

## ORIGINAL ARTICLE

# An evaluation of 910 premolars transplanted in the anterior region—A retrospective analysis of survival, success, and complications

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## Abstract

**Aim:** The aim this retrospective analysis was to evaluate the survival, success and possible complications of transplanted premolars to the anterior region subdivided in development stage and patient's age.

**Materials and Methods:** The material comprised patients that underwent a tooth transplantation between April 2004 and December 2021. A total of 910 premolars were transplanted in 707 patients. Tooth mobility, oral hygiene, and periodontal parameters were clinically evaluated. Standardized radiographs were used to evaluate pulpal and periodontal healing and root formation. The cumulative survival rate was calculated using the Kaplan–Meier method.

**Results:** The data were subdivided in three groups based on the stage of root development and patient's age. The average age at surgery was 16 years. The main indication for transplantation was trauma, followed by agenesis and other indications. Two premolars were lost during the whole observation period. The overall survival and success in the immature premolars group after an observation period of 10 years was 99.8%. The 10-year survival and success rate when fully developed premolars were transplanted in the anterior region in adolescents were 100% and 96.3%, respectively. In adults, the 10-year survival and success rate were 87.5%.

**Conclusion:** Transplantation of premolars with developing and fully developed roots to the anterior region in children, adolescents, and adults is a predictable treatment modality.

## KEYWORDS

autotransplantation, dental trauma, missing teeth, tooth agenesis

## 1 | INTRODUCTION

The clinical management of traumatic dental injuries represents one of the most challenging problems in dentistry. Most traumatic dental

injuries occur in children and adolescents and the anterior maxilla is the primary site for such injuries.<sup>1–3</sup> It has been estimated that 70%–90% of all traumatic dental injuries take place before the age of 19 years and the incidence of trauma reaches its peak between 8

and 12 years.<sup>1-4</sup> Around 8% of these injuries leads to tooth loss due to unfavourable crown root or root fracture or due to the fact that an avulsed tooth cannot be replanted, or a replanted tooth develops progressive root resorption.<sup>2</sup>

If left untreated, early tooth loss in the anterior maxilla leads to a collapse of the alveolar bone along with changes in the craniofacial growth.<sup>5,6</sup> The resulting defect makes the replacement of the missing tooth difficult once the patient is fully grown, meaning that the patient will most likely require a complicated and costly treatment with unpredictable success. Additionally, it has been shown that school-age children with a visible untreated dental injury are more likely to experience a reduction in their quality of life compared to those who either have sustained injury but have been treated or those who have never had such an injury.<sup>7</sup>

Next to traumatized teeth that cannot be maintained, congenitally missing teeth, teeth with developmental abnormalities such as dilaceration or impacted or ectopic teeth that cannot be preserved are indications for replacement of teeth in the anterior region.

In children and adolescents, few options exist for the replacement of missing teeth. The following treatment modalities should be evaluated: orthodontic closure, prosthetic fixed appliance (bonded bridge), removable appliance or autotransplantation. Ideally, the substitute should adapt with the growth and development in the oral region, restore soft and hard tissues and have potential for long-term survival.<sup>8</sup>

Autotransplantation of premolars is especially suited for the anterior region when they have to be extracted for orthodontic reasons. Due to their root morphology also, atraumatic extraction is technically feasible.<sup>9</sup> In addition, transplantation of premolars to the anterior region can be considered when sacrificing a premolar may solve a major aesthetic and functional problem in the anterior region, while creating a minor problem at the donor site that can be corrected orthodontically.<sup>10</sup> This may be the case especially in adult patients with large bone and soft tissue defects in the anterior region as result of trauma. Such large defects make other treatment options, such as implantology, complicated, costly, and less predictable.

Several studies have shown premolar transplantation to the anterior region to be a very reliable procedure, surpassing most other treatment alternatives regarding its long-term prognosis.<sup>9,11-18</sup> In addition, a study of transplantation of premolars to the maxillary incisor area, with a mean observation period of 4 years, has reported no clinically or radiographically detectable difference between transplants and adjacent teeth.<sup>18</sup> The aesthetic result, from the patient's and dentist's point of view, is considered very satisfying.<sup>17</sup> However, the sample size of the available studies is limited. The aim of this retrospective analysis was to evaluate the survival, success, and possible complications of a large number of transplanted premolars to the anterior region subdivided in development stage and patient's age.

## 2 | MATERIALS AND METHODS

### 2.1 | Source of data and participants

This is an observational retrospective analysis. For the preparation of this manuscript the checklists for reporting items specific to observational studies using routinely collected health data (STROBE and RECORD) were used.<sup>19</sup>

The patient population of this retrospective analysis comprised patients who were referred from multiple orthodontic, paediatric, and general practices in a period of 17 years between April 1, 2004 and December 31, 2021, to a clinic specialized in periodontology in Rotterdam, The Netherlands. The patients had to be in good general health at the time of surgery (i.e., not suffering from any disease that might influence post-operative healing) and had not suffered from a new traumatic dental injury affecting the transplanted tooth during the observation period.

All procedures performed in relation to the treatment of patients were in accordance with the 1964 Helsinki Declaration and its later amendments. The obtained data were anonymized and as a consequence de-identified irreversibly. Thereby, it was made impossible to reveal any information that could be traced back to one specific individual. Patients had in advance provided permission that data related to their treatment could anonymously be used for further analysis.

