Objective: To assess the alveolar bone formation after autogenous tooth transplantation by conventional radiographic method and digital subtraction radiography.

Study design: This retrospective study was done in 54 of 136 patients who received the third molar tooth transplantation and attended the first week, as well as the 1-, 3-, 6-, 9-, and 12-month follow-up. Postoperative periapical radiographs were subsequently evaluated by direct visual interpretation and digital subtraction radiography. The data were analyzed by using McNemar test and 1-way repeated-measure analysis of variance as well as Bonferroni multiple comparison.

Results: Fifty-four cases of transplantation were studied. Most of them had normal wound healing. The direct radiographic interpretation and digital subtraction radiography found significant alveolar bone formation in the first- and the third-month follow-ups (P < .05). Lamina dura appeared in the third month and kept increasing until the sixth month.

Conclusions: Postoperative radiographs revealed the distinctive bone formation up to the third month. The clinical and radiographic assessment found that the third molar transplants could bear a normal chewing load within 3 months.


Autogenous tooth transplantation was introduced >50 years ago. Since then, most studies of the transplanted teeth were more concerned with the effects and changes of periodontium, root development, and other factors influencing pulp and periodontal healing.1-5

Presently, there are only a few reports on the time sequence on periodontal tissue healing. Kim et al.6 reported a wide range of time for completed bone healing between 2 and 8 months after surgery, whereas Andreasen et al.’s studies showed that the bone healing was completed within 2 months in human premolars, and in 2-4 weeks in monkey incisors.7,8 Therefore, to allow patients to resume normal mastication after tooth transplantation, in practice, many surgeons have assumed a time of healing based on the study of a normal extraction wound, i.e., bone formation starting peripherally at the base and the walls of the socket after 1 week.9-11 The entire osteogenic process consists of the beginning of osteoid secretion and culminates in the development of a mineralized trabecular pattern. An active phase of bone formation occurred between 4 and 8 weeks, followed by a quiescent period of 4 weeks in which the individual trabeculae became mature and increased in volume. Twelve to 16 weeks after the tooth extraction, the newly formed bone was stabilized and retained the architecture of a normal bone.9

To determine success or failure of the tooth transplantation, clinicians used clinical and radiographic methods to evaluate many aspects of the transplants. According to Chamberlin and Georgi,12 the modified criteria of success for transplanted teeth are as follows: 1) The tooth is fixed in its socket without residual inflammation; 2) mastication function is satisfactory and without discomfort; 3) the tooth is not mobile; 4) a pathologic condition is not apparent on the radiograph; 5) the lamina dura appears normal on the radiographs; 6) the tooth shows radiographic evidence of further growth of the root; and 7) the depth of the sulcus, gingival contour, and color are normal. One of the determinants in these criteria was the periodontal healing. The assessment of alveolar bone healing around the transplanted tooth was one of the parameters used to evaluate the operation’s success and prognosis. However, the objective of the present study was not about a success or failure rate, but the periodontal healing (lamina dura and bone formation).

There have been many methods to assess the quantities of bone formation, but in human studies, radiography is the most convenient and noninvasive. Periapical radiographs show bone trabeculation, periodontal ligament space, and lamina dura. However, it is difficult to detect early bone changes by conventional radiography, because the changes show only when the bone mineralization reaches 30%-60%.13-15 Because visual
reading from periapical film has some limitations (i.e., interpretation of small differences between 2 images), digital subtraction radiography was added to enhance the accuracy.\textsuperscript{16-18}

Digital subtraction radiography has been used in dentistry for >20 years to detect the slow progression of lesions such as periodontal and periapical disease.\textsuperscript{18} It has the ability to reduce the complex anatomic background, resulting in increased detectability of small bone change. Today, the digital imaging software usually includes a histogram tool and others for adjusting and normalizing the acquired images. The use of computer algorithms resolved the problem of projection geometry of nonstandardized radiographs. Therefore, in the present study, the Images-Pro-Plus version 5.0 software program was used in viewing small bone changes surrounding the transplanted teeth.

