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Transplantation of primary canines after loss or ankylosis of upper permanent incisors. A prospective case series study on healing and survival

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Abstract – Primary canines were transplanted to replace lost or ankylosed permanent upper incisors. Healing, healing complications and loss and survival were evaluated in a prospective case series study. In total, 27 primary canines were transplanted. Extraorally posts made of titanium were inserted into the root canal from a retrograde direction as an immediate endodontic treatment and as an elongation of the short autologous roots. In some cases antiresorptive-regenerative therapy was used. Inclusion criteria for the evaluation were a minimal observation period of 12 months or the observation of complications. The median observation period of the analyzed 17 transplants was 26.6 months (min: 6.7 months, max: 54.6 months). Sixteen out of seventeen transplants exhibited functional healing until the end of the observation or the occurrence of an external influence (another trauma, resorption by neighbored tooth). In no case ankylosis or arrest of alveolar growth was recorded. In some transplants resorptions not related to infection or ankylosis were observed. One transplant exhibited an early infection-related complication and was removed. One transplant was resorbed by the developing permanent canine and lost. Following another trauma five transplants were lost. External influence and new trauma were significantly related to the loss of transplants (Fisher's exact test; $P = 0.0006$ and 0.0034). The estimated survival according to a Kaplan–Meier analysis was 40.7 months for all transplants. It was significantly shorter for teeth which were lost in relation to an external influence (survival 28.4 months vs 44.7 months; log rank test: $P = 0.0093$). The transplantation of primary canines maintains bone and soft tissues of the alveolar process. The healing rate is high. However, there is a high incidence of repeated trauma episodes, causing a high loss rate. The observation period is still limited.

Introduction

The loss of teeth and – in growing persons – the ankylosis of teeth result in the loss of bone and soft tissues. A definite prosthetic treatment including insertion of dental implants cannot be performed before facial growth is largely completed. Extensive augmentation is required due to functional and esthetic demands (1–3). The missing teeth have to be replaced by temporary prosthesis for many years which have to be repeatedly adjusted or renewed according to changes in the jaw growth and in the developing dentition. Orthodontic space closure may be considered but is restricted to cases with specific indications (4, 5). Decoronation of ankylosed teeth as a preprosthetic therapy is an option to maintain bone and soft tissues but requires temporary tooth replacement for several years (6–8). Intentional replantation of ankylosed teeth, comprising a partial removal of the root, an extraoral endodontic treatment and the use of enamel matrix derivative may result in functional healing when the ankylotic areas are small (9, 10). Transplantations of premolars exhibit excellent healing results, long-term survival and esthetics (11–18). However, there should be an orthodontic indication for the removal of premolars. The healing results are dependent on the root development which should be 50–80%. Such a situation can be expected for children with an age above 10 years.

For younger children the transplantation of primary canines to replace lost or ankylosed permanent incisors has been described (19). This option has been the treatment of choice in our clinics in cases of missing or ankylosed permanent incisors of the upper jaw whenever primary canines seemed to be usable. The aim of the present investigation was to evaluate healing, healing complications and loss and survival of transplanted primary canines in a prospective case series study.

Material and methods

Before the proposal of a transplantation of primary canines an orthodontic consilium was obtained to check the possibility of orthodontic space closure. The children and their parents were then extensively informed on alternatives and on the newness and possible consequences of the transplantation of primary canines, resulting in a written informed consent. All patients agreed with the proposed transplantation.

Primary canines were transplanted into the region of incisors of the upper jaw that had been lost in an accident or had to be removed because of complications after a severe trauma. The transplantations were performed immediately after tooth loss or tooth extraction or up to several weeks to months after tooth loss. Thus, the primary canines were transplanted into a complete alveolus or into regions with a collapsed alveolar process requiring the preparation of a transplant bed. The roots of the transplants were more or less physiologically resorbed (Fig. 1) depending on the position of the succeeding permanent canines. Especially the upper primary canines exhibited resorptions that were not only located apically but also at the palatal aspect (Fig. 2) while the primary canines of the lower jaw showed resorptions more evenly progressing from the apex (Fig. 3). Transplantations were performed only when a minimal root length of at least 2–3 mm could be maintained.

All transplantations were performed in local anesthesia except in one case in which a general anesthesia was used. In this case a severe and painful infection had established about 10 days after trauma with a root fracture and the avulsion of the coronal fragment. Due to the infection it seemed improbable to achieve a sufficient analgetic effect by a local anesthesia. Recently a study was started concerning sedation and trance in oral surgery. Thus four patients were treated while receiving 50% nitrous oxide and/or watching videos with a headset (Fig. 4).

After extraction the primary canines were intensively rinsed with a flow of sterile isotonic saline and then stored in a tissue culture medium at room temperature for at least 30 min. Being easily available the medium of the tooth rescue box Dentosafe® (Dentosafe GmbH, Iserlohn, Germany) was used. This medium maintains the vitality and proliferative capacity of periodontal ligament (PDL) cells for at least 48 h *in vitro* and *in vivo* (20–23). Whilst the storage period an extraoral endodontic treatment was performed (24). The root tip was resected to remove the apical ramifications using diamonded disks; roots partially resorbed were leveled. The root canal was prepared from a retrograde direction

Fig. 1. Upper primary canine. Residual autologous root length of 2–3 mm.

Fig. 3. Lower primary canine. Less difference between lingual and labial root length compared to upper primary canine (Fig. 2).

Fig. 2. Upper primary canine. Resorption at the palatal aspect, completely maintained root length at the labial aspect.

Fig. 4. Child watching a video through a headset during plantation.

using machine-driven burs from a standardized bur-post-system (RetroPost®; Brasseler/Komet, Lemgo, Germany) offering 4 diameters (1.6, 2.0, 2.5 and 3.0 mm). The burs and the roots were intensively cooled with physiologic saline. The root canal was prepared from the apex beyond the most coronal aspect of the cemento-enamel junction. Due to the conical shape of the root canal a wide preparation was necessary to secure a complete root canal preparation also in the marginal region of the roots. The posts made of ceramics (no longer available) or titanium (surface as machined) were tried in and shortened to the desired length. It was intended to approach the normal root length of a permanent incisor by the apical projection of the posts (Fig. 5). The intracanal part of the posts was roughened using diamonded disks to enhance the cementation. After drying of the root canal using sterilized paper points the posts were cemented into the root canal with endodontic sealers. During an initial setting for about 2–3 min in the air the PDL was kept moist using sterilised paper points soaked in tissue culture medium. The primary canines were again stored in the tissue culture medium for at least 10 min for further setting of the sealer. Thereafter excess sealer was removed using small excavators and sterilized dental floss. In case of a maintained alveolus the transplants were tried in. The cemento-enamel junction was placed at or below the osseous margin of the alveolus. However, a flap was normally not prepared and therefore there was not a visual control but instead an estimation taking into account the length of the root and the crown of the transplant as well as the alveolar margin as defined by palpation. If an insufficient depth of insertion was observed the fundus of the alveolus was deepened with the bur used last for the preparation of the root canal to meet the length and the diameter of the post and/or the alveolus was widened according to the diameter of the root of the transplant. The aim was to position the transplant without contact to the bone of the alveolus. In cases of a collapsed alveolar bone a transplant bed was prepared using internally cooled surgical burs. During this procedure the transplants were tried in repeatedly, if necessary. The transplants and the transplant beds were then intensively rinsed with sterile isotonic saline and the transplants were definitely inserted.

