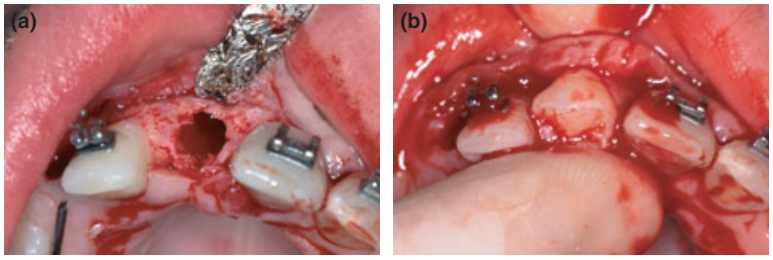

Figure 2 Surgically prepared recipient alveolar bed of the autologous tooth in anterior jaw pre-implantation (a) and post-transplantation clinical appearance in the recipient area (b).

premolar was retrieved with gauze and inserted into the prepared alveolar bony crypt. Vertical positioning was determined according to the stage of root development of the donor premolar, which was then placed according to degree of eruption, but always in infra-occlusion. Buccal–palatal and mesiodistal positions were determined according to the width of the recipient alveolar process, with palatal placement if necessary, and depending on the final restoration needs. Once in position, the autotransplanted tooth was sutured in place with triple-zero suture silk, using two stitches crossed labiolingually. Six months after transplantation, all patients received orthodontic treatment from an experienced practitioner (E.S.R). Appliance therapy with 0.018 pre-torqued brackets was initiated with a sequence of NiTi levelling arch wires and completed with a 0.017×0.025-inch finishing arch wire. Total orthodontic treatment time averaged 32 ± 6 months.

Post-surgical follow-up protocol

Post-surgical follow-up (10–14 years) started 1 week after the intervention, when the first radiographic check-up was performed and the two sutures removed. From then on, post-operative monitoring for potential pulp necrosis or root resorption involved successive clinical and radiographic examinations conducted after 3 weeks, 3 and 6 months and then periodically up to 14 years.

Clinical parameters

Pulp sensibility testing. Electric pulp sensibility was undertaken using a standardized testing procedure and a pulp tester (DENTOTEST, TB-08, Malek, Switzerland). A contralateral incisor was used as the control tooth. For both teeth, the electrode was positioned on the buccal aspect after drying with a cotton-wool swab. The scale was graduated from 0 to 10 and the test performed in triplicate in all cases, with a 5-min interval between tests. In both the transplanted tooth and the control, the test was considered positive if the patient noticed any degree of sensitivity (1–8) in the tooth in at least two of the three tests carried out at each examination.

Periodontal healing and colour parameters. Clinical evaluation of the transplanted teeth included the following parameters: tooth mobility, probing pocket depth, percussion sound and colour. The mobility of the transplanted tooth was rated by means of a mobility test based on a scale of 0–4 (0: physiological tooth mobility; 1: abnormal horizontal mobility of less than 1 mm; 2: abnormal horizontal mobility of more than 1 mm; 3: abnormal horizontal and axial mobility; 4: no mobility).

Probing pocket depth was recorded at six sites, measured from the gingival margin to the tip of the calibrated periodontal probe (Hu-Friedy, Leimen, Germany) inserted into the pocket at defined locations with a moderate probing force. Probing pocket depths were

measured for transplanted as well as neighbouring and contralateral teeth. Probing depth was recorded to the nearest 1 mm. Pockets more than 3 mm deep at any one site were considered pathological.

As part of the clinical assessment, the percussion sound of the transplanted tooth was used to diagnose potential ankylosis. A high-pitched percussion sound compared to the contralateral tooth was rated positive for ankylosis.

Transplanted tooth colour was scored on a scale of 0–2 [0: normal crown colour; 1: minor discolouration (light yellow); 2: major discolouration (dark yellow)] and compared with the natural tooth contralateral to the donor site and teeth adjacent to the recipient site.

Radiographic parameters. Standard intra-oral apical radiographs were taken of all transplanted teeth, using a standardized angle of view and the long-cone technique (CCX Digital; Trophy TREX Group, Vincennes, France). The same type of film holder was used on every occasion (Dentsply Rinn's XCP Instrumentation Kit, Elgin, USA). The exposure parameters for periapical radiographs on anterior teeth were 70 kV, 7 mA and 0.16 s. Radiographic examination included intra-oral films to help assess radiographic parameters, such as root resorption, obliteration of the pulp cavity, pulp necrosis and the possibility of ankylosis.