In this study, we used both conventional and digital subtraction radiographic images to study the bone formation after tooth transplantation. We hoped that the findings would assist surgeons in better determining the time of bone healing so that they can adopt a more accurate timeline for fully functional transplanted teeth. This would result in a more accurate time of healing which could be shared with patients.

The objective of our study was to determine the formation of bone and lamina dura in terms of the sequential time after tooth transplantation by direct visual interpretation of the radiograph. The other objective was to evaluate the formation of the transplant’s alveolar bone by means of radiodensity in relation to the postoperative time sequence by using digital subtraction radiography.

**MATERIALS AND METHODS**

This retrospective study, approved by the Ethics Committee of Mahidol University Institutional Review Board (MU-IRB), Bangkok, Thailand, (COA no. MU-IRB 2009/200.1009), was performed by reviewing 136 patient files who received an autogenous third molar tooth transplantation by the same surgeon at the Oral Surgery Clinic, Faculty of Dentistry, Mahidol University, Bangkok, Thailand, during 1995-2004. These records were useful because the Oral Surgery Department required that each tooth-transplanted patient adhered to the department’s follow-up schedule. These follow-up sessions were performed with both clinical and radiographic examinations, 1 week after the surgery for suture removal, then 1 month and every 3 months after the operation date for a period of 1 year. In the second year, the follow-up appointments were made every 6 months, and then once a year from the third year onward. These sequential follow-up schedules were set up to monitor the periodontal and pulpal healing and the root development. They also helped the surgeon to detect any sign of complications, such as inflammatory root resorption, irreversible pulpitis, etc., which may occur in the first few months of the healing.

The patient files included in the present study were of those who adhered to the follow-up schedules for the study in the first-year period. The donor teeth, either the upper or the lower third molars, were chosen from all stages of root development according to Schwartz et al.’s classification\textsuperscript{19}: stage 1: root length <1/2; stage 2: root length 1/2-3/4; stage 3: root length >3/4, open apex; stage 4: 1/1 root length, closed apex. The recipient sites, the maxillary or mandibular premolar or molar regions, were created under local anesthesia. The operation was as follows: first preparing a new socket in either immediate or delayed extraction wounds, then atraumatically removing the donor tooth and immediately transferring it to the new socket by placing its occlusal table 1 mm below its adjacent teeth’s occlusal plane. 4-0 Ethilon (Ethicon, Edinburgh, UK) was used to secure the transplant by suturing cross over its occlusal surface. If the recipient site needed minor adjustment, the tooth would be kept in its original socket for a while. One gram of amoxicillin was given orally 1 hour before the surgery and 500 mg every 6 hours for a week. Analgesic, ibuprofen 400 mg, was taken 3 times a day after meals for 3 days, as well as acetaminophen 500 mg every 4 hours as needed.

Transplanted teeth were not to be chewed on in the first month. The patients could accept soft diet during the second month as tolerated, and the chewing load was gradually increased to normal function within 3 months.

The clinical data of these transplanted teeth were collected from the tooth-transplantation patient forms of the oral surgery clinic, which recorded all signs and symptoms. They were: 1) pain at rest or on chewing (classified as no pain, mild, moderate, or severe); 2) the surrounding gingival inflammation. The classification was mild (slightly change in color and edema), moderate (redness and edema), or severe (marked redness, moderate, or severe).

