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Evaluation of Maxillary Sinus Floor Augmentation on Digital Panoramic Radiographs with an Image Manipulation Programme after Simultaneous or Staged Dental Implant Insertion*

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Abstract: Sinus floor augmentation is an effective method to regain bone height for the successful insertion of dental implants into the posterior maxilla. The aim of the study was to evaluate the behaviour of augmentation material following simultaneous or staged dental implant insertion, as visible on digital panoramic radiographs using the GNU Image Manipulation Program (GIMP). We evaluated one-stage (group 1) or two-stage (group 2) maxillary sinus floor augmentation procedures in 19 patients, using a high temperature-treated bovine porous hydroxyapatite material. Digital panoramic radiographic measurements were captured pre-operatively in both groups, pre-implant insertion in group 2, and immediately postoperatively and 6 months postoperatively in both groups. Forty parallel-walled bone-level implants were placed in a one-stage (n=18) or two-stage (n=22) protocol, with a mean residual bone height of 4.9±1.8 mm and survival rate of 100%. Mean bone height increased by 8.6±1.6 mm immediately post-implantation and by 7.9±1.7 mm after 6 months. Mean distal and mesial bone losses after abutment connection were 0.42±0.24 mm and 0.34±0.27 mm, respectively. No significant intergroup or intragroup differences between simultaneous and staged dental implant procedures were found. Our results show that the histogram tool in GIMP is useful for documentation of the area of the augmentation material used in maxillary sinus floor augmentation.

Keywords: Dental Implants; Radiographic Image Interpretation, Computer-Assisted; GNU Image Manipulation Program (GIMP), Sinus Floor Augmentation

Introduction:

Dental implants are widely used and have a good long-term survival rate (E. Jung *et al.*, 2012; Pjetursson *et al.*, 2012). Further, maxillary sinus floor augmentation is a reliable method for increasing bone height in the posterior maxilla (Del Fabbro *et al.*, 2008; Danesh-Sani *et al.*, 2016), and can be performed via either of two approaches; external sinus lift (lateral access) (Boyne and James, 1980) or internal sinus lift (transalveolar access) (Summers, 1994), with or without use of augmentation material (Silva *et al.*, 2016). When an augmentation material is required, an allograft, alloplastic material, or xenograft can be used (Esposito *et al.*, 2014) to avoid the disadvantages of autogenous bone, which include increased morbidity, limited availability, and high volumetric change (Papageorgiou *et al.*, 2016; Wu *et al.*, 2016). Using lateral access, closure of the lateral window with a membrane and fixation with tension-free seams after augmentation is recommended (Garg and Quinones, 1997; Wallace and Froum, 2003; Suarez-Lopez Del Amo *et al.*, 2015).

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Dental implants can be inserted in two stages, whereby a 4–6-month healing period is allowed between sinus floor augmentation and insertion of the implant. However, this strategy has some disadvantages, including a long wait time until final prosthetic restoration, a need for two surgical procedures, and the expense for patients (Al-Nawas and Schiegnitz, 2014; Esposito *et al.*, 2014). A one-stage surgical technique whereby the implant is inserted immediately after the surgical sinus lift procedure in one sitting has been introduced as a more effective treatment. No differences in implants placed using a one-stage or two-stage technique have been observed (Esposito *et al.*, 2014; Felice *et al.*, 2014). However, the risk of implant failure has been reported to be higher if there is a residual bone height below the maxillary sinus of 1–3 mm when a one-stage procedure is performed (Felice *et al.*, 2014).

In many studies of maxillary sinus floor augmentation techniques and implant placement, histological and histomorphometric analysis of the newly formed bone has required a bone biopsy to be taken preoperatively (Danesh-Sani *et al.*, 2016). However, digital panoramic radiography, computed tomography, and/or cone beam computed tomography (CBCT) can now be used for non-invasive measurement of augmentation status before and after implantation (Shanbhag *et al.*, 2014; Danesh-Sani *et al.*, 2016). The market for CBCT has expanded markedly in recent years (Jacobs and Esposito, 2016). However, the radiation burden of CBCT is considerably higher than that of conventional two-dimensional (2D) radiography (Harris *et al.*, 2012), and users of CBCT are heavily dependent on the manufacturer because the system is essentially a closed one (Friedland and Metson, 2014). Further, a method for assessment of change in the behaviour of the augmentation material that is easy to perform in routine clinical practice using digital panoramic radiography has yet to be established.