In some cases antiresorptive-regenerative therapy (ART) was used (22, 24). After completion of the endodontic therapy and following a last intensive rinsing the transplants were stored for another 20 min in the tissue culture medium to which a glucocorticoid (Fortecortin® inject; Merck, Darmstadt, Germany) at a concentration of 40 μg ml^{-1} was added. Alternatively teeth were stored for 5 min in the medium to which 1 mg tetracyclin was added. After rinsing the alveolus with physiologic saline an enamel matrix derivative (Emdogain®; Straumann, Basle, Switzerland) was applied onto the root surface and into the alveolus. Doxycyclin was administered for systemic use for 1 week according to the patients' weight.

After plantation the transplants were splinted with a non-rigid splint, either a bracket-splint, a wire splint or a titanium trauma splint (TTS®; Medartis, Basle, Switzerland), each applied with an acid-etch technique (Fig. 6). One sound tooth on each side of the transplant was integrated in the splint. The splint was removed when the horizontal Periotest values (Periotest®; Medizintechnik Gulden, Bensheim, Germany) of the transplant were below 25 when still splinted. Immediately or soon after splint removal the crowns of the transplants were built up using composites to mimic the shape and color of a regular tooth in this position. This was mainly done by the treating dentist who also decided to incorporate a space maintainer in the donor region when clinical observations revealed a tendency toward spontaneous space closure.

Definition of healing

Immediately after transplantation an intraoral radiograph was taken. The clinical examinations at the follow-up examinations comprised palpation, percussion, vertical and horizontal probing of the tooth damping characteristics with the Periotest®-device, and – after some healing - pocket probing. After an initial healing phase with clinical controls every 1–3 weeks the

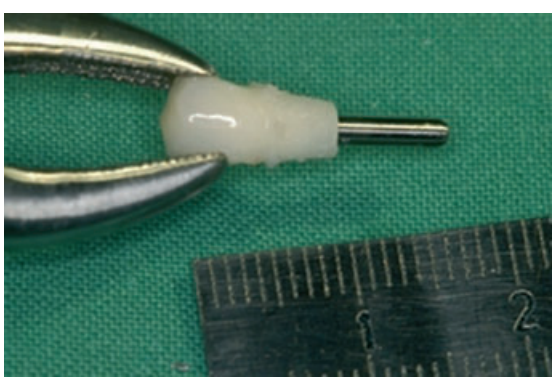

Fig. 5. Titanium post inserted into root canal prepared from a retrograde direction. Projection of post elongates the short root of a primary canine which has already undergone a certain physiologic resorption. Same case as in Fig. 3.

Fig. 6. Primary canine transplanted into the maintained alveolus of an ankylosed and just removed tooth that had been in an infraposition (4 mm). The non-rigid splint (TTS) includes both sound neighbored teeth and secures the position of the transplant.

interval for clinical examinations was 3–6 months. Intraoral radiographs were taken about 6 weeks after transplantation and then every 6–12 months.

According to clinical and radiographic findings healing was defined (*healing*). *Infection-related complications* were diagnosed when pain to percussion and/or palpation, swellings/abscesses or fistulas were present. Radiographically *apical periodontitis* (radiolucencies at the apex) and *infection-related resorption* (radiolucencies along the autologous root and the opposite bone) were recorded. *Ankylosis-related resorption (ankylosis/replacement resorption)* was diagnosed when the transplants showed a high percussion tone, negative Periotest values and progressing infrapositions and, in the radiographs, a partial or complete loss of the radiolucent space surrounding the root and/or a replacement of the root substances by bony structures. *Functional healing* was recorded when none of the described pathologies were present. Normal mobility, normal percussion sound and a radiolucent space surrounding autologous root and alloplastic post were the criteria. Functional healing comprised *regeneration* (no resorption or other pathologies at all) and resorptions not related to infection or ankylosis (i.e. *healing-related resorption,* formerly named surface resorption).

When only a clinical examination was performed the diagnosis was set to *ankylosis*, *infection* or *no complication* according to the abovementioned clinical criteria (*clinical healing*).

The data were inserted into a database (MS Access 2003). SPSS for Windows 12.0 was used for descriptive statistics and a survival analysis.

Results

In total, 27 primary canines were transplanted in 24 patients and in 26 operations (Table 1). In one patient two primary canines were transplanted simultaneously, and in two patients two transplantations were performed at different times. The median age of the patients at the time of transplantation was 8.8 years (mean: 9.0 ± 1.14 years, min. 7.6 years, max. 12.4 years). In nine girls 11 teeth and in 15 boys 16 teeth were transplanted (ratio female:male = 1:1.7 for patients). The permanent incisors had mainly been lost due to an avulsion. Ten teeth were not available for replantation after avulsion (avulsion loss). Twelve teeth exhibited complications (ankylosis, infection, vertical fracture) after a former trauma. One tooth was removed due to a malformation. Two primary canines were transplanted after the trauma-related loss of formerly transplanted primary canines. The original trauma that resulted in the loss of the permanent incisor and the consecutive transplantation occurred at the age of 8.0 years (median; mean: 8.2 ± 1.28 years; min: 6.0 years; max: 10.7 years).

The time that elapsed between the loss of the permanent incisor and the transplantation of a primary canine was 4.0 days (median). Fifteen primary canines were transplanted into a completely maintained alveolus, and no surgical adjustments of the alveolus were necessary. In five cases some surgical corrections of a preformed alveolus were performed. A completely new transplant bed had to be prepared in seven cases. Four primary canines were transplanted immediately after the removal of a tooth that had caused an infection. Five transplants were inserted into regions which had healed after the removal of an infected tooth.

The recipient sites were the regions of the upper central incisors; only one primary canine was transplanted into the region of an upper lateral incisor. Except three canines from the lower jaw the donor region was the upper jaw.

The material of the inserted post was ceramic (n = 2; no longer available) or titanium (n = 25, RetroPost®; Brasseler/Komet). Predominantly the diameter of the post was 2 mm, and as a sealer, Diaket (Diaket®; 3 M Espe, Seefeld, Germany) was used. ART was used with 13 transplants, and a systemic antibiosis was used with 13 transplants.

