

A Method to Assess the Clinical Outcome of Ridge Augmentation Procedures

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Background: Alveolar ridge augmentation procedures are often needed prior to implant placement or prosthetic rehabilitation. The purpose of this study was to develop a quantitative method to assess the clinical outcome of such procedures.

Methods: Two volumetric methods, based on the volume difference between the pre- and postoperative ridge, were developed. Either a transparent vacuum stent material (method A) or a silicone impression material in a custom acrylic tray (method B) was used to make an impression of the postoperative stone cast. This impression was then filled with polyvinylsiloxane bite registration material (PBRM) and placed on the preoperative cast. The volume of PBRM at the site of the augmented ridge (corresponding to the achieved ridge volume increase, in ml) was measured gravimetrically. Two independent examiners used both methods, in random order, to assess the outcome of 6 diverse clinical cases. Triplicate measurements were made (method precision). Method accuracy was assessed by fabrication of metal castings (known volumes) applied on a preoperative cast to simulate an augmentation procedure.

Results: Intra- and inter-examiner reproducibility was high (intraclass correlation coefficients ≥ 0.84) for both methods. The volumetric measurements obtained by method B showed excellent correlation with the predetermined augmentation volumes ($r^2 = 0.99$; $y = 0.94x + 0.12$), in contrast to the measurements obtained by method A ($r^2 = 0.46$; $y = 0.43x + 1.37$).

Conclusions: The developed volumetric method (method B) is both precise and accurate in assessing the outcome of ridge augmentation. This simple, cost-effective, and easy to implement method should be helpful in clinical studies of ridge augmentation procedures. *J Periodontol* 2002;73:302-306.

KEY WORDS

Alveolar ridge augmentation; comparison studies; outcome assessment; process assessment.

Alveolar ridge augmentation is often necessary prior to implant placement or prosthetic rehabilitation. A variety of methods and materials have been used for implant placement, the most common being the use of autogenous bone grafts harvested from extraoral¹⁻⁴ or intraoral sites.⁵⁻⁸ Xenografts,^{9,10} allografts,^{11,12} and alloplastic grafting materials^{13,14} have also been used. Most recently, growth factors have been studied for this purpose.¹⁵⁻¹⁷ For pre- and postprosthetic ridge augmentation, soft tissue grafting procedures have also been used.¹⁸⁻²¹ Regardless of graft type (hard or soft tissue) or surgical technique, resorption of the augmented ridge over time has been consistently observed.^{1-5,15,17,19,21-23}

Whether individually or in combination, various methods have been used to evaluate longitudinally the outcome of ridge augmentation procedures, as well as the associated resorption process. These include radiographic measurements,^{1,3,5,22} visual interpretation,^{6,14,17,19} photographs,²⁴ bone sounding using periodontal probes,^{15,24} use of various types of calipers during surgery and re-entry or second stage surgery,^{7,23-26} evaluations using a fixation screw⁷ or a dental implant²⁷ as a reference, and laboratory volumetric analysis of casts by optical projection methods.^{21,28}

The purpose of the present study was to develop and validate a clinical method to measure the changes in volume of the alveolar ridge after ridge augmentation procedures. Two methods, based on measurement of the volumetric size dif-

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Table 1.
Case Distribution

| Case | Augmentation Sites [†] |
|------|---------------------------------|
| 1 | 18-20 |
| 2 | 12-15 |
| 3 | 2-5 |
| 4 | 29-31 |
| 5 | 18-20 |
| 6 | 23-26 |

[†] Corresponding tooth number.

ference between the pre- and post-operative ridge, were developed and tested.

MATERIALS AND METHODS

Experimental Design/ Volumetric Analysis

Six archival alveolar ridge augmentation cases, treated by hard tissue grafting, were used. For each case, 2 stone casts were available (pre- and post-operative; average healing time: 8 months). Case selection was made to represent both maxillary and mandibular sites, including anterior and posterior areas (Table 1).

