ORIGINAL ARTICLE

Outcome of tooth transplantation: Survival and success rates 17-41 years posttreatment

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The literature contains no follow-up studies of transplanted teeth with mean observation times exceeding 10 years. This article describes long-term outcomes, including gingival and periodontal conditions, and the patients' attitudes about treatment and outcome. The material comprised all accessible patients in the files of the Department of Orthodontics, University of Oslo, Norway, on whom treatment had been performed at least 17 years ago (n = 28). Established clinical criteria were used to assess tooth mobility, plaque and gingival indexes, and probing pocket depth. Standardized radiography was used to evaluate the presence of pathology, pulp obliteration, and root length. Similar recordings were obtained from the in situ tooth contralateral to the initial position of the grafted tooth. Criteria for determining treatment success were established. All patients responded to questions about their treatment using visual analogue scales. The mean age at surgery was 11.5 years, and the mean observation period was 26.4 years (range, 17-41 years). Of the 33 teeth transplanted in the 28 patients, 3 teeth were lost after 9, 10, and 29 years, respectively. Therefore, the 30 teeth in the 25 patients we examined yielded a survival rate of 90%. The success rate was 79% because 2 transplants had ankylosed, and 2 others failed to fulfill the proposed criteria. The patients generally responded very favorably regarding their perception of the treatment. Their only hesitation was related to some discomfort during surgery. It was concluded that survival and success rates for teeth autotransplanted when the root is partly developed compare favorably in a long-term perspective with other treatment modalities for substituting missing teeth. (Am J Orthod Dentofacial Orthop 2002;121:110-9)

Missing teeth in children are a particular challenge. The replacement should preferably adapt to growth and developmental changes in the oral region. Furthermore, the substitute should have the potential for long-term, even lifelong, survival. In this perspective, few, if any, studies are available.

Of the alternative replacement means, autotransplantation of developing premolars[1,2] is a treatment modality that has received increasing attention in recent years. This is because transplanted teeth also have the capacity for functional adaptation[3,4] and preservation of the alveolar ridge.[5,6] Andreasen et al[7] reported survival rates of more than 90% in a comprehensive study, but only a few of their transplants had an observation period of more than 10 years. So far, Schwartz et al[8] presented the longest mean observation time of 10 years with a range of 1 to 25 years (1 tooth) for transplanted teeth. However, even longer follow-up periods are needed to document the applicability of tooth transplantation for lifelong survival in children and adolescents.

More than 4 decades ago, the method for autotransplantation of immature premolars was developed by Drs Slagsvold and Bjercke,[2-4] and they reported successful results in publications from the University of Oslo about 30 years ago. The files of their patients are still available. Because this material comprises transplantations performed according to a strict protocol, it represents an opportunity for a truly long-term follow-up study of transplanted teeth. The purposes of this study were to evaluate the long-term survival and success rates of transplanted teeth and to compare them with natural in situ teeth. An additional objective was to examine the patients' own assessments of the treatment process and outcome.

MATERIAL

The transplantation files until 1980 (when Dr Slagsvold passed away) comprised 63 patients; of these, 28 persons with a total of 33 transplanted teeth could be found and were willing to participate (44%). Three patients had each lost 1 transplanted tooth before this study. Therefore, 30 transplanted teeth in 25

