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Assessment of the healing of vascularized fibula bone graft in the reconstruction of the mandible using computed tomography

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Thesis

ASSESSMENT OF THE HEALING OF VASCULARIZED FIBULA BONE
GRAFT IN THE RECONSTRUCTION OF THE MANDIBLE
USING COMPUTED TOMOGRAPHY

by

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requirements for the degree of
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I would like to thank Dr. Andrew Salama for allowing me to use the data of his patients and for his continuous support. I would also like to thank Peter Hoang for his significant contribution and help in this project.
Purpose: Vascularized bone graft has become the standard for the reconstruction of large Mandibular defects, those with soft tissue defect or after radiation to the area. Fibula free flap represents the workhorse for simultaneous bone and soft tissue reconstruction of the Mandible. The aim of this study is to quantify bone formation, if any, in the graft-mandible and graft-graft gaps using computed tomography (CT) scans by developing a reliable threshold-based post-imaging processing tool, compare the healing of fibula to the mandible to the healing of the fibula to itself using this tool, and to investigate potential factors affecting bone formation specifically the linear distance between the bony edges during surgery.

Patients and Methods: This is a multicenter study centered at Boston medical center. DICOM images were analyzed using Osirix software (V.3.7.1, 32 bits) after blinding identifying data. The inclusion criteria for this study: 1) patients received a vascularized Fibula free flap for Mandible reconstruction; 2) patients who have at least 2 postoperative CT scans with at least one month interval; 3) the first CT is within the first 3 months after the surgery; 4) no signs of clinical failure of the graft or hardware failure. The reliability of this technique was tested using two independent blinded examiners. Each blinded examiner tested each scan three times. Pearson’s correlation coefficient was used to
assess inter-rater reliability while the mean, Standard deviation error, and standard deviation of the mean assessed the intra-rater reliability. Paired T-test was used to compare the amount of volume change over time in participants who had both graft-graft gaps and graft-Mandible gaps. Multiple linear regressions were used to investigate the relation between the initial linear distance between the bony edges of the gap, age, and time interval against the percentage of change in gap volume. All statistics were conducted using Microsoft excel software and SPSS.

**Results:** Twenty bony gaps from nine subjects were included in this study. This includes five graft-graft gaps and fifteen graft-Mandible gaps. The first post-operative CT scan was done within first three months after surgery (range= 2-77 days, mean= 22.2 days). Each subject had two CT scans with time interval ranging between 33 days to 390 days (mean= 191.1 days). The subjects’ age ranged between 30 and 72 years (mean= 56.1 years). 12 bony gaps were used for assessing inter-rater and intra-rater reliability. The Pearson’s correlation coefficient for inter-rater reliability was 0.94. Inter-reliability standard deviation error average was 0.03 and the standard error of the mean average was 0.003. Two-tailed paired T-test comparing the interval change in volume of graft-graft gaps to graft-Mandible gaps was 0.304. We found a significant negative correlation between absolute volume change and distance in mm (Pearson =-0.476, p-value=0.017). 22.7% of the variability in volume change can be explained by the initial linear distance between the bony edges of the gaps in millimeter.

**Conclusion:** Small bony gaps between the fibula bone graft and the mandible after mandibular reconstruction can be reliably assessed. The healing of the fibula to itself was
not found to be significantly different from the healing of fibula to the mandible in the same subject. The initial linear distance between the bone edges of the gap is inversely related to subsequent bone formation. It is recommended to adapt the bony segments as close as possible to increase bone formation.
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INTRODUCTION

Mandibular reconstruction was traditionally achieved using non-vascularized cortico-cancellous bone grafts for small defects without a soft tissues defect. Larger bony defects, those with soft tissue loss, or post-radiotherapy defects are typically reconstructed using a vascularized free flap. Vascularized free Fibula osteocutaneous flap has become the workhorse for the reconstruction of maxillofacial oncological defects.1

Different radiographic modalities have been used in monitoring bone healing including plain and three-dimensional imaging techniques. The value of plain radiographic films for the evaluation of bone healing after fractures has been challenged.2-4 This can be explained by the inherent limitations of conventional radiography, e.g. bone or hardware overlap, and the subjectivity of interpreting the results. High resolution computed tomography (CT), Micro CT, and MRI can be used to evaluate the trabecular bone structure.5,6 Cone beam computed tomography (CBCT) became a widely used tool in the office of oral and maxillofacial surgeons over the past decade.7 It has also been proved to be useful in assessing the healing of bony defect in an animal model.8