For the first method (method A), the postoperative stone cast was used to fabricate a transparent vacuum stent.[§] After confirming the fit of the stent on the preoperative stone cast, polyvinylsiloxane bite registration material^{||} was placed into the stent at the location of the augmented alveolar ridge. The stent was then placed on the preoperative cast (Fig. 1). The bite registration material was allowed to set and was removed from the stent and excess material trimmed. The borders between the grafted area and the non-grafted preoperative area could be easily identified by the shape of the preoperative area and the thinness of the bite registration material. The material was then weighed and its volume calculated, based on its specific gravity. The volume of the material represented the change in volume of the augmented alveolar ridge.

For the second method (method B), a photopolymerized acrylic resin[¶] custom tray was fabricated on the postoperative cast. An impression of the post-operative cast was then made using a silicone material.[#] Separating medium^{**} was then applied onto the silicone and on the stone cast. Then the same bite registration material as used in method A was placed into the impression at the location of the augmented alveolar ridge. The tray, along with the silicone and the

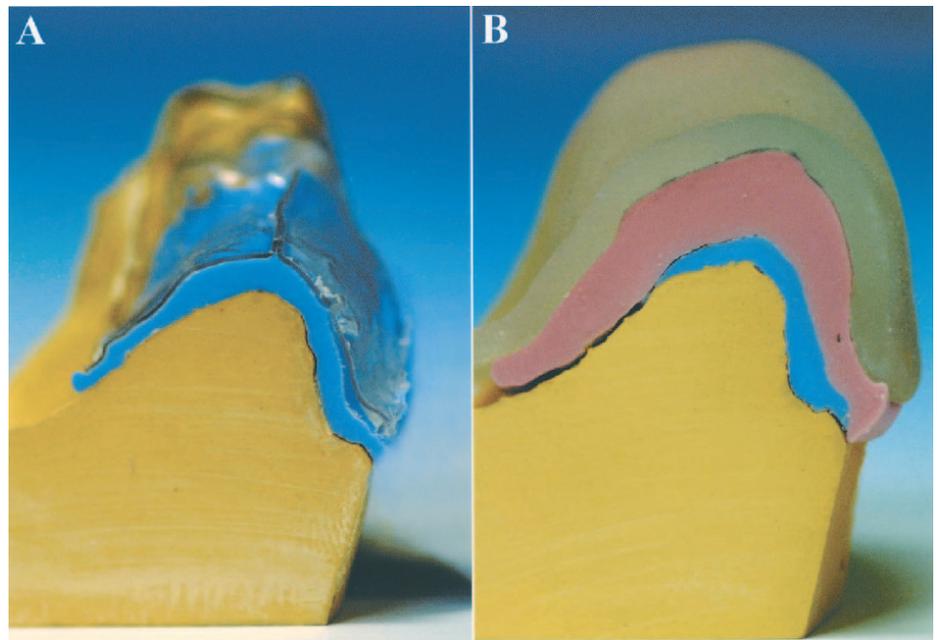


Figure 1.
Ridge augmentation assessment methods. Cross-section of a case as registered by method A (A) and method B (B).

bite registration material, was then seated on the pre-operative stone cast (Fig. 1). After allowing time for setting, the tray was removed and the excess bite registration material was trimmed. Similarly to method A, the volume was determined gravimetrically.

Method Reproducibility

Two independent examiners performed 3 separate measurements each with each of the 2 methods. The order between methods was randomly chosen for each of the 6 cases. Examiners were blinded regarding the results of previous measurements, and a minimum of 48 hours elapsed before the next set of measurements were made. For each set of triplicate measurements, the same matrix (vacuum stent or custom tray) was used.

Method Accuracy

A postoperative ridge was simulated on the edentulous area of a preoperative cast by applying 1 to 3 sheets of base plate wax.^{††} In this manner, 3 different volumes of simulated outcome were produced. The wax sheets were then cast in a chrome alloy.^{‡‡} Casting volumes were then calculated based on the specific gravity of the alloy.

[§] Ultradent Products Inc., S. Jordan, UT.