The workflow used in these patients was a modification of what in 1990 Andreasen et al. introduced based on indication, development stage of donor tooth, and recipient tooth site.

A detailed description of the pre-surgical, surgical and follow-up phase can be found in the supplement as well as in our previous published paper<sup>20</sup>

The only addition to the previous described protocol is that from 2015 onward, during the 6-week follow-up visit, all transplanted premolars were restored to their recipient tooth morphology using a composite resin build-up. This restoration was performed before subjecting the teeth to orthodontic loading. The composite resin build-up was following the orientation of the root and the angulation of the crown to the root. Neither the reshaping of the transplanted premolars was performed nor was the palatal cusp ground or altered in shape. The position of the tooth would further be corrected by the orthodontic movement.

### 2.2 | Data collection

Demographic data of the patients such as gender, age, and smoking habits were extracted from patient records including the following variables:

1. Donor tooth
  - Tooth type
  - Stage of root development using Moorrees et al.<sup>21</sup> staging
  - Number of roots

2. Recipient site
  - Position of recipient site
  - Presence or absence of peri-apical or periodontal inflammation
  - Presence or absence of predecessor
3. Endodontic treatment timing: pre-operatively or post-operatively.
4. Cause of tooth loss.
5. Antibiotic coverage, timing and type of antibiotics used.

The healing response was evaluated based on both clinical and radiographic assessments, which included:

1. Clinical parameters
  - Probing pocket depth.
  - Bleeding on probing.
  - Tooth mobility/percussion sound (absence of tooth mobility and/or high metallic percussion sound was considered indicative of ankylosis).
2. Radiographic assessment
  - Formation of a periodontal ligament space and intact lamina dura surrounding the entire root periphery. Loss of lamina dura or widening of the peri-radicular space were indicative of unfavourable healing. Any signs of ankylosis and/or related replacement resorption were recorded as unfavourable healing. Surface resorption, repair-related or infection-related (inflammatory) that had been treated effectively with endodontic treatment was considered favourable.
  - (partial) Pulp canal obliteration or continued root formation. Pulpal inflammation and necrosis were considered to have occurred when transplanted teeth presented with a periapical radiolucency or resorption. If no signs of obliteration were observed the apical zone was closely monitored for signs of periapical radiolucency and clinically signs of inflammation. Pulp canal obliteration was recorded according to the classification of Jacobsen and Kerekes (1977).<sup>22</sup>

Success of the transplantation was evaluated using the following criteria:

- Teeth with immature root formation showing a completed root formation following transplantation.
- Successful endodontic treatment performed in immature teeth with pulpal necrosis after transplantation or in teeth with complete root development.
- Favourable periodontal healing with absence of deep pockets and normal tooth mobility.
- In case of root resorption whether the resorption was effectively treated and controlled.

## 2.3 | Data management and statistical analysis

Data were transferred to SPSS (Version 25; IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM

Corp.) for statistical analysis. Descriptive analysis including means and ranges was computed. The cumulative survival rate was calculated using the Kaplan–Meier method. In order to present the collected data in a comprehensible way, the data was subdivided in three groups. Firstly, the division was based on the stage of root development being either incomplete (up to Moorrees Stage 6) (immature group, IMRD) or completed root formation (Moorrees Stage 7) (mature group, MRD). Subsequently, the mature group was subdivided based on patient's age in a group below 18 years of age (MRD <18y) and a group of 18 years of age or older (MRD ≥18y). The results were considered statistically significant at a *p*-value <.05.

## 3 | RESULTS

A total of 910 premolars were transplanted during a period of 17 years to the anterior region in 707 patients (Table 1). Fourteen patients were excluded from the analysis of which seven patients did not comply with the post-operative protocol, four patients had a traumatic injury to the transplanted tooth and three patients did not provide permission to use their data. The average patient's age was 16 years with a range of 8.8–59.7 years. 56.5% of the patients were male. 1.1% of the patients were smokers; 1.2% in the MRD <18y group and 4.1% in the MRD ≥18y group, respectively.

The main indication for transplantation was trauma (*n*=721) followed by agenesis (*n*=148) and various other indications, that is, impacted or malformed teeth (*n*=41). At most recipient sites a predecessor was present (*n*=605). According to the criteria by Moorrees et al. (1963)<sup>21</sup> 493 premolars (54.2%) had an open apex, while 417 premolars (45.8%) had fully developed roots (Moorrees Stage 7). Of the 417 premolars with completed root formation, 247 premolars were transplanted in the MRD <18y group and 170 premolars were transplanted in the MRD ≥18y group.

### 3.1 | Donor teeth

In all three groups the upper second premolar was the most used donor tooth with a range of 31.8%–45.1% (Table 2). First upper and lower premolars were the least frequently used donor teeth. Most predominant were Moorrees Stage 4 (46.9%) and Stage 5 (42.6%) of root development. In case of donor teeth with fully developed roots (Moorrees Stage 7), in most of the cases the endodontic treatment was performed before transplantation.

### 3.2 | Recipient sites

Table 3 presents the distribution of recipient sites. The most frequent recipient site for all groups was the maxillary central incisor (89.5%, 76.5%, and 77.6%, respectively), followed by the maxillary lateral incisor (7.5%, 16.6%, and 12.9%, respectively).