The healing of non-vascularized bone graft to the maxillofacial region has been well described in the literature. However, to the best of our knowledge, the bony healing of the Fibula-to-Fibula and the Fibula-to-Mandible has not been studied until now. The aim of this study is to quantify bone formation, if any, in these gaps using computed tomography (CT) scans by developing a reliable and precise computed tomography
threshold-based post-imaging processing tool. Moreover, we present two null hypotheses:
1) No difference in healing across the Graft-graft versus Graft-Mandible gaps 2) The initial linear distance across the gaps does not affect subsequent bone formation.

**Background**

*Anatomy and physiology of the Mandible*

The lower jaw (mandible) consists of a horseshoe-shaped segment harboring the alveolar segment that supports the dentition. It connects posteriorly with two vertical rami, which articulate with the temporal bones via round condylar heads forming the temporomandibular joints (TMJs). It defines the appearance and profile of the lower third of the face. The Mandible serves as the site of attachment of several muscles and ligaments including the muscles of mastication and the supraphyoid muscle groups. The muscles of mastication include the masseter, medial pterygoid, lateral pterygoid, and temporalis muscles. Their actions result in Mandibular opening, closing, and lateral excursions. The Mandible is exposed to significant amount of forces and stress during speech, yawning and mastication. Tensile forces mainly affect the superior part of the Mandible while compressive forces affect the inferior part. Champy et al defined the lines, just below the roots of the teeth, where tensile and compressive forces are equal. Anterior to the canines (Symphysis area) the Mandible is affected by a torque of alternating tension and compression zones. The Mandible is thicker anteriorly in the symphysis area with an average thickness of 14 mm in males and 13.2 mm in females.

*Classification of Mandibular continuity defects*
Continuity defects of the Mandible may result from trauma or surgical treatment. Several diseases require surgical resection of the affected segment of the Mandible. These include benign and malignant tumors, resistant bone marrow infection (osteomyelitis), and bone necrosis secondary to radiation or bisphosphonate medication. Several classifications exist to characterize the continuity defect. Jewer et al proposed a classification system where the area between the lower canines is designated “C” for central segment. Lateral defects not involving the condyle is designated “L” while hemimandibular defects involving the condyle are designated “H”.

Boyd et al added to this classification the soft tissue component using lower case letters; skin (s), mucosa (m), or osseous only (o). A more complex classification was described by David et el into six classes depending on location, size and laterality of the defect. More recently, Baumann et al suggested a simple and useful classification system derived from their experience in the reconstruction of osteoradionecrosis Mandibular defects. A type one defect is a segmental defect where the condyle is intact while a type two defect is posterior or hemimandibular defect where the condyle is missing. They further classified the defect based on the soft tissue involvement into (a) simple mucosal defect and (b) through and through soft tissue defect.

**Bone reconstruction options for the Mandible**

Reconstruction of the lower jaw avoids severe functional and esthetic debilitation. The ideal reconstruction should re-establish oral continuity, allow for dental rehabilitation, restore sensation of the lower lip, restore facial form and cosmesis, and
must withstand radiation therapy if needed. The continuity of the mandible can be maintained with titanium reconstruction plates and screws alone. This is usually preserved for patients who are poor surgical candidates, small lateral defects, and patients with short life expectancy. However, bony reconstruction is needed to avoid the likely hardware failure especially in larger defects. It provides better esthetics and allow for dental rehabilitation with dental implants or prosthesis. Some of these defects may have a soft tissue component (e.g. malignant tumors and gun shot wounds), which also need to be addressed prior to the bony reconstruction or simultaneously.

