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**Research Article**

# Evaluation of Digitally Customized Titanium Mesh-Guided Alveolar Ridge Augmentation

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**Abstract**

***Background***: Different bone augmentation methods are used to increase the alveolar crest following the loss of one or more teeth. Guided bone regeneration is an alternative to increasing the amount of hard tissues for subsequent implant placement in the best three-dimensional position. ***Objectives***: To evaluate the effects of bone regeneration utilizing a customized titanium mesh scaffold covered with a combination of autologous bone transplant and xenograft for the restoration of complex jaw deformities. ***Methods***: This prospective clinical interventional study included ten patients receiving ridge augmentation of the partly edentulous mandible or maxilla after the alveolar ridge had resorbed (horizontally). A pre-surgical cone beam computed tomography (CBCT) scan was performed to assess pre-surgical ridge size and fabricate the customized titanium mesh (CTM). A CBCT scan will be performed immediately after surgery, followed by a second CBCT scan 6 months later to measure width and volumetric analysis. ***Results***: Both arches had a rise in volumetric gain from preoperative to postoperative, with no significant difference. Females gained more than males, although the difference was not statistically significant (males lost density after surgery). They also discovered that age, gender, and arch were not substantially associated with mesh size exposure. ***Conclusions***: Using tailored titanium mesh scaffolds in conjunction with autogenous bone and xenografts for alveolar ridge augmentation can efficiently increase bone mass, but future research must address many limitations.

***Keywords***: Guided bone regeneration, Platelet rich fibrin, Pseudo-periosteum, Titanium mesh.

**تقييم زيادة الحويصلات السنخية الموجهة بشبكة التيتانيوم المخصصة رقميًا**

**الخلاصة**

**الخلفية**: يمكن إجراء زيادة العرف السنخي بعد فقدان واحد أو عدة أسنان باستخدام تقنيات تكبير العظام المختلفة. يعد تجديد العظام الموجه بديلاً لزيادة حجم الأنسجة الصلبة لوضع الغرسات لاحقًا في الموضع الأمثل ثلاثي الأبعاد. **الأهداف**: تقييم نتائج تجديد العظام باستخدام سقالة شبكية من التيتانيوم مخصصة لتغطية خليط من طعم عظمي ذاتي مع طعم أجنبي لإعادة بناء العيوب المعقدة في الفكين. **الطرق**: شملت هذه الدراسة التداخلية السريرية المستقبلية عشرة مرضى يتلقون تكبير التلال في الفك السفلي جزئيا أو الفك العلوي بعد إعادة امتصاص الحافة السنخية (أفقيا). تم إجراء فحص التصوير المقطعي المحوسب بالشعاع المخروطي قبل الجراحة (CBCT) لتقييم حجم التلال قبل الجراحة وتصنيع شبكة التيتانيوم المخصصة (CTM). ثم إجراء فحص CBCT مباشرة بعد الجراحة ، يليه فحص CBCT ثان بعد 6 أشهر لقياس العرض والتحليل الحجمي. **النتائج**: أظهرت الدراسة أن الزيادة الأفقية للعظم في جميع الحالات كانت 1.213 ملم حيث كانت هناك زيادة في عرض العظم بعد العملية ولكن ليست كبيرة. تمت زيادة الزيادة الحجمية في كلا القوسين من مرحلة ما قبل الجراحة إلى مرحلة ما بعد الجراحة مع عدم وجود فرق كبير، حيث كانت القيمة المتوسطة للزيادة العظمية الحجمية في جميع الحالات 10.078 مم2. حققت القياسات مكاسب أكبر في الإناث مقارنة بالذكور ولكن مع عدم وجود فروق ذات دلالة إحصائية (أصبحت الكثافة خسارة بعد العمل الجراحي عند الذكور) وتوضح أنه لا يوجد ارتباط ذو دلالة إحصائية بين العمر والجنس والقوس مع التعرض لحجم الشبكة. **الاستنتاجات**: يمكن أن يكون استخدام سقالات شبكية من التيتانيوم مخصصة مع العظام الذاتية والطعم الطيني لزيادة الحافة السنخية فعالاً في تحقيق مكاسب العظام، وهناك العديد من القيود التي يجب معالجتها في الأبحاث المستقبلية.