Accurate quantification of bone regeneration on digital radiography images is now possible using the GNU Image Manipulation Program (GIMP 2.8.18), which is freely available for analysis of digital images (Schonberger *et al.*, 2010). GIMP contains several tools that are useful for enhancement and investigation of features seen on panoramic images (alyona; Kim TG, Lee YS, Kim YP, Park YP, Cheon MW, 2014; 22: 361–368; Carolina Sparavigna, 2015), in particular changes in alveolar bone density around dental implants (Ramachandran *et al.*, 2016).

The aim of this study was to examine digital panoramic radiographs using the histogram tool of GIMP for changes in the porous hydroxyapatite material used in one-stage and two-stage sinus floor augmentation procedures during the initial healing period (up to 6 months; Delilbasi and Gurler, 2013).

Material and Methods

Patients

The patient database at the Centre for Oral and Maxillofacial Surgery, Danube Private University, Krems, Austria, was retrospectively reviewed to identify all sinus floor augmentation procedures performed from 2013 to 2015. These procedures were then classified into two groups, according to whether sinus floor augmentation and implantation were undertaken simultaneously (one-stage technique, group 1) or in separate sessions (two-stage technique, group 2). Digital panoramic radiography (Orthophos SL 3D; Dentsply Sirona, Himmelreich, Austria) was performed in all patients prior to the surgical procedures being undertaken. All patients were then informed verbally and in writing about the risks, potential side effects, alternative treatment methods available, and the consequences of not undergoing surgery. By signing a formal anamnesis questionnaire, the patients agreed the use of their data in this study which were conducted according to the World Medical Association (WMA) Declaration of Helsinki – Ethical Principles for Medical Research. Further the study protocol was approved by the central Ethical Review Board of the federal state of Lower Austria (approval number GS4-EK-4/451-2017).

The study inclusion criteria were as follows: availability of preoperative digital panoramic radiographs (groups 1 and 2); availability of digital panoramic radiographs immediately after implantation (group 1); availability of digital panoramic radiographs 6 months after sinus floor augmentation and prior to implantation (group 2); and availability of digital panoramic radiographs 6 months after implantation (groups 1 and 2).

Twenty-three sinus floor augmentation procedures performed in 19 patients (six women, 13 men; age range 31–68 years) were eligible for inclusion in the study. Thirteen surgical procedures involved the left side, 10 involved the right side, and three patients underwent bilateral sinus floor augmentation. The medical history was unremarkable in 12 patients; in the remaining seven patients, the history included medical treatment for hypothyroidism (n=2) or hyperthyroidism (n=1), documented hypertension (n=2), penicillin allergy (n=2), antidepressant therapy (n=1), and asthma (n=1).

Surgical protocol

All the surgical procedures were performed by the same surgeon (DT) during the study period. Prior to each surgical procedure, oral disinfection was performed by rinsing with chlorhexidine-digluconate

solution 2% (GlaxoSmithKline Pharma, Vienna, Austria) for 1 minute. Surgery was performed under local anaesthesia using Ultracain D-S Forte (Sanofi, Vienna, Austria) or 2% Xylocaine Dental with epinephrine 1:50,000 (Dentsply Sirona). In both groups, an alveolar crest incision was performed, followed by elevation of a full-thickness flap to expose the posterior and lateral maxillary area and creation of a lateral bone window using diamond burs (Komet Dental, Lemgo, Germany). The Schneiderian membrane was elevated carefully using conventional sinus lift instruments (Hu-Friedy Mfg. Co., LLC. Tuttlingen, Germany) while taking care to avoid perforating the membrane. If a perforation did occur, the elevation was extended in all directions, and the defect in the sinus membrane was covered using a fibrinogen-thrombin-collagen patch (TachoSil®; Takeda, Linz, Austria). This membrane was applied underneath the Schneiderian membrane to prevent dislocation of the grafting material.