TABLE 1 Total number of transplanted premolars to the anterior region from 2004 to 2022 and subdivided three groups based on root development and age.

	N	Mean age (range)	Gender	Smoking (%)	Indication			Recipient site		
					Agensis	Trauma	Other	Tooth present	Edentulous	Impacted tooth
Anterior	910	16 years (8.8–59.7 years)	♀43.5%; ♂56.5%	1.1	148	721	41	601	297	12
Immature	493	11.8 years (8.8–15.9 years)	♀41.4%; ♂58.6%	0	71	410	12	362	123	8
MRD <18y	247	15.1 years (10.5–18 years)	♀36.0%; ♂64.0%	1.2	56	179	12	154	90	3
MRD ≥18y	170	29.8 years (18–59.7 years)	♀60.6%; ♂39.4%	4.1	21	132	17	85	84	1

TABLE 2 Donor teeth to the anterior presented based on root development stage and age group.

	Donor teeth		Root development Moorrees stage							Endodontic treatment before transplantation	Endodontic treatment after transplantation						
	Total	IMRD	14	15	24	25	34	35	44			45	3	4	5	6	7
MRD <18y	247	3 (1.2%)	110 (44.5%)	2 (0.8%)	99 (40.1%)	2 (0.8%)	9 (3.6%)	2 (0.8%)	20 (8.1%)	NA	NA	NA	NA	NA	97.2%	2.8%	
MRD ≥18y	170	1 (0.6%)	54 (31.8%)	1 (0.6%)	59 (34.7%)	5 (2.9%)	23 (13.5%)	3 (1.8%)	24 (14.1%)	45 (9.1%)	0.2%	46.9%	42.6%	10.3%	NA	98.8%	1.2%

Abbreviation: NA, not applicable.

**TABLE 3** Location of the recipient site to the anterior presented based on root development stage and age group.

	N	Location recipient site				
		Incisors			Cuspids	
		Upper		Lower	Upper	Lower
		Central	Lateral			
Immature	493	441 (89.5%)	37 (7.5%)	3 (0.6%)	11 (2.2%)	1 (0.2%)
MRD <18y	247	189 (76.5%)	41 (16.6%)	2 (0.8%)	14 (5.7%)	1 (0.4%)
MRD ≥18y	170	132 (77.6%)	22 (12.9%)	2 (1.2%)	13 (7.6%)	1 (0.6%)
Total	910	762 (83.7%)	100 (11%)	7 (0.8%)	38 (4.2%)	3 (0.3%)

### 3.3 | Failures

[Table 4](#) presents a detailed overview of the failed transplants. In total two transplants were lost during the observation period. One transplant was lost in the immature group because of poor oral hygiene and non-compliance to the post-operative control protocol, and one transplant was lost in the MRD ≥18y group due to progressive external cervical root resorption. Both were replaced successfully by another transplant.

### 3.4 | Complications

The complications can be divided into endodontic and periodontal complications.

### 3.5 | Endodontic complications

Endodontic complications after transplantation were observed only in the immature group (IMRD) ([Table 5](#)). Inflammatory root resorption, due to disturbed revascularization, was observed only once (0.2%) in a transplant with Moorrees 5 root development, 6 months after transplantation. Endodontic treatment resulted in resolution of the inflammation, repair of the root surface and further uneventful healing.

Apical inflammation, being the result of an infected necrotic pulp, was observed in 26 transplants (0.5%), 2.1–139.1 months after transplantation ([Table 5](#)). The majority of the transplants with apical inflammation had Moorrees 5 root development at the time of transplantation. All cases were successfully managed with endodontic treatment.

When antibiotic prophylaxis was prescribed 1h before transplantation, as proposed by Andreasen et al. (1990), the percentage of complications in the endodontic healing was reduced from 14.7% without antibiotic prophylaxis to 3.3% in cases of prophylactic use of antibiotics. The highest reduction was observed in donor teeth with Moorrees 5 and 6 root development (20.9% without antibiotic prophylaxis vs. 4.1% after use of antibiotics) ([Table 6](#)).

No endodontic complications were observed in the MRD groups.

### 3.6 | Periodontal complications

Periodontal complications, defined as severe damage to the periodontal membrane leading to ankylosis, are presented in [Table 7](#). Ankylosis was determined by radiographical loss of lamina dura and clinically by very limited or absent tooth mobility and a “high metallic” percussive sound. In some cases, infra-position was also observed.

In all cases with periodontal complications the timepoint of diagnosis was within the first year after transplantation (between 36 and 361 days after transplantation). Insufficient or delayed orthodontic loading was the primary cause of periodontal membrane distortion, followed by disturbed periodontal healing and surgical trauma. Periodontal complications were observed in all groups. In total, 22 cases were observed (2.4%) of which one in the IMDR group, nine in the MRD <18y group and 12 in the MRD ≥18y group (0.2%, 3.6%, and 7%, respectively).