Two patients could not be followed up for more than some days because the patients were from abroad and on holidays near our clinics and returned home soon after transplantation. The transplants in the other patients were splinted for 46.0 days (median), and the crowns were reconstructed with composites 73.0 days (median) after transplantation.

Healing following transplantation

For further analyses only cases with a minimal observation period of 12 months or exhibiting complications were considered. Thus 17 transplants were included (Table 2). Healing was evaluated clinically and radiographically (*healing*) after an observation period of 26.1 months (median), and only clinically (*clinical healing*) after 26.6 months (median).

In no case ankylosis and ankylosis-related resorptions were observed. In one case an infection-related resorption was recorded. All other transplants exhibited functional healing up to the last observation or the occurrence of an external influence. All these transplants exhibited a radiolucent gap surrounding autologous root and alloplastic post. Clinically, percussion sounds were normal. The transplants had a normal or slightly increased mobility compared to contralateral sound teeth, the horizontal Periotest values ranging between 5 and 20 (Fig. 7). Probing depths were within the ranges of non-injured neighbored incisors.

Some transplants exhibited root resorptions that were not related to clinical or radiographic signs of infection or ankylosis. The edges of the resection plane were rounded. In few cases the resorptions progressed over the years and left only minimal cervical parts of the autologous root, however without any clinical or radiographic hints for any complications. In the radiograph the autologous root was surrounded by a radiolucent gap (representing PDL) of normal width (Figs 8–14). The transplants were still sufficiently stable and were used by the patients in normal function. No increased probing depths were recorded. Despite the root resorption the alveolar process was kept in its horizontal width (Figs 11 and 14).

The case with the infection-related resorption showed a widely functional healing without any signs of anky-

Table 1. Pre-, peri- and postoperative parameters related to all transplanted primary canines ($n = 27$) and descriptive statistics

Transplant	Patient	Gender	Age (years)	Recipient region	Donor tooth	Original trauma	Age original trauma (years)	Original trauma – loss (days)	Indication	Loss–trans (days)	Alveolus	Infection recipient	Post	Diameter	Sealer	Splint	Splint (days)	Reconstruct (days)
1	1	f	9.5	21	63	Lateral disloc.	7.1	873	IRR	12	Maint.	Healed	Ti	2.0	Diaket	TTS	30	30
2	2	m	10.7	11	63	Avulsion – loss	10.6	0	Avulsion – loss	47	Corr	No	Ti	2.0	Diaket	Bracket	55	134
3	3	m	9.5	12	63	Avulsion – loss	9.5	1	Avulsion – loss	2	Maint.	No	Ti	2.0	Diaket	Bracket	7	43
4	4	m	9.0	11	53	Avulsion	6.2	993	IRR	4	Maint.	Yes	Cer	1.6	Jodoform	Bracket	12	
5	1	f	7.9	21	53	Avulsion – unphys	7.1	317	IRR	0	Maint.	Healed	Ti	1.6	Sealapex	Bracket	24	24
6	5	m	8.0	11	63	Avulsion – loss	8.0	0	Avulsion – loss	7	Maint.	Yes	Cer	1.6	Sealapex	Bracket	30	119
7	6	f	9.7	21	63	Root fract. cervic.	9.6	0	Root fract. cervic.	49	New	No	Ti	2.0	Aptalharz	Wire	29	29
8	7	f	8.4	11	53	Avulsion – unphys	8.0	155	Ankylosis	0	Maint.	No	Ti	2.0	Diaket	Wire	44	44
9	7	f	8.4	21	63	Avulsion – unphys	8.0	155	Ankylosis	0	Maint.	No	Ti	2.0	Diaket	Wire	44	44
10	8	m	9.2	21	73	Avulsion – unphys	9.2	0	Ankylosis	16	Maint.	No	Ti	2.5	Diaket	TTS	76	76
11	9	m	7.6	11	53	Avulsion – loss	7.4	0	Avulsion – loss	76	New	No	Ti	1.6	Diaket	TTS	42	120
12	10	m	9.0	11	63	Fract. vertical	9.0	0	Fract. vertical	0	Maint.	No	Ti	2.0	Diaket	TTS	59	141
13	11	f	8.1	11	53	Avulsion – loss	7.8	0	Avulsion – loss	111	New	No	Ti	1.6	Diaket	Bracket	21	
14	12	m	8.2	11	53	Avulsion – unphys	7.1	403	Ankylosis	0	Maint.	No	Ti	2.0	Diaket	TTS	95	95
15	13	m	7.6	21	73	Avulsion – unphys	7.5	26	Ankylosis	0	Maint.	Healed	Ti	2.0	Diaket	TTS	71	71
16	14	m	7.6	11	53	Avulsion – loss	6.0	3	Avulsion – loss	581	New	No	Ti	2.0	Diaket	TTS	75	164
17	5	m	9.3	11	53	Avulsion – loss	8.0	490	Avulsion – loss	2	Corr	No	Ti	1.6	Diaket	Bracket	25	48
18	15	m	8.7	21	53	Avulsion – unphys	7.5	425	Avulsion – unphys	0	Maint.	No	Ti	2.0	Diaket	TTS	47	184
19	16	m	8.8	11	63	Avulsion – loss	8.3	0	Avulsion – loss	160	New	No	Ti	2.0	Diaket	TTS	45	
20	17	f	12.4	21	63	Avulsion – unphys	9.3	1129	Ankylosis	0	Maint.	Yes	Ti	2.0	Diaket	TTS	73	73
21	18	f	9.2	11	53	Intrusion	8.8	48	IRR	98	New	Healed	Ti	2.0	Diaket	Bracket	47	
22	19	f	8.6	21	63	Concussion	6.6	651	Fract. vertical	79	Corr	Yes	Ti	2.0	Diaket	TTS	58	58
23	20	m	8.6	11	73	Avulsion	8.0	162	IRR	28	Corr	Healed	Ti	2.0	Diaket	TTS		
24	21	f	8.2	11	53				Dilaceration	0	Corr	No	Ti	2.0	Diaket	TTS	63	
25	22	m	10.8	11	53				Malformation	106	New	No	Ti	1.6	Diaket	TTS	111	111
26	23	m	10.7	21	63	Avulsion – loss	10.7	0	Avulsion – loss	1	Maint.	No	Ti	2.0	Ketac-Endo	Bracket		
27	24	f	10.0	11	53	Avulsion – loss	10.0	0	Avulsion – loss	0	Maint.	No	Ti	1.6	Diaket	TTS		
	Median		8.8				8.0	26.0		4.0							46.0	73.0
	Mean		9.0				8.2	233.2		51.1							49.3	84.6
	SD		1.1				1.3	344.5		115.0							25.7	48.5
	Min.		7.6				6.0	0.0		0.0							7.0	24.0
	Max.		12.4				10.7	1129.0		581.0							111.0	184.0

Alveolus – Maint., maintained; Corr, corrected/adjusted. Post – Ti, titanium; Cer, ceramics. Splint – TTS, titanium trauma splint. Wire, wire composite splint.
Original trauma - loss: time elasped between the original trauma and the loss of the permanent incisor.
Loss-trans: time elapsed between the loss of the permanent incisor and the transplantation of the primary canine.