The bone substitute material (Endobon® Xenograft Granules; Zimmer-Biomet, Palm Beach Gardens, FL, USA) was rehydrated in sterile saline solution and placed into the newly created space between the fibrinogen-thrombin-collagen membrane and the sinus floor. When the one-stage technique was used, the implant positions were marked with a round bur, and drilling for site preparation followed the surgical protocol recommended by Zimmer-Biomet for a parallel-walled bone-level implant (T3 [n=2], Osseotite Certain 2 [n=2], T3 Non-Platform switched [n=14]). All implants demonstrated good primary stability and a healing cap was used. A second membrane was placed on the bone substitute material exposed on the lateral aspect of the sinus. The mucoperiosteal flap was positioned and sutured using saliva-proof polypropylene single sutures (Perma Sharp 4.0 or 5.0; Hu-Friedy), and then allowed to heal for 3 months. A panoramic radiograph was taken preoperatively as a radiological control. When a two-stage technique was used, a standard implant (T3 [n=9] or T3 Non-Platform switched implant [n=13]) was inserted and a panoramic radiograph was taken as a radiological control at the end of the 6-month healing period.

All patients received amoxicillin/clavulanic acid 1 g orally twice daily or clindamycin 300 mg orally three times daily for 7 days as antibiotic prophylaxis, and were advised to avoid sneezing and to use a nasal spray when required. A nonsteroidal anti-inflammatory agent was prescribed for analgesia during the week following surgery. All patients were reviewed and had their sutures removed after 10–12 days. No postoperative antimicrobial rinses were prescribed. Mild postoperative oedema and surgical wound pain were noted. No infections or other complications were recorded.

Implants and prosthetic technique

Bone-level parallel wall implants (T3 parallel wall implant, Osseotite Certain 2 Implant and T3 Non-Platform switched parallel wall implant; Zimmer-Biomet) were inserted, using a one-stage or two-stage technique. Of 40 implants installed, 26 were 3.25 mm in diameter, one was 4.0 mm in diameter, and 13 had a mean diameter of 4 mm with a mean Platform switch diameter of 3 mm (Table 1). Four patients underwent bilateral sinus surgery and 15 patients underwent a unilateral procedure. In all cases, long implants (8.5, 10, and 11.5 mm) were used according to the amount of newly formed bone at the site of the implant. Routine prosthetic procedures were undertaken after the 6-month healing period. In 15 cases, a single crown restoration was connected to the implant and in 25 cases a bridge restoration was performed. All restorations were screw-retained; 12 constructions were metal/resin crowns and 28 were zirconium/ceramic crowns. The access holes through the occlusal surfaces were closed with composite fillings (G-aenial anterior/posterior; GC Europe, Leuven, Belgium).

Radiographic reference lines

GIMP is a free open-source software application used for processing images and free-form drawing (Carolina Sparavigna, 2015; Requena-Mendez *et al.*, 2015). Using this software, it is possible to analyse digital panoramic radiographs. For the measurements taken in this study, the original digital panoramic radiographs were exported without compression from Sidexis 4 imaging software (Dentsply Sirona) as tagged image file format files (Varma, 2012). During this process, all patient data were anonymised by the removal of patient data (DICOM; Digital Imaging and Communications in Medicine).

The radiographic reference lines are shown in colour in Figure 1. These reference lines are the same as those used in the studies by Si et al. (Si *et al.*, 2013; Si *et al.*, 2016). First, the implant axis {a} is drawn in green. The next two lines ({e} and {b}) are rotated by 90º from line {a} and pushed to the end points of the implant. The jaw is drawn in red (mesial {cm}, distal {cd}). The blue lines {dd} and {dm} are, respectively, mesial and distal to the bony sinus floor. The apical bone line after sinus augmentation is marked as{f}.