^{||} Exabite II NSD, GC America, Alsip, IL.

[¶] Triad, Dentsply International Inc, York, PA.

[#] Lab-putty, Coltene/Whaledent Inc, Mahawan, NJ.

^{**} Al-Cote, Dentsply International Inc, York, PA.

^{††} Tri-wax, Dentsply International Inc.

^{‡‡} Rexillum N.B.F., Jeneric/Pentron Inc., Wallingford, CT.

The 3 metallic specimens (simulations of a grafting procedure) were then placed on the preoperative cast. A minute amount of wax^{§§} was placed along the periphery of each metallic specimen to secure it during impression taking. Both method A and B were then applied for each of the 3 metallic specimens in order to assess the volume of the alveolar ridge augmentation. Two independent measurements for each method were made for each metallic specimen by a single blinded examiner. A minimum of 48 hours was required between each set of measurements.

Statistical Analysis

Descriptive statistics were expressed as mean ± standard deviation. Data were analyzed by analysis of variance (ANOVA) for repeated measures to determine the effect of examiner and method for volume determination. Post-hoc multiple comparison was performed when a significant effect was detected. Intra- and inter-examiner reproducibility was evaluated by intra-class correlation coefficient.^{29,30} Differences between replicate measurements (measurement 1 versus measurement 2, 1 versus 3, 2 versus 3) were analyzed by ANOVA for repeated measures to determine the effect of examiner and method. Correlations were examined by linear regression. Significance level for rejection of the null hypothesis was set at $\alpha = 0.05$.

RESULTS

Measured ridge augmentation volumes (ranging between 0.52 and 1.39 ml) were analyzed by ANOVA, which indicated no effect for method or examiner (data not shown). No significant interactions between independent variables existed.

Regardless of the method used, both intra- and inter-examiner reproducibility was excellent (intraclass correlation coefficients ≥ 0.84) (Table 2).

When the accuracy of the methods was assessed (Fig. 2), method B resulted in a significantly stronger correlation with the predetermined augmentation volumes ($r^2 = 0.99$; $y = 0.94x + 0.12$; $P < 0.0001$) as compared to method A ($r^2 = 0.46$; $y = 0.43x + 1.37$; $P = 0.046$).

Table 2.

Intra- and Inter-Examiner Reproducibility in Relation to Method for Ridge Volume Determination

| | Method A | Method B |
|------------------|----------|----------|
| Intra-Examiner 1 | 0.84* | 0.98* |
| Intra-Examiner 2 | 0.97 | 0.96 |
| Inter-Examiner | 0.95 | 0.98 |

* Intra-class correlation coefficients.

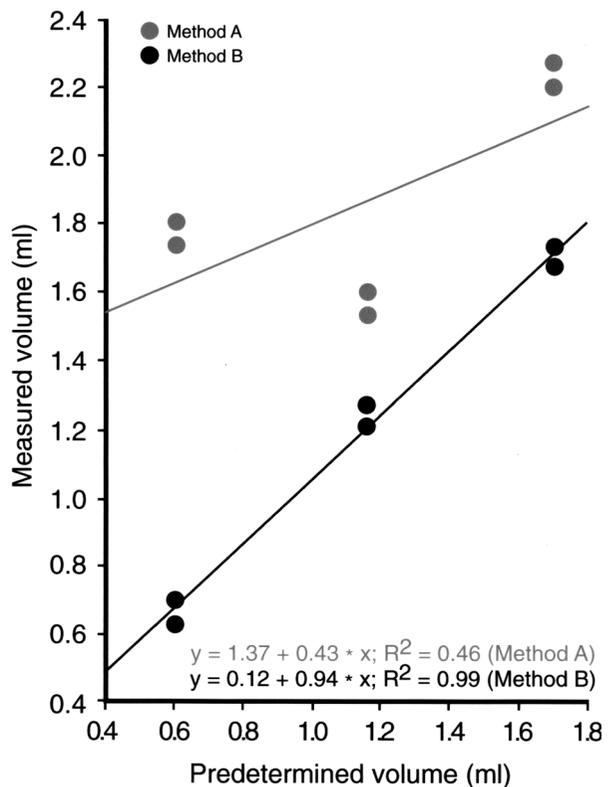


Figure 2.