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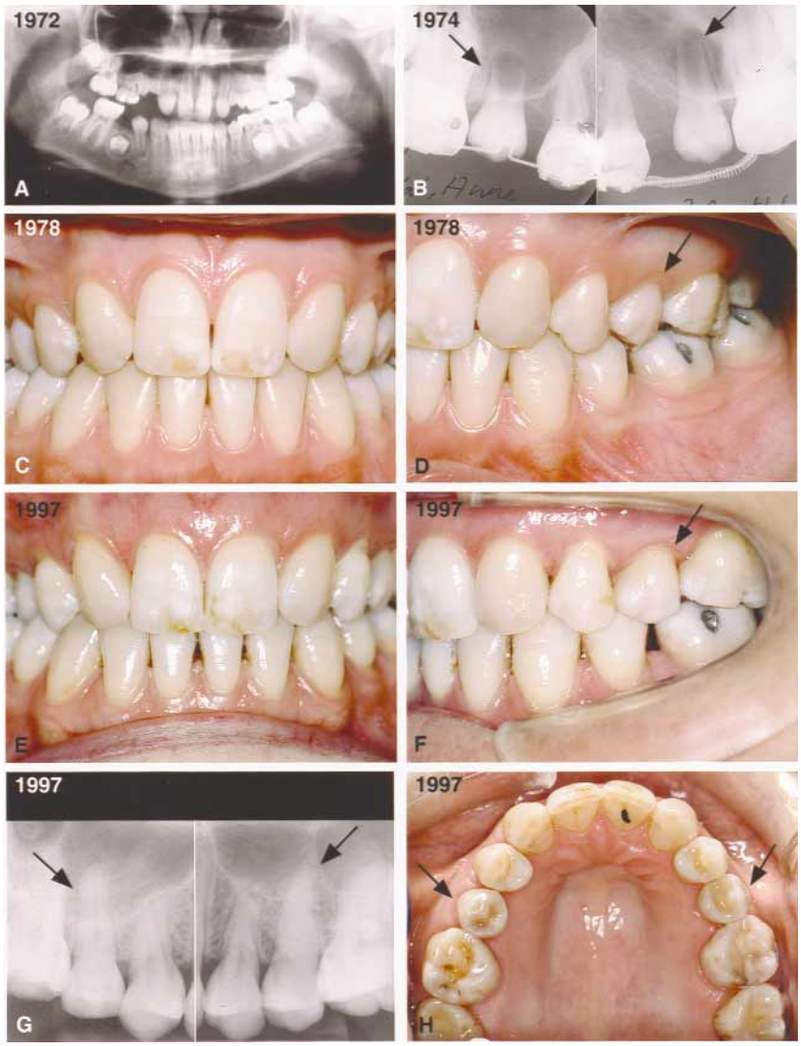


Fig 1. Long-term outcome 23 years after transplantation of 2 mandibular second premolars to maxillary second premolar region in 12-year-old girl. Because of agenesis of 4 teeth in maxilla (both second premolars and both lateral incisors) and none in the mandible (**A**), 2 mandibular second premolars were transplanted to maxilla in 1974 when patient was 12 years old (**B**). Orthodontic space closure was performed with canines replacing lateral incisors (**C, D**). Stability was satisfactory 19 years later (**E, F, H**). Radiographs of transplanted premolars 23 years after operation (*arrows* in **G**) demonstrate normal root length, no sign of apical root resorption, and normal pattern of pulp obliteration in part of root formed before transplantation, but not in part formed afterwards. There is no sign of pathology.

patients were examined. The mean age at the time of surgery was 11.5 years (range, 8-15 years), and the mean postoperative period was 26.4 years (range, 17-41 years).

All operations were performed by Dr Bjercke according to an established protocol.[2] An important step in this procedure was the careful dissection and immediate transfer of the tooth germ to the prepared new socket, preferably with the dental follicle intact. All

Table I. Donor teeth and recipient sites

Tooth	*Donor tooth*	*Recipient site*
Upper central incisor	-	6
Upper lateral incisor	2	3
Upper canine	-	5
Upper premolars	10	7
Lower incisors	-	2
Lower premolars	16	7
Supernumerary teeth	2	-