Magnification of the X-ray machine was determined by taking a radiograph using a film holder with a 5-mm-diameter steel ball attached; this enabled the subsequent calibration and calculation of magnification at 0.03–0.04 per millimetre.

Post-transplantation root development. This parameter was measured from the anatomical neck of the tooth to the apex. Post-transplantation root-development measurements were compared with those obtained from the remaining premolar in the same maxillary segment. Teeth contralateral to the donor premolar were not used as control for this purpose because of extraction or for orthodontic reasons.

Degree of pulp obliteration. This radiographic assessment was based on the following radiological pulp stages for classifying the extent of pulp obliteration: (i) obliteration of the pulp chamber; (ii) one-third radicular pulp obliteration in the coronal aspect; (iii) two-thirds radicular pulp obliteration; and (iv) total obliteration of the canal system.

Pulp necrosis. Pulp necrosis was diagnosed when there was radiographic evidence of radiolucency and/or inflammatory root resorption. Negative pulp sensibility tests supported the diagnosis.

Root resorption. Root resorption was diagnosed as surface resorption, inflammatory resorption and replacement resorption (Andreasen 1985).

Statistical analysis

Descriptive analysis was performed by calculating means and standard deviations or percentages, depending on the type of variable. Statistical analyses for the association between observed variables and clinical and radiographic parameters used Fisher's exact test of independence. To estimate intra-examiner variation for the radiological evaluation, all radiographs were evaluated twice by the same experienced examiner (A.M.M). To estimate inter-examiner variation, all radiographs were evaluated by a second experienced examiner (E.S.R). Simple and weighted *k* statistics were computed to determine intra-examiner and inter-examiner agreements on radiographical parameters, obtaining an

excellent intra- and inter-examiner agreement for all evaluated parameters (>0.9). All analyses were performed with SPSS version 14.0 (LEAD technologies, Chicago, IL, USA).

Results

Pulp sensibility

Increasing root development was followed by decreasing electronic sensibility levels in every case, as shown in Table 1. Pulp sensibility tests were positive for almost the entire first year of follow-up for just one of the transplants performed. After 6 months, while no detectable pulp response was observed in transplants performed at root stage 4, stage 3 donor premolars did show a positive pulp reaction. After that period, however, pulp sensibility gradually decreased from 25% in the second year and was no longer detected at subsequent time points. Significantly, no pulp reaction was observed during the entire follow-up period for the autotransplant using a donor premolar root development of more than ¾ (Moorrees stage 5) (Moorrees *et al.* 1963).

Periodontal healing and root resorption

Periodontal healing of the whole sample was stable and satisfactory for the first 6 years. After that time, during the sixth year, inflammatory root resorption was detected in one of the autotransplanted teeth, which was extracted. Two of the 12 transplanted premolars were extracted during the 14-year period as a result of inflammatory root resorption or pulp necrosis: one at 6 years and the other after 10 years. This represents a success rate of 83.4%. The highest success rate occurred in teeth transplanted at stage 3 of root development (Table 1). The two transplants that suffered inflammatory resorption were performed at stage 4 (Moorrees *et al.* 1963, donor premolar root development ¾). While it had no effect on overall periodontal healing, surface root resorption was observed radiographically in the autotransplant performed at stage 5 (root development complete) during the first 6 months (Fig. 3a–b). Nevertheless, this temporary reaction remained stable throughout the observation period (Fig. 3c–f), and the absence of pathological probing depth or mobility parameters in the transplanted tooth during follow-up indicated good progress (Fig. 4a,b). However, while these parameters remained physiological throughout the observation period, secondary discolouration was noted in most of the autotransplants.

Autotransplant root development

Progressive root growth was observed in all transplanted teeth, even those that had to be extracted after 6 and 10 years when they developed inflammatory root resorption in the apical third.

Pulp healing

Of the 12 teeth transplanted, two were extracted because of inflammatory root resorption and pulp necrosis, one 6 years after autotransplantation and the other after 10 years (Table 1). However, progressive pulp obliteration was seen in every case where pulp revascularization occurred, and from year 2 onwards, in only the two teeth transplanted at stage 3 (28.75%), was obliteration of the apical third of the root canal not observed (Table 2). These teeth suffered subsequent pulp necrosis. The two transplants that suffered pulp necrosis were carried out at Moorrees' stage 4 (¾ root). Considering all the