Of the 22 premolars, 19 premolars were carefully luxated, while in three cases no luxation was performed. As described by Biederman,<sup>23</sup> the ankylotic tooth was carefully luxated in order to break the bony bridge between the root surface and alveolar bone in the ankylotic area. The tooth was grasped firmly by forceps and moved bucco-lingually and mesio-distally with the axis of the movement being the apex, as not to impair the apical nutrient vessels, in case of vital teeth. Immediately after luxation orthodontic forces were applied and reactivated every 7 days afterward to prevent re-ankylosis. In seven cases luxation resulted in normal mobility afterward. Radiographically, a normal periodontal ligament space was observed. In 11 cases, luxation was not successful and permanent ankylosis and replacement root resorption was observed (1.2% of all transplants and 1.2% in the MRD <18y group and 4.7% in the MRD ≥18y group).

### 3.7 | Survival and success analysis

The follow-up period was 10 years ([Figure 1](#)). A total of 667 transplants were available for analysis after 1 year (371 in the IMRB group, 163 in MRD <18y group and 132 in the MRD ≥18y group, respectively). After 3 years 282 transplants were available for analysis (177, 51 and 54 in each group, respectively), while after 5 years, 96 transplants were available (59, 18, and 19 in each group, respectively).

TABLE 4 Autotransplants placed in anterior lost presented based on root development stage and age group.

Autotransplant failures												
	Gender	Age at transplantation	Smoking	Indication	Donor tooth	Moorrees	Recipient site	Type recipient	Antibiotics	Tooth removal	Survival	Reason for tooth loss
Immature	f	10years 9 months	No	Trauma	15	4	1	Edentulous	Post-transplantation	01/25/2018	7 months 1 week	Insufficient oral hygiene: not following recall program
MRD ≥18y	f	18 years	No	Trauma	15	Endo before transplantation	11	Edentulous	Post-transplantation	02/10/2022	6 years 2 months	External cervical root resorption

After 10 years, 11 transplants were available for analysis (7, 2, and 2 in each group, respectively). For the analysis the Kaplan–Meier test was used.

Figure 2 presents the survival and success analysis of the premolars with developing roots (IMRD group) In total 493 premolars were available for analysis. Twenty-eight premolars presented with complications, while one premolar was lost in the first year after transplantation (7 months after transplantation). The overall survival and success in this group after an observation period of 10 years was 99.8%.

In the MRD <18y group, 247 premolars were available for analysis (Figure 3). Over a period of 10 years, no premolar was lost. Nine complications were observed. Therefore, the survival rate after 10 years was 100%. Success was calculated at 96.3%.

In the MRD ≥18y group, 170 premolars were available for analysis (Figure 4). One premolar was lost 6 years after transplantation. At the 5-year follow-up, the survival was 100%. The survival percentage dropped to 87.5% after 10 years. In total 12 complications were observed. The success rate after 5 years was 95%. After 10 years the success rate was calculated to 87.5%.

#### 4 | DISCUSSION

The present retrospective analysis reports the survival and success rate of 910 premolars with developing or fully developed roots transplanted to the anterior maxilla and mandible in 707 patients. To our knowledge, this is the first paper that reports on such a large number of transplanted premolars to the anterior region. Because of the large sample size, it was feasible to divide the available data based on the patient's age in three groups: premolars with developing roots (IMRD group), fully developed premolars that were transplanted in adolescents (MRD <18y group) and fully developed premolars transplanted in adults (MRD ≥18y group).

The success and survival rates reported in the present retrospective analysis for all groups (IMRD, MRD <18y, MRD ≥18y) are similar or higher to those published in the literature.<sup>11,15,16,24–26</sup> Long-term studies of autotransplanted teeth to the anterior site have shown success rates between 98%–99% within 5 years, 87%–95% within 10 years and 79% within 26.4 years and a single long-term study (33 years) showed a survival rate of 90 percent, a survival rate not exceeded by any other type of tooth replacement (fixed or removable prosthetics, implants).<sup>10</sup>

Of the 910 premolars included in the present retrospective analysis, 493 premolars had developing roots. The overall survival and success in this group after an observation period of 10 years was 99.8%. These high survival and success rates are in accordance with a recent systematic review that reported a survival rate of 96.7% for premolars transplanted to the anterior maxilla.<sup>27</sup>

It is well documented that a high survival and success rate can be achieved with immature premolars. In case of premolars with fully developed roots, a reduced success and survival rate have been reported by some studies.<sup>16,28,29</sup> However, a systematic review

**TABLE 5** Endodontic complications after transplantation as divided by early complications (inflammatory resorption) and late complications (apical inflammation). The endodontic complications were managed with an endodontic treatment after transplantation.

Endodontic complications		N	Management with endodontic treatment after transplantation Mean in months (range)	Patient's age Years	Gender	Root development Moorrees Stage			Tooth loss
Complication	4					5	6		
IMDR	Inflammatory resorption	1 (0.2%)	6 (6–6)	12.2 (12.2–12.2)	♀0% ♂100%	0	1	0	0
	Apical inflammation	26 (0.5%)	35.1 (2.1–139.1)	12.3 (9.7–15.4)	♀38% ♂62%	5	15	6	0

**TABLE 6** Comparison of the effect of antibiotic prophylaxis (implemented to the protocol after June 2016) on the incidence of endodontic complications for transplants with Moorrees Stage 4, 5, 6 of root development and more specifically for transplants with Moorrees Stage 5 and 6 of root development.