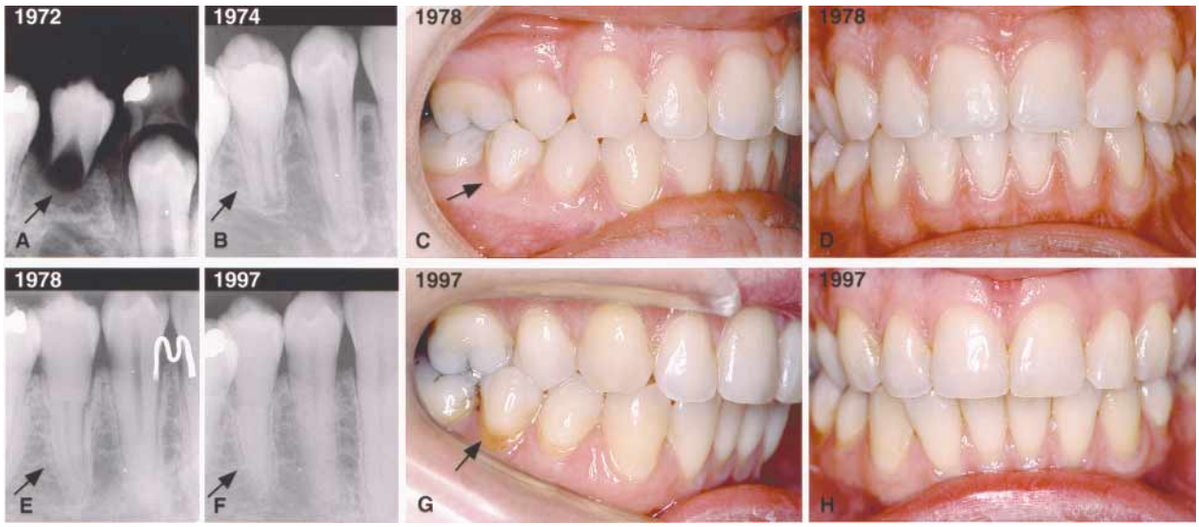


Fig 2. Because of agenesis of mandibular right second premolar in 12-year-old girl, maxillary second premolar in same side was transplanted to mandible in 1972 (*arrow* in **A**). Root development continued (*arrow* in **B**), and eventually root achieved similar length as that of neighboring first premolar (**E**). Intraoral photographs show result in 1978 (**C, D**) and 19 years later (**G, H**) with buccal crossbite of graft (**C**). Note normal radiographic appearance, albeit with some continuation of pulp obliteration (compare **F** with **E**).

teeth were transplanted when the root development was incomplete. No endodontic treatment had been performed. The preoperative positions of the donor teeth and the locations of the recipient sites are given in Table I. Most donors were premolars transplanted in patients with at least 1 tooth missing because of agenesis of premolars (Figs 1, 2, and 3), maxillary lateral incisors, or canines (Figs 3, 4). The remaining transplants replaced teeth lost because of trauma (4 patients), surgical removal due to pathological processes (2 patients), or malformation (1 patient) (Fig 5).

Twenty-two patients had received orthodontic treatment with fixed appliances after the transplantation. Ten transplanted teeth had been fitted with crowns, 3 of which served as abutments for fixed prosthodontic replacements. Ten teeth had amalgam or composite fillings (Fig 3) at the time of examination.

METHODS

All persons were assessed clinically and radiographically by the same examiner (E.M.C.) to determine the success rate. Standardized intraoral photographs and study models were also used for documentation. The transplanted teeth were compared clinically with their in situ, natural teeth contralateral to the donor site when those teeth were present (intraindividual comparisons).

The following variables were recorded for the transplants and the reference teeth: tooth mobility, plaque index, and gingival index. These were scored according to the indexes described by Nyman and Lindhe,[9] Silness and Löe,[10] and Löe and Silness,[11] respectively. Probing pocket depth was recorded at 4 sites for each tooth with a graduated periodontal probe. A percussion test and recording of distinct infraocclusion were included to detect ankylosis.

Standardized intraoral radiography was used to evaluate obliteration of the pulp cavity, general status of the periradicular area, root length, outline of the periodontal membrane, and external root resorption. The crown-to-root ratios of the transplanted teeth were calculated and compared with contralateral crown-to-root ratios.[6] The linear distance between the marginal bone level and the cemento-enamel junction was also recorded for both groups of teeth to assess marginal periodontal attachment loss.

The survival rate is given as the percentage of transplanted teeth still present at the examination relative to the total number of teeth that were transplanted.

The success rate was calculated as the percentage of the transplanted teeth fulfilling defined success criteria relative to the total number of transplants in the sample.

The success criteria were adapted from Schwartz et al,[8] Kristerson and Lagerström,[12] and Kugelberg et al,[13] and