Standard radiographic evaluation

The radiographs were selected from the database at the Centre for Oral and Maxillofacial Surgery, University of Dental Medicine and Oral Health, Danube Private University, Krems, Austria. During the study period, the same operator acquired all the radiographs taken in our dental department and all patients were positioned with the head oriented in the Frankfurt horizontal plane parallel to the floor. All

radiographs were acquired using a 2D/3D hybrid X-ray unit (Orthophos SL 3D). The radiographic settings included a digital cadmium-telluride sensor with direct conversion sensor technology measuring 146 mm × 6 mm with a resolution of 100 µm/pixel, a tube voltage of 60–90 kV, and a current of 3–16 mA, with 14.4 s of exposure time and an effective (Ludlow) dose for high definition of 57–273 µSv.

The digital panoramic radiographs were used to obtain the following measurements: (1) the height of the residual bone at each implant site (RBH); (2) the height of the newly formed bone in the maxillary sinus after 6 months; and (3) the marginal bone-level changes around each implant. The distance from the shoulder of the implant to the first bone-to-implant contact (DIB) was measured. The time of the abutment connection was set as the baseline for measurement of the distance from the implant shoulder to the DIB. If a vertical bone defect was observed, the most apical level of the defect was measured.

As shown in Figure 2, the following values were measured:

- the residual bone height (RBH) as an average measured by mesial (RBH_m) and distal (RBH_d); the distance from the intersection implant to {cm} to {dm} or intersection of the implant with {cd} to {dd} parallel to {a}
- the distance from the intersection {ae} to the apical {af} parallel to {a}
- the implant length, measured from {b} to {e} parallel to {a}
- the implant protrusion (IPL) as an average measured by mesial (IPL_m) and distal (IPL_d); the distance from the intersection implant to the {dm} to {e} and intersection implant with {dd} to {e} parallel to {a}
- apical bone height as the distance between {e} and {f} measured on {a}
- the crestal bone level (CBL) as an average measured by mesial (CBL_m) and distal (CBL_d); the distance from the intersection implant to {cm} to {b} and intersection of the implant with {cd} to {b} parallel to {a}
- The bone growth to the implant. The sum of IPL of the initial position and the apical bone height of the respective measurement.

Evaluation of radiographic area

The original digital panoramic radiography image was entered into the GIMP and magnified, as shown in the upper panel of Figure 1. In this manner, using the tool "free choice", the newly gained area could be framed and displayed in yellow {f}. Applying the "histogram" tool, it was possible to calculate and display the area with a certain number of pixels. Because of slight changes in patient positioning during multiple recordings, the distortion of the image had to be subtracted first by taking the inserted implants as a reference. If multiple implants were present, only the implant situated closest to the mesial aspect was taken as a reference. By means of two green lines {b/e} parallel to {a}, the implant could be displayed in its full length. Using the "measuring tape" tool, the distance between the intersections {ab} and {ae} could be measured and expressed in the form of a pixel value.

Based on this value and the original length (mm) of the implant, it was possible to determine a factor on each digital panoramic radiograph. Starting from this factor, the newly gained area of the bone replacement material could be determined by simply converting the pixel number in mm^2 (factor and area calculation; Figure 2). The digital panoramic radiographs taken immediately and 6 months after the implantation procedure were also separately inserted into the GIMP. A separate factor was calculated for digital panoramic radiographs taken at each of these two time points.

Statistical analysis

All study data were tested for normality using the Kolmogorov-Smirnov adaptation test. Data were compared between the groups using the *t*-test for inter-rater reliability. All data are shown as the mean and standard deviation. Statistical analysis was performed using SPSS version 23.0 software (IBM Corp., Armonk, NY, USA). A p-value of <0.05 was considered to be statistically significant.

RESULTS

Clinical findings

No implants were lost during the study period (mean 26.1 ± 9.7 months). A perforation of the sinus mucosa occurred during sinus floor augmentation in one patient in group 2 (1/23, 4.4%). No complications occurred during the healing period. One patient in group 2 developed emphysema after the sinus lift, which resolved after 1 week. No crowns showed loosening of their assembly screws or other complications during follow-up.