Linear regression plot of predetermined (x-axis) versus measured (y-axis) ridge augmentation volume, by method.

Table 3.

Differences Between Replicate Measurements of Ridge Augmentation Volume

| Examiner | Method A | Method B |
|----------|--------------|--------------|
| 1 | 0.06 ± 0.11* | 0.03 ± 0.07* |
| 2 | 0.02 ± 0.06 | 0.05 ± 0.11 |

* Mean ± SD.

Table 3 provides differences between replicate measurements in relation to method for ridge volume determination and examiner. No significant effect on differences between replicate measurements was observed for any independent variable or their interactions.

DISCUSSION

The diversity in the reported alveolar ridge augmentation outcomes among the different studies may be attributed, at least in part, to the lack of a consistent method for measuring the volume of the augmented alveolar ridge.

§§ Kerr Co., Romulus, MI.

The present study evaluated 2 methods for assessing the clinical outcome of ridge augmentation procedures. Although both methods were highly reproducible, only method B was sufficiently accurate. The lack of accuracy for method A may be ascribed to the clinically-observed expansion of the stent material during the volume registration step. The rigidity of the custom tray-lab putty combination and resultant lack of distortion probably account for the high level of accuracy of method B. The method provides a 3-dimensional assessment of the achieved augmentation and measures the volume that the grafting procedure has added to the atrophic alveolar ridge.

Method B reported in this study is not without limitations. The biggest disadvantage is the lack of information regarding the quality of the tissue at the augmented site, since the calculated volume of the alveolar ridge augmentation may represent bony and/or soft tissue changes. Combining the method with radiographic analysis would help minimize this shortcoming in cases treated by hard tissue grafting. An additional limitation is that the method cannot be applied during a surgical procedure and probably should be avoided during the immediate postsurgical healing period. Use of this method would not be feasible in cases with significant tooth mobility, tooth movement (pathologic or orthodontic), or restorative modification(s) during the postoperative healing period under study. It has not yet been tested whether the developed method could be adapted to serve fully edentulous cases.

However, the developed method has several advantages when used in appropriate cases. It is non-invasive, simple, easily implemented in any clinical setting, cost-effective, harmless to the patient, and equally applicable to either hard- or soft-tissue ridge augmentation procedures.

A complicated optical projection method (Moiré) that makes use of pre- and postoperative casts appears to be the only other non-radiographic method that has been validated as accurate and precise in determining volumetric differences after ridge augmentation.^{21,28} Although the Moiré projection method is complex, time-consuming, and requires specialized equipment²¹ (hence costly and difficult to implement), it may be the only quantitative method useful for measurement of very small (50 mm³) volumetric changes after soft tissue procedures.

Among the various methods used for outcome assessment of hard tissue ridge augmentation procedures, radiographic evaluation is the most common one. Panoramic,^{1,3,5,13} cephalometric,^{2,4,5,22,25} and intraoral^{27,31} radiographs have been used for this purpose. The limitations of quantitative radiographic analysis by any of the above types of radiographs are 1) the 2-dimensional representation of three-dimensional

structures and the consequent loss of information regarding one dimension of the ridge; 2) the need for standardized projection geometry; and 3) the exposure of patients to ionizing radiation. Computed tomography (CT) scans, which have also been used for evaluation of ridge augmentation procedures,¹⁵ may provide information on all 3 dimensions. However, the high cost of this procedure limits its application. The use of any type of radiographic outcome assessment method at frequent time intervals, during a longitudinal study, may represent a significant health concern for the participants.