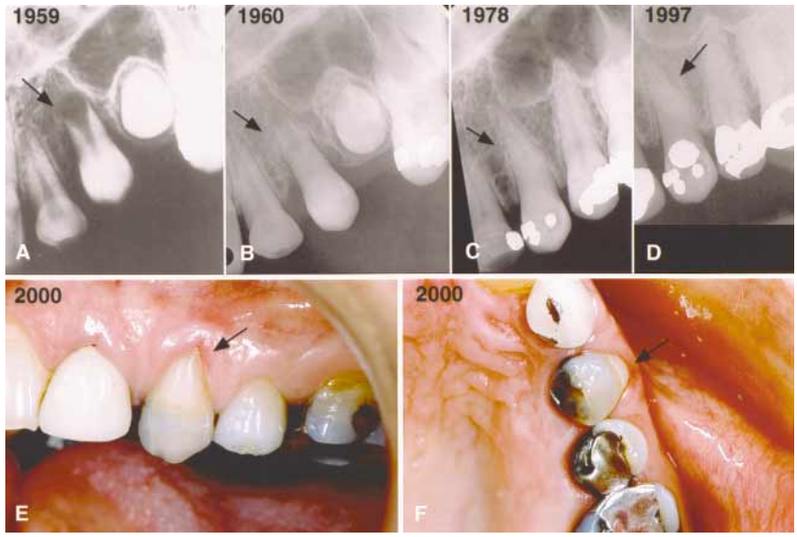


Fig 3. Three missing neighboring teeth in maxillary left quadrant (lateral incisor, canine, first premolar) in 12-year-old girl. Mandibular right first premolar was transplanted to maxillary canine area in 1959 (*arrow* in **A**). Spaces were closed orthodontically, and persisting deciduous left canine was crowned. Continued root development is shown in **B** and **C**, and long-term radiographic appearance 38 years later is shown in **D**. Despite lingual amalgam and buccal composite resin fillings (**E, F**), radiographic and clinical appearance 41 years after operation is uneventful, with no signs of pathology, except some gingival hyperplasia.

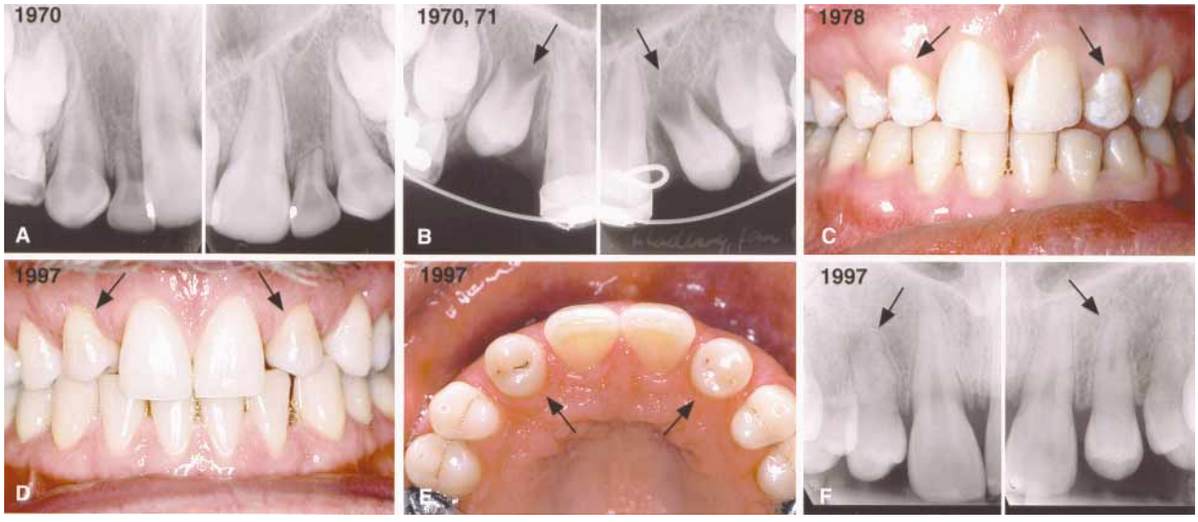


Fig 4. Two mandibular second premolars were transplanted to maxillary anterior region in 1970 and 1971, respectively, to substitute for congenital absence of 4 anterior teeth (**A**). Both right and left canines and lateral incisors were absent. Operations were performed when patient was 11.4 (left side) and 12.0 years old (right side), respectively (**B**). Intraoral photographs show clinical appearance in 1978 (**C**) and 27 years after operation in 1997 (**D-E**). Radiographs in **F** demonstrate usual appearance for autotransplanted premolars and confirm continued root development, with pulpal obliteration in part of tooth that was formed at time of operation, but not afterwards. Root of right premolar is somewhat shorter than that of left transplant (*arrows* in **F**), but crown-to-root ratio is still satisfactory.

