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ORIGINAL ARTICLE

Primary tooth autotransplantation: update and retrospective clinical study

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ABSTRACT

Objective: A new technique of primary tooth autotransplantation has recently been published demonstrating reliable replacement of missing permanent incisors in young children due to trauma or agenesis. This retrospective clinical study reports on the longterm success of this new technique in a larger patient group regarding its potential to support bone and soft tissue growth.

Study design: 40 children (age range: 2.7–17.6 years) received 53 primary tooth autotransplants (49 canines and 4 incisors) due to traumatic tooth loss (73%), agenesis (19%) or dysplasia/displacement (8%). Clinical and radiological follow-up examinations were performed to check up on root resorption, bone and soft tissue growth, survival and success.

Results: 22 transplants still present in the oral cavity of 18 patients yielded a success rate of 77%. The Kaplan-Meier estimator measured a median survival time of 86 months (7.2 years) for all 53 grafts. In all cases, increasing soft tissue and bone development enabled a successful prosthetic rehabilitation regarding aesthetics and function.

Conclusions: Primary tooth autotransplantation reliably restores edentulous anterior space in children experiencing traumatic tooth loss or agenesis and acts as an immediate therapy before other therapies such as premolar transplantation or orthodontic space closure can be carried out at a later time. It guarantees the co-development of soft tissue and bone in the teenage jaw which is associated with high patient satisfaction and acceptance of this method.

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Tooth transplantation; primary tooth; deciduous tooth; dental trauma; tooth agenesis

Introduction

Every third child suffers tooth trauma before the age of 16 [1–4]. 7–8% of these dental injuries cause loss of permanent teeth [5,6]. Thereby, vertical and horizontal alveolar process growth is stunted and has a negative impact on the development of hard and soft tissues.

In the phase of early mixed dentition (age 6–10), prompt restoration of edentulous spaces due to primary absence or trauma is not possible. Intraosseous implantation is not yet a treatment option due to well-known inhibition of jaw growth in the respective region [7,8].

There are different therapeutic concepts to treat traumatic anterior tooth spaces or agenesis. This anatomical area remains the functionally and aesthetically most critical one. Orthodontic space closure presents one of the treatment options. In the upper lateral incisor area this approach should be the therapy of choice, but it does not apply for the upper central incisor space in the early phase of primary or mixed dentition (age 6–10) due to technial reasons. Likewise, the time window for premolar transplantation is still too early, since in this period of dentition the eruption of the premolars is still pending and the stage of ideal root growth for transplantation ($^2/_3$–$^3/_4$ root length) has not yet been reached [5]. Therefore, in the majority of cases only fixed or removable prosthetic constructions (e.g. adhesive bridges, children's dentures) are in use to rehabilitate the young children.

Autogenous transplantation of primary (deciduous) canines is a new therapy which gained little attention so far, even though it has become known for its quick rehabilition of the children's tooth spaces in terms of aesthetics and function [9,10]. A particular advantage of this method is its inherent potential to induce the development of bone and soft tissue growth according to the age of the children, similar to the autotransplantation of permanent teeth [11,12].

This study provides new data about the method of primary tooth autotransplantation by extending the clinical findings of a previous report [10].

Materials and methods

Patients

From 2006 to 2018, 40 patients (22 females, 18 males; mean age 9.3 ± 2.9 years; min 2.7; max 17.6) suffering traumatic loss

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Table 1. Number of all autotransplanted primary teeth sorted by donor and recipient site (40 patients with $n = 53$ transplants).

	Donor site									
	Upper quadrants					Lower quadrants				
	Incisors					Incisors				
	Central	Lateral	Canines	Premolar	Molar	Central	Lateral	Canines	Premolar	Molar
Sum	3	1	24	–	–	0	0	25	–	–
%	6	2	45	–	–	0	0	47	–	–
Total %			53					47		
	Recipient site									
Sum	36	9	2	3	0	1	1	0	1	0
%	67	17	4	6	0	2	2	0	2	0
Total %			94					6		

or agenesis in the maxillary anterior region were treated. A total of 53 deciduous teeth (49 primary canines, 4 primary incisors) was engrafted (Table 1). The data of the present study were collected and ensuing anonymized according to the requirements of the ethics committee. The clinical examination of the patients and subsequent analysis of the data was performed by an experienced examiner.

The follow-up examinations took place in 2018 involving patients with transplants *in situ* at least one year after the surgery. The protocol was reviewed by the appropriate institutional review board, each subject in the project signed a detailed informed consent form which includes case details and images of patients obtained and is available by the authors. The guidelines of this study have followed the declaration of Helsinki, the study was approved by the ethics committee of the medical faculty of the Ludwig Maximilian University – Munich, project number 18-514.

Exclusion criteria for study

Patients were excluded from the study if the following criteria for participation were given: lack of cooperation or consent to participate in the study, lack of ability to give consent due to language deficit or to understand the study content with certainty. Furthermore, excluded were patients with severe general diseases (e.g. malignant tumors), cerebral seizure disorders, neurological or mental diseases with severe mental retardation. Inclusion criterion was that all grafts performed at the dental clinic in Munich from 2006 to 2018 were included in this study, yielding 53 primary grafts in 40 patients. The exclusion criteria did not apply to any of the involved patients.

Data collection and study design

In order to record as much retrospective data as possible collected since 2006, the patients were divided into two subgroups (split study design) consisting of survival-group (surv-group) and success group (succ-group) which is defined in the following:

Patients of the survival-group ($N = 22$ patients, $n = 31$ transplants) already lost or got extracted their engrafted teeth or were not able to participate in the study at the time of examination. The transplants of patients of the survival-group were screened with regard to whereabouts, oral long-term prognosis (survival rate and time) and ensuing prosthetic treatment. If data was not completely to be collected, the number of teeth and/or patients is explicitly stated in figures and tables.