Table 2. External influences, healing and survival after transplantation of primary canines with observation periods >12 months or exhibiting complications and descriptive statistics

						Before external influence last radiographic control				After external influence				
										Last radiographic control		Last clinical control		
Transplant	Patient	Emdogain	Corticoid	Local tetra	Antibiosis	Healing 1	Observation 1 (months)	External influence	External influence (months)	Healing 2	Observation 2 (months)	Healing 3	Observation 3 (months)	*In situ*
1	1	Yes	Yes	No	Doxy	FH	47.4	Lateral disloc.	53.2	IRR	54.6	Infection	54.6	X
2	2	Yes	No	No	No	FH	25.9	Crown-root fract	28.4	–	28.4	–	28.4	X
3	3	Yes	No	No	No	FH	8.2	Resorption by tooth	12.9	–	26.4	–	26.4	X
4	4	No	No	No	No	FH	11.9	Fracture post	17.4	Apic. inf.	26.1	Infection	26.1	X
5	1	No	No	No	No	FH	6.6	Lateral disloc.	8.5	IRR	18.7	Infection	18.7	X
6	5	No	No	No	Unknown	FH	9.7	Avulsion - loss	15.9	–	15.9	–	15.9	X
7	6	Yes	No	No	Doxy					IRR	6.7	Infection	6.7	X
8	7	Yes	Yes	No	Doxy					FH	40.2	No complic	47.6	*In situ*
9	7	Yes	Yes	No	Doxy					FH	40.2	No complic	47.6	*In situ*
10	8	No	No	No	Doxy					FH	37.1	No complic	37.1	*In situ*
11	9	No	No	No	No					FH	31.1	No complic	31.1	*In situ*
12	10	No	No	No	No					FH	26.4	No complic	26.6	*In situ*
13	11	Yes	No	No	Pen					FH	25.7	No complic	27.8	*In situ*
14	12	No	No	Yes	Doxy					FH	23.5	No complic	23.5	*In situ*
15	13	No	No	Yes	Doxy					FH	21.8	No complic	28.5	*In situ*
16	14	No	No	No	No					FH	21.0	No complic	21.0	*In situ*
17	5	Yes	No	No	No					FH	13.4	No complic	13.4	*In situ*
		median					10.8		16.7		26.1		26.6	
		mean					18.3		22.7		26.9		28.3	
		SD					15.9		16.4		11.5		12.6	
		min					6.6		8.5		6.7		15.9	
		max					47.4		53.2		54.6		54.6	

Antibiosis: doxy, doxycyclin; pen, penicillium.
Healing - FH, functional healing; IRR, infection related resorption; Apic inf., apical inflammation; no complic, no complication.

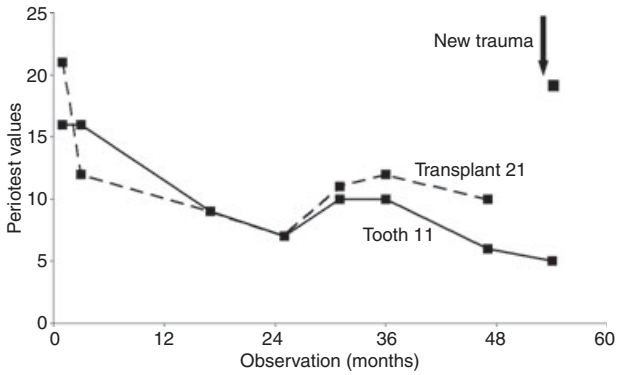

Fig. 7. Tooth damping characteristics as measured by the Periotest® device, related to observation period. Normal values are between 5 and 15, representing ARPA class 0. Note increased value after new trauma about 4.5 years after transplantation.

Fig. 8. Primary canines 53 and 63 transplanted into the sockets of the ankylosed and removed permanent incisors 11 and 21. Intraoral radiograph immediately after transplantation.

losis about 10 weeks after transplantation (Fig. 15). At the mesial aspect of the root there was a decent resorption lacuna of the root (Fig. 16). However, the opposite bone showed no radiolucency but a dense radiographic appearance representing cortical bone. About 6.7 months after transplantation the transplant exhibited pronounced radiolucencies typical of an infection-related resorption with the loss of nearly all the root substances. The apical portion of the post was surrounded by sound bone from which it was separated by a narrow radiolucent gap (Fig. 17), most probably representing connective tissue (24, 25).

The root of the primary canine transplanted into the region of a lost lateral incisor was partially resorbed by the developing neighbored permanent canine (Figs 18–21); the transplant was removed after 26.4 months.

Fig. 9. Same case as in Fig. 8. Radiographic situation 12 months after transplantation. Apically located resorptions of about one-third of the transplanted autologous root substances. Surrounding radiolucent space of normal width, no radiolucencies, no ankylosis-related resorption.

Fig. 10. Same case as in Fig. 8. Radiographic situation 40.2 months after transplantation. Further progression of resorption of autologous root substances. No hints for infection or ankylosis-related complications.

Five transplants were lost following one or more traumas that affected the transplant. One was avulsed during the third (!) trauma within 16 months. One showed a fracture of the inserted ceramic post apically to the autologous root which resulted in an increased

Fig. 11. Same case as in Fig. 8. Clinical situation 47.6 months after transplantation. Horizontal width of alveolar process completely maintained.

Fig. 12. Primary canine 73 transplanted into the socket of ankylosed and removed permanent incisor 21. Intraoral radiograph immediately after transplantation.

mobility of the transplant and the development of a periapical inflammation. Another transplant exhibited a non-restorable crown-root fracture. Two transplants were loosened and dislocated. Following the trauma they were sensitive for several days to percussion and exhibited periods of pain consecutively. Several weeks to months later there were fistulas and pronounced radiolucent root and bone resorptions visible on the radiograph. The diagnosis was set to infection-related resorption.

In no case infrapositions or the arrest of the alveolar growth were observed. In contrast, infrapositions that had resulted from an ankylosis of a previously traumatized permanent incisor were compensated after the transplantation (Figs 24–26). In cases without infections no tissues were lost. In some cases there was a clear gain in tissues (Figs 22 and 23). Infections resulted in loss of tissues (Fig. 17).