<table>
<thead>
<tr>
<th>Developmental stages of the donor teeth (third molar)</th>
<th>Root formation (n = 54)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper molar</td>
</tr>
<tr>
<td>Stage 1: root length &lt;1/2</td>
<td>1</td>
</tr>
<tr>
<td>Stage 2: root length 1/2-3/4</td>
<td>3</td>
</tr>
<tr>
<td>Stage 3: root length &gt;3/4, open apex</td>
<td>20</td>
</tr>
<tr>
<td>Stage 4: root length 1/1, closed apex</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>27</td>
</tr>
</tbody>
</table>
edema with bleeding on probing); 3) sulcus depth measurement started from the third month, using periodontal probe UNC-12 (Hu-Friedy, Chicago, IL, USA); 4) degree of tooth mobility by using the Miller index, which scored as follows: 0 = normal mobility (no mobility or physiological mobility), 1 = first distinguishable sign of movement greater than “normal,” 2 = movement of the crown ±1 mm in any direction, 3 = movement of the crown >1 mm in any direction and/or vertical depression or rotation of the crown in its socket; and 5) electrical pulp testing (the present research omitted the results of this test). Clinical success was established by using the reference point alignment method.22 A pair of images between the baseline and follow-up were superimposed and aligned with 4 point marks. Such an anatomic landmark provided an image at the exact same position and the area to be determined on each film. After this, the brightness of images was adjusted to the same level by using a program tool to normalize illumination.

The studied area of the transplant’s surrounding bone was marked at the same extent and location, on the baseline and the follow-up radiograph, to indicate the area for measurement as shown in Fig. 1. Then the threshold was set and the gray-value differences of pixels (256 gray levels) in the studied area were converted into digital format and calculated. Bone density in the region of interest was measured per area. The mean values of bone density on each follow-up period and the baseline were analyzed.

By comparing the alveolar bone changes at each follow-up period, the McNemar test was used for statistical analysis of the different bone formation by the visual interpretation, whereas the mean value of bone density from the digital subtraction radiography was tested by repeated-measures analysis of variance (ANOVA) and the Bonferroni multiple comparison. A P value of ≤.05 was considered to be a significant difference.

RESULTS

Fifty-four patients (12 male, 42 female), also 54 teeth, from a total of 136 patients met the inclusion criteria. Twenty-seven were the maxillary teeth, and 27 were mandibular teeth. The donor tooth’s root development (Table I) was stage 3 (root length >3/4, open apex) in 39/54. The donor teeth were transplanted to upper and lower arch as presented in Table II.

Clinical assessment

At the first-week and first-month follow-up sessions, the records showed no pain at rest or during chewing. Chewing was not allowed on the transplant sites. In the third month, every patient reported having normal mastication on the transplants. The surrounding gingiva of most transplants showed mild inflammation during the first week. All of them became normal again at the first-month follow-up. The sulcus depth measurement, started at the third month, ranged between 1 and 3 mm. In the first month, 39% of transplants had normal mobility and 55% first-degree mobility. Between the first and the third months, the degree of tooth mobility decreased significantly, and a slower rate of decrease was apparent thereafter. Four teeth still had first-degree mobility at the twelfth month (Table III).
Radiographic assessment

The direct visual interpretation revealed bone formation taking place from the first month onward. The rate of bone healing from none to complete trabeculation rapidly increased from the first month (n = 20; 37%) to the third month (n = 48; 89%), and then it slowed down (Table IV). The McNemar test showed a significant change of bone formation in the first- and the third-month follow-ups (P < .05).

Digital subtraction radiography also showed the mean value of bone density increasing during the first year (Table V). The comparison of bone density after transplantation was assessed by 1-way repeated-measures ANOVA. The Mauchly test of sphericity was significant (Mauchly W = 0.01; df = 14; P < .01); therefore, the more conservative Greenhouse-Geisser test was used for the analysis. One-way repeated-measures ANOVA revealed an effect of time on bone density. The Bonferroni post hoc analysis indicated that the bone density significantly increased after treatment for 1 month (P < .05). There were only minimal changes from the third to the sixth month (P > .05). However, a substantial increase in bone density was observed at the first-year follow-up.