In the success-group transplanted teeth were still present in the oral cavity of patients ($N = 18$ patients; $n = 22$ transplants). Data collection was performed according to the surgical protocol of tooth transplantation [10] and in the following timeframes: before surgery; on the first and seventh postoperative day; three weeks as well as 3, 6 and 12 months after the transplantation. Thereafter check-ups took place annually. All data both of the survival- and the success-group was documented in the database TransDat® (German Trademark no. 30 2018 107 792) specially developed for the documentation of tooth grafting. Examinations included appraisal of the oral hygiene status, carious lesions and the periodontal condition *via* the Periodontal Screening Index (PSI). The parameters of bone regeneration, pulp obliteration, root length and root resorption were assessed [13].

As the juvenile (growing) dentition does not provide a fixed reference point, soft tissue (red aesthetics) and vertical bone levels were traced as relative change compared to the adjacent teeth using photo- and radiographs (Figure 1, from [10]). A magnification factor was defined *via* the crown width of the mandibular anterior teeth to ensure comparability of radiographs. In the event of dental change of the adjacent teeth, the next neighbouring tooth was used.

Soft tissue deficits (mm) were indicated with a minus, excess with a plus. Bone height (mm) around the transplant was determined by a connecting line of the mesial cementoenamel junction of the distal adjacent tooth to the distal cementoenamel junction of the mesial neighbouring tooth. Alveolar bone growth was mesially and distally measured (Figure 1).

In addition, static/dynamic occlusion and interproximal contacts were used to check on the effects of early stress on the long-term healing process. Sensitivity of the transplanted tooth was evaluated with a cryogenic spray and electrometric pulp testing (EPT, Vitality Scanner, Sybron Endo, Orange, CA, USA). At last, the susceptibility on percussion of the transplanted tooth was noted.

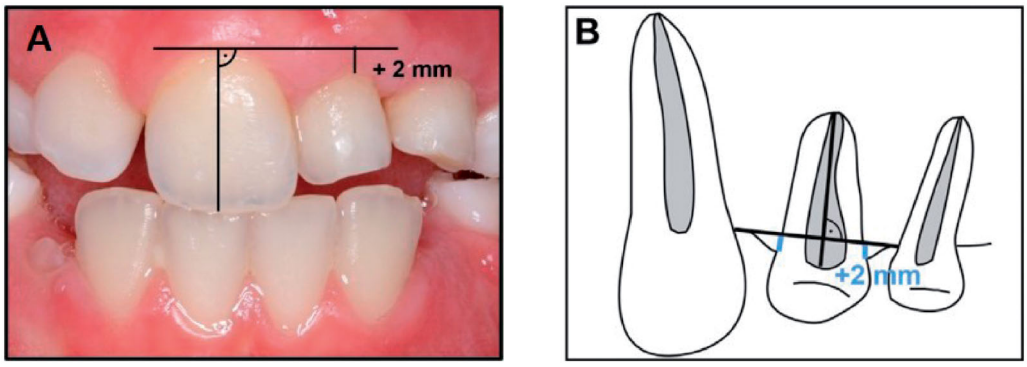

Figure 1. Measurement of soft tissue and bone levels around transplants (method from [10]). Owing to the lack of a fixed point for referring to the growing jaw of children, soft tissue and bone levels of the transplants were evaluated in relation to the corresponding adjacent teeth. Soft tissue and bone levels were assessed mesially and distally of the transplant parallel to the tooth axis as shown in the figures. (A) Soft tissue level was assessed in the middle of the transplant parallel to the tooth axis and vertically to the tangent through the gingival margin of the adjacent tooth; '+ 2' mm indicates vertical soft tissue growth by 2 mm. (B) Bone level was assessed mesially and distally of the transplant and parallel to the transplant axis and vertically to a line through the cemento-enamel junction of both adjacent teeth. '+ 2' mm indicates transplant in 2 mm exceeding vertical growth compared with the adjacent tooth.

Radiographic controls were performed before surgery and at the above named times starting at three month. Dental films were made by trained dental technicians using the same X-ray machine (Heliodent, Dentsply Sirona, Salzburg, Austria). Evaluation was carried out with the X-ray software program Sidexis (Dentsply Sirona, Salzburg, Austria).

Surgical procedure

The method of primary tooth transplantation [14] is developed further in this study:

There is no more preference in using either the lower or upper primary tooth as transplant. The decision depends on the residual root length of the transplant and/or the aesthetic suitability. The residual root length should remain more than 50% to guarantee good long-term results.

The surgery is usually performed under general anaesthesia to avoid further stress to the traumatised young patients. After marginal incision, the transplant is gently extracted using customised forceps (Medicon, Tuttlingen, Germany). If the preparation of a new alveolus socket is required (neoalveolus), the primary tooth transplant is stored either in its alveolar pocket or temporarily outside the mouth in a culture medium consisting of 4 mg dexamethasone, 100 mg doxycycline, and 10 ml physiological saline solution. Otherwise the transplant is directly engrafted into the extraction alveolus. The transplant is fixed in its new position by a suture that passes over the crown (Vicryl 4–0, Ethicon, Norderstedt, Germany) or semi-rigidly with a titanium splint (TTS; Medartis, Basel, Switzerland) and composite (Ivoclar Vivadent, Ellwangen, Germany).

The suture is removed after 2–3 weeks (Figure 2(E,F)); the titanium-composite splint after 4–6 weeks. The after-care takes place in close consultation with the orthodontist. Three months after the transplantation the graft can be integrated into the orthodontic appliance or built-up into occlusion using a resin-based adhesive.