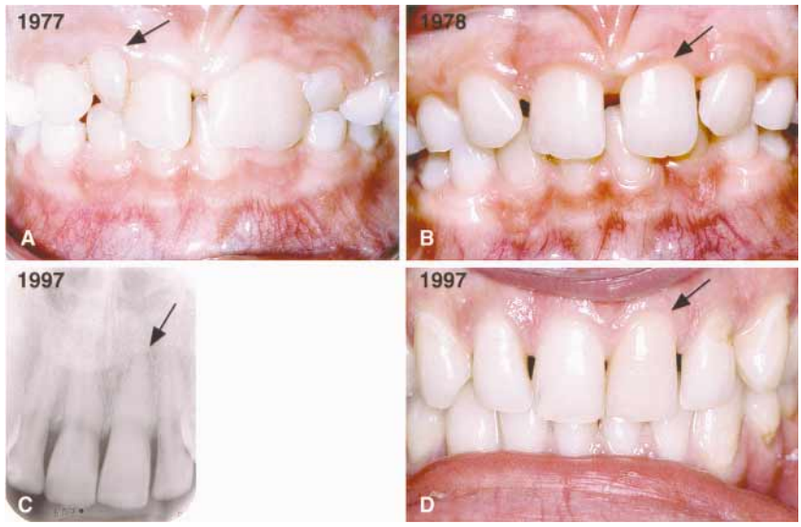


Fig 5. Transplantation in 1977 of supernumerary maxillary right lateral incisor (*arrow* in **A**) to replace malformed (fused) maxillary left central incisor (**A, B**). No orthodontic treatment was performed. Radiograph 20 years after transplantation (**C**) shows normal periradicular appearance and pronounced obliteration of root canal (*arrow* in **C**). Marked obliteration may explain why transplanted incisor (*arrow* in **D**) has more yellowish color than do neighboring incisors.

Table II. Error of method for radiographic measurements (for definition of landmarks, see Czochrowska et al[6])

Measurement	*Dahlberg's calculation*	*Houston's coefficient of reliability (%)*
Transplanted teeth		
Suprabony part	0.19	98
Intrabony part	0.3	99
Anatomic crown	0.21	96
Anatomic root	0.35	97
Control teeth	0.21	96
Suprabony part	0.29	93
Intrabony part	0.6	92
Anatomic crown	0.33	90
Anatomic root	0.4	96

included (1) the absence of progressive root resorption, (2) normal hard and soft periodontal tissues adjacent to the transplanted tooth, and (3) a crown-to-root ratio less than 1 (ie, the suprabony part shorter than the intrabony part).

The Wilcoxon signed rank test was applied to examine the statistical differences between the transplanted and the control teeth for pocket depth and crown-to-root ratios. The marginal homogeneity test was used to test the differences in mobility, plaque, and bleeding index. The level of significance was set at 0.05.

The measurements were repeated twice within 4 weeks by the same observer (E.M.C.). The errors were calculated according to Dahlberg[14] and supplemented by the coefficient of reliability described by Houston[15] (Table II). The measurement errors of the estimated crown and root lengths ranged from 0.19 to 0.60 mm, and the coefficients of reliability varied from 90% for the crown length of the control tooth to 99% for the intrabony root length of the transplanted teeth.

All patients who had at least 1 transplanted tooth present at the examination were asked to fill out a questionnaire that included 8 questions (Fig 6). Anamnestic perceptions of the transplantation procedure (3 questions) and the present status of the transplanted tooth (5 questions) were recorded on a 50-mm visual analogue scale (VAS).[16] The patients indicated their opinion by making a mark along the VAS; 0 was entirely positive and 50 was entirely negative.

RESULTS

The survival rate was 90% because 3 patients had each lost 1 transplanted tooth before the examination. These transplants had been lost 9, 10, and 29 years postoperatively, 2 of them because of ankylosis. Figure 7 represents a life-table analysis[7,17] in 3-year intervals of the number of teeth present and lost.