Two general categories of reconstruction techniques are available for defects of the Mandible. Non-vascularized cortico-cancellous is the older technique that is still used today for small defects (less than 5 cm) without history of radiation or concomitant soft tissue defect. It has the advantages of higher bone volume, shorter surgical procedure, easier technique, and less morbidity. The most common donor site is the anterior iliac bone, which can provide about 50 CC of cortico-cancellous bone.\textsuperscript{15,16} A posterior approach is used to harvest bone from the iliac bone and is reported to provide about twice the amount of the anterior iliac approach with less morbidity.\textsuperscript{15} However, it requires switching to a prone position intra-operatively excluding simultaneous head and hip approach (two teams) and risking extubation. Costochondral rib grafts have proved useful for the reconstruction of Mandibular defect involving the temporomandibular joint (TMJ), especially in growing patients.\textsuperscript{17} Other sources include the calvarium, the tibia, Mandibular chin, and ramus.
More recently, vascularized bone graft has become the standard for the reconstruction of large Mandibular defects, those with soft tissue defect or after radiation to the area. It has a high success rate and provides reconstruction in one stage. Potential vascularized bony flaps include the fibula, ileum, scapula, and radius bones. The workhorse for mandibular reconstruction is the vascularized fibula free flap (FFF). It was introduced in 1975 by Taylor et al for the treatment of post traumatic defect of the lower extremity.\textsuperscript{18} In 1989, Hidalgo was the first to describe its use to reconstruct the Mandible.\textsuperscript{16} This flap is based on the peroneal vessels (artery and 2 vena comitantes) that are one of the main three branches supplying the lower extremity and the foot, along with anterior and posterior tibial vessels. It can provide up to 27 cm of bone and allow segmentation without devascularization.\textsuperscript{19} It allows two-team approach, thus reducing the operative time. Moreover, it can provide composite soft tissue and bone reconstruction based on skin perforators. However, it has relatively small bone thickness compared to the Mandible. Different imaging modalities are used preoperatively to assess the patency of the blood vessels of the lower extremity and to rule out anatomic variations that would exclude the use of the FFF. Angiography is the gold standard but due to its invasive nature and low incidence of anatomic variation, less invasive techniques are routinely used. Those include computed tomography angiogram (CTA), magnetic resonance angiogram (MRA), and color-flow Doppler.\textsuperscript{20} Reconstruction of shorter segments of the Mandible can be achieved using a single segment of the fibula, creating proximal and distal bony gaps between the fibula and the Mandible. However, if the continuity defect is long it will require the segmentation of the fibula to imitate the curvatures of the
Mandible by removing a wedge of the fibula bone. This will result in the creation of a third and possibly a fourth bony gaps between the segments of fibula. Fibular segments are secured in place using titanium plates and screws.

*The healing of bone grafts*

Bone is a unique connective tissue in that it heals and remolds by cellular regeneration rather than scar formation. This cellular regeneration makes the non-vascularized bone grafts possible. The immature mesenchymal stem cells can differentiate into different tissues e.g. bone, muscle, cartilage, and fibrous tissues. In bone, they are located in the bone marrow, endosteum, and the cambium layer of the periosteum.\(^{21}\) The number of these cells have been found to decrease with age making the bone more osteoperotic and less regenerative.\(^{21}\)

Bone formation occur by three mechanisms: 1) Osteogenesis by forming new bone from stem cells; 2) Osteoconduction by forming new bone from host-derived or transplanted stem cells along biologic or alloplastic framework; 3) Osteoinduction by the guided differentiation of progenitor stem cells into bone forming cells “osteoblasts” by bone inductive proteins (e.g. bone morphogenic proteins “BMP”). Cancellous non-vascularized bone graft cells initially survive by the plasmatic circulation. Lactic acid build-up and hypoxia initiates the formation of new blood vessels from the surrounding tissues, which is usually completed around two weeks. The surviving progenitor cells form unorganized woven bone (phase 1 bone). Over the next few months, remodeling occurs to form the lamellar structure of the bone (phase 2 bone).
Vascularized free flap has the advantage of transferring a viable bone with its cells thus bypassing the need for bone formation across the continuity defect. The only exception to that is at the graft-mandible and graft-graft interfaces. The healing along these gaps has not been studied specifically but it is fair to assume that bone formation along these gaps occurs by osteogenesis, osteoinduction, and / or osteoconduction. Clinical experience also showed that healing along these gaps might result in fibrous tissue formation rather than true bony healing in some cases. This may be a result of the initial size of the gap, type of fixation, systemic host factors, radiotherapy or a combination. This study is intended to develop a reliable technique to assess bone formation along these gaps. This can be utilized in future studies to identify factors affecting the healing along these gaps.
METHODS

This is a multicenter study centered at Boston Medical Center. Institutional review board (IRB) approval was obtained. The DICOM images were analyzed using OsiriX software (V.3.7.1, 32 bits) after blinding identifying data in the scans. The inclusion criteria for this study: 1) received a vascularized fibula free flap for mandible reconstruction; 2) had at least 2 postoperative CT scans with at least one month interval; 3) the first CT is within the first 3 months after the surgery; 4) no signs of clinical failure of the graft or hardware failure.