The biologic approach of this method bases on the physiologic loss of primary teeth in order to stimulate natural jaw growth [10,14]. Endodontic therapy of the primary teeth is only advisable if signs of inflammatory resorption with clinical symptoms are observed. In this case, the root canal is treated by an orthograde filling with $Ca(OH)_2$ [15]. If resorption proceeds, alloplastic root canal material such as guttapercha or retrograde titanium pins are inadvisable. These materials remain in the bone and need to surgically be removed and go along with the loss of raised bone. The omission of endodontic therapy distinguishes this therapeutic approach from the two previous case reports [16,17] and one case study on primary canine transplant [9].

Statistical analysis

Data analysis was performed with Excel 2016 (Microsoft Corp., Redmond, USA) and PASW Statistics 18 (SPSS Inc., Chicago, Illinois, USA). The demographic characteristics of the participants were descriptively analysed. The number of teeth showing vitality signs like pulp obliteration is presented in detail, as are the changes in bone level during the follow-up period and patient satisfaction. The following parameters were used for calculation of sample size: Test-design - one-sided dependent t-test; Effect size: set at 0.8; Level of significance: 0.05; and Power – set at 0.9. The G*Power 3 test according to Faul et al. [18] was then applied for calculation.

The 'success' of the surgical intervention was defined by the following indicators: A pocket probing depth (PPD) of $\leq$ 3 mm at six measuring points from the gingival margin to the bottom of the pocket, a mobility grade of $\leq$ II – measured clinically and with the Periotest device (Periotest, Med Gulde, Modautal, Germany), a negative percussion test and the absence of inflammatory resorptions.

'Survival' was defined as number of teeth present in the oral cavity regardless of the clinical and radiographic findings divided by the number of all transplanted teeth [10] and calculated with the Kaplan-Meier estimator [19]. The analysis of changes within the groups over time was calculated using the one-sided dependent *t*-test, the global alpha level was set at 0.05.

Figure 2. Case of a 7 year-old girl experiencing a complicated crown-root fracture with loss of tooth 11 treated by primary canine autotransplantation 83 (autoTX 83→11). (A) Pre-op orthopantomogram shows an oblique fracture line up to the middle third of the root of central right incisor. (B) Intraoperative view of tooth 11 before extraction. (C) The extracted tooth shows an oblique lengthwise fracture and thus could not be preserved. (D) Post-op orthopantomogram directly after auto-TX 83→11. Note the long root of the primary tooth 83. (E) Clinical view directly after autoTX 83→11. Due to the dimension of the extraction alveolus, the transplant was positioned in infra-occlusion and fixed with a cross-over suture for 2 weeks. (F) Clinical view 2 weeks post-op directly after suture removal. (G) Post-op dental film 1 year later shows marked reduction of root length and root obliteration. An intact PDL space is clearly visible. (H) Frontal view 1 year post-op shows equal soft tissue height to adjacent tooth 21. (I) Occlusal view 1 year later: Vitality of tooth +, no gingival irritation. (J) Dental film 6 ½ years post-op shows further bite elevation. Further progression of root obliteration and rounding of root apex is notable. PDL space is clearly visible (no ankylosis). (K) Frontal and (L) occlusal views 7 ½ years post-op show uncomplicated gingival healing. Clinical findings show absence of pain; vitality +; mobility of transplant: grade 0; bone & soft tissue levels have reached up with the adjacent tooth 21 being slightly hyperplastic by about +1 mm gingival height, indicating adequate co-development during pubertal growth over the past years. The meanwhile 15 year old girl has only recently decided for a build-up of the tooth crown with a composite structure. Implantation is planned after loss of the graft be placed as late as possible.

Results

A total of 53 primary tooth transplants on 40 patients was documented over a median observation period of 40 months (min: 1 month, max 107 months). The subdivison between donor and recipient sites is given in Table 1, updating the previous study from originally 10 patients with 14 primary transplants [10]. To reach a Power of 90%, a retrospective sample size calculation was conducted *via* G*Power 3 (Faul et al. [18]) resulting in a recommended sample size of 15 patients. Given a total sample size of 40 patients, this criterion was exceeded.

Clinical data

The results of this retrospective clinical study are fully summarised in Table 2:

On average, 12 ± 30 (SD) weeks passed between trauma and transplantation. Reasons for the surgery were traumatic tooth loss (73%), tooth agenesis (19%), dysplasia (4%), and orthotopic transplantation due to displacement or eruption disturbancy (4%).

In 23 cases (43%), the preparation of a neoaveolus was necessary. This surgical step has no effect on the overall survival time compared to transplants directly inserted into the extraction socket.

The mean extraoral storage time (min) of the transplants was 3.0 ± 3.8 (SD). Transplants were splinted 4.6 ± 2.1 weeks, on average. In principle, the duration of splinting was an individual decision on a case-by-case basis, taking into account the remaining root length of the transplant and the risk of renewed trauma. The longer splinting times were chosen mainly for safety reasons since 6% of all grafts were lost due to early re-trauma (Table 3) and since re-ankylosis of the primary grafts was not observed in any of the grafts, irrespective of the duration of splinting. Documentation of wire-composite or suture splinting (decision based on clinical situation) was incomplete and can therefore not be reported.

84% of all patients received postoperative orthodontic treatment, emphasising the interdisciplinary collaboration between surgeon and orthodontist (Table 2). As stated previously, the number of teeth and/or patients in figures and tables may differ if data was not completely to be collected.