In lieu of or in conjunction with radiographs, several investigators have used direct measurements; e.g., using calipers or periodontal probes.^{7,8,15,23,24,26,32} Although several methods have been proposed to standardize the measuring process,^{7,15,16,23,24} there appears to be no data regarding the reproducibility or accuracy of such direct methods. The main limitation of these methods is that they can be used only during first stage or second stage/re-entry surgery. When such methods are designed or adapted for use between (or after) surgical procedures, they require local anesthesia.³²

Visual interpretation of direct clinical observations,^{6,14,17,19} or clinical photographic records²⁴ has also been used to assess the outcome of alveolar ridge augmentation procedures. These methods, although attractive because of their simplicity, are prone to subjective estimation that lacks the reproducibility required for rigorous comparisons within or between studies.

In summary, a simple, easy to implement, reproducible and accurate clinical method (method B) has been developed to assess the outcome of ridge augmentation procedures.

ACKNOWLEDGMENTS

The authors thank Mr. Gary Hill, CDT for technical assistance during the casting procedure of the metallic specimens; Dr. G.J. Zimmerman for expert statistical advice; Mr. Neil Jessop for laboratory assistance; Mr. R. Tinker and Mr. R. Cross for graphic and photographic support, respectively; and Dr. M.B. Lee for helpful comments on the manuscript. This study was supported by the Loma Linda University School of Dentistry.

REFERENCES

1. Baker RD, Terry BC, Davis WH, Connole PW. Long-term results of alveolar ridge augmentation. *J Oral Surg* 1979; 37:486-489.
2. Freihofer HP, Hoppenreys TJ. Mandibular ridge augmentation by visor osteotomy combined with a subperiosteal rib graft. *J Maxillofac Surg* 1986;14:301-307.
3. Vermeeren JIJF, Wismeijer D, van Waas MAJ. One-step reconstruction of the severely resorbed mandible with onlay bone grafts and endosteal implants. A 5-year follow-up. *Int J Oral Maxillofac Surg* 1996;25:112-115.
4. Verhoeven JW, Cune MS, Terlou M, Zoon MA, de Putter