The image-processing pipeline starts by uploading the DICOM files into OsiriX software. Next, the Mandible is outlined in each slice (Fig.1) and the areas outside that region of interest (ROI) are set to zero. The Mandible images are then exported into a new DICOM file for analysis (Fig.2). There are 2 types of bone gaps that will be analyzed. Graft-Mandible gaps which exist at the proximal and distal ends of each scan. Subjects with larger defects requiring segmentation of the fibula, to mimic the curvature of the Mandible, will also have a graft-graft gap. The brush tool function is used. It has a scale of 1 to 10 for the size of the brush. We selected the size that approximates 0.5 cm\(^2\) (Fig.3). Next, the gap is marked using the brush tool centering the marking on the center of the gap and ensuring including the margins (fig. 4). Then a “grow region” segmentation option is used with a threshold (500 to 2800) Hounsfield Units (HU) (fig.5). Finally, the segmented region volume is calculated using the ROI compute volume tool. This will provide a three-dimensional graph and volume of the gap area as marked (fig.6).
Figure 1: The mandible is outlined in each slice and isolated from the rest of the head and neck.

Figure 2: Three-dimensional reconstruction of the isolated Mandible.

Figure 3: The brush tool is selected and adjusted to approximate 0.5cm².
Figure 4: The brush tool is used to paint over the center of the gap.
Figure 5: a) The ROI segmentation tool with the threshold set between 500 and 2800 HU. b) The segmentation result is shown in green color.

Figure 6: The result of three-dimensional volume calculation of the segmented area.
The reliability of this technique was tested using two independent blinded examiners. Each examiner tested each scan three times. Pearson’s correlation coefficient used to assess inter-rater reliability while the mean, Standard deviation error, and standard deviation of the mean assessed the intra-rater reliability.

Power analysis was used in estimating the sample size using the following equation: 
\[ d = \frac{2r}{\sqrt{1 - r^2}} \]

Riegger et al performed quantitative assessment of bone defect healing by multi-detector CT in a pig model.\(^{22}\) Although they did not report the t value and the df, we used published tables to estimate the t value from their p value then used it in the equation below:

\[ d = \frac{2 \times 0.82}{\sqrt{1 - 0.82 \times 0.82}} = 2.86 \]

Based on this result, 8 bony gaps will have 95% of detecting a difference between groups.

Paired T-test was used to compare the amount of volume change over time in 5 subjects who had both graft-graft gaps and graft-mandible gaps. Multiple linear regressions were used to investigate the relation between the initial linear distance between the bony edges of the gap, age, and time interval against the percentage of change in gap volume. All statistics were conducted using Microsoft excel software and SPSS (IBM SPSS statistics for Windows, version 21.0).
RESULTS

Twelve bony gaps were used for assessing inter-rater and intra-rater reliability. The Pearson’s correlation coefficient for inter-rater reliability was 0.94. Inter-reliability standard deviation error average was 0.03 and the standard error of the mean average was 0.003 (table.1).

Table 1: Inter-rater and intra-rater reliability were tested by two blinded raters.

*SDE= standard deviation of the error, SEM= standard error of the mean

<table>
<thead>
<tr>
<th>No.</th>
<th>Rater 1 Mean</th>
<th>Rater 2 Mean</th>
<th>Inter-rater T-test</th>
<th>SDE</th>
<th>SEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50</td>
<td>0.51</td>
<td>0.94</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>0.62</td>
<td>0.60</td>
<td>0.01</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>3</td>
<td>1.44</td>
<td>1.48</td>
<td>0.05</td>
<td>0.05</td>
<td>0.006</td>
</tr>
<tr>
<td>4</td>
<td>0.89</td>
<td>0.88</td>
<td>0.02</td>
<td>0.02</td>
<td>0.002</td>
</tr>
<tr>
<td>5</td>
<td>1.19</td>
<td>1.17</td>
<td>0.01</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>6</td>
<td>0.82</td>
<td>0.81</td>
<td>0.01</td>
<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>7</td>
<td>0.63</td>
<td>0.62</td>
<td>0.03</td>
<td>0.03</td>
<td>0.003</td>
</tr>
<tr>
<td>8</td>
<td>1.37</td>
<td>1.37</td>
<td>0.12</td>
<td>0.12</td>
<td>0.013</td>
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<tr>
<td>9</td>
<td>1.07</td>
<td>1.08</td>
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<td>0.01</td>
<td>0.001</td>
</tr>
<tr>
<td>10</td>
<td>0.51</td>
<td>0.43</td>
<td>0.03</td>
<td>0.03</td>
<td>0.004</td>
</tr>
</tbody>
</table>