Transplants of the success-group ($n = 22$ transplants in $N = 18$ patients) underwent additional clinical examinations:

All patients had good to moderate oral hygiene. The average PSI was 1 (min: 0, max: 3) and the average pocket probing depths (mm) were 2.2 ± 0.4. Bleeding on probing (BOP) occurred in 10% of the cases, plaque index was 14%. Six of the transplants needed no further prosthetic treatment (27%), 15 were built-up in a composite-adhesive technique (68%) and one transplant (5%) was partially crowned.

Table 2. Summary of results of the clinical study.

	Sum/mean	%	± SD
All transplants (40 patients with $n = 53$ transplants)			
Gender			
Female	22	55	
Male	18	45	
Age of patient / transplant (years)	9.3		± 2.9
Reason for surgery			
Traumatic loss	39	73	
Agenesis	10	19	
Dysplasia	2	4	
Orthotopic transplantation	2	4	
Surgical procedure			
Duration of pre-OP edentulism (weeks)	12		± 30
Extraoral storage time (min)	3.0		± 3.8
Preparation of neo-alveolus	23	43	
Duration of transplant splinting (weeks)	4.6		± 2.1
Follow-up duration after surgery (months)	40		± 24
Root length (mm)			
Upper jaw	9.4		± 2.6
Lower jaw	9.4		± 2.0
Crown-root ratio at surgery	1 : 2.0		
'Pseudoankylotic' percussion sound	3	7	
Endodontic treatment	6	11	
Orthodontic treatment ($N = 37$ patients; $n = 48$)			
No treatment	4	11	
Pre-OP treatment	15	41	
Post-Op treatment	31	84	
Endosseous implantation	6	11	
Median survival time (months)	86		30
Transplants of 'success'-group (18 patients with $n = 22$ transplants)			
Success rate (%)	17	77	
Follow-up duration after surgery (months)	40		± 28
Oral hygiene in general (all teeth)	good		
PSI	Grade I		
BOP		10	
Plaque index		14	
Pocket probing depth (mm)	2.2		± 0.4
Crown length (mm)	8.0		± 1.6
Prosthetic restoration			
No restoration	6	27	
Composite	15	68	
(Partial) crown	1	5	
Occlusal contact points			
Static	11	50	
Dynamic	7	32	
Interproximal contact points			
Mesial	15	68	
Distal	14	64	
Percussion test +[a]	2	9	
Mobility of transplant[b]			
Clinically (grade 0–3)	1.5		± 1.0
Periotest (from 0 to 30)	17		± 7
Sensitivity +[c]	17	77	
Caries	0	0	
Elongation of antagonist	1	5	
Bone level compared to neighbouring teeth (mm)			
mesial	−0.49 (n.s.[d])		± 0.88
distal	−0.47 (n.s.[4])		± 0.89
Pulp obliteration	5	23	
Endodontic treatment	0	0	
Loss of soft tissue	1	5	
Transplants of 'survival'- group (22 patients with $n = 31$ transplants)			
Follow-up duration after surgery (months)	39		± 21
Bone level in comparison to adjacent teeth (mm)	−0.15 (n.s.[4])		
Pulp obliteration	7	23	
Endodontic treatment	6	19	

Values are either sum or mean ± SD as indicated.
[a]Indicates pain
[b]Assessed by clinical mobility grades 0–3 and the Periotest device.
[c]Assessed by electrometric testing (see text).
[d]Not statistically significant different from healthy adjacent tooth (*t*-test).

Static and dynamic occlusal points were present in 11 and 7 transplants, respectively; interproximal contact points

were mesially and distally present in 15 and 14 transplants, respectively. No transplant was directly blocked by one of the adjacent teeth at the time of the follow-up appointments. 84% of patients received postoperative orthodontic treatment, emphasising the interdisciplinary collaboration between surgeon and orthodontist (Table 2).

Percussion test was positive in 2 transplants (9%).

Loosening was low to moderate indicated by a mobility grade of 1.5 ± 1.0 and confirmed by the measurements of the Periotest analysis (17 ± 7). Two transplants out of 22 showed an increased mobility of grade III. All patients were able to normally chew and bite. Carious lesions, discolouration or recessions were not observed; one case showed an elongation of the antagonist (5%).

17 out of 22 transplants were classified as vital (77%) after evaluation of sensitivity testing with cold spray and electrometry (Vitality Scanner 2006, Sybron Endo, Orange, United States).

Table 3. Encountered complications.

Complications	No. of affected transplants	No. of patients	% of all grafts
Re-trauma	3	3	6
Root Resorptions			
Physiologic resorption (=natural exfoliation)	42	31	79
Undermining resorption by adjacent tooth	7	6	13
'Pseudoankylotic' percussion sound	3	3	6
Inflammatory resorption	6	5	11
No root resorption	3	3	6

Complication rates are presented for all 40 patients ($n = 53$ transplants). For more details, see text.

The radiological exams of the success-group showed five transplants (23%) with a root canal obliteration considered as a physiological healing process after trauma in permanent autotransplanted teeth. Therefore, it may also be interpreted as vital sign in primary teeth [20].

Considering all transplanted teeth ($n = 53$ transplants), 6 teeth (11%) received an endodontic treatment over time due to inflamed apical or periodontal signs associated with pain (Table 3). Endodontic treatment was not necessary in any of the 18 patients of the Success-group. This supports the biological approach to deliberately desist from endodontic treatment if possible.

Bone height and soft tissue

Vertical bone growth was observed in all clinical cases of the Success-group. As there is no solid anatomical reference point in the growing jaw to determine the bone level on the transplant it was compared to the bone height of the adjacent teeth (Figure 1(B)). The bone height on the transplants was found decreased mesially by 0.49 ± 0.88 mm and distally by 0.47 ± 0.89 mm (mean ± SD) at the time of clinical examination (Figure 3). Statistically, this change in bone height is not significantly different compared to the adjacent teeth (Table 2). Clinically, this is clearly supported since the peri-transplant bone levels kept pace with the natural growth of the healthy adjacent teeth (Figures 1(B) and 2(K)).

