Title
Survival rate in autotransplanted premolars with complete root formation: a retrospective clinical survey.

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The purpose of this study was to analyze the survival rate in autotransplanted premolars with complete root formation in dental clinics. Participating dentists were requested to provide information on transplantations they had undertaken between 1 January 1990 and 31 December 2010. Data on a total of 708 teeth from 637 patients were collected. Data for other tooth types and for teeth with incomplete root formation were eliminated. In this study, data on 40 teeth in 35 patients were analyzed. Participants consisted of 17 men and 18 women ranging from 24 to 79 years in age (mean age, 43.7 years). The cumulative survival rate was 100% at the 5-year mark and 72.7% at 10 years, as calculated by the Kaplan-Meier method. Single-factor analysis revealed that “transplanted to the molar regions” was a significant risk factor ($p < 0.05$) influencing the survival of transplanted teeth. However, a Cox regression analysis showed no significance. The results of this study suggest that, in cases where there is a suitable donor tooth and the oral condition is good, premolar autotransplantation is a viable treatment option, even when there is complete root formation in the donor teeth.
Introduction

Autotransplantation of teeth with complete root formation has been reported often since around 1980.1–4,12,14,15,25,26–31. A number of previous studies investigating the survival rate in autotransplanted teeth have reported on cases involving complete root formation of the donor teeth. Watanabe et al. 29) reported on 38 tooth autotransplantations involving all types of teeth in 32 patients, where the mean age at the time of surgery was 24.1 years. More than 6 years after autotransplantation, 5 teeth had been lost. The survival rate was 86.8%, with a mean observation time of 9.2 years. Sugai et al. 26) conducted 117 transplants of all types of teeth in 109 patients ranging from 11 to 75 years in age (mean age, 39.0 years). The overall 5-year survival rate was 84%. Mejare et al. 18) studied 50 patients ranging from 21 to 66 years in age (mean age, 36.7 years) in which a total of 50 third molars with completely developed roots were autotransplanted to replace lost first or second molars in the same number of admitted patients. During a 4-year follow-up period, 7 teeth were lost, so the cumulative survival rate was 81.4%. Nethander23) transplanted 35 teeth of all types with complete root formation and recorded a survival rate of 97.1% over a mean observation period of 5.5 years. In our previous study,30) a total of 614 teeth in 552 patients (37 dentists) ranging in age from 17 to 79 years (mean age, 44.1 years) were examined. A total of 102 transplanted teeth were lost, and the survival rate of all types of teeth was 90.1% at 5 years and 70.5% at 10 years. In another of our previous studies,31) 183 third molars in 171 males ranging from 20 to 72 years in age (mean age, 44.8 years) were examined. The cumulative survival rate was 86.0% at the 5-year mark and 59.1% at 10 years.

Non-functional teeth such as third molars, malpositioned teeth, or teeth extracted during orthodontic treatment are often used as donor teeth for autotransplantations.1–4,12,14,15,18,19,23,26–31. Premolars often erupt with malalignment and do not serve a functional purpose. The anatomy of the premolar is very different from that of third molars: they are usually smaller and often have a single root. In fact, many studies have reported transplantation of premolars, and it is well known that there is a good prognosis for survival in such cases. However, few reports have focused on premolars with complete root formation.

The purpose of this study was to investigate the survival rate in autotransplanted premolars with complete root formation at dental clinics.

Materials and Methods

Questionnaires were sent to 42 dentists who were members of a clinical research organization and who had performed tooth autotransplantation. These dentists were requested to provide information about all autotransplantations they had performed since opening their clinic. The observation period was from 1 January 1990 to 31 December 2010. A total of 39 dentists responded, providing data on a total of 637 patients and 708 transplanted teeth. Data from two of the dentists (38 patients, 42 teeth) were excluded because the respondents did not include data from all transplantations conducted at their clinics. Data concerning all teeth transplanted during 2010 (47 patients, 52 teeth) were also excluded, as it was not possible to ascertain what kind of prostodontic treatment was used in these cases. After excluding these data, 614 teeth in 552 patients (mean age, 44.1 years) were analyzed in our previous study. In this study, we conducted further
Premolar Autotransplantation with Complete Root Formation

screening and elimination of the data. Cases involving teeth other than premolars were eliminated, as well as cases where the donor teeth had incomplete root formation (one tooth). In this study, data on 40 teeth in 35 patients was analyzed.