Mean | 0.03 | 0.003 |

Twenty bony gaps from nine subjects were included in the study. This includes five graft-graft gaps and fifteen graft-mandible gaps. The first post-operative CT scan
was done within first three months after surgery (range= 2-77 days, mean= 22.2 days). Each subject had two CT scans with time interval ranging between 33 days to 390 days (mean= 191.1 days). The subjects’ age ranged between 30 and 72 years (mean= 56.1 years) (table.2).

Table 2: Subject’s age and time interval after surgery for first and second CT scans.

<table>
<thead>
<tr>
<th></th>
<th>Age (years)</th>
<th>CT1 (days after surgery)</th>
<th>CT 2 (days after surgery)</th>
<th>Interval (days)</th>
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<td>1</td>
<td>61</td>
<td>45</td>
<td>210</td>
<td>165</td>
</tr>
<tr>
<td>2</td>
<td>68</td>
<td>7</td>
<td>150</td>
<td>143</td>
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<td>51</td>
<td>7</td>
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<td>5</td>
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<td>420</td>
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</tr>
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<td>7</td>
<td>55</td>
<td>77</td>
<td>390</td>
<td>313</td>
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<td>8</td>
<td>30</td>
<td>7</td>
<td>164</td>
<td>157</td>
</tr>
<tr>
<td>9</td>
<td>61</td>
<td>7</td>
<td>240</td>
<td>233</td>
</tr>
<tr>
<td>Mean</td>
<td>56.11</td>
<td>21</td>
<td>212.11</td>
<td>191.11</td>
</tr>
</tbody>
</table>

Two-tailed paired T-test comparing the interval change in volume of graft-graft gaps to graft-Mandible gaps was 0.304 (table.3). Multiple linear regressions were calculated to investigate the effect of age, time interval and the linear distance from buccal and lingual cortices (Appendix.1). We found a significant negative correlation between absolute volume change and distance in mm (Pearson =-0.476, p-value=0.017).
22.7% of the variability in volume change can be explained by the initial linear distance between the bony edges of the gaps in mm.

**Table 3: Paired T-test to compare the bone formation across graft-graft gaps to graft-Mandible gaps. NM: not-measurable, GG: graft-graft, GM: graft-Mandible**

<table>
<thead>
<tr>
<th></th>
<th>GM- right</th>
<th>GM- left</th>
<th>GM- mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG</td>
<td>-0.163</td>
<td>-0.081</td>
<td>-0.122</td>
</tr>
<tr>
<td>GM- right</td>
<td>0.078</td>
<td>0.016</td>
<td>0.045</td>
</tr>
<tr>
<td>GM- left</td>
<td>0.039</td>
<td>-0.100</td>
<td>-0.142</td>
</tr>
<tr>
<td>GM- mean</td>
<td>0.207</td>
<td>0.356</td>
<td>0.357</td>
</tr>
<tr>
<td>GM</td>
<td>0.034</td>
<td>NM</td>
<td>0.756</td>
</tr>
</tbody>
</table>

**Paired T test** 0.304
DISCUSSION

The mineral density of bone correlates linearly with signal intensity in CT scan.\textsuperscript{23} Reich et al demonstrated in a cadaver study the linear correlation between calcium content of bone and CT measured signal.\textsuperscript{24} CT scan was used to quantify the mineralization and volume of the callus during fracture healing using a manual segmentation technique in an animal study.\textsuperscript{25} However, the callus is easy to identify on CT scan in contrast to the fibula-mandible and fibula-fibula gaps being investigated in this study. The difficulty in using a similar tool is that the definition of the gap can be challenging. This is the result of the small size of the gap, the ill-defined boundaries of the gap, the adjacent hardware, the remodeling at the margins of the gap, and the variable density of the bone in the gap that could be identical to the margin bone density. Segmenting the whole mandible including the gaps and measuring the difference after an interval of healing is another option. However, this also can be misleading due the natural bone remodeling of the mandible and fibula away from these small interface gaps.