All 18 study participants of the success-group provided semi-quantitative data regarding the change in soft tissue heights. This data is also collected in comparison to the soft tissue height of the adjacent teeth (Figure 1(A)). A deterioration of the red aesthetics was only seen in one case (5%),

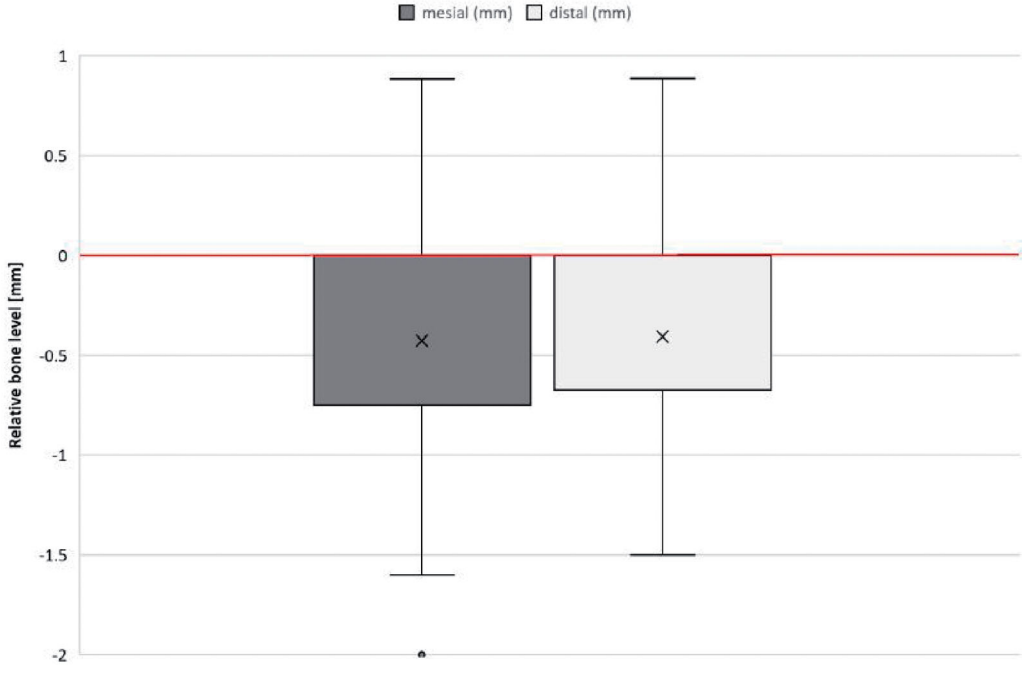

Figure 3. Bone level around transplants compared with adjacent teeth at the end of treatment. Measurements were made from the available radiographs. '0' (red line) indicates bone level of adjacent tooth (see Figure 2(B)). There is no statistically detectable difference between bone level height of the transplant versus adjacent tooth as assessed mesially (−0.49 ± 0.88 mm) and distally (−0.47 ± 0.89 mm) of the transplant, indicating adequate growth of the alveolar process in the transplant region. (X indicates mean value; $n = 22$ transplants; $N = 18$ patients; success-group).

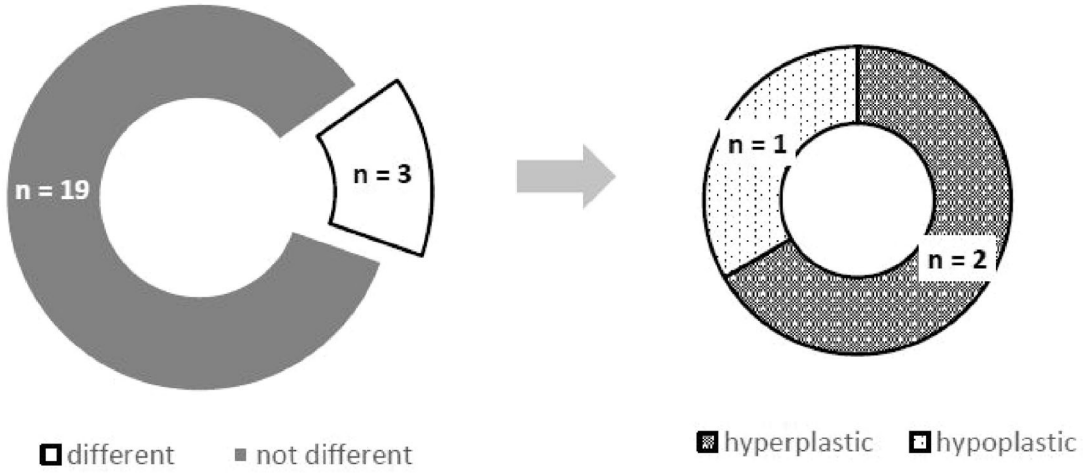

Figure 4. Soft tissue level around transplants compared with adjacent teeth at the end of treatment. Measurements were made from the available photographs (see Figure 2(A)). Only in three transplants a difference was visible compared to the adjacent healthy teeth. Of those, two showed hyperplastic and only one transplant hypoplastic gingival growth, indicating adequate to hyperplastic soft tissue growth in 95% of cases. ($n = 22$ transplants; $N = 18$ patients; success-group).

the remaining 95% of cases showed a solid maintenance of the soft tissue height, of which two cases even showed a hyperplastic reaction (Figure 4).

Figure 2 gives visual impressions of the excellent soft tissue levels on the transplant 11 over an observation time of 7.5 years.