The clinics were located in the Tohoku (2 clinics), Kanto (30 clinics), or Tokai region (4 clinics) of Japan. The mean period of time the dentists had been practising since graduation from dental school was 23.2 years (ranging from 11 to 44 years) as of April 2010. Data collected included information about the patients, condition of donor teeth and recipient sites, date of last examination, prosthodontic treatment on and condition of transplanted teeth, and primary reason for tooth loss.

The distribution of patients by age group is shown in Table 1. Participants consisted of 17 men and 18 women ranging from 24 to 79 years in age (mean age, 43.7 years).

The observation period was from 1 January 1990 to 31 December 2010. Transplanted teeth which were still present at a patient’s last visit to a clinic were considered to be surviving and therefore treated as censored cases under the Kaplan-Meier method. Tooth survival time was defined as the number of months from transplantation until the time at which the tooth was extracted or recorded as lost at the clinic. Observation period by year of operation is shown in Table 2.

All unsuccessful transplants were included in the analysis, irrespective of the cause of failure. Failure was defined as loss of the transplanted tooth, and the main causes of failure were categorized as follows: root resorption, attachment loss, root fracture, caries, or other (including failure of initial healing). Transplanted teeth judged as surviving fell into the following categories: clinical success, root resorption, ankylosis, or other. Clinical success criteria were based on the work of Kallu et al.\(^{11}\). The criteria were no deep pockets (less than 4 mm), no excessive tooth mobility (below Group 2 on Miller’s mobility index\(^{20}\)), bone loss of less than one third of root length, and no ankylosis or root resorption.

Prosthodontic treatment of transplanted teeth was categorized as follows: single crown (including resin filling and connecting crowns),

<table>
<thead>
<tr>
<th>Age group</th>
<th>Males</th>
<th>Females</th>
<th>Total</th>
<th>%</th>
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<td>20–29</td>
<td>2</td>
<td>3</td>
<td>5</td>
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</tr>
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<td>30–39</td>
<td>7</td>
<td>4</td>
<td>11</td>
<td>(31.4)</td>
</tr>
<tr>
<td>40–49</td>
<td>2</td>
<td>6</td>
<td>8</td>
<td>(22.9)</td>
</tr>
<tr>
<td>50–59</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>(14.3)</td>
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<td>60–69</td>
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<td>2</td>
<td>5</td>
<td>(14.3)</td>
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<tr>
<td>70–79</td>
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<td>1</td>
<td>1</td>
<td>(2.9)</td>
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<tr>
<td>Total</td>
<td>17</td>
<td>18</td>
<td>35</td>
<td>(100)</td>
</tr>
</tbody>
</table>

<table>
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<th>Year of operation</th>
<th>Observation period (years)</th>
<th>0–4</th>
<th>5–9</th>
<th>10–14</th>
<th>15–19</th>
<th>Total</th>
<th>%</th>
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<td></td>
<td>3</td>
<td>1</td>
<td>4</td>
<td></td>
<td>4</td>
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<td>1995–99</td>
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<td>9</td>
<td>(22.5)</td>
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<td>4</td>
<td>6</td>
<td></td>
<td>10</td>
<td></td>
<td>(25.0)</td>
</tr>
<tr>
<td>2005–09</td>
<td></td>
<td>16</td>
<td>1</td>
<td></td>
<td>17</td>
<td></td>
<td>(42.5)</td>
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<tr>
<td>Total</td>
<td></td>
<td>22</td>
<td>14</td>
<td>3</td>
<td>1</td>
<td>40</td>
<td>(100)</td>
</tr>
</tbody>
</table>

Table 1 Number of patients by age group (n = 35)

Table 2 Observation period by year of operation (number of teeth)
The number and distribution of occlusal supports was determined by analyzing post-operative dental records. Any opposing pair of maxillary and mandibular teeth with the same tooth number was counted as one occlusal support. We used the Eichner index to classify the patients into 6 groups based on distribution of occlusal support teeth. The Eichner index is based on the presence or absence of occlusal contact in each of the premolar and molar regions, which are called supporting zones. A maximum of 4 supporting zones can exist, each of which must have at least 1 tooth in contact with an antagonist in order to be counted. In this study, participants were divided into 6 groups as follows: A (4 supporting zones), B1 (3 supporting zones), B2 (2 supporting zones), B3 (1 supporting zone), B4 (anterior tooth contacts but no supporting zones), and C (no occlusal contact among the few remaining teeth).