The developed tool is a semiautomatic threshold-based CT scan tool that allows measurement of small gaps with ill-defined margins. The technique is based on the idea of using a standardized brush size (0.5 cm\textsuperscript{2}) to mark the center of the gap manually while capturing both margins of the gap. The Hounsfield unit threshold used in segmenting the gap is set at 500 to 2800. This ensures capturing different densities of bone in variable stages of healing and both margins of the gap. We assumes that capturing one margin more than the other won’t affect the results over an interval because of fixed brush size
which is centered on the visual center of the gap. So although the measured volume of the
gap may not be exact, the interval change in volume is.

However, as with any manual processing technique, Subjectivity of the examiner
can be a complicating factor. This was addressed by evaluating the inter-rater and intra-
rater reliability, which proved this technique is reliable.

Five out of the nine subjects had both graft-graft and graft-Mandible gaps. A
paired T-test showed that there was no significant difference in the percentage of volume
change. We thus accept the first null hypothesis indicating no difference in the healing of
the fibula to itself versus to the Mandible. We also found statistically significant inverse
relationship between the initial distance in mm between the bony gaps and subsequent
increase in bone volume formation. (Pearson =-0.476, p-value=0.017). For every one mm
decrease in the distance between the gaps (i.e. better adaptation of the bony edges during
surgery), 22.7% of increased bone volume was noted. Thus, we reject the second null
hypothesis and accept the alternative hypothesis indicating an inverse relation between
bone volume increase and the initial linear distance in mm.

Possible limitations of this study include small sample size and possibility of
subclinical hardware movement that can affect the gap size. Although semi-rigid fixation
using at least 2 screws in each fibular segment was used, minor movement cannot be
excluded. Future studies should include bigger sample size and standardized time interval
to minimize cofounding factors.

In conclusion, the healing of bone can be measured using computed tomography.
Small bony gaps between the fibula bone graft and the Mandible after Mandibular
reconstruction can be reliably assessed using the presented image procession pipeline in OsiriX software. The healing of the fibula to itself was not found to be significantly different from the healing of fibula to the Mandible in the same patient. Moreover, the surgeon should attempt to minimize the linear distance between the fibula and the mandible or itself (in closing osteotomies) as this is inversely related to subsequent bone formation.
APPENDIX

Linear regression analysis using volume change as dependent variable and “Distance in mm” as independent variable:

<table>
<thead>
<tr>
<th>Correlations</th>
<th></th>
<th>Volume_change</th>
<th>Distance_mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>Volume_change</td>
<td>1.000</td>
<td>- .476</td>
</tr>
<tr>
<td></td>
<td>Distance_mm</td>
<td>- .476</td>
<td>1.000</td>
</tr>
<tr>
<td>Sig. (1-tailed)</td>
<td>Volume_change</td>
<td>.</td>
<td>.017</td>
</tr>
<tr>
<td></td>
<td>Distance_mm</td>
<td>.017</td>
<td>.</td>
</tr>
<tr>
<td>N</td>
<td>Volume_change</td>
<td>2:</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Distance_mm</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

There is a significant negative correlation between absolute volume change and distance in mm (Pearson = -0.476, p-value=0.017).

<table>
<thead>
<tr>
<th>Model Summary</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>R</td>
<td>R Square</td>
<td>Adjusted R Square</td>
<td>Std. Error of the Estimate</td>
<td>R Square Change</td>
<td>F Change</td>
<td>df1</td>
<td>df2</td>
</tr>
<tr>
<td>1</td>
<td>.476</td>
<td>.227</td>
<td>.184</td>
<td>20093537318 991</td>
<td>.227</td>
<td>5.282</td>
<td>1</td>
<td>18</td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Distance_mm
b. Dependent Variable: Volume_change

22.7% of the variability in volume change can be explained by distance in millimeter.
ANOVA

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>.213</td>
<td>1</td>
<td>.213</td>
<td>5.282</td>
<td>.034</td>
</tr>
<tr>
<td>Residual</td>
<td>.727</td>
<td>18</td>
<td>.040</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>.940</td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Dependent Variable: Volume_change
b. Predictors: (Constant), Distance_mm