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## INTRODUCTION

It is well established that tooth extraction is followed by a reduction of the buccolingual as well as apicocoronal dimensions of the alveolar ridge at the edentulous site [1]. Implant placement must be carefully planned based on prosthetic needs in order to achieve a good esthetic result. Thus, the concept of 'restoration-driven implant placement' has been developed to maximize function and aesthetics [2]. Therefore, the reconstruction of alveolar bone in the implant area is a key point in oral implantology. There are many clinical methods for alveolar bone defect recovery, including guided bone regeneration technique (GBR), onlay bone grafting, bone extrusion technique, bone splitting technique, and distraction osteogenesis. Due to its simple operation, low technical sensitivity, osteogenic stability, and multidirectional osteogenesis ability, GBR is one of the most commonly used techniques to repair alveolar bone defects [3]. The biological basis of this technique focuses on the “PASS” principles: primary closure, angiogenesis, space maintenance, and blood clot stability [4]. Barrier membranes are divided into two categories: absorbable and nonresorbable. Nonresorbable membranes are PTFE (expanded or high density) and titanium mesh [5]. The e-PTFE and resorbable membranes usually need to be covered by soft tissue or closed off first to stop soft tissue from growing in, bacteria getting inside, an infection, membrane migration, early membrane breakdown, and graft exposure [6]. Titanium mesh shows similar results for alveolar ridge deficiencies because of its excellent mechanical properties for bone graft stabilization, such as high strength, low density, plasticity, and low weight. In addition, its rigidity provides space maintenance and prevents contour collapse; its smooth surface decreases bacterial contamination; and its stability wards off graft displacement [7]. Titanium mesh has excellent biocompatibility, thus avoiding intolerance problems. The formation of a layer of $TiO_2$ (titanium dioxide) on the surface seems to stimulate the osteogenic activity of osteoblasts [8]. Despite the use of commercially available flexible titanium meshes for manually cutting, bending, and adjusting during surgical intervention, getting the final shape for containing the particulate graft is still a complex process for bone regeneration of the maxilla and mandible arches [9]. More recently, some authors have proposed the execution of custom-made meshes using CAD-CAM technology in order to have the device planned and produced before the surgery with rounded corners and margins, accurate fitting, and adaptation in situ, consequently having intrinsic stability [10]. A new study by Cucchi et al. also looked at volumetric augmentation with customized titanium mesh in 10 patients and found that 89% of the defects healed [11]. Dahlin et al. describe the observation of a layer of connective tissue, known as the pseudo-periosteum, above the newly formed bone. Many other authors reported similar tissue above augmented sites [12]. This tissue may play a role in preventing graft infection and resorption [10]. The present study aims to investigate the outcomes of bone regeneration using a customized titanium mesh scaffold covered with a combination of autologous bone transplant and xenograft for the restoration of complex jaw deformities.

## METHODS

### *Study design and setting*

The Department of Oral and Maxillofacial Surgery, College of Dentistry, conducted this clinical prospective interventional study from November 2022 to March 2024. The protocol for this study (protocol 692122) was approved by the Institutional Research Ethics Committee, and all enrolled patients signed informed consent after receiving information about the study's purpose and nature. The patients in this study needed ridge augmentation because they were missing one or more teeth in the atrophic maxilla and mandible area. The patients had to have a horizontal bone dimension (HBD) of 5 mm of alveolar width. A pre-surgical cone beam computed tomography (CBCT) scan was performed to evaluate pre-surgical ridge dimensions and for the customized titanium mesh (CTM) fabrication.

### *Inclusion criteria*

Healthy individuals, regardless of gender, who are over 18 years of age and are losing one or more teeth in the maxilla and/or mandible, as well as those who have horizontal bone loss in the alveolar ridge that necessitates three-dimensional bone regeneration for prosthetically guided implant placement (ridge width less than 5 mm), are willing to participate in the study and provide their consent.

### *Exclusion criteria*

Individuals who are medically compromised and have any conditions that could potentially impede normal healing, such as bleeding disorders, uncontrolled diabetes mellitus, current use of chemotherapy, bisphosphonate, or corticosteroids, radiotherapy of the head and neck within the past two years, psychiatric disorders, and ongoing pregnancy.