Comparison efficacy antibiotic prophylaxis on endodontic healing						
Immature	t	N	Prophylaxis	Complications (N)	Complications (%)	Tooth loss
Moorrees Stage 4, 5, 6	Before June 2016	95	0	14	14.7	0
	After June 2016	398	122	13	3.3	0
Moorrees Stage 5 & 6	Before June 2016	67	0	14	20.9	0
	After June 2016	196	108	8	4.1	0

published in 2014 by Chung et al. concluded that transplantation of teeth with complete root formation can also be a favorable treatment.<sup>30</sup> In the present evaluation, 417 premolars were included with fully developed roots, of which 247 were transplanted in adolescents (MRD <18y group) and 170 in adults (MRD ≥18y group). A high survival and success rate were observed, especially in the MRD <18y group. Our result show that the transplantation of premolars with fully developed roots in adolescents can be as successful as the transplantation of immature teeth. The time of the endodontic treatment (before transplantation), orthodontic loading before transplantation, preferably with an extrusive force, to facilitate a-traumatic extraction, timely orthodontic loading not later than 8 weeks after transplantation, no reshaping of the transplanted tooth at the time of the build-up and a strict post-operative follow-up protocol which allows for timely and appropriate management of complications may account for these findings.

In 2004, Schätzle and co-authors<sup>31</sup> published a study evaluating tooth mortality. They analyzed a database that followed Norwegian middle-class men for 26 years. The teeth were divided in three groups based on the presence and severity of gingival inflammation. Group 1 included teeth with healthy gingival tissues that never bled on probing during the entire study period. Group 2 included teeth with healthy gingival tissues in some examinations and at other examinations showed gingival inflammation. Group 3 included teeth with inflamed gingival tissues at all examination points. The authors calculated the survival rate of teeth based on an approximation of the time of tooth eruption into the oral cavity. The 10-year survival of teeth in Groups 1 and 2 were 100%. Moreover, the 10-year survival

of teeth in Group 3 (i.e., teeth that always had gingival inflammation) was 99%. Furthermore, the authors calculated the 50-year survival of the evaluated teeth and the survival rate for Group 1 to be 99.5%. The 50-year survival rate for teeth in severity Group 2 was also quite high, at 93.8%. On the other hand, the 50-year survival rate for teeth that always presented gingival inflammation was significantly lower, at 63.4%.<sup>31</sup> When these results are compared with the survival rate of transplanted premolars, it can be concluded that successfully transplanted teeth perform similar to non-transplanted teeth.

One of the challenges when transplanting premolars to the anterior region is to create a pleasing color of the crown and width in the cervical area.<sup>28</sup> A too wide or a too narrow cervical width of the crown could make it difficult for the prosthodontist to create the ideal emergence profile to match the contralateral natural tooth. It is speculated that a rotation of 90° of the transplant during surgery may improve the emergence profile aesthetically.<sup>32</sup> However, this may result in a too wide cervical width and consequently to compromised aesthetics. None of the transplanted premolars in the present retrospective analysis were rotated. Czochrowska et al. (2002) also did not rotate the transplanted premolars. They compared 22 reshaped autotransplanted premolars to incisor morphology, with their natural contralaterals.<sup>17</sup> And found that most of the transplanted premolars matched the contralateral incisor and the majority of the patients were satisfied.<sup>17</sup>

In case of donor teeth with developing roots it is important to maintain vitality by not for example insulting the pulp during preparation of the tooth for aesthetic build-up. Any preparation of the tooth should remain in enamel to prevent exposure of the dentinal

TABLE 7 Periodontal complications presented per subgroup and root development.

Periodontal membrane distortion/ankylosis											
Complication	N	Diagnosis after transplantation	Luxation		Luxation after transplantation	Age		Antibiotics		Permanent ankylosis	
			Yes	No		Years	Gender	Yes	No	Yes	No
Immature	1	36 days (36)	1	0	78 days (78–78)	13.8 (13.8–13.8)	♀ 100% ♂ 0%	0	100%	0	0
MRD <18 years	3	39.3 days (35–48)	3	0	83 (79–91)	16.3 (16.3–16.3)	♀ 0% ♂ 100%	67%	33%	0	0
Late/low/improper orthodontic forces	6	191.8 days (91–361)	5	1	373.8 (164–802)	16.5 (14.9–17.4)	♀ 33% ♂ 67%	0	100%	3	0
MRD ≥18 years	4	123.8 days (36–184)	4	0	281.5 (104–503)	26.5 (19.9–42.3)	♀ 50% ♂ 50%	100%	0	2	0
Late/low/improper orthodontic forces	8	73.3 days (42–98)	6	2	150.3 (84–254)	34.6 (18.9–50.4)	♀ 38% ♂ 62%	75%	25%	6	0

<sup>a</sup>Late: Refers to loading of the transplants later than 8 weeks after transplantation. Low/improper orthodontic forces: Indicates forces that are insufficient to stimulate cellular activity within the periodontal ligament (PDL) space or lead to compression and complete occlusion of blood vessels, resulting in cellular death within PDL areas.

<sup>b</sup>Delayed periodontal healing: Implies the occurrence of early pocket formation (within the first 3 weeks after transplantation) and/or severe gingival inflammation.

<sup>c</sup>Surgical trauma: Refers to challenging extractions involving the use of excessive forces.