- C. The combined use of endosteal implants and iliac crest onlay grafts in the severely atrophic mandible: a longitudinal study. *Int J Oral Maxillofac Surg* 1997;26:351-357.
5. Jensen J, Sindet-Pedersen S. Autogenous mandibular bone grafts and osseointegrated implants for reconstruction of the severely atrophied maxilla: A preliminary report. *J Oral Maxillofac Surg* 1991;49:1277-1287.
 6. Misch CM, Misch CE, Resnik RR, Ismail YH. Reconstruction of maxillary alveolar defects with mandibular symphysis grafts for dental implants: A preliminary procedural report. *Int J Oral Maxillofac Implants* 1992;7:360-366.
 7. Buser D, Dula K, Hirt HP, Schenk RK. Lateral ridge augmentation using autografts and barrier membranes: A clinical study with 40 partially edentulous patients. *J Oral Maxillofac Surg* 1996;54:420-432.
 8. Raghoobar GM, Batenburg RH, Vissink A, Reintsema H. Augmentation of localized defects of the anterior maxillary ridge with autogenous bone before insertion of implants. *J Oral Maxillofac Surg* 1996;54:1180-1185.
 9. Hislop WS, Finlay PM, Moos KF. A preliminary study into the uses of anorganic bone in oral and maxillofacial surgery. *Br J Oral Maxillofac Surg* 1993;31:149-153.
 10. Callan DP, Rohrer MD. Use of bovine-derived hydroxyapatite in the treatment of edentulous ridge defects: a human clinical and histologic case report. *J Periodontol* 1993;64:575-582.
 11. Wolford LM, Epker BN. The use of freeze-dried bone as a biologic crib for ridge augmentation. A preliminary report. *Oral Surg Oral Med Oral Pathol* 1977;43:499-505.
 12. Allard RH, Lekkas C, Swart JG. Autologous versus homologous bone grafting in osteotomies, secondary cleft repairs and ridge augmentations: A clinical study. *Oral Surg Oral Med Oral Pathol* 1987;64:269-274.
 13. Block MS, Kent JN. Long-term radiographic evaluation of hydroxylapatite-augmented mandibular alveolar ridges. *J Oral Maxillofac Surg* 1984;42:793-796.
 14. Salyer KE, Hall CD. Porous hydroxyapatite as an onlay bone-graft substitute for maxillofacial surgery. *Plast Reconstr Surg* 1989;84:236-244.
 15. Howell TH, Fiorellini J, Jones A, et al. A feasibility study evaluating rhBMP-2/absorbable collagen sponge device for local alveolar ridge preservation or augmentation. *Int J Periodontics Restorative Dent* 1997;17:124-139.
 16. Barboza EP, Duarte ME, Geolas L, Sorensen RG, Riedel GE, Wikesjö ÜME. Ridge augmentation following implantation of recombinant human bone morphogenetic protein-2 in the dog. *J Periodontol* 2000;71:488-496.
 17. Tatakis DN, Koh A, Jin L, Wozney JM, Rohrer MD, Wikesjö ÜME. Peri-implant bone regeneration using recombinant human bone morphogenetic protein-2 in a canine model: A dose-response study. *J Periodont Res* 2002; in press.
 18. Seibert JS. Reconstruction of deformed, partially edentulous ridges, using full thickness onlay grafts. Part I. Technique and wound healing. *Compend Contin Educ Dent* 1983;4:437-453.
 19. Allen EP, Gainza CS, Farthing GG, Newbold DA. Improved technique for localized ridge augmentation. A report of 21 cases. *J Periodontol* 1985;56:195-199.
 20. Miller PD Jr. Ridge augmentation under existing fixed prosthesis. Simplified technique. *J Periodontol* 1986;57:742-745.
 21. Studer SP, Lehner C, Bucher A, Scharer P. Soft tissue correction of a single-tooth pontic space: A comparative quantitative volume assessment. *J Prosthet Dent* 2000;83:402-411.
 22. Mercier P, Zeltser C, Cholewa J, Djokovic S. Long-term results of mandibular ridge augmentation by visor osteotomy with bone graft. *J Oral Maxillofac Surg* 1987;45:997-1004.
 23. Widmark G, Andersson B, Ivanoff CJ. Mandibular bone graft in the anterior maxilla for single-tooth implants. Presentation of surgical method. *Int J Oral Maxillofac Surg* 1997;26:106-109.
 24. Barboza EP. Clinical and histologic evaluation of the demineralized freeze-dried bone membrane used for ridge augmentation. *Int J Periodontics Restorative Dent* 1999;19:601-607.
 25. Zins JE, Whitaker LA. Membranous versus endochondral bone: implications for craniofacial reconstruction. *Plast Reconstr Surg* 1983;72:778-785.
 26. Parodi R, Carusi G, Santarelli G, Nanni F. Implant placement in large edentulous ridges expanded by GBR using a bioresorbable collagen membrane. *Int J Periodontics Restorative Dent* 1998;18:266-275.
 27. von Arx T, Walkkamm B, Hardt N. Localized ridge augmentation using a micro titanium mesh: A report on 27 implants followed from 1 to 3 years after functional loading. *Clin Oral Implants Res* 1998;9:123-130.
 28. Studer SP, Sourlier D, Wegmann Ü, Scharer P, Rees TD. Quantitative measurement of volume changes induced by oral plastic surgery: Validation of an optical method using different geometrically-formed specimens. *J Periodontol* 1997;68:950-962.
 29. Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. *Psychological Bulletin* 1979;86:420-428.
 30. Fleiss JL. *The Design and Analysis of Clinical Experiments*. New York: John Wiley and Sons, Inc; 1986;17-32.
 31. Sindet-Pedersen S, Enemark H. Mandibular bone grafts for reconstruction of alveolar clefts. *J Oral Maxillofac Surg* 1988;46:533-537.
 32. Buser D, Bragger Ü, Lang NP, Nyman S. Regeneration and enlargement of jaw bone using guided tissue regeneration. *Clin Oral Implants Res* 1990;1:22-32.
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Accepted for publication September 18, 2001.