### *Radiological examination*

Three cone beam computed tomography examinations were performed to each patient in the Radiology Department. In order to assess the bone dimensions for virtual planning, we acquired a preoperative CBCT. In order to reduce any intra-examiner discrepancies, we conducted all measurements three times and recorded the mean value. In the axial view, the defected area is divided into two equal zones (in the event of multiple missing teeth) and all measurements are taken at the middle point (Z1, Z2) and the middle point (M) of the entire defected area. All measurements are conducted at the midpoint in the event of a single missing tooth, as illustrated in Figure 1.

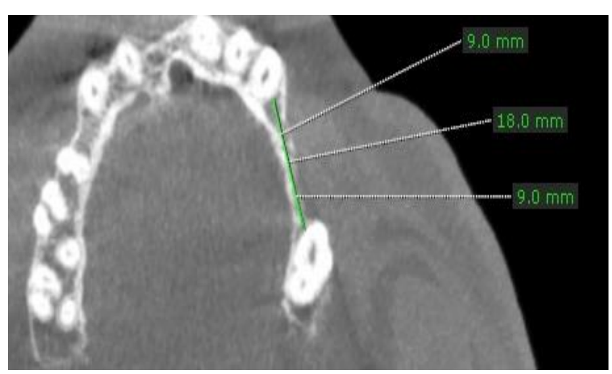


**Figure 1**: Axial view demonstrates (Z1, M, Z2) points.

The density, width, and ridge volume of the bone were evaluated. The ridge breadth was quantified at three distinct elevations. The patient's eligibility for the study is determined by measuring the apex of the alveolar ridge at the first level, approximately 5 mm apical to the crest ridge, and 10 mm apical to the crest ridge at the second and third levels, as illustrated in Figure 2.

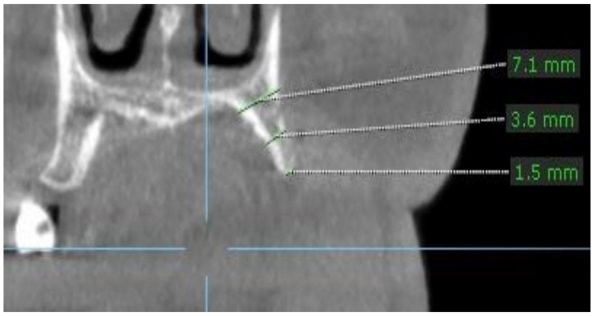


**Figure 2**: Preoperative CBCT reveal the available bone width at the Z1 point in three levels (0, 5, and 10) at the coronal view.

The area of the ridge was used to measure its volume, as the mesiodistal dimension was fixed. To operate it, merely click around the entire circumference of the bone using the "Area" measuring tool, as illustrated in Figure 3. A second CBCT scan was conducted to assess the vital structure immediately following surgery and to determine the ridge width as a baseline of data from the inside corner of the mesh in order to reduce the scattering effect of the mesh.


**Figure 3**: CBCT images of the ridge volume to measure the area of the defected segment at Z1 point preoperatively in the coronal view.

### *Surgical Procedure*

In order to mitigate the potential for additional oral contamination sources, the patient was draped in sterile surgical drapes prior to surgery. Immediately prior to anesthesia, the patient is instructed to gargle with 0.2% chlorhexidine mouth rinse for one minute and to apply 10% Povidone iodine to their facial skin. The midcrestal incision was extended intracranially, mesially, and distally, both buccally and orally. In order to facilitate angiogenesis in the regenerated bone, small surgical burs were employed to conduct vertical perforations in the local bone following flap reflection. A digital scale was used to measure the weight of a mélange of 30% autologous bone harvested with a scraper and 70% xenograft particles with the aspirated PRF until it became sticky bone. The grafting material was inserted into the titanium mesh and gently compressed. It was subsequently secured with self-tapping screws, as illustrated in Figure 4.