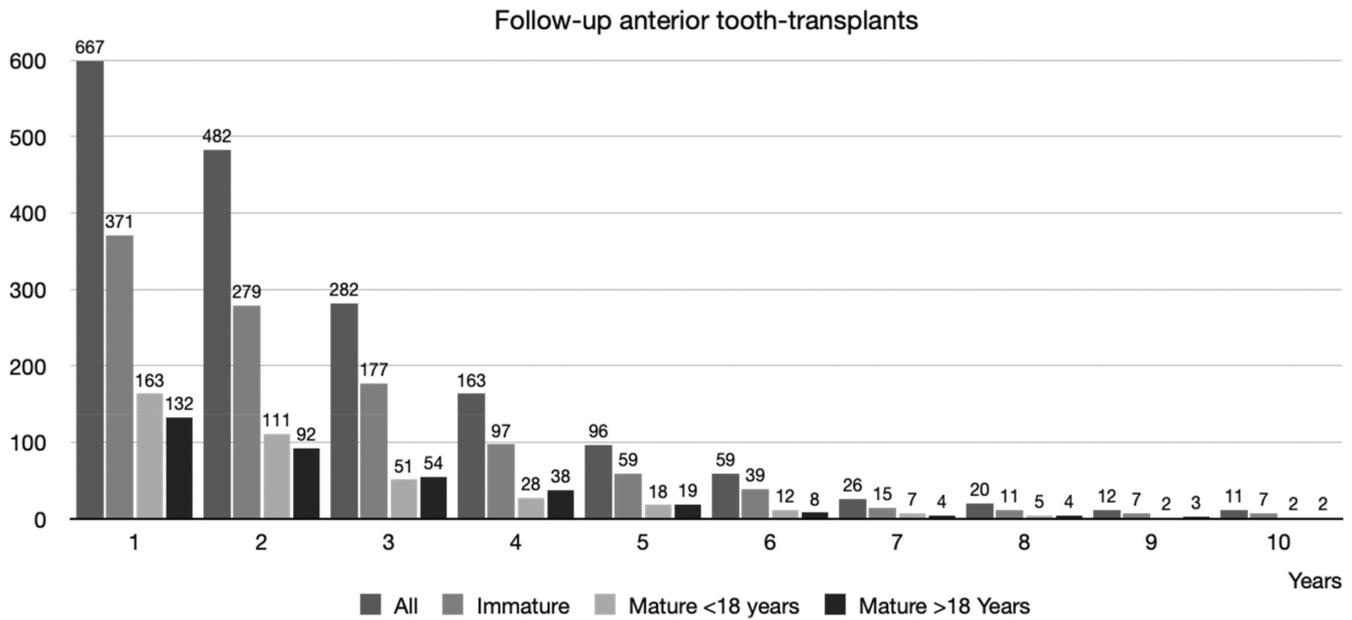
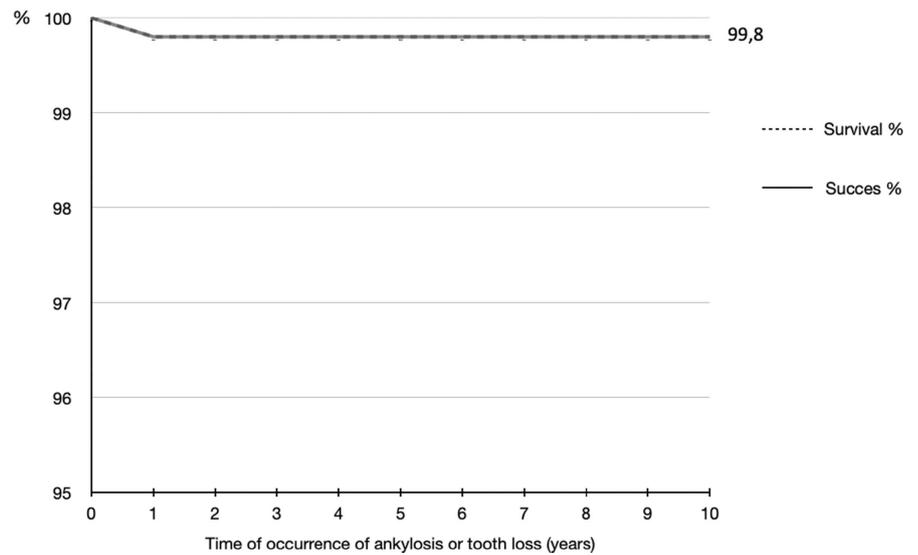


FIGURE 1 Follow-up from 1 year of tooth transplants to the anterior for all and presented based on root development stage and age group.