Radiological findings

The mean height of the residual bone at the implant site was 5.1 ± 2.3 mm in group 1 and 4.8 ± 1.2 mm in group 2. The mean height of the residual bone when groups 1 and 2 were combined was 4.9 ± 1.8 mm. Six months later, the mean height of the newly formed bone in the maxillary sinus was 7.7 ± 1.3 mm in group 1 and 8.0 ± 1.5 mm in group 2. The mean height of the newly formed bone in the maxillary sinus when groups 1 and 2 were combined was 7.9 ± 1.7 mm. The distance from the implant shoulder to the most coronal bone-to-implant contact (DIB) was

measured at the time of the abutment connection; the mean distal and mesial bone loss was 0.42 ± 0.24 mm and 0.34 ± 0.27 mm, respectively.

Statistical findings

When groups 1 and 2 were combined, there was no statistically significant difference between the mean area measured immediately after implantation and that measured 6 months later (82.4 ± 33 mm^2 vs 79.2 ± 30.7 mm^2; p=0.092, *t*-test). There was also no statistically significant difference between groups 1 and 2 with regard to the mean areas measured immediately after implantation (88.9 ± 33.8 mm^2 vs 76.5 ± 32.5 mm^2; p=0.379, *t*-test) or at 6 months after implantation (85.2 ± 30.7 mm^2 vs 73.7 ± 30.9 mm^2; p=0.372, *t*-test). Figure 3 shows the area measurements as a box-and-whisker plot.

Discussion

Sinus floor augmentation is a necessary standard pre-prosthetic surgical procedure for insertion of dental implants in patients with advanced atrophy of the maxillary alveolar ridge (Danesh-Sani *et al.*, 2016), and use of grafting materials for this purpose is predictable and reliable (Silva *et al.*, 2016).

The lateral window technique requires a minimum residual bone height of 4–5 mm as a threshold for simultaneous sinus floor elevation to obtain sufficient primary stability of the implant without disturbing the osseointegration process (Del Fabbro *et al.*, 2008), which is easier to obtain after two treatment sessions. However, the reliability of a one-step method and the behaviour of the augmentation material after implantation are of considerable interest. A healing period of approximately 6 months has been the standard of care for implants placed with simultaneous sinus floor elevation in the past 25 years (Checchi *et al.*, 2010; Kahnberg *et al.*, 2011; Rasmusson *et al.*, 2012), and meets the demands for a short treatment time and reliable results. However, there is always the question of how to document and measure the results of treatment so that any postoperative changes in the area of the augmentation material can be identified.

In the present study, we sought to find a way of obtaining reliable measurements of bone augmentation that would be both easy to perform and simply integrated into routine clinical practice.

Standard non-invasive methods for radiological measurement of augmentation status before and after dental implantation include digital panoramic radiography, computed tomography, and CBCT (Shanbhag *et al.*, 2014; Danesh-Sani *et al.*, 2016). With the ongoing technological improvements in the quality of radiography, more detailed 2D panoramic images have become available. Because of the lower costs, 2D radiography still seems to be the standard for many practitioners for documentation and follow-up purposes.

In 2015, Sparavigna recommended use of the GIMP for enhancement of panoramic radiographs (Carolina Sparavigna, 2015). There are numerous fields of application for computer graphic software programmes like GIMP or Adobe Photoshop (Adobe Systems Inc., San Jose, CA, USA). These programmes have several tools that can be useful for investigation of details of panoramic images (Kim TG, Lee YS, Kim YP, Park YP, Cheon MW, 2014; 22: 361–368). Processing of the images can increase the visibility of details by simply adjusting the brightness and contrast or using other methods available in the programme tools (Solomon, 2009; Carolina Sparavigna, 2015). One of the most commonly used tools is the histogram function which analyses differences in grayscale values (Hoppe *et al.*, 2013; Carolina Sparavigna, 2015; Meshram *et al.*, 2015).