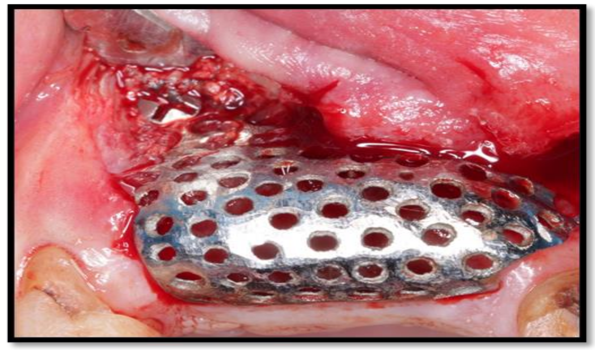

**Figure 4**: Titanium mesh and grafting material in situ and fixed with screws.

After periosteal releasing, absorbable periosteal mattres sutures were used to conduct sutures without tension. Subsequently, a monofilament Nylon 4/0 non-absorbable suture was used to close the wound at the flap's margin. The appropriate antibiotics were prescribed to the patients.

### *Follow up and data collection*

The third CBCT was conducted six months after the titanium mesh was removed. The CBCT machine (OP 3D Pro Kavo) was operated in coronal and sagittal views using the same software (OnDemand 3D Dental 1.0.10.746) and the same configuration protocol as described in the preoperative CBCT scan acquisition and data analysis. The assessment of volumetric bone gains and RBH, RBW, and bone density was conducted. A blinded examiner, who was not involved in the surgical interventions, recorded all outcomes and simultaneously used two laptops to adjust the axial view until the two images coincided as much as possible in the same mesiodistal width. This was done in order to ensure greater accuracy and standardization between pre- and postoperative CBCTs, depending on the similarity of the slices and the availability of landmarks.

### Statistical analysis

We used the Statistical Package for Social Science (SPSS version 22, Chicago, Illinois, USA) to describe, analyze, and display our data. When the percentage of predicted cell counts less than 5 surpasses 20%, use the Fisher's exact method to test the relationship between two qualitative variables. The two-independent sample t test is a parametric test for determining the statistical difference between two groups. Mann-Whitney U-test The U test compares the statistical differences in the mean rank of two independent groups. Repeated Measure One-Way Analysis of Variance (ANOVA) is a statistical test used to compare the differences between k-related averages. The Paired t-test is used to determine the differences between two related variables. A p-value less than 0.05 indicates statistical significance.

## RESULTS

Ten patients aged 35–55 years old (35.4±6.88) participated in this study: 7 males and 3 females, 7 cases in the maxillary arch, 3 cases in the maxilla, 5 cases in right and 5 cases on the left side, as illustrated in Table 1. Nine cases persist in the study, and one subject drops out.

**Table 1**: Patients distribution in relation to (age, gender, arch and side).

| Variables | | n(%) |
|---|---|---|
| Age (year) | ≤45 | 5(50) |
| | >45 | 5(50) |
| Gender | M | 7(70) |
| | F | 3(30) |
| Arch | Max. | 7(30) |
| | Mand. | 3(70) |
| Side | R | 5(50) |
| | L | 5(50) |

Eight cases of postoperative complications show early mesh exposure, and one case shows early exposure and numbness. Five cases show early exposure in ≤45 years and males, while three cases are in ≥45 years and females. There are 6 cases of early exposure in the maxilla and 2 cases in the mandible. The distribution of these postoperative complications among age, gender, and arch revealed no significant association, as shown in Table 2. The maxillary arch shows a width increase from preoperative to immediate and postoperatively, with no significant change, while the mandible shows a decrease from preoperative to immediate, followed by an increase postoperatively, as Table 3 illustrates. Table 4 shows the postoperative measurements of width, area, and bone density.

**Table 2**: Postoperative complications according to the age, gender, and arch

| Complication | | 1 n(%) | 2 n(%) | *p*-value* | Total n(%) |
|---|---|---|---|---|---|
| Age (year) | early exposure | 5(62.5) | 3(37.5) | 0.437 | 8(88.89) |
| | early exposure + numbness | 0(0.0) | 1(100) | | 1(11.11) |
| Gender | early exposure | 5(62.5) | 3(37.5) | 0.999 | 8(88.89) |
| | early exposure + numbness | 1(100) | 0(0.0) | | 1(11.11) |
| Arch | early exposure | 6(75) | 2(25) | 0.532 | 8(88.89) |
| | early exposure + numbness | 1(100 | 0(0.0 | | 1(11.11) |

Age, 1≤45y, 2≥45y, Gender, 1=Male, 2=Female, 1=Maxillary, 2=Mandible. * Fisher exact test.