The criteria for success were not fulfilled for 4 teeth because 2 were ankylosed according to the percussion test, and 2 had a crown-to-root ratio greater than 1, indicating a short root. By including the 3 transplants lost

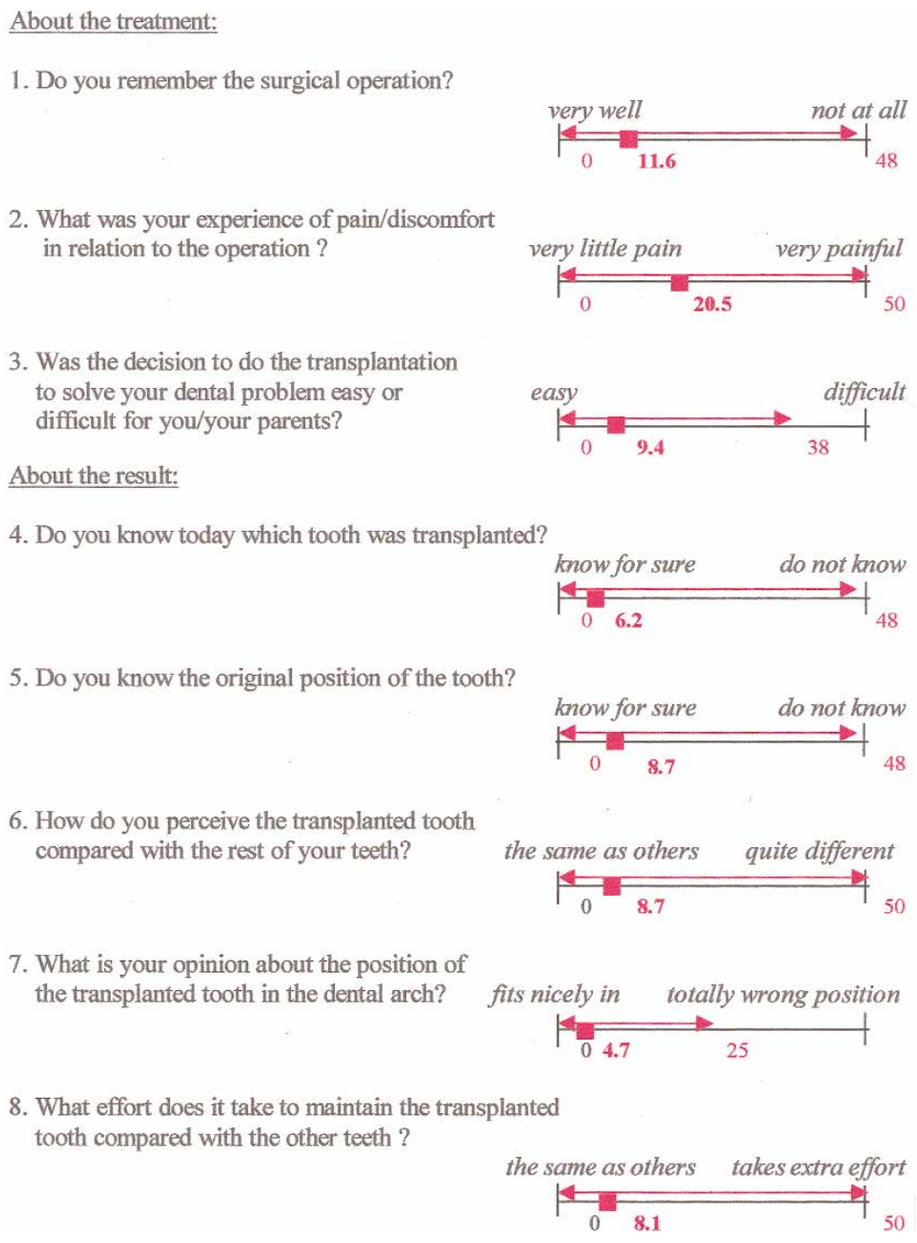
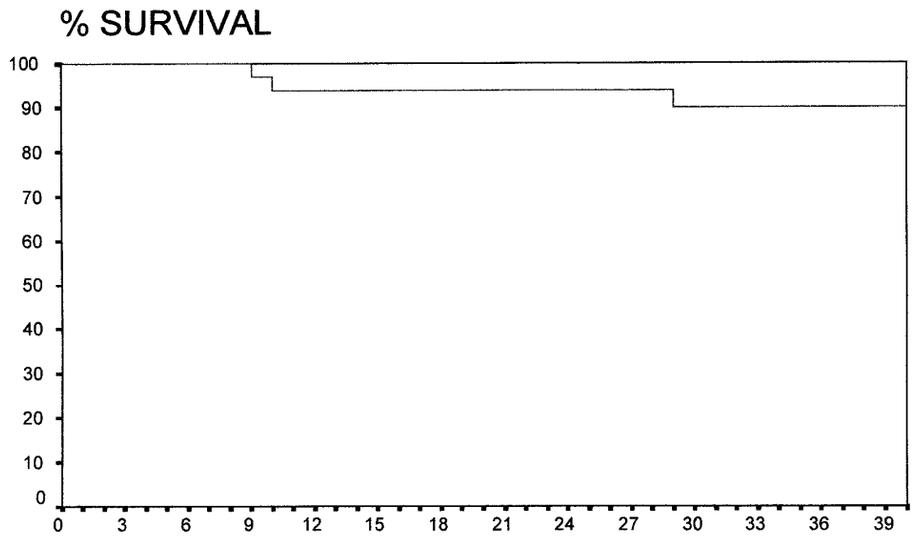