Fig. 13. Same case as in Fig. 12. Radiographic situation 37.1 months after transplantation. Apically distally located resorptions of about one half of the transplanted autologous root substances. Surrounding radiolucent space of normal width, no radiolucencies, no ankylosis-related resorption.

Fig. 14. Same case as in Fig. 12. Clinical situation 37.1 months after transplantation. Horizontal width of alveolar process completely maintained. Palatal splint (TTS) as an effort of protection against severe injuries in case of new traumas.

With only one healing complication in the cases without external influences no statistical relations were found. Healing was independent of the use of ART (chi-squared, $P > 0.1$).

Survival and loss of transplants

Of the 17 transplants seven were lost after an observation period of 26.6 months (median; min: 6.7 months, max: 54.6 months). External influence and new trauma were significantly related to the loss of transplants (Fisher's exact test, two-sided; $P = 0.0006$ and 0.0034, respectively).

Fig. 15. Primary canine 63 transplanted into the socket of ankylosed and removed permanent incisor 21. Intraoral radiograph immediately after transplantation. Tooth 11 root fracture.

Fig. 16. Same case as in Fig. 15. Radiographic situation 10 weeks after transplantation. Decent resorption lacuna at the mesial aspect of the autologous root.

The estimated survival expectation according to a Kaplan–Meier analysis was 40.7 months (median) for all cases. The expected survival was 28.4 months for teeth lost due to external reasons and 44.7 months for the other group (Table 3, Figs 30 and 31). The log rank test revealed a significant difference ($P = 0.0093$).

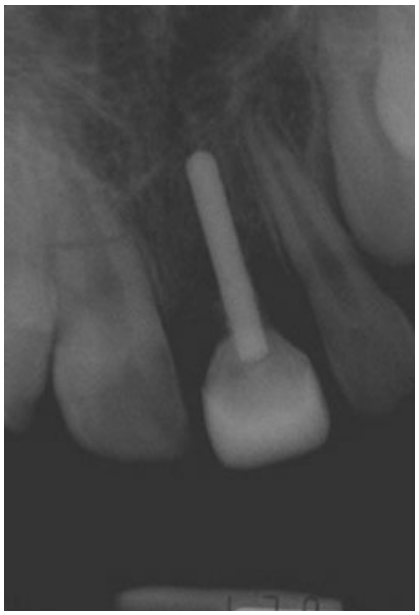

Fig. 17. Same case as in Fig. 15. Radiographic situation 6.7 months after transplantation. Nearly complete resorption of autologous root substances. Radiolucencies indicate infection-related resorption. Apical part of titanium post separated by a thin radiolucent space from bone that appears sound.

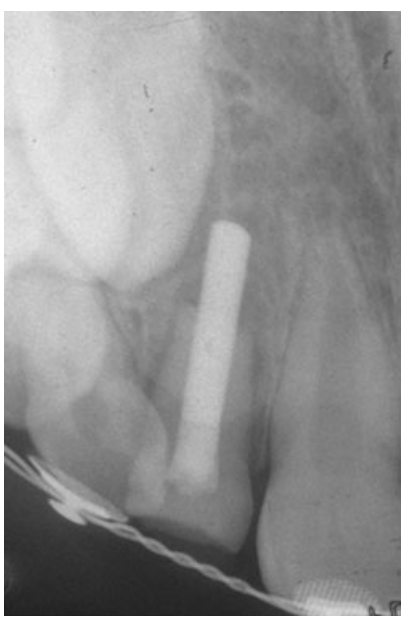

Fig. 18. Primary canine 63 transplanted into the socket of lost tooth 12. Intraoral radiograph immediately after transplantation.

Discussion

Tooth loss or tooth ankylosis during the growth period result in horizontal and/or vertical deficiencies of bone and soft tissues. For a definite treatment augmentations of bone and soft tissues are most often required,

Fig. 19. Same case as in Fig. 18. Radiographic situation 8.2 months after transplantation. Functional healing (normal periodontal space, no radiolucencies, no resorptions).

Fig. 21. Same case as in Fig. 18. Radiographic situation 17.9 months after transplantation. Further progression of root resorption.

Fig. 20. Same case as in Fig. 18. Radiographic situation 12.9 months after transplantation. Starting root resorption at the disto-apical aspect of transplant, but no hint of ankylosis or infection. Direct neighborhood of tooth crown of developing permanent canine 13.

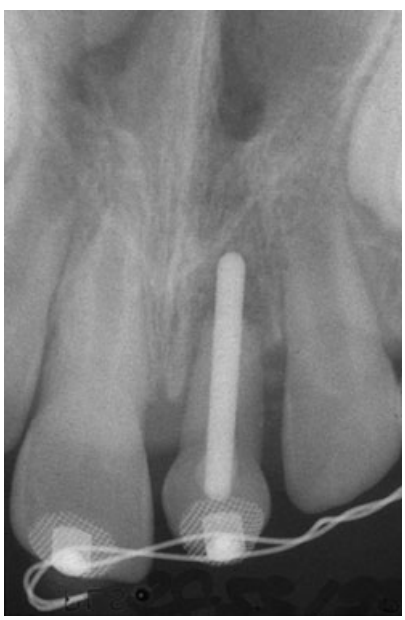

Fig. 22. Primary canine 53 transplanted into the socket of lost tooth 21. Radiographic situation immediately after transplantation. Note radiolucent areas apically and distally indicating missing bone.

especially when implants are planned (1–3). The treatments require extensive surgery and are very expensive. Therapies such as orthodontic space closure (4, 5), intentional replantation of ankylosed teeth (9, 10), decoronation of ankylosed teeth (6–8) or transplantation of premolars (11–18) have specific indications.

Primary canines are normally lost during the change in dentition. They are exfoliated at an age of about 9–12 years. The roots of primary canines are progressively resorbed starting some years earlier. We decided to use these teeth with a limited lifetime at their original position for the replacement of lost or ankylosed incisors of the upper jaw. It was supposed that, like after

successful transplantation of premolars, bone and soft tissues would be maintained or even regenerated and the growth of the alveolar process would progress.

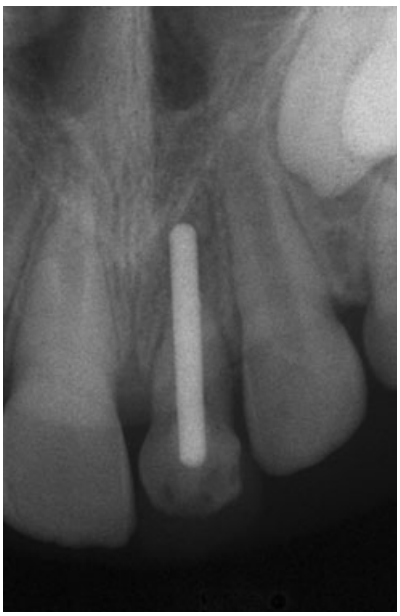

Fig. 23. Same case as in Fig. 22. Radiographic situation 5 months after transplantation. Regeneration of bone apically and distally even in a vertical direction.