All patients were examined radiographically by CBCT to assess the ridge width at three points (Z1, M, and Z2) at the crest of the ridge, 5 mm away from the crest and 10 mm away from the crest of the ridge. This study found a statistically non-significant increase in ridge width in the maxillary arch from preoperative to immediate and postoperative periods.

**Table 3**: Relation of ridge width gain (mm) according to arches

| Arch | | Pre | Imed. | Post | *p*-value (ANOVA) |
|---|---|---|---|---|---|
| Max. | Range | 0.40-0.22 | 2.09-7.34 | 2.99-8.33 | |
| | Mean±SD | 4.74±2.58 | 5.14±1.63 | 5.68±1.7 | 0.111 |
| Mand. | Range | 6.27-6.8 | 4.91-7.58 | 8.58-8.82 | |
| | Mean±SD | 6.54±0.37 | 6.247±1.89 | 8.70±0.17 | |

Max: maxillary arch, Mand: mandibular arch.

**Table 4**: Total mean measurements gain of (width, area and density)

| Parameter | Width | Area | Density |
|---|---|---|---|
| Range | -0.243-2.59 | -3.023-32.55 | -176.63-260.23 |
| Mean±SD | 1.21±1.03 | 10.08±12.09 | 23.20±133.3 |
| Median | 1.027 | 9.987 | 38.967 |
| Mean rank | 5 | 5 | 5 |

## DISCUSSION

GBR techniques are widely applied to treat the bone defects of the dental alveolar ridge [13]. Titanium meshes, with their mechanical stiffness and ability to maintain adequate space underneath, allow undisturbed osteogenesis, resulting in a predictable alveolar ridge augmentation in either localized or extended bone defects [14]. In the present research, the study patients ages ranged from 35 to 55 years, with a mean of 35.4±6.8 years. The male-to-female ratio was 7:3.

For instance, the preoperative ridge width in the maxillary arch was 4.739 mm, the immediate ridge width was 5.144 mm, and the postoperative ridge width was 5.680 mm. However, in the mandible, the ridge width decreased from preoperatively, with a mean value of 6.537 mm to immediate 6.247 mm. The cause of this decrease is unclear, and the postoperative ridge width increased to 8.700 mm without any significant difference. This could be due to the small sample size, as this study only included two mandible cases. In this study, the mean value of the horizontal bone gain in all cases was 1.213 mm, indicating an increase in bone width postoperatively but not significant. Regarding bone gain with titanium mesh, studies show bone gains in width of up to 5 mm and vertical gains of up to 7 mm. The horizontal gain was 1.88±1 mm, and the vertical gain was 4±1 mm. The obtained bone gain aligns with the planification, enabling us to place implants [15]. Both arches experienced a significant increase in volumetric gain from preoperatively to postoperatively, with a mean value of 10.078 mm$^2$ across all cases. Similarly, a retrospective study by Lizio *et al*. (2014) reported a mean vertical bone gain of 4.5 mm and a mean horizontal bone gain of 6.35 mm, which demonstrate a statistically significant increase in the volumetric bone gain [10]. The study by Ciocca *et al*. (2018) reported an even higher exposure rate of 66%, suggesting that this is a common complication associated with titanium mesh procedures [16]. In our study, we employed extensive periosteal scoring to enhance the flap's extensibility, aiming to achieve a tension-free wound closure that fully covers the extensively augmented bone defect. However, this approach compromised the flap's vascularity, resulting in marginal ischemia and a failure to heal, ultimately leading to partial mesh exposure. Corinaldesi *et al*. [17] assert that exposing the titanium mesh and stabilizing the biomaterial ensures regeneration and prevents superinfection, as the mesh pores play a crucial role in maintaining blood flow and promoting hygiene.

## Study limitations

The limitation of this study include a small sample size and did not include a control group to compare the results of the customized titanium mesh with other bone regeneration techniques.

## Conclusion

The utilization of customized titanium mesh scaffolds, in combination with autogenous bone and xenografts, has proven to be an effective method for enhancing bone mass in alveolar ridge augmentation. However, further investigation is required to overcome many constraints in this field.

## Conflict of interests

No conflict of interests was declared by the authors.

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The authors did not receive any source of fund.

## Data sharing statement

Supplementary data can be shared with the corresponding author upon reasonable request.

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