Patient satisfaction

35 patients answered a questionnaire on treatment satisfaction by themselves or with the help of their parents (Figure 5). The participants were asked to give school grades from 1 (very good) to 6 (insufficient): The average grade given considering satisfaction about the aesthetic result was a 1.5; regarding functionality, a 1.5; current complaints of the patient, a 1.2. Expectations regarding the surgery were mostly met and rated with a 1.6.

This led to an overall score of 1.4. All patients stated that they would undergo the surgery again (100%), 34 would recommend the procedure (97%).

Complications

The encountered complications are presented in Table 3. Three patients suffered re-traumatization (6%). One patient luxated his transplant leading to an increased mobility at the follow-up exam [10]. Another patient lost his autotransplant after renewed trauma followed by orthodontic space closure. The third patient lost his transplant at play so that a second primary tooth transplantation was performed. At the age of 13, the patient received a premolar autotransplant as subsequent prosthetic therapy according to the TPTX-concept [14].

All transplants were radiologically analysed. Derived from the findings on these radiographs, physiological resorption is considered a natural, non-inflamed process of primary tooth resorption and was found in 42 transplants (79%). This type of resorption is void of pain or inflammation, but predicts premature transplant loss due to continuous decrease of root length on the long-term [10].

Undermining resorption by adjacent erupting teeth is clinically the most relevant type for premature graft loss. A total of 7 transplants (13%) was affected. This type of resorption appeared predominantly in patients suffering tooth agenesis of the upper lateral incisors and was caused by the medially erupting permanent canines.

Ankylosis (replacement resorption) in its classical sense was not observed in any of the 53 transplanted primary teeth. Three of the re-examined transplants of the success-group featured a high percussion sound, indicating ankylotic healing, but did not show an impairment of vertical bone growth. This clinical finding is described by us as 'pseudoankylotic' percussion sound. The term needs to be separated from true ankylosis as it is not associated with impaired vertical bone growth [21].

Six transplants (11%) showed signs of inflammatory resorption and were endodontically treated with bioresorbable $Ca(OH)_2$.

Survival and loss of transplants

Of all 53 transplants, 15 transplants within the survival-group were lost over an observation period of 33 months (median 33 months; min: 1 month, max: 86 months). Of those 15 lost transplants, five had external causes for their extraction: Retrauma followed by transplant loss was observed after a median time of 17 ± 12 months in 3 cases (10%). Transplant loss due to missing postoperative stability occurred in 2 cases (6%) with a median survival time of 1.5 months. Another 10 transplants (32%) were lost due to natural exfoliation of the root in 4 cases and undermining resorption of the root in 7 cases (one transplant showed both physiologic and undermining resorption). While undermining resorption was associated with an early loss of the transplants, naturally resorbed grafts were functionally *in situ* for several years. These 10 losses are regarded as having no external causes for extraction from the oral cavity.

The other 16 transplants within the survival-group (52%) were electively extracted after the last re-examination on

grounds of premolar transplantation ($n = 13$ transplants), orthodontic space closure ($n = 1$) or other reasons ($n = 2$). These transplants are therefore counted as functionally healthy up to the last re-examination in the survival analysis. Figure 6 summarises the reasons for transplant losses in the survival-group.

22 transplants of the success-group remained in place in the oral cavity at time of re-examination without later extraction. Using the Kaplan-Meier estimator [19] the median survival time of transplants at 50% cumulative survival rate (%) yielded 86 months ($SE = 30$ months) (Figure 7, red dashed line).

Success of transplants

17 out of the 22 grafts still present in the patients' mouths fulfilled the postulated parameters of a pocket probing depth (PPD) of ≤ 3 mm, a mobility grade of $\leq$ II, a negative percussion test and the absence of inflammatory resorptions yielding an overall success rate of 77%.

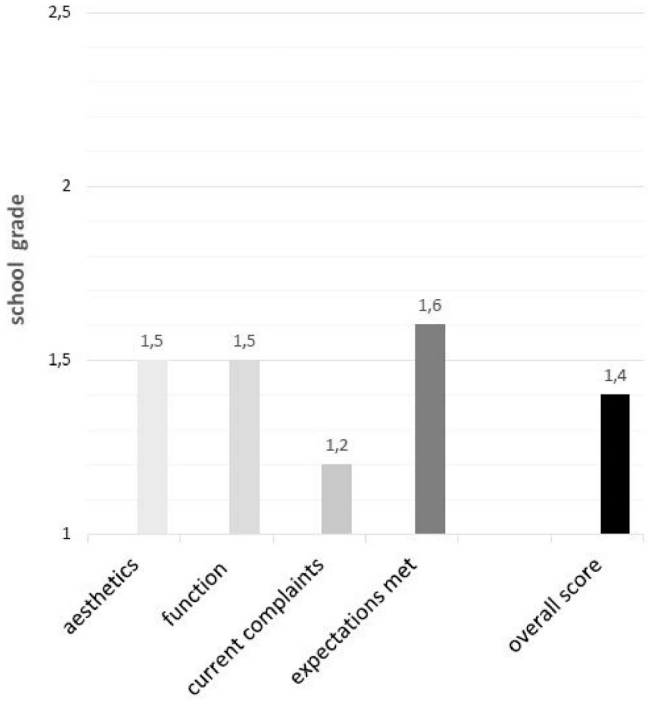

Figure 5. Patient satisfaction assessed with a questionnaire (grade 1 = very good to 6 = insufficient). The overall score of 1.4 indicates a high level of acceptance of the method. ($N = 35$ patients).