Many of the participating dentists based their treatment procedures on Andreasen et al. and Tsukiboshi. Surgical procedure did, however, vary slightly. The details of the procedures used by the 37 dentists are provided in our previous reports.

1. Statistical analysis

The cumulative survival rate and mean survival time of the transplanted teeth were calculated using the Kaplan-Meier method. In the factor analysis, the statistical significance of the difference between the survival curves of the two groups was calculated by the log rank test. Cox regression analysis was used to assess the variables. The level of significance was set at 0.05. The data were analyzed using the computerized statistical package SPSS, version 15.0 (SPSS Japan, Inc., Tokyo, Japan).

For analysis, the subjects were divided into two groups and cut-off points were determined by reference to previous reports and receiving operator characteristics curves. Factors were as follows: sex; age under 40 years or 40 years or over; smoker or non-smoker at time of operation (4 participants whose smoking habits were unknown were excluded from this analysis); whether the dentist’s professional experience at the time of the operation was under 15 years or 15 years or over; whether the status of the residual ridge in the recipient site was a prepared socket or the socket of an extracted tooth; whether the recipient site was in the molar region or elsewhere; vital or pulpless donor tooth; whether the prosthodontic treatment of the donor tooth was single crown or abutment of bridge or denture; fewer than 25 present teeth or 25 or more; and whether the occlusal status was group A of the Eichner index or other groups.

This study was approved by the ethical committee of Tokyo Dental College (Approval Number 269).

Results

The mean observation period of transplanted teeth was 63.7 months (ranging from 3 to 196 months).

The number of transplanted teeth, distributed by donor tooth and recipient site, is shown in Table 3. The lower first molar region was the most common recipient site at 37.5%, followed by the upper and lower second premolar region (15.0%).

Prosthodontic treatment of transplanted teeth consisted of a single crown in 72.5% of cases, abutment of bridge in 12.5% of cases, and abutment of overdenture in 15.0% of cases (Table 4).

Among surviving teeth (35 teeth), 68.6% were deemed clinically successful, while 14.3% had root resorption, 11.4% had ankylosis, and 5.7% had other problems.

The cumulative survival rate was 100% at the 5-year mark, 72.7% at 10 years and 54.5% at 15 years (Fig. 1) as calculated by the Kaplan-Meier method.

A total of 5 transplanted teeth were lost during the observation period (Table 5). Of the lost teeth, 80% were not vital, 100% were placed into a prepared socket, 80% were transplanted to the lower molar regions, and
80% were in participants with fewer than 25 present teeth. The reasons for tooth loss were root resorption (60.0%) and attachment loss (40.0%).

Single factor analysis showed that “transplanted to the molar regions” had a significant risk influence ($p < 0.05$) on the survival of transplanted teeth.

Cox regression analysis was used to examine 4 factors: sex, age, smoking status, and trans-
planted to the molar regions. It showed no significant influence of these factors on loss of transplanted teeth.

Discussion

In this study, clinical success criteria were based on the work of Kallu et al.\textsuperscript{11}. The criteria were no deep pockets (less than 4 mm), no excessive tooth mobility (below Group 2 on Miller’s mobility index\textsuperscript{20}), bone loss of less than one third of root length, and no ankylosis or root resorption. These success criteria were adapted from Slagsvold and Bjercke\textsuperscript{25}, Schwartz et al.\textsuperscript{24}, Czochrowska et al.\textsuperscript{6}, and Kristerson and Lagerström\textsuperscript{13}.