Fig. 24. Situation 10.5 months after avulsion of tooth 11 in a 7-year-old boy. Due to unphysiologic rescue development of ankylosis and infraposition of about 2 mm.

Acceptance of treatment

All patients consented to the proposed treatment. Before the decision they were informed of the consequences of no treatment (loss of tissues, interim prostheses, augmentation and prosthetic treatment at the end of the growth period) and also of the transplantation treatment (surgical interventions with two wounds) and the possible complications (infection, loss of transplant and another surgical intervention for removal). They were informed of the costs of the treatment which are normally not covered by public insurances. A decisive argument was that a tooth with no (long-term) value in its original position might possibly improve the situation at the recipient region. Even the uncertain prognosis resulting from the complete lack of experience with transplanted primary canines overweighed the concerns on the expenditures and possible complications.

One transplantation was performed in general anesthesia. Due to a massive and painful infection preoperatively it was doubtful whether a local anesthesia would be sufficiently effective for a painless surgery. All other cases were performed in local anesthesia. In all planned cases except one the transplantation could be completed. This one patient rejected further treatment after the injection of the local anesthetic. Several weeks before the planned transplantation the removal of the permanent incisor in local anesthesia had been very painful due to an acute inflammation, and the patient feared the same for the transplantation. At that time treatment with nitrous oxide was not introduced and other procedures (sedation, general anesthesia) were rejected by the patient and the parents.

In several instances the patients had already undergone the replantation of avulsed incisors or transplantation of primary canines. After the loss of a transplanted primary canine in two cases another transplantation of primary canines seemed possible, and both patients agreed to a second transplantation. Except the two early dropouts all patients kept the scheduled appointments, and the crowns of all transplants were reconstructed. Despite the necessity of multiple injections for local anesthesia and of two wound regions, and despite the young age and pertinent experience, the treatment was well accepted. This may be also related to the fact that the patients, at least if the alveolus was still maintained, were involved for only short moments during anesthesia, extraction, plantation and splinting. The more difficult and time-consuming treatment steps (preparation of transplant including endodontic treat-

Table 3 Survival analysis according to Kaplan-Meier

			Survival time									Log rank		
	n	Censored	Mean	Limited to	SE	5%	95%	Median	SE	5%	95%	Statistic	d.f.	Significance
All data	27	20	40.7		4.8	31.3	50.2	54.6	0.0					
Loss due to external reasons														
Yes	6	0	28.4		5.6	17.3	39.4	26.1	4.8	16.8	35.4	6.8	1	0.0093
No	21	20	44.7	47.6	2.8	39.2	50.2							

All data and stratified for the occurrence of an external influence resulting in the loss of transplants.

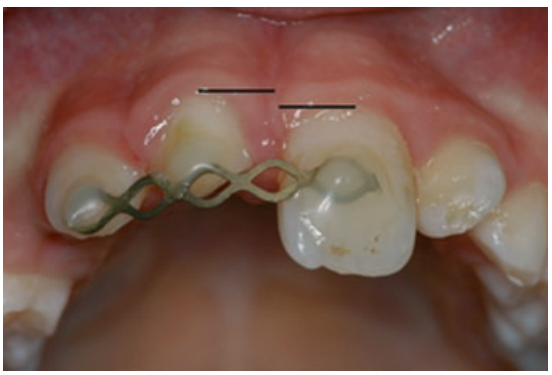

Fig. 25. Same case as in Fig. 24. Situation 3 weeks after transplantation of primary canine 53 into the alveolus of tooth 11. Transplant in infraposition.

Fig. 26. Same case as in Fig. 24. Situation 11 months after transplantation of primary canine. Compensated infraposition.

ment and ART) were performed extraorally without bothering the patient. Very positive were the experiences with the video-headset resulting in a good trance. The device for the nasal application of nitrous oxide hindered the accessibility to the upper front region and was therefore removed after the application of local anesthesia.

Immediate endodontic treatment and elongation of autologous root by titanium post

Primary canines at the time of transplantation are mature, the root development is completed. Thus revascularization cannot be expected (26) and a root canal treatment is necessary to prevent the establishment of an endodontic infection which causes infection-related resorptions and early tooth loss. The root of a primary canine to be transplanted may be very short due to physiologic resorption. The insertion of titanium posts from a retrograde direction offers two advantages: the immediate endodontic seal prevents the microbial contamination of the endodontium. Thus the trigger for infection-related resorption falls sideways (19, 24, 25, 27). The apical elongation of the autologous root shifts the fulcrum more apically and thus stabilizes the transplant (19, 24, 25, 27). Normal mobility can be

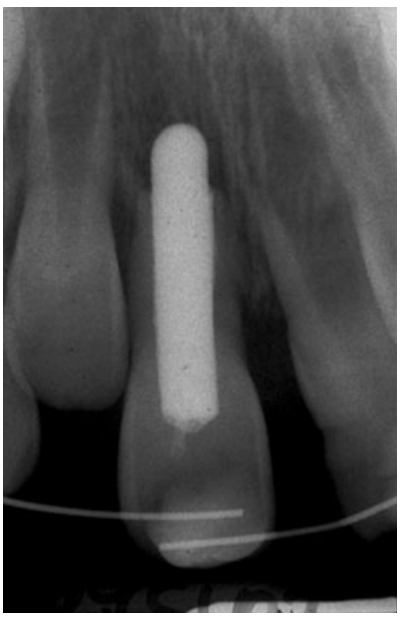

Fig. 27. Same case as in Fig. 24. Situation immediately after replantation of the avulsed tooth 11 that had been rescued in unphysiologic conditions. Developing tooth 12 in a 'risky' position with a potential for resorbing the root of a possible transplant. Therefore, replantation of 'hopeless' tooth 11 as an intermediate solution, thus maintaining the width of the alveolar process in order to facilitate the following transplantation. Further reason for a delayed transplantation was the root fracture of tooth 21. The replantation of tooth 11 with a root perfectly fitting into the alveolus promised better stability for the splint than a transplanted primary canine with a somewhat incongruent root.

Fig. 28. Same case as in Fig. 24. Situation 4 months after replantation. Tooth 12 developing, no hints for infection-related complications at tooth 11.