Discussion

This clinical study updates a previous report on autotransplantation of primary canines [10]. Meanwhile, the patient clientele increased to 40 patients with 53 primary transplants being retrospectively analysed. The surgical technique previously described [10,14,22] and applied in this study represents a proper alternative therapy to sustainably treat local defects in the anterior maxilla of children and adolescents missing a permanent incisor. At the moment, prosthetic constructions (e.g. adhesive bridges, removable dentures) are the most popular therapeutic options. These often imply a psychological burden for patients and parents [23,24]. Furthermore, constructions like these have a negative impact on the bone and soft tissue growth in the juvenile dentition due to unphysiological stress. Thus, successful implantation at the age of 17–18 often comes along with a considerable surgical effort [7].

This new surgical technique intends to act as a 'transitional technology' [14,15]. It offers immediate functional and aesthetic rehabilitation of young children with loss of a permanent incisor [10,25] before other steady and hopefully life-long treatment strategies such as orthodontic space closure, premolar transplantation or implantation take over.

Considering the patients of the survival-group (22 patients with 31 grafts) who lost their transplants either due to elective extraction, missing stability or re-trauma (Figure 6), even more than every second transplant (52%) successfully reached its point of destination and was electively extracted for the subsequent permanent therapy. The TPTX (Two-phase transplantation) concept, comprising primary tooth transplantation in children at the age of 6–10 years followed by premolar transplantation between 12 and 14 years [14], was the most commonly chosen therapy followed by orthodontic space closure and implantation. This intended premature removal of the primary transplants should be kept in mind when analysing the survival time and rate of the transplants with this procedure.

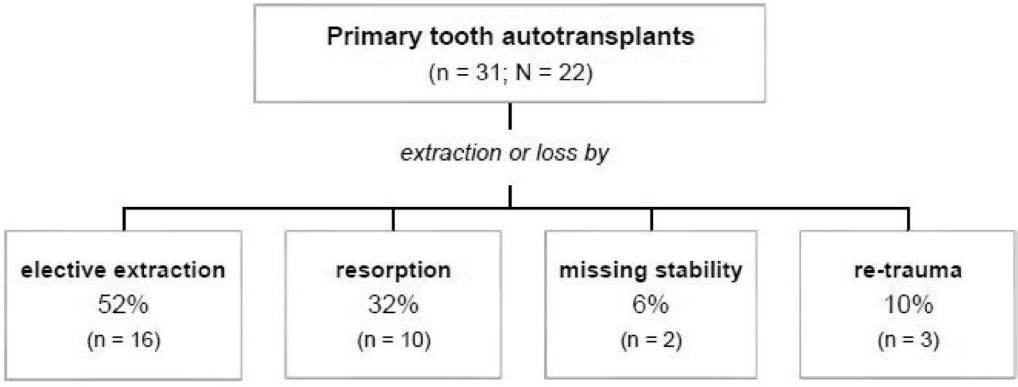

Figure 6. Postoperative whereabouts of primary transplants of the survival-group. ($n = 31$ transplants; $N = 22$ patients).

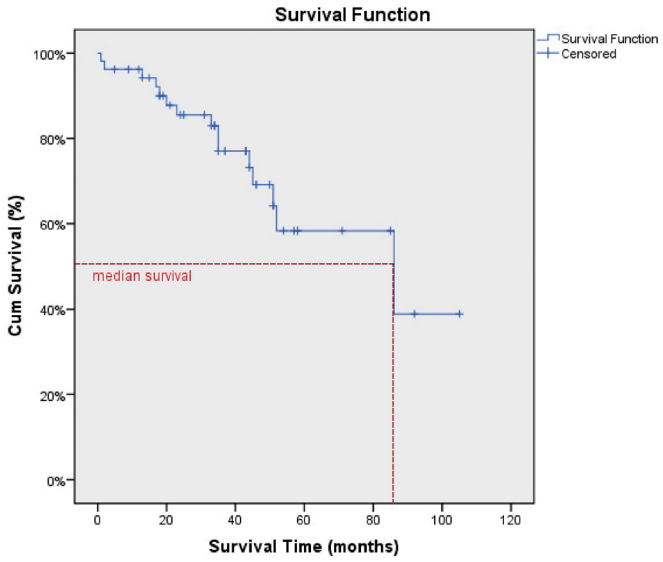

Figure 7. Kaplan-Meier cumulative survival times of all transplants ($n = 53$ transplants; $N = 40$ patients). The median survival time of transplants at the 50% cumulative survival rate is 86 months ($SE = 29.98$ months) as indicated by the red dashed line. For detail see text.

The fundamental question, whether the previously reported induction of bone and soft tissue growth in the transplant area [10] can also be confirmed by this retrospective study in a larger number of cases, is raised. In a previous study 14 transplants were examined in 10 patients, providing a good correlation between the bone heights on the transplants compared to the adjacent teeth. On average, an increase of 0.1 mm bone height (minimum −3.4 mm; maximum +4.1 mm) was seen. Applying the same method of measurement in this study, the bone heights on the transplants were found slightly decreased by less than ½ mm at the time of the clinical re-examination (Figure 3). This difference was clinically too low to reach statistical significant difference in bone height compared to the adjacent teeth, indicating that the peri-transplant bone levels kept pace with the natural growth of the healthy adjacent teeth in the juvenile dentition. The assessment of red aesthetics around the transplants in relation to the healthy adjacent erupting teeth confirms this finding. 21 out of 22 transplants (95%) of the cases showed adequate to hyperplastic soft tissue levels compared to the neighbouring teeth, hypoplastic gingival growth was recorded on just one transplant (Figure 4). The patient case in Figure 2 documents a slight hyperplastic gingival margin around the transplant in the central incisor position 11 compared to the healthy central left incisor 7.5 years after transplantation (Figure 2(K)).