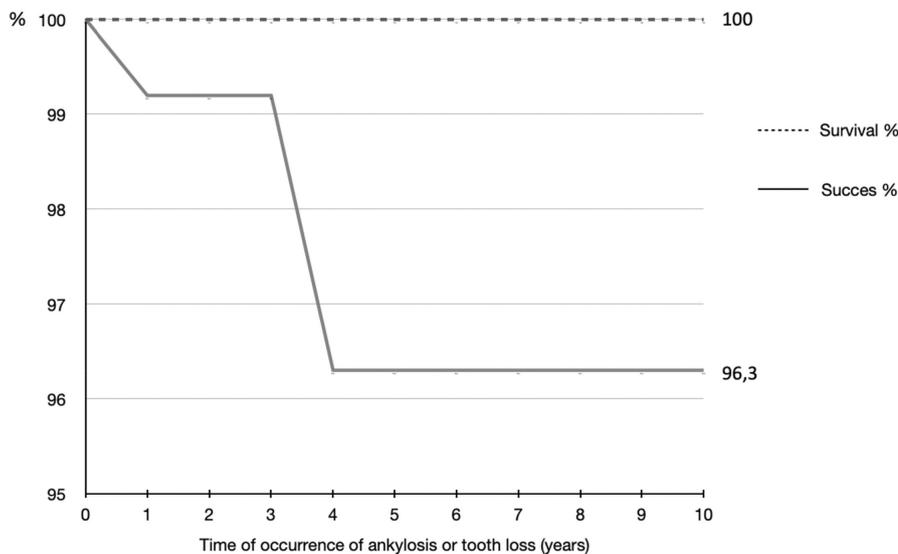
FIGURE 2 Survival and success analysis for immature tooth transplants.



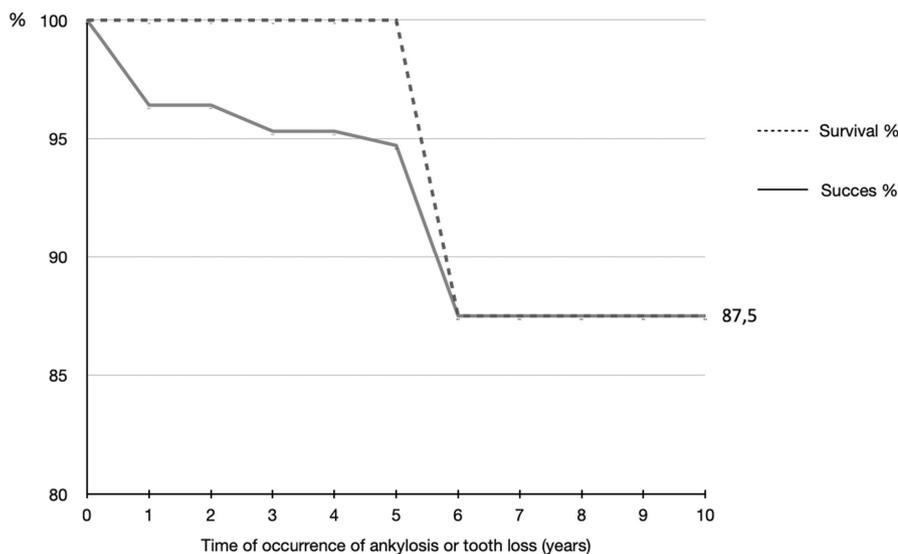
tubules, which would provide a route of ingress of bacteria into the vulnerable pulp. Obviously, a premolar transplanted into a central incisor location will need a cover-up. This is usually achieved with a composite resin facing. The preparation of these teeth, for example for crowns or to reduce a palatal cusp, should be avoided as this can further damage an already vulnerable and healing pulp, which could lead to pulpal necrosis.<sup>33</sup> In a study by Díaz et al. (2008) ten immature lower premolars were transplanted in the anterior maxilla in six patients. Pulp healing was observed in six of ten teeth. The other transplanted teeth developed pulp necrosis and apical inflammation 6–8 months post-operatively (40%).<sup>34</sup> The authors commented that the factors that are most likely to be the cause for the observed pulp necrosis may have been an extensive pressure, heat, and desiccation with diamond and carbide burs during the aesthetic composite resin

build-up. They concluded that dentine exposure may cause bacterial invasion resulting in pulpal inflammation and necrosis.<sup>34</sup> In the abovementioned study a higher percentage of pulp necrosis was reported than the one observed in the present retrospective analysis. Resin build-ups of the transplanted premolars were performed 6 weeks post-operatively and prior to orthodontic loading to provide the orthodontist a good indication of the optimal form in relation to the position of the transplanted tooth in order to facilitate treatment planning of the orthodontic regulation. The transplanted premolars were not re-shaped, nor the palatal cusp was removed or reduced in size, which resulted in an uneventful pulpal healing.

The major advantage of tooth transplantation is the ability to promote alveolar bone development in the recipient site. It is generally presumed that a recipient site with adequate alveolar bone



**FIGURE 3** Survival and success analysis for mature tooth transplants <18 years.



**FIGURE 4** Survival and success analysis for mature tooth transplants ≥18 years.

dimensions is a prerequisite to ensure primary stability of the transplanted tooth and that alveolar ridge augmentation is necessary when the available bone is insufficient and is unable to surround and support the donor tooth with bone.<sup>35,36</sup> However, in a retrospective study evaluating the success of 56 donor teeth transplanted in the anterior maxilla and mandible of 46 patients there was no difference in the success rate of the autotransplantations between the patients who were treated with alveolar bone grafting before autotransplantation or those who did not receive bone augmentations.<sup>37</sup> In the present retrospective analysis, recipient site alveolar bone status was found (prior to or during surgery) to be either sufficient or deficient. In none of the cases bone grafting procedure was performed prior to or during the transplantation procedure. The recipient site alveolar bone status was not found to have an impact on healing (data not shown). Michl et al. (2017) in a prospective clinical case study assessing the vertical changes of peri-transplant tissues in the maxillary anterior region in children and adolescents after premolar transplantation has observed osseointegrative and soft tissue inductive effects of tooth transplantation.<sup>38</sup> In addition,