Changes in alveolar bone density around a dental implant seem to be particularly amenable to investigation using these programmes (Ramachandran *et al.*, 2016). Use of GIMP has also been reported in several other dental indications. Alzahrani et al. examined the influence of platelet-rich fibrin on post-extraction socket healing (Alzahrani *et al.*, 2017). Further, the success of osseous regeneration after enucleation of cystic lesions can be examined (Meshram *et al.*, 2015). In forensic odontology, the need to estimate the age of living adults has increased, and panoramic and periapical radiographs have been used to evaluate the correlation between the tooth and pulp to facilitate estimation of dental age (Azevedo *et al.*, 2015). In a cariology study, bitewing radiographs were analysed to quantitatively determine the grayscale value of the affected dentin beneath restorations and compare it with that of healthy dentin (Kielbassa *et al.*, 2017). External and internal infiltration of resin into natural proximal subsurface carious lesions was analysed using confocal laser microscopy and GIMP as a dedicated image manipulation programme (Kielbassa *et al.*, 2017). These programmes can also be used for shade-taking, shade analysis, and creation of the final restoration (McLaren *et al.*, 2017), or to ascertain tooth colour, e.g., when assessing the effectiveness of bleaching (Zanjani *et al.*, 2015).

A number of studies in medicine have also used GIMP for measurement purposes and to improve the ability to recognise pathological changes, in particular for robust and serial evaluation of breast radiographs. GIMP can also be used to evaluate changes in the echogenicity of tumour tissue after

chemotherapy (Lin *et al.*, 2013).

The quality of panoramic radiographs improved when the Retinex filter was utilised in the GIMP software (Carolina Sparavigna, 2015) In 2009, Solomon compared GIMP with Adobe Photoshop, and concluded that both programmes are similar in their processing abilities and that a good processing programme need not be expensive (Solomon, 2009). Therefore, we elected to use GIMP in our research.

In this study, area measurements were analysed using the histogram tool in the image analysis software. The mean pixel grayscale values obtained with the aid of the histogram range from 0 (completely black appearance resulting from the total absence of pixels) to 255 (completely white appearance resulting from the presence of the maximum possible pixel density). Referenced on the original implant length (mm), it was possible to determine a specific factor for each panoramic radiograph. Starting from this factor, the newly gained area of the bone replacement material could be determined by simply converting the pixel number to mm^2. Using this method, it was easy to measure the initial bone height and the augmented area in regard to the implants and the changes in the augmentation material in respect to bone formed in the maxillary sinus after 6 months. Distal and mesial crestal bone loss could also be observed. Alzahrani et al. used a similar approach in their study of the effect of platelet-rich fibrin on post-extraction socket healing (Alzahrani *et al.*, 2017), in which they measured the surface area of the extraction sockets using Adobe Photoshop according to the method described by Chiapasco et al. (Chiapasco *et al.*, 2000). First, the radiographic images were transferred to grayscale tonalities of 256. The extraction socket was then marked and converted to a histogram and finally calculated in millimetres (Alzahrani *et al.*, 2017). A further study by Meshram et al. used a grayscale histogram for radiological follow-up of osseous regeneration after cystic enucleation (Meshram *et al.*, 2015). GIMP and other programmes like Adobe Photoshop have a wide range of applications. The histogram tool provides an opportunity for follow-up of bone healing or, in our case, the behaviour of bone replacement material (Hieu *et al.*, 2010).

A number of studies have examined whether there are any postoperative changes in maxillary sinus volume or the dimensions of the grafts used in maxillary sinus augmentation (Kirmeier *et al.*, 2008; Zijderveld *et al.*, 2009; Hieu *et al.*, 2010; Cosso *et al.*, 2014; Favato *et al.*, 2015; Alzahrani *et al.*, 2017). Hieu et al. evaluated the changes in height of grafts containing xenogenic materials on radiographs and reported significant resorption of these materials over a 2-year period (Hieu *et al.*, 2010; Shanbhag *et al.*, 2014). The air pressure in the maxillary sinus, the augmentation material and membranes used, and factors such as bone density, implant material, surface quality, and implant length and width may influence the results (Degidi *et al.*, 2013; Felice *et al.*, 2014; Shanbhag *et al.*, 2014). Wanschitz et al. reported an approximate mean loss in volume of the bone replacement material of 13.9% ± 1.9%; (Wanschitz *et al.*, 2006) depending on the material used, the contraction in volume has ranged from 25% to 40% (Hieu *et al.*, 2010; Cosso *et al.*, 2014). Other studies of force loading on dental implants concluded that implant loading has a positive effect in terms of the ability of the graft to maintain its height (Nyström *et al.*, 1993; Hieu *et al.*, 2010). The reasons for the mean distal and mesial bone loss could be related to the remodelling phase postoperatively (Kahnberg *et al.*, 2011). In our present study, there was no significant difference in the measured areas between the one-stage and two-stage techniques immediately after implantation or 6 months later. This finding is in line with that of previous studies that have compared the one-stage and two-stage techniques (Kahnberg *et al.*, 2011; Degidi *et al.*, 2013), and confirms the usefulness of the histogram tool in GIMP for documentation of the behaviour of the augmentation material used during sinus lift procedures.