The cumulative survival rate was 100% at the 5-year mark and 72.7% at 10 years. This was a better result than obtained in previous studies\textsuperscript{30,31}. It was also better than the results of previous studies of transplantation of teeth with complete root formation (Table 6). The relative success of premolar transplantation may be related to merits of its anatomy, such as its smaller size and fewer roots. Mejare et al.\textsuperscript{18} investigated the prognosis for autotransplantation of 50 third molar teeth with fully developed roots. The results of a Cox regression analysis showed that the lack of a buccal bone plane was the only remaining statistically significant independent variable. It may be that premolars can be transplanted into prepared sockets in narrow recipient sites while preserving the buccal bone.

Andreasen et al.\textsuperscript{3} indicated that transplanted teeth with complete root formation were at a higher risk for damage to the periodontal ligament, root resorption, and pulp necrosis than those with incomplete roots. In an analysis of 40 premolar transplantations which included donor teeth with incomplete root formation, Jonsson and Sigurdsson\textsuperscript{9} reported a survival rate of 97.5% during a mean observation period of 10 years and 4 months. Tanaka et al.\textsuperscript{27} reported on the transplantation of 28 premolars which had a survival rate of 100% for a 9-year period. Our results showed a lower survival rate at 10 years of 72.5%.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Type of donor teeth</th>
<th>Root development</th>
<th>Age</th>
<th>Observation period</th>
<th>Study design</th>
<th>Calculation method</th>
<th>Survival rate %</th>
</tr>
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<tr>
<td>Altonen et al.\textsuperscript{2}</td>
<td>28 canines</td>
<td>Complete</td>
<td>25.2</td>
<td>17.8m</td>
<td>PS</td>
<td>%</td>
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<td>Andreasen et al.\textsuperscript{3}</td>
<td>55 premolars</td>
<td>Complete</td>
<td>7–35</td>
<td>5y</td>
<td>PS</td>
<td>Cutler-Ederer</td>
<td>(98.0)</td>
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<td>Nethander\textsuperscript{25}</td>
<td>35 all types</td>
<td>Complete</td>
<td>51.6</td>
<td>5.5y</td>
<td>PS</td>
<td>%</td>
<td>(97.1)</td>
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<td>Mejare et al.\textsuperscript{18}</td>
<td>50 third molars</td>
<td>Complete</td>
<td>36.7</td>
<td>4y</td>
<td>PS</td>
<td>Cutler-Ederer</td>
<td>(81.4)</td>
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<td>Sugai et al.\textsuperscript{26}</td>
<td>117 all types</td>
<td>Complete</td>
<td>39.0</td>
<td>5y</td>
<td>PS</td>
<td>Kaplan-Meier</td>
<td>(84.0)</td>
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<td>Watanabe et al.\textsuperscript{28}</td>
<td>38 all types</td>
<td>Complete</td>
<td>24.1</td>
<td>9.2y</td>
<td>PS</td>
<td>%</td>
<td>(86.8)</td>
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<td>Yoshino et al.\textsuperscript{20}</td>
<td>614 all types</td>
<td>Complete</td>
<td>44.1</td>
<td>5y</td>
<td>RS</td>
<td>Kaplan-Meier</td>
<td>(90.1)</td>
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<td>(70.5)</td>
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<tr>
<td>Yoshino et al.\textsuperscript{30}</td>
<td>183 third molars (Male)</td>
<td>Complete</td>
<td>44.8</td>
<td>5y</td>
<td>RS</td>
<td>Kaplan-Meier</td>
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<td>(59.1)</td>
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</table>

PS: prospective; RS: retrospective.
years, which may be related to the fact that the teeth had complete root formation and that the participants had a higher average age (43.7 years old).