Plakwicz et al. (2021) in a study comparing the dimensions of the alveolus at the site of autotransplantation with the contralateral unaffected/control site using cone beam computed tomography (CBCT) found no difference in the bone thickness, weight and height of the alveolar process.<sup>39</sup>

Ankylosis and replacement root resorption represent the most severe periodontal complications following tooth transplantation, with the impact of these complications influenced by a size factor. In cases where the damage to the periodontal ligament does not exceed 20% of the radicular surface, this process can be reversible.<sup>40</sup> Animal experiments have shown that defects smaller than 4 mm<sup>2</sup> typically experience complete healing or temporary ankylosis that later undergoes resorption, leading to repair-related root resorption. Conversely, defects larger than 4 mm<sup>2</sup> tend to result in permanent ankylosis.<sup>41</sup> Early diagnosis is essential to determine the optimal timing for interventions, which can potentially reduce morbidity and lead to improved long-term outcomes.<sup>42</sup> One proposed treatment option for managing ankylosis, particularly in its early stages, is surgical luxation of the ankylotic tooth, in order to break the bony bridge

between the root surface and alveolar bone in the ankylotic area.<sup>23</sup> This procedure results to the formation a new fibrous tissue which becomes co-extensive with the periodontal ligament and therefore, effectively restores its continuity and enables further tooth eruption. Luxated teeth should be reactivated every 7 days to prevent re-ankylosis. There is no definition in the literature concerning the amount of preferred force level. Forces must be continuous and kept at an appropriately high level for a prolonged period to maintain the distraction momentum and prevent re-ankylosis.<sup>43</sup> However, it is important to acknowledge that this approach may rarely come with some complications, such as root fracture, especially in case of multi-rooted teeth or pulpal devitalization, if the apical nutrient vessels are torn.<sup>43</sup> The prognosis of this procedure seems to be very good in case of single rooted teeth with spot ankylosis.<sup>44</sup>

Andreasen et al.,<sup>9</sup> Kristerson and Lagerström<sup>15</sup> and Czochrowska et al.<sup>18</sup> reported ankylosis in 14%, 12%, and 4.4% of the transplants, respectively. It has been associated with damage to the periodontal membrane during the surgical procedure.<sup>45</sup> It has also been related the stage of root development.<sup>45</sup> In the study carried out by Kristerson,<sup>46</sup> progressive root resorption was observed in 8% of the teeth with an open apex and in 48% of the teeth with closed apex. The explanation could be that immature teeth are easier to remove with gentle movements to preserve an intact periodontal membrane than fully developed teeth. In the present retrospective analysis root resorption was observed in 2.4% of the transplanted teeth. Ankylosis was observed in 1.2% of the transplanted teeth and none in the IMRD group. The prevalence of root resorption and ankylosis was lower than the percentages reported in a published systematic review and meta-analysis, where the root resorption percentages ranged from 3% to 10% (effect size 4%) and from 4.2% to 18.2% for ankylosis (effect size 4.8%).<sup>47</sup> This outcome could be the result of careful management of the donor tooth during the surgical procedure and good interdisciplinary planning.

In addition, from 2017, fully erupted donor teeth (Moorrees Stage 6 and 7 root development) were additionally pre-loaded by the use of an orthodontic appliance on average 2–4 weeks prior to transplantation. Through this additional loading presumably an increase cell proliferation of the periodontal ligament can be induced to promote healing at the receptor site and ease tooth extraction; both of these outcomes may be beneficial for tooth transplantation.<sup>48</sup>

Despite their low prevalence, resorption, and ankylosis may influence the prognosis of transplanted teeth. However, it should be emphasized that transplantation may involve other benefits in addition to the actual tooth replacement. Most important is the potential for bone induction and re-establishment of a normal alveolar process after traumatic bone loss. Even if the transplant fails at a later stage, an intact recipient area may be preserved or re-established by the transplant and could subsequently be used for another prosthetic solution in adulthood.<sup>18</sup>

One of the limitations of the current analysis is its retrospective design, which inherently imposes certain constraints. A notable drawback is the limited number of subjects who attended follow-up visits beyond 6 years. This limitation arises primarily due to travel

costs and time constraints, particularly since the study population comprised patients from diverse locations across the country. Moreover, some patients, along with their parents or guardians, chose not to continue visiting our clinic for control visits after completing the orthodontic treatment, particularly in cases where they did not experience any complaints or discomfort. However, the large population size included in this cohort does contribute to a robust data set to support statistical analysis.

## 5 | CONCLUSION

Transplantation of premolars in the anterior region to replace one or more missing teeth is a viable biological treatment modality that has the potential to preserve and restore the hard and soft tissues. Transplantations of premolars with fully developed roots had good success and survival rates, similar to those of immature premolars. It should be considered a predictable treatment modality.

### AUTHOR CONTRIBUTIONS

Manfred Leunisse, Edwin Eggink, and Dick Barendregt conceived the idea. Anna Louropoulou, Marcel Linssen, and Dick Barendregt collected the data. Dick Barendregt and Jens Ove Andreasen analyzed the data.

Anna Louropoulou, Fridus van der Weijden, and Dick Barendregt contributed to the writing.

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### CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

### ETHICS STATEMENT

No ethical approval needed for this retrospective analysis.

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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