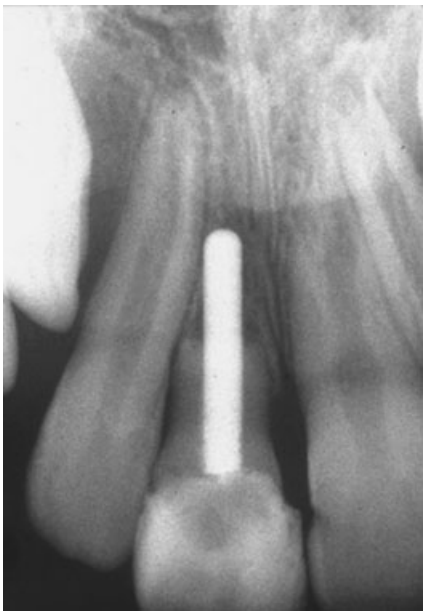

Fig. 29. Same case as in Fig. 24. Situation 11 months after replantation and immediately after transplantation of primary canine. Crown of tooth 12 no longer in the 'risky' position neighboring the root of the transplant.

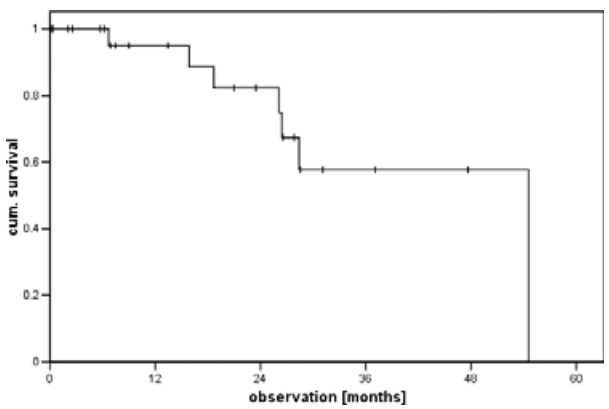

Fig. 30. Survival curve for primary canines transplanted into the region of lost or ankylosed permanent incisors in the upper jaw. All data.

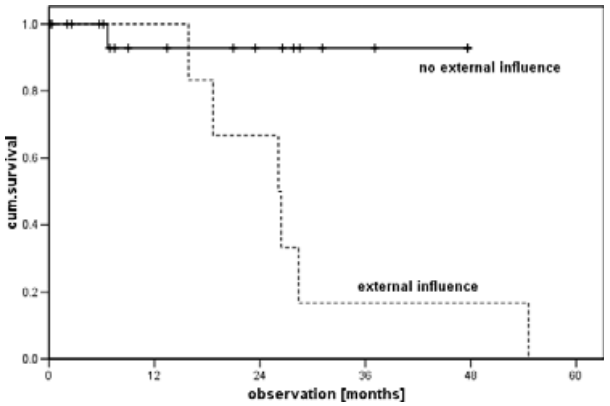

Fig. 31. Survival curve for primary canines transplanted into the region of lost or ankylosed permanent incisors in the upper jaw. Stratified for the occurrence of an external influence resulting in the loss of transplants.

achieved despite the short and thin autologous root substances (Fig. 7). According to experiences with the transplanted primary canines and also with dilacerated (28) and root fractured (29, 30) teeth treated with the same method (retrograde insertion of posts), an autologous root length of just 2–3 mm seems to be sufficient for long-term success. The 'biologic collar' with its dento-gingival fibers is a regular shelter against microorganisms and epithelial downgrowth. The post is separated by dense connective tissue from the bone (24, 25). Thus it does not hinder alveolar growth or orthodontic treatment. Extraoral treatment does not impair periodontal healing to clinically or radiographically detectable levels as no transplant exhibited ankylosis. This corroborates the results of studies on teeth replanted or transplanted with the same method in other indications (27, 28, 30, 31).

The roots of primary canines are resorbed 'asymmetrically'. Resorption affects not only the apex but also the oral aspect of the roots, thus leaving more and longer root substances at the vestibular aspect. If – with the intention of keeping as much autologous root length as possible – the root is not resected perpendicular to the long axis, the resulting oblique plane may force the bur into a para-central direction during the preparation of the root canal. Therefore, it seems sensuous to sacrifice a not resorbed vestibular part of the root up to a more coronal level which is chosen according to the palatally located resorption lacunae.

A conventional root canal treatment seems not possible due to the oblique and asymmetric resorption (Fig. 2). Already the definition of the working length would fail and a lateral perforation of the root canal might occur. It cannot afford an elongation of partially resorbed roots (Fig. 1). There is a high risk of the establishment of endodontic infections and infection-related complications which cannot be treated with predictable success (27).

Choice of donor tooth

The choice of the transplant depends on several considerations. Upper primary canines normally have a higher mesio-distal width than lower primary canines, thus promising better esthetics, especially when replacing central permanent incisors of the upper jaw. If upper primary canines are chosen there are wounds only in one region or jaw. The asymmetric physiologic resorption is more pronounced in upper primary canines and therefore also the misjudgment from the preoperative radiograph concerning the usable root length. However, with the method of elongating the autologous roots by the insertion of posts this is of little clinical relevance as long as an autologous root length of about 3 mm can be kept. From the few experiences

with lower primary canines there is the impression that they have a more straight root with a more round root canal which is easier to prepare. Recent investigations revealed that persistent primary canines of the lower jaw merely exhibited resorptions while primary canines of the upper jaw were resorbed to some extent even if a successor was absent (32, 33). Thus it is now intended to use more often primary canines from the lower jaw. Further studies are needed to clarify resorption patterns and esthetic results.

Healing and healing complications

Sixteen out of seventeen transplants exhibited functional healing at the end of the observation or until the occurrence of an external influence (another trauma, resorption by neighbored tooth). In no case was ankylosis recorded. The damage in the PDL caused by the treatment – extraction, extraoral storage, insertion of posts – must have been so little that healing is not impaired.

In one transplant an early infection-related complication was observed. Infection-related complications are caused by microorganisms. As a first etiology, microorganisms from the sulcus might enter patent dentinal tubules from the periodontal aspect and cause a 'periodontal infection root resorption' (34), resulting for example in a cervical resorption. The little root substances of transplanted primary canines may be resorbed very soon. A second etiology is that a primarily infection-free resorption (healing-related resorption, ankylosis-related resorption or a kind of physiologic resorption related to primary canines) may progress and reach the sulcus and thus acquire contact with microorganisms. Such an observation was reported on permanent incisors that showed a complete replacement resorption before a cervically or intracoronally located infection-related resorption started after an observation period of more than 14 months (27). In those cases permanent incisors with a complete root had been avulsed and replanted. In the actual case the root was described as 'largely resorbed' in the patient's record and the length of the autologous root was recorded as just 2–3 mm. Thus a contact to the sulcus is likely to occur much faster in transplanted primary canines. However, infection-related complications are mostly of endodontic origin. This implies an incomplete preparation of the root canal and left necrotic pulp tissues which are related to the complication (35) or might indicate an insufficient cementation of the post. From the localization of the resorption lacuna in the radiograph 10 weeks after transplantation it must be assumed that this third etiology was the reason for the infection-related resorption in the presented case. However, this seems to be a rare observation with the extraoral insertion of posts, as indicated by the present study (1 out of 17 cases) and plantations in other indications (27, 28, 30, 31).