Concerning the factor of age, Altonen et al.\textsuperscript{2} reported on the transplantation of 28 maxillary canines in 22 patients with an average age of 25.2 (SD 9.9) years. The roots were fully developed. The mean immobilization time was 6.6 weeks and the mean follow-up period was 17.8 months. The results seemed to be better for the age group of 13–20 years than for the 21–30 and 31–47 year-old groups. Statistically significant better results were found in the youngest group in the return of vitality, vertical bone resorption, and periodontal space in the lamina dura. Sugai et al.\textsuperscript{26} and Yoshino et al.\textsuperscript{30} found that participants under 40 years of age showed a significantly better prognosis than older patients by the log rank test. Tsukiboshi\textsuperscript{28} noted a success rate of nearly 90% in patients under 40 years old. Kvint et al.\textsuperscript{14} reported that the success rate in patients over 20 years of age was lower than that in younger patients. These reports suggest that age is a primary risk factor.

There are many other risk factors affecting the survival of transplanted teeth\textsuperscript{1–4,8,9,12,14,18,19,22,23,26–31}, but no clear significance by Cox regression analysis was found in this study. Concerning the status of the 5 teeth that were lost in this current study, 80% were not vital, 100% were placed into prepared sockets, 80% were transplanted to molar regions, and 80% were in participants with fewer than 25 present teeth.

All lost teeth were placed in prepared sockets rather than using sockets vacated by extraction, so this means that more time was spent on preparing the socket. Hupp et al.\textsuperscript{8} indicated that extended extra-oral time of the donor tooth significantly affects the viability of the periodontal ligament cells. More extraoral time causes inflammation or root resorption to occur more easily. Nethander et al.\textsuperscript{22} developed a two-stage operation technique for tooth transplantation. He suggested that optimal contact with the recipient site can improve the blood supply and the level of nutrition to the periodontal ligament cells, which can increase the success rate of autotransplantation. These reports support the notion that using prepared sockets poses a risk to the survival of transplanted teeth, but it was not shown to be a significant factor in this study. Future studies focusing on the effect of using prepared sockets are needed.

Sugai et al.\textsuperscript{26} performed a single-factor analysis and found that the factors which were significantly associated with unsuccessful transplantation were age of 40 years or more, molar as donor tooth, probing pocket depth of 4 mm or more, history of root canal treatment, multi-rooted teeth, and fixation with sutures. Pocket depth of 4 mm or more and history of root canal treatment appeared to increase the risk of unsuccessful transplantation in the multivariate analysis. In our previous study\textsuperscript{31} of third molar transplantations in males, risk factors influencing survival rate were fewer than 25 present teeth and recipient site extraction due to periodontal disease. These factors may have influenced our results. In our study, the factor of “transplanted to the molar regions” was shown to be significant by single-factor analysis. It is well known that molar teeth are more likely to be lost than anterior and premolar teeth\textsuperscript{17,21}, which may explain the influence of this factor.

Treatment options for filling a space vacated by one or two missing teeth include bridgework, removable partial denture, implant, and autotransplantation. There are merits and demerits associated with each type of treatment such as cost, the preparation of teeth required for bridgework, the implanting of artificial materials, youth of patient, and patient comfort. In Japan, national health insurance covers autotransplantation only in the case of third molars, so the cost of premolar autotransplantation is higher than that of third molar transplantation. However, premolar autotransplantation can be provided at a lower cost than implants. The mean cost of a premolar autotransplantation at our members’ clinics (members of Kyushikai), including prosthodontic treatment, was JPY ¥160,000 (USD $2,000 or EUR €1,600). On the other
hand, the cost of a single implant, including prosthodontic treatment, was JPY ¥360,000 (USD $4,000 or EUR €3,600). Of course, the survival rate of implants at 10 years is higher than that of autotransplantation. Lekholm et al.\textsuperscript{15} reported on the Brånemark Implant System, which has a survival rate of 90.2% at 10 years. Blanes et al.\textsuperscript{5} also reported a 10-year cumulative survival rate of 97.9% in ITI dental implants placed in the posterior region. However, implants are not always better than transplanted teeth. In a review of single crown restorations on implants, 5-year survival was 96.8%\textsuperscript{10}. A cost-benefit analysis favors premolar transplantation in some cases.

In the case of successfully transplanted teeth, there are other merits such as orthodontic tooth movement, and the preservation of alveolar bone. The results of this study suggest that, in cases where there is a suitable donor tooth and the oral condition is good, premolar autotransplantation is a viable treatment option, even when the donor tooth has complete root formation.

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