Conclusion

Image manipulation programmes have a range of potential applications. Within the limitations of digital panoramic radiographs, these programmes afford an opportunity to obtain area measurements of bone augmentation material. In this study, we found no significant difference in the measured area between the one-stage and two-stage techniques immediately after implantation or at follow-up period of 6 months. GIMP allows reliable augmentation graft measurements to be obtained easily. Further, the software is freely available, increasing its potential for implementation in routine dental practice.

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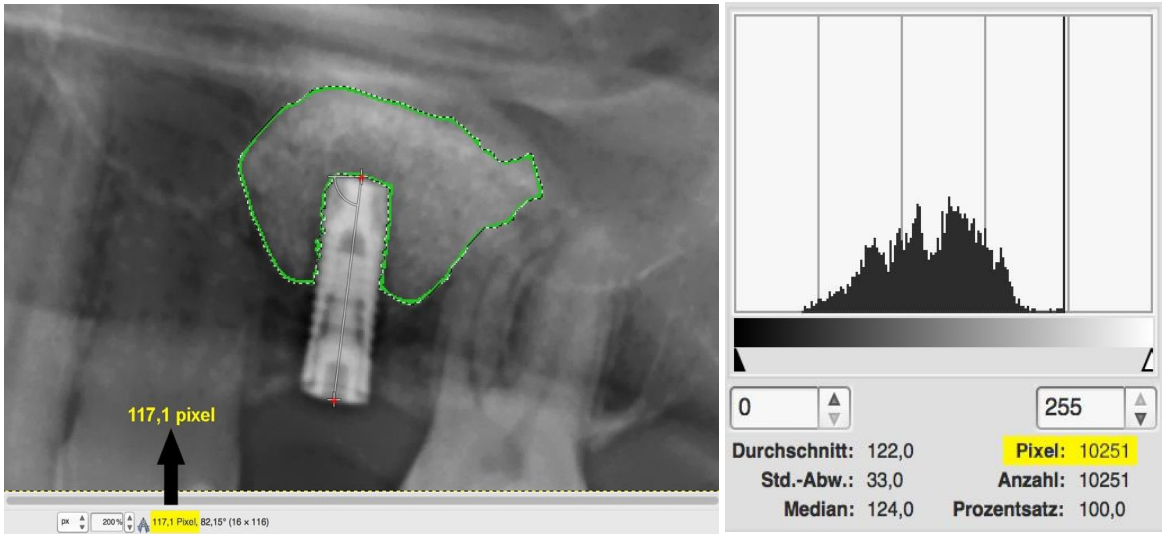
Declarations of interest: none.

Figure Captions

Figure 1 (a) Newly gained area framed and displayed in green. (b) The "histogram" tool showing the number of pixels (10,251) within the area bordered in green on the left side. Using the "measuring tape" tool, the distance between the two red dots could be measured and expressed in the form of a pixel value (117.1 pixels).

Figure 2 Factor (pixels) and area (mm^2) calculations

Figure 3 Box-and-whisker plot of the measured areas (mm^2) in groups 1 and 2



Newly gained area framed and displayed in green colour. The tool "histogram" on the right side shows the certain number of pixels (10251) within the green boardered area. Using the tool "measuring tape" the distance between the two red dots could be measured and expressed in form of a pixel value (117,1).