The root of one transplant was resorbed by the neighbored developing permanent canine. Till then it exhibited functional healing. Traumatized teeth (= planted teeth) seem to be prone to resorptions by neighbored teeth (36). In the present study only one primary canine was transplanted into the region of a lateral incisor, and no calculations with respect to risk can be performed. To prevent such a risk it may be to temporarily store extracted primary canines by cryopreservation (37–40) until the permanent canines have reached 'riskless' positions. If a central incisor shall be replaced by a primary canine and if the position of lateral incisor could represent a risk for resorption, a delayed transplantation after the eruption of the lateral incisor can be performed. The intermediate replantation of a 'hopeless' avulsed permanent incisor will result in an ankylosis but maintains the width of the alveolus and facilitates later transplantation (Figs 27–29). Prerequisite is a high certainty that no infection-related complications establish and result in the destruction of tissues. An immediate extraoral endodontic treatment should therefore be performed (27, 31).

In several cases there were some resorptions not related to complications (infection or ankylosis). The roots were 'rounded' at the edges of the resection plane. In few cases the resorptions progressed and left only minimal cervical parts of the autologous root, however without any clinical or radiographic hints for any complications. These resorptions might represent a kind of physiologic resorption related to primary teeth. In a recent investigation persistent primary canines showed complication-free resorptions of the root despite the absence of a succeeding permanent canine (32, 33). Nevertheless these primary canines were stable and in normal function in patients with an age of up to 70 years. Being *in situ* without any complications at this age the progression of the resorptions must have started very late, must have stopped or extremely slowed down. However, that study was a cross-sectional study, and no reliable conclusions can be drawn concerning the prognosis and survival of persistent primary teeth or the progression of resorptions. Transplanting a tooth inflicts certain damage to the PDL. This might initiate and/or accelerate resorptions. The continuation of the study must reveal whether resorptions in transplanted primary canines stop or progress until contact with the sulcus results in a secondary infection and the loss of the transplant.

Complications after new trauma

In relation to another trauma five transplants were lost. Two were lost because of avulsion or fracture, three exhibited infection-related complications several weeks to months after the new traumas which had resulted in the fracture of the inserted ceramic post or loosening and dislocation of the transplants. The trauma might have resulted in infractions of the tooth crown or root, thus enabling access to microorganisms. The trauma may have initiated progressive resorptions which may have reached contact to microorganisms located in the sulcus. The marginal periodontium may have been destructed, opening pathways for microorganisms from the sulcus which might cause a 'periodontal infection root resorption'. The little autologous root substances of the transplanted primary canines, sometimes just 2–3 mm in length, could be rapidly resorbed.

Careful extraction and ART

By extraction a certain damage to the periodontium has to be assumed, leading to cell death and the release of toxic breakdown products. When kept in the periodontium they may damage further tissues. Injured and damaged tissues initiate a nonspecific inflammatory response which is initially directed to remove the damaged tissues and to repair rather than to regenerate and re-establish tissue with specific function. It is assumed that the inflammatory reaction itself causes additional damage to the tissues (41). The resulting effective damage is much higher than the initial damage, and a higher rate of complications (namely resorption and ankylosis) is likely. A careful extraction and a special treatment of the root surface are intended to reduce the damage and therefore optimize the healing prognosis.

In some cases a special treatment (ART: Emdogain®, glucocorticoid, tetracyclin, doxycyclin) was applied to enhance the periodontal healing. The statistical analysis of the (limited number) of the present cases revealed no significant influence of ART. A similar observation was reported when avulsed teeth were immediately stored in optimal conditions (tooth rescue box). Independent of the use of ART all cases exhibited functional healing. In contrast, avulsed teeth that were damaged but not in hopeless conditions (limited unphysiologic rescue) seemed to profit from ART (22). It is concluded that the damage that is inflicted by the extraction and/or the extraoral endodontic treatment upon the PDL of primary canines is that minimal that additional efforts enhancing healing are not necessary.

However, all transplants underwent a 'minimal therapy of the PDL' comprising rinsing, storage in tissue culture medium, non-rigid splinting. It remains speculative whether transplantations without these methods would give alternative results. However, several publications support the theory that a certain 'reconditioning' (including washing off bacteria and toxic breakdown products) results in less healing complications (42–46). Immature premolar transplants showed diverse resorption types in 14% when transplanted immediately but only in 3% when stored for 30 min before transplantation (44). Others (42, 43, 45–47) report similar observations in clinical and animal studies. They are thoroughly discussed elsewhere (22, 48).

Loss and survival

The loss rate of the transplants was high (7 out of 17). However, only one transplant was lost due to a healing complication (infection-related resorption) that was not related to an external reason. The other six lost transplants showed functional healing up to the occurrence of external influences. The transplant in the position of a lateral upper incisor was resorbed by the developing permanent canine. Most of the losses (5 out of 7) occurred following one or more severe traumas that affected the transplants. The occurrence of an external event was the single predictor for tooth loss and reduced survival that could be statistically proved. Whether there were additional traumas which were minor and which were judged by the patients to be not treatable or not worth presenting remains unknown.

The incidence of repeated severe traumas within quite short observation periods was high. It is known that age is a predictor of multiple trauma episodes: the younger the children at the time of the first trauma the higher the risk and the shorter the periods until the next traumas occur (49). Primary canines are only suitable for transplantation in young children, and the median age of the patients was 8.8 years at the time of transplantation. The original trauma that finally resulted in the loss of an incisor and the consecutive transplantation occurred at the age of 8.0 years. Children who undergo transplantations of primary canines after trauma-related tooth loss are young and therefore at a special risk of suffering from one or more additional traumas which threaten the survival of the transplants. The current but unproved strategies comprise information of patients and parents (including recommendation of mouth guards in certain sports) and the application of permanent splints at the palatal aspect (Fig. 14) as an attempt to provide some protection.

Conclusion

The transplantation of primary canines to replace lost or ankylosed upper incisors results in high rates of functional healing, thus maintaining and even regenerating bone and soft tissues and enabling the progress of the alveolar growth. The treatment is easy if the alveolus of the lost tooth is still intact. The extraoral insertion of titanium posts provides an immediate and definite endodontic treatment, the projecting part of the post elongates the sometimes already physiologically resorbed roots and enables an acceptable stability. The treatment is well accepted by young patients and their parents. Losses of transplants are mainly related to external reasons, predominantly to additional traumas. Future studies should focus on complication-free but progressing resorptions.

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