Table II. Numbers of donor teeth (third molar) on the recipient sites

<table>
<thead>
<tr>
<th>Recipient site (posterior region)</th>
<th>Donor teeth (n = 54)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Upper molar</td>
</tr>
<tr>
<td>Maxilla</td>
<td>8</td>
</tr>
<tr>
<td>Mandible</td>
<td>19</td>
</tr>
</tbody>
</table>

Fig. 1. Postoperative radiographs showing alveolar bone changes at: a, 1 week; b, 1 month; c, 3 months; d, 6 months; e, 9 months; f, 1 year.
DISCUSSION

A number of the third molar teeth were discarded by surgical removal until tooth transplantation was introduced in the 1950s.23-29 The transplanted tooth gave the juvenile an advantage over dental prosthesis, because a natural tooth would not only prevent the alveolar bone resorption but also promote the bone formation.

The present retrospective study was conducted by using collected data from the files of autogeneous tooth transplantation at our oral surgery department. The patients were required to observe the same follow-up schedule. However, most patients only met the schedule when it was convenient for them. Because the objective of this study was to see what happened in the alveolar bone surrounding the transplants at certain stages and times during the postoperative recovery phase, it was necessary to eliminate any patients who did not comply with the scheduled outline in the study, thus reducing any significant variations within the study groups. Therefore, many cases (n = 82) were excluded from the study. We discussed the clinical part only briefly, because the data were collected only to correlate with the radiographic images.

All 54 transplants in this study did not need any root canal treatment within the first year of follow-up. In the “early studies,” endodontic treatment was said to be always required after a transplantation of full root length with closed apex. However, we found in our study that 7 cases of closed apices (stage 4) showed otherwise, thus showing that the early studies’ conclusion was somewhat inaccurate. The study of Andreasen et al. said that the significant factor for pulp revascularization was the root apex of 1 mm.7,30 Our discovery of unnecessary root canal treatment was also consistent with Reich (2008),29 who found that a 95% success rate of the molar transplantation did not require any endodontic treatment.

Inflammatory root resorption, replacement root resorption (ankylosis) and other signs of failure did not appear in our study. We prevented the undesirable outcome by: 1) atraumatically harvesting the donor tooth, and only handling it at the crown portion to avoid scraping the root surface; and 2) minimizing the extra-alveolar time of the donor tooth by keeping it in its own socket during minor adjustment of the recipient bed, so that the periodontal ligament would stay vital.31-33 However, small areas of ankylosis could have occurred in our study but were all undetectable. Because high-pitch metallic sound on percussion would be noticeable only when >20% of root surface was affected, and a radiographic image would reveal ankylosis only when it occurred at the proximal surface of a root, a diagnosis of ankylosis was difficult.34

Four out of 54 transplants still had first-degree mobility at the twelfth-month follow-up, but discomfort when chewing was nil. The mobility was probably caused by improper placing in the position owing to a limited selection of appropriate size and shape of donor

### Table III. Degree of tooth mobility on each follow-up period (n = 54)

<table>
<thead>
<tr>
<th>Mobility score</th>
<th>1 mo</th>
<th>3 mo</th>
<th>6 mo</th>
<th>9 mo</th>
<th>12 mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>21 (39)</td>
<td>43 (80)</td>
<td>42 (78)</td>
<td>49 (91)</td>
<td>50 (93)</td>
</tr>
<tr>
<td>1</td>
<td>30 (55.5)</td>
<td>11 (20)</td>
<td>12 (22)</td>
<td>5 (9)</td>
<td>4 (7)</td>
</tr>
<tr>
<td>2</td>
<td>3 (5.5)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Table IV. Number of transplants (n = 54) showing complete and incomplete bone formation as evaluated by direct radiographic interpretation

<table>
<thead>
<tr>
<th>Follow-up</th>
<th>Incomplete bone healing</th>
<th>Complete bone healing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Without lamina dura</td>
<td>With lamina dura</td>
</tr>
<tr>
<td>Test statistic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 wk</td>
<td>54</td>
<td>—</td>
</tr>
<tr>
<td>1 mo</td>
<td>34</td>
<td>20</td>
</tr>
<tr>
<td>3 mo</td>
<td>6</td>
<td>39</td>
</tr>
<tr>
<td>6 mo</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td>9 mo</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>1 y</td>
<td>—</td>
<td>2</td>
</tr>
</tbody>
</table>

<sup>a,b,c</sup>Groups labeled with the same superscript are not significantly different.