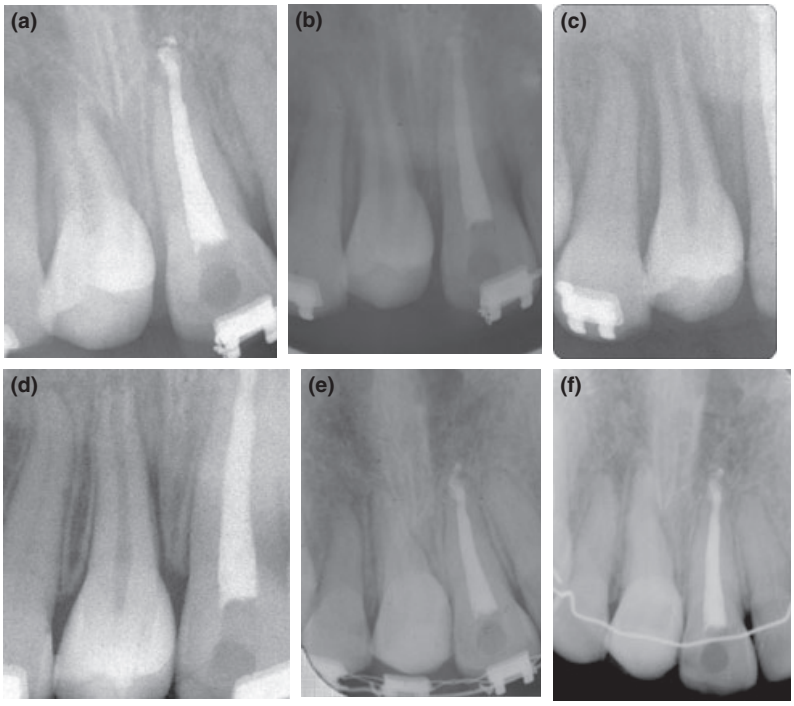

Figure 3 Radiographic situation at 3, 6 and 9 months (a, b, c) and 1, 4, 14 years (d, e, f) after transplantation, respectively. Note progressive pulp canal obliteration and root growth until complete pulp canal obliteration; radiolucent gap surrounding the root; tooth 21 pulp necrosis and root filling (a–f).

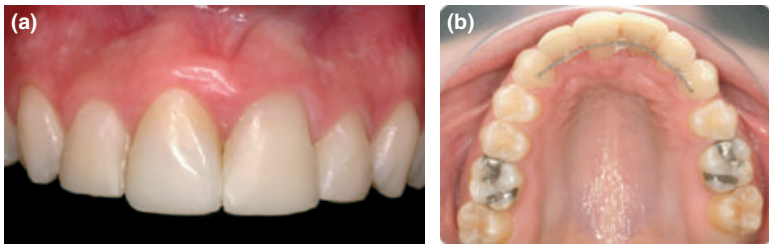

Figure 4 Clinical situation 14 years after transplantation. Note that the normal gingiva and papilla of acceptable aesthetics have been provided by means of a crown reconstruction with composite (a, b).

data, the results showed an overall success rate of 83.4% for pulp and periodontal healing after 10 years, and an 80.0% success rate after 14 years.

Discussion

Few previous studies have evaluated tooth autotransplantation in association with pulp sensibility testing and root development in the transplanted tooth (Andreasen *et al.* 1990a). In agreement with the study by Andreasen *et al.*(1990b), which included over 370 transplants, the present study confirms that increasing root development is followed by a progressive decrease in electrometric sensibility levels. With regard to increase in root length, all patients in this study underwent orthodontic treatment after autotransplantation and the contralateral premolar was extracted in every case. When the transplanted pre-molar was compared with the one that remained in the same quadrant, root growth

Table 2 Autotransplant tissue pulp reaction follow-up

Root stage	Autotransplants	Pulp reactions (% cases)				
		6 mth (%)	1 ys (%)	2 ys (%)	6 ys (%)	10 ys (%)
1/2 R	4	ChO (100)	1/3O (100)	2/3O(100)	T (100)	T (100)
3/4 R	7	ChO (100)	1/3O (100)	2/3O (71.4)	T (71.4)	T (71.4)
				1/3O (28.6)	N (14.3)	N (28.6)
					1/3O (14.3)	
R c	1	ChO (100)	1/3O (100)	2/3O (100)	T (100)	T (100)

ChO, pulp cavity obliteration; 1/3O, 1/3 radicular pulp obliteration; 2/3O, 2/3 radicular pulp obliteration; N, pulp necrosis; T, total pulp obliteration.

similar to that of the non-transplanted premolar was confirmed (Czochrowska *et al.* 2002, Table 1). However, Paulsen & Andreasen (1998) found arrested root growth in 19% of cases in a longitudinal radiographic study of 118 autotransplants. This could, perhaps, be explained by the pulp necrosis observed in 16 of the 118 autotransplants after 6 months.