Coefficients

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>95.0% Confidence Interval for B</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>(Constant)</td>
<td>.268</td>
<td>.081</td>
<td>-</td>
<td>3.308</td>
<td>.004</td>
<td>.098</td>
</tr>
<tr>
<td>1 Distance_mm</td>
<td>-.047</td>
<td>.021</td>
<td>-.476</td>
<td>-2.298</td>
<td>.034</td>
<td>-.091</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Volume_change

Regression equation:

Volume Change = 0.267 – 0.047 (Distance in mm) + 0.21
For every millimeter reduction in distance at the bone graft site, the bone volume change will increase by 0.047.
The linear regression using volume change as dependent variable and “distance in mm”, “age”, and “interval” as independent variables:

### Correlations

<table>
<thead>
<tr>
<th></th>
<th>Volume_change</th>
<th>Distance_mm</th>
<th>Age</th>
<th>Interval_days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume_change</td>
<td>1.000</td>
<td>-.476</td>
<td>-.210</td>
<td>-.152</td>
</tr>
<tr>
<td>Distance_mm</td>
<td>-.476</td>
<td>1.000</td>
<td>.306</td>
<td>.060</td>
</tr>
<tr>
<td>Age</td>
<td>-.210</td>
<td>.306</td>
<td>1.000</td>
<td>.062</td>
</tr>
<tr>
<td>Interval_days</td>
<td>-.152</td>
<td>.060</td>
<td>.062</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The only variable that is significantly correlated with volume change is the distance

### Model Summary

<table>
<thead>
<tr>
<th>Model</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
<th>Change Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>.496</td>
<td>.246</td>
<td>.105</td>
<td>.210471018342</td>
<td>.246</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>R Square Change</th>
<th>F Change</th>
<th>df1</th>
<th>df2</th>
<th>Sig. F Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Predictors: (Constant), Interval_days, Distance_mm, Age
b. Dependent Variable: Volume_change
When age and interval were added to the model, R-square slightly increase. However, the model becomes statistically not significant.

### Coefficients\(^a\)

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
<th>95.0% Confidence Interval for B</th>
<th>Collinearity Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>Std. Error</td>
<td>Beta</td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
</tr>
<tr>
<td>(Constant)</td>
<td>.376</td>
<td>.234</td>
<td></td>
<td>1.609</td>
<td>.127</td>
<td>-.120</td>
</tr>
<tr>
<td>Distance_mm</td>
<td>-.045</td>
<td>.023</td>
<td>-.449</td>
<td>-1.969</td>
<td>.067</td>
<td>-.093</td>
</tr>
<tr>
<td>Age</td>
<td>-.001</td>
<td>.004</td>
<td>-.065</td>
<td>-.283</td>
<td>.781</td>
<td>-.010</td>
</tr>
<tr>
<td>Interval_days</td>
<td>.000</td>
<td>.000</td>
<td>-.121</td>
<td>-.557</td>
<td>.585</td>
<td>-.001</td>
</tr>
</tbody>
</table>

\(^a\) Dependent Variable: Volume change

Regression equation:

Volume change = 0.376 – 0.045(distance) -0.001 (age)+ 00001(Interval)
REFERENCES


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Email  mnadershah@gmail.com
Date of birth  December 26, 1980

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Masters in Science in Medical Bioimaging  2012-2015
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Fellowship in Head and Neck Oncology and Microvascular Reconstruction  2011-2012
Boston University/ Boston Medical Center

General Surgery Internship  2008-2009
Boston University/ Boston Medical Center

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1998-2005

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2011-2012

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**Oral and Maxillofacial Surgery Chief Resident**  
2010-2011

Boston University

**Oral and Maxillofacial Surgery Senior Resident**  
2009-2010

Boston University

**General Surgery Intern**  
2008-2009

Boston University

**Oral and Maxillofacial Surgery Intern**  
2007-2008

Boston University

**Junior Faculty in OMFS Department**  
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**BOOK CHAPTERS**


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Best Scientific Poster Award, American College of Oral and Maxillofacial Surgery Meeting 2011
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Certificate of Appreciation, Healing the Children Organization 2009

Scored 99 percentile (OMSITE) examination during 1st year of residency 2007

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Valedictorian Dentistry Graduate, King Abdul Aziz University 1999-2004

Honors certificate for 1st rank in dental school, King Abdul Aziz University 2004

“Best student of the year award" 2002-2003

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