Fig 6. Patients' responses to questionnaire regarding their perception of tooth transplantation using 50-mm visual analogue scales (see text). Numbers below lines represent means and ranges.

before the examination, the success rate for all transplanted teeth in this study was 79%.

The 2 ankylosed teeth had been transplanted 17 and 28 years before the examination and, according to available information, had become ankylosed shortly after the transplantation.

At the time of examination, all 30 remaining transplanted teeth were present in normally appearing alveolar processes. Intraindividual comparisons between transplanted and natural, control teeth could be made for 11 pairs; some patients had agenesis of more than 1 tooth, which resulted in more than 1 transplantation. Moreover, some contralateral teeth were missing, or transplants and control teeth had been crowned. None of the recorded clinical and radiographic variables of the transplanted teeth was statistically different from



Time after transplantation (years)

	3yr.	6yr.	9yr.	12yr.	15yr.	18yr.	21yr.	24 yr.	27yr.	30yr.	33yr.	36yr.	39yr.
At risk	33	33	32	31	31	27	26	21	17	3	1	1	1
Lost	0	0	1	1	0	0	0	0	0	1	0	0	0

Fig 7. Life-table analysis for 33 autotransplanted teeth. Number of teeth present and at risk at time shown after operation is stated below.

those of the control teeth, except for pulp obliteration in all transplants.

The means and ranges of the patients' responses are presented in Figure 6. All 8 mean response scores were located between 0 and 25 mm on the VAS scale, and 6 of them were located below 10 mm, or 80% of an entirely positive response. Generally, the patients remembered the transplantation procedure as a somewhat painful experience (questions 1 and 2), and they generally felt comfortable with the decision to undergo the procedure (question 3). The patients were quite aware of which teeth had been transplanted (questions 4 and 5). Most patients perceived the transplanted tooth as no different from the others (question 6). They considered the transplanted tooth to fit nicely in the dental arch (question 7) and had taken no particular measures to care for the transplants (question 8).

DISCUSSION

The present study has demonstrated that transplantation of developing premolars in children may have a successful outcome decades later when the patients are middle-aged adults. Several factors have contributed to the high survival and success rates. All transplantations were made by the same experienced oral surgeon, according to a strict protocol. Furthermore, patients and donor teeth had been selected according to criteria believed,[2,3] and later verified,[7,18] to provide a favorable prognosis.

Methodology. Considerable efforts were made to find the patients because of the long time period since their operations. The attendance rate of 44% was satisfactory with the mean follow-up period of 26 years in mind. The transplanted teeth that were examined are considered to be representative of the long-term outcome of tooth transplantation in this group of patients. The success criteria were based on presence or absence of pathology, ankylosis, and decreased root length, all of which are threats to the longevity of the teeth. From a patient's perspective, however, the validity of the criteria for success might appear too strict. Four of the persisting transplanted teeth were apparently perceived as satisfactory by the patients, although they were judged as unsuccessful by these criteria. Two teeth had long-standing evidence of ankylosis. It is generally agreed that a gradual, progressive resorption of the tooth can be expected with ankylosis. This process may be very active in children,

so the compromised tooth can survive only a few years. In adults, on the other hand, replacement resorption is significantly slower, allowing the affected tooth to survive 10 and sometimes even 20 years or more.[19-21]

Indications for transplantation and orthodontic treatment. As discussed elsewhere,[22] the primary indications for transplantation of teeth in children and adolescents are agenesis and trauma. The distribution of recipient sites in the present study demonstrates that a range of replacement needs in children may be considered by applying the transplantation modality. With the exception of molars, recipient sites represented the normal location for all categories of teeth, and the sites included maxillary central and lateral incisors, mandibular incisors, maxillary canines, and maxillary and mandibular premolars. The most frequent grafts were premolars (26 of 30). Two maxillary lateral incisors and 2 supernumerary teeth also served as transplants.