### Table V. Value of bone density measured by digital subtraction radiography (n = 54)

<table>
<thead>
<tr>
<th>Follow-up</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 wk</td>
<td>0.721098&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.2182951</td>
</tr>
<tr>
<td>1 mo</td>
<td>0.820641&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.1771537</td>
</tr>
<tr>
<td>3 mo</td>
<td>0.880000&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.1440000</td>
</tr>
<tr>
<td>6 mo</td>
<td>0.892230&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.1446258</td>
</tr>
<tr>
<td>9 mo</td>
<td>0.920000&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.1280000</td>
</tr>
<tr>
<td>1 y</td>
<td>0.954628&lt;sup&gt;e&lt;/sup&gt;</td>
<td>0.1119434</td>
</tr>
</tbody>
</table>

<sup>a,b,c,d,e</sup>Groups labeled with the same superscript are not significantly different.
teeth. Poor fitting and malposition of the transplant in a new socket could affect the periodontal healing, leading to tooth mobility.

Eight of the 82 excluded cases had the transplants removed during the first year period owing to either inflammatory root resorption, severe tooth mobility, or infection. Patients who did not adhere to the follow-up schedule had a higher chance of failure. However, failure and success rates were not the objective of this study, because they depended on many factors, not just bone formation.

By direct visual interpretation, bone formation statistically showed significant difference between the first and third months. Complete bone formation was found for 37% (20 cases) in the first month and 89% (48 cases) in the third month. Lamina dura appeared for 17% (9 cases) in the third month and 63% (34 cases) in the sixth month. This finding differed from Andreasen et al. (1990). In their study, successful periodontal healing was marked by the presence of a lamina dura, and the periodontal healing was completed within 2 months in most cases. Also in their study, all the donors were premolars, whereas our teeth were third molars. Because the root in the third molar could diverge more, in preparing the socket more bone would have to be removed than in a single-root or converged-root tooth. Therefore, in such cases, bone healing would take a longer time. Staging of root development was also considered to be another factor that could affect the healing of bone. However, in our study, most of the donor teeth were in stage 3 of root development (39 teeth, 72%), and owing to the small amount of sample size in other stages, tests were not run in these categories.

The digital subtraction technique revealed that the bone density significantly increased up to the third month; after that, only minor changes occurred. Normally, in digital subtraction radiography, the standardized radiographs should be used to achieve the reliance of image processing and better results. However, because our study method was to gather radiographic films from the past, the films were not standardized. Standardized radiographs need customized occlusal stents to control an accurate projection geometry, thereby increasing the cost in both money and time. However, the fact that we lacked standardized films did not cause any significant difference, which is supported by Dove et al. In their study of a digital subtraction method, where the radiographic images taken with identical projection geometry compared with varying projection geometry ±10 degrees of horizontal and vertical beam angulation showed no significant difference.

To correct any discrepancy due to the lack of radiographic standardization, certain computer software programs were used to adjust positions of the radiographic images of all follow-up sessions to the exact position as in the reference film of each patient (alignment correction) as well as the brightness (normalized illumination).

In conclusion, to determine an appropriate time to begin functioning on the transplanted third molar, we need both clinical and radiographic assessments. The patient should have neither pain nor discomfort during chewing. Regarding radiography, the present study found that in most cases a sufficient amount of bone with and without lamina dura to support functioning of the third molar transplant appeared in the third month after surgery. Therefore, such a transplant could have a full function within 3 months if there are no other complications.

The authors appreciate the statistical analysis assistance of Professor Sittichai Koontongkaew, Faculty of Dentistry, Thammasat University, Pathum-Thani, Thailand.

REFERENCES

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