As was the case in this study, several reports found that the best success rate in terms of pulp and periodontal healing was observed when the donor tooth was at the ½ to¾ stage of root development (Andreasen *et al.* 1990b,c, Czochrowska *et al.* 2000, Kallu *et al.* 2005). Moreover, total pulp obliteration was observed in all transplants carried out at Moorrees' stage 3, which is at ½ root development. A similar result was observed for a transplant performed at stage 5 with complete root development. The success rate reported in the latter case requires confirmation by further studies with a larger sample size.

It is generally agreed that progressive pulp obliteration is synonymous with success in this form of treatment (Andreasen *et al.* 1990b, Czochrowska *et al.* 2000, 2002, Kallu *et al.* 2005). In the present study, progressive pulp obliteration was observed in every case and did not interfere with an increase in root length, despite the extended length of orthodontic treatment. Interestingly, in only two cases diagnosed with pulp necrosis and inflammatory root, resorption was no pulp obliteration found in the apical region. Secondary dark yellow discolouration was also noted in most autotransplants. There is therefore no relationship between discolouration and autotransplant success.

In the two cases described previously, it is not clear why pulp necrosis or inflammatory resorption occurred many years after normal healing. In this respect, cementoblasts or cementum is thought to protect against resorption (McKee *et al.* 2011). Resorption would be more likely to develop if one or both components were missing. Nevertheless, it is difficult to explain why there were 6–10 years of good healing, indicating the existence of a cementum/cementoblast layer, suddenly followed by resorption, suggesting its absence. Pulp necrosis or inflammatory root resorption may occur after some years as the result of dental trauma creating cracks in the dentine and enabling bacterial invasion of the dentinal tubules (Love 2002). Bacterial products diffuse through the dentinal tubule towards the pulp, causing inflammatory changes that may nevertheless be contained for years (Love 2002). Characteristics such as age have been described as having an influence on the bacterial infection of dentinal tubules; this occurs to a lesser extent in older patients, possibly because of increased tubular constriction (Kakoli *et al.* 2009). It seems that the recognition of type I collagen may make bacterial adhesion to dentine easier, as well as a morphological growth response manifested in the long chain of streptococcal cells (Love 2002). As, in the study cases, there was no evidence of further trauma and the patients were of similar ages; one possibility may be that a slow, undetectable but progressive process of replacement resorption may have been set in motion. Although there were no pathological findings of a clinical (percussion sound, tooth mobility) or radiographic (resorption) nature in the study, this does not necessarily mean that healing was absolutely normal. In this respect, it has been reported that ankylosis/replacement

resorption can only be detected if more than 10–20% of the root surface is involved (Andersson *et al.* 1984). At the same time, no infrapositions were reported in the two cases studied either, so that the main circumstances allowing at least 10 years of clinical function and radiographic monitoring followed by inflammatory resorption, remain unclear.

Most authors report a success rate of approximately 80% with autotransplants (Czochrowska *et al.* 2000, Tsukiboshi 2002, Jonsson & Sigurdsson 2004, Kallu *et al.* 2005, Andreasen *et al.* 2009). In another study with a smaller sample size involving 10 premolar autotransplants (Diaz *et al.* 2008), long-term pulp health was described in six cases, while the remaining four suffered pulp necrosis after 6–8 years of follow-up. In all these cases, aesthetics and function were maintained throughout. Although the sample limitations are similar, the main value of the present study is the long-term follow-up over ten to fourteen years, a crucial aspect in an overall assessment of the feasibility of autotransplantation as a valid long-term treatment option. The results showed overall success rates of 83% for pulp and periodontal healing after 10 years and of 80% after 14 years, after taking lost transplants into account. Nevertheless, the present study is consistent in that the two failures were because of pulp necrosis.

Conclusions

Transplants into the anterior maxilla where the traumatized tooth has already been lost are a technically demanding area of autotransplantation as well as a technically difficult clinical situation. In this retrospective study, there was an 80% success rate for premolar autotransplantation to the maxillary central incisor area after a follow-up period of 14 years. The success rate for the autotransplanted tooth justifies it as a suitable long-term treatment option for replacing lost teeth, provided that the intervention is performed with a partially developed root (Moorrees' stage 3 or 4). This makes autotransplantation a suitable therapeutic option for replacing lost teeth in growing patients who also need orthodontic treatment.

Conflicts of interest

None declared.

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