The treatment alternatives vary depending on the location of the missing tooth. Ninety percent of Scandinavian children with agenesis lack only 1 or 2 teeth, and those most frequently missing are the mandibular second premolars, the maxillary second premolars, and the maxillary lateral incisors, in that order.[23] Only about 3% of a Scandinavian population with agenesis are missing 2 or more teeth in the same quadrant. The traumatic injuries resulting in accidental loss of incisors generally occur around 10 years of age.[24] The alternative treatment options to transplantation in patients with agenesis of the mandibular second premolars generally include space closure in connection with routine orthodontic treatment involving extraction of 2 maxillary premolars or leaving the deciduous second molars for as long as possible.[20,21]

When maxillary second premolars are absent, the most common treatment alternative is to extract the deciduous molars and secure mesial movement of the first molars. However, in some Class III situations and in patients with tooth/jaw size discrepancies, replacement with implants or bridgework may be needed. The common alternative to transplantation when maxillary lateral (and central) incisors are missing may include orthodontic space closure,[25-27] conventional or resin-bonded bridges, or single-tooth implants.

Longevity of bridgework and implants. The long-term outcome after autotransplantation should therefore be compared with the longevity data for the 3 other options, ie, fixed bridges, resin-bonded prostheses, and single implants.

The survival rate of conventional fixed bridges and the influence of several factors—such as extension, cantilever versus noncantilever design, vital versus nonvital abutments, and location in the mouth—were recently examined by several authors.[28-31] The survival rate of 1674 fixed bridges from 40 Dutch general practices was 87% at 12 years.[28] Bridges made by senior dental students at the University of Oslo had a survival rate of 80% after 10 years, 70% after 20 years, and 65% after 25 years.[30] In a literature review, it was found that the median lifetime of fixed bridges can be expected to be about 20 years[31]; after that, replacement is needed.

Bonded bridges to replace missing maxillary incisors generally provide excellent esthetic results, at least in the short term. The limited preparation is attractive from a tooth conservation viewpoint. However, their durability is often limited. In a recent examination of the clinical performance of 325 resin-bonded fixed partial dentures, the survival rate was only 76% after 5 years and 60% after 10 years.[32] There is some evidence that 2-unit cantilevered resin-bonded bridges may perform equally well or even better than the conventional design with 3 units.[33-35]

Further studies are needed to compare the clinical performance of different designs of resin-bonded bridges.

The introduction of osseointegration gave restorative dentistry new perspectives, with its proven success in treating edentulous patients.[36] These encouraging results then gave rise to the implant-supported single-tooth restoration, and experience gained to date with single-tooth implants is favorable,[37] with survival rates in multi-center studies of about 90% at 10 years.[38,39] However, filling an anterior gap with an implant-supported crown is a major challenge from both esthetic and functional aspects. Clinical success depends not only on persisting osseointegration, but also on harmonious integration of the crown into the dental arch.[40-42] Recent studies indicate that the esthetic result for single implants replacing maxillary incisors is often suboptimal.[43,44] From this perspective, it seems easier to obtain a normal marginal gingival contour around transplanted teeth[6] than around single-implant replacements.[40,43]

It is evident in comparisons of the above techniques that a successful transplantation is probably the best long-term treatment alternative in the posterior region of the mouth and at least as good as the other alternatives in the anterior region.

CONCLUSIONS

Transplantation of developing premolars in children may have a successful outcome decades later, and this method compares favorably with other treatment

modalities for replacing missing teeth. This conclusion is based on the high success and survival rates observed in this study of 33 transplanted teeth examined with a mean follow-up period of 26 years. Furthermore, comparisons between the transplants and the natural control teeth demonstrated no clinical and radiographic differences except for pulp obliteration. This method is also recommended because hard and soft tissues adjacent to the transplanted teeth appeared normal, and because most patients perceived the transplants as no different from their other teeth.

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