The overall satisfaction of patients and their parents results in a total grade of 1.4 (very good = 1, insufficient = 6) . This is close to the outcome of the previous study with a total grade of 1.5 and indicates the high acceptance of this method. The participants' expectations were fully met in terms of functionality (speaking, biting) and aesthetics (Figure 5). The rare occurrence of pathological findings assessed by the clinical parameters of the PSI, bleeding on probing, pocket probing depth and grade of mobility in the re-examined transplants (Table 2), and the low severity of complications may explain the high acceptance. Re-trauma associated with transplant loss occurred to three patients (6% of transplants) and can therefore not be attributed to a failure of the procedure (Table 3). Pohl et al. [9] reported a markedly higher incidence of repeated trauma episodes after primary canine transplantation of 19% whereas the study by Tschammler et al. [10] reported a frequency rate of 14%. There is strong evidence that a preceding trauma increases the risk for another dental trauma as previously reported in a systematic review and meta-analysis by Magno et al. [26]. In this respect, preventive measures such as mouthguards should be considered and recommended to this patient clientele.

Andreasen described various types of root resorptions in permanent teeth following traumatic dental injury [27]. In this study, six inflammatory resorptions (11%) were detected in five patients in the entire patient clientele (Table 3). To reduce this complication, primary tooth transplantation should be performed as early as possible to ensure sufficient root length on the date of surgery. The affected teeth underwent a root canal treatment with bioresorbable $Ca(OH)_2$ [15] and remained *in situ* until the subsequent permanent therapy. The root-filled teeth also provided a good local bone quality for the following endosseous implantation which was performed in 6 out of 53 (11%) transplants (Table 2). In all those cases, implantation could be performed without the need for complicated bone augmentation [25], underlining the inherent potential of this method to reliably stimulate the growth of the alveolar process [9,10]. Undermining resorption occurred with a frequency of 13% (Table 3) in regions where transplants were inserted into the space of the upper lateral incisors. Predominantly, the mesial eruption of the permanent canine led to early transplant loss. Therefore, it is advisable that when transplanting into this area special attention should be paid to the direction of the erupting adjacent permanent canine. In addition, patients and their parents must be informed about this potential complication. As a consequence, it is preferred to transplant into the position of the central incisors, given the fact that the loss of the lateral incisors can be well treated by orthodontic space closure. This led to a decrease of the high rate of undermining resorption from 40% in the previous study [10] to 13% in this study.

The majority of transplants (79%) was resorbed by natural exfoliation representing the postulated resorption process of the primary transplants *via* reduction of the root length over time [10] and keeping pace with the alveolar process growth of the neighbouring teeth (Figure 3). With a mean deviation of approximately ½ mm bone height compared to the neighbouring teeth continuously erupting in this crucial growth period, this difference is clinically negligible.

Ankylosis associated with infraposition of a transplant was not observed in any of the 53 grafts. Three transplants had a high percussion sound suggesting ankylosis which was not associated with an inhibition of the alveolar process growth. This finding has therefore been named as 'pseudoankylotic' percussion sound (Table 3). This observation in primary

transplants needs to be differentiated from true ankylosis to avoid unnecessary extraction of the affected transplants.

The median survival time of primary transplants reported in the literature is limited to two case reports [16,17] reporting of 16 and 24 months, respectively, and one prospective study [9] analysing 17 transplants with a median survival time of 26.6 months (2.2 years). Endodontic treatment by retrograde titanium posts [9,16] or classical root fillings with gutta-percha [17] were common practice in both studies. The preceding study [10] applying the same surgical technique as in this retrospective study reported on a median survival time of 62 months (5.2 years) in a total of 10 grafts. The median survival time of all 53 grafts in this retrospective study was calculated with the Kaplan-Meier estimator being 86 months (7.2 years, Figure 7). Apart from five transplants lost due to early missing instability ($n = 2$) or re-trauma ($n = 3$), all transplants successfully reached the start of the planned follow-up therapy. The presented case of a girl experiencing complicated crown-root fracture with loss of tooth 11 at the age of 7 is still ongoing (Figure 2). The by now 15 year-old girl and her parents decided on implantation as follow-up therapy at a later time. Another case of a girl with multiple tooth agenesis, who introduced herself at the age of 10, reports on the so far longest documented survival time of primary canine grafts, receiving implant therapy after transplant loss at the age of 21 [25].

Previous orthodontic treatment occurred in 41% of the patients, 11% of patients were not involved. After transplantation, the percentage of patients receiving postoperative orthodontic treatment rose to 84%, emphasising the importance of the interdisciplinary collaboration between surgeon and orthodontist (Table 2). The authors appreciate and recommend this interdisciplinary work to allow for timely decision-making with regard to the most appropriate follow-up therapy for the patient.

Conclusion

This study reaffirms and extends previous findings on primary tooth grafting by reliably replacing missing permanent incisors due to trauma or agenesis. With a median survival time of the grafts of 7.2 years and a success rate of 77% this new method facilitates the successful functional and aesthetic restoration of the children's bite as a temporary measure lasting from primary and early mixed dentition into late mixed dentition. This may be ascribed to the inherent potential of the grafts to support the formation of bone and soft tissue keeping up with the eruption process of the neigbouring healthy teeth. The documented tooth transplants provide very stable soft tissue conditions with only minimal bone loss, yielding no statistically significant difference from the healthy adjacent teeth. The high patient satisfaction and acceptance of the method make the authors hope that this new technique will become a standard therapy for rapid functional and aesthetic rehabilitation of children and adolescents with traumatic tooth loss or agenesia, functioning as a 'transitional technology' before the other well-known follow-up treatments can take over.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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