Fig. 1 Measurements and marks in GIMP

Example for factor calculation:
Implant length real = 10 mm
Implant length in pixel (GIMP) = 117,1 px
How long is a pixel (px) in GIMP = $\mathbf{1\ px = \frac{10\ mm}{117{,}1} = 0{,}0853917\ mm}$

Example for area (mm^2) calculation:
Factor = **0,0853917 mm**
Number of pixels form the measured area = 10'251
How big is an area (mm^2) in GIMP = $(\mathbf{0,\ 0853917\ mm})^2 * 10'251 = 74{,}75\ mm^2$

Fig. 2 Factor (px) and area (mm^2) calculation

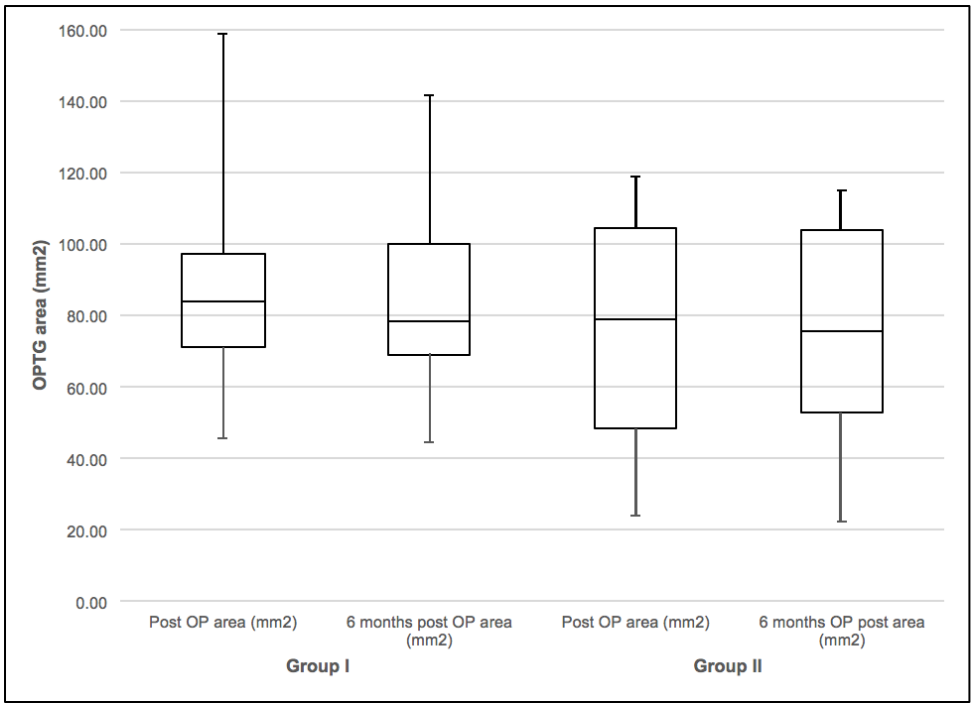


Fig. 3 Box-Whisker-Plot of the measured area (mm^2) in Group I and Group II

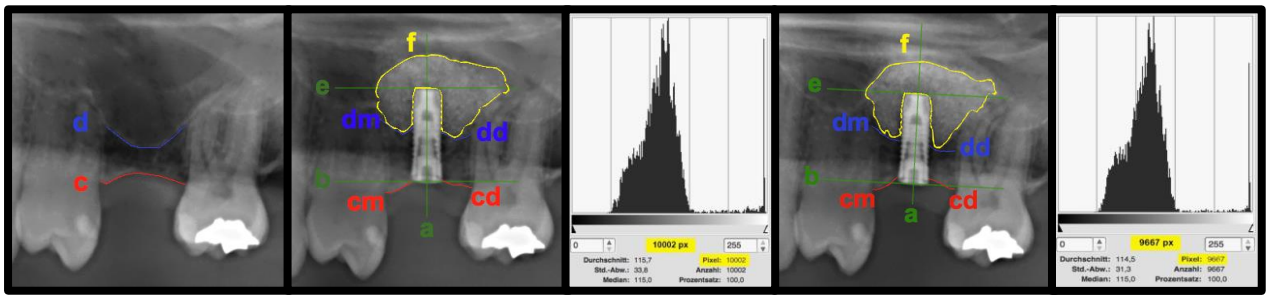


Fig. Group I;
A: Initial situation. B: Situation direct after implantation. C: Histogram direct after implantation. D: Situation 6 months after implantation. E: Histogram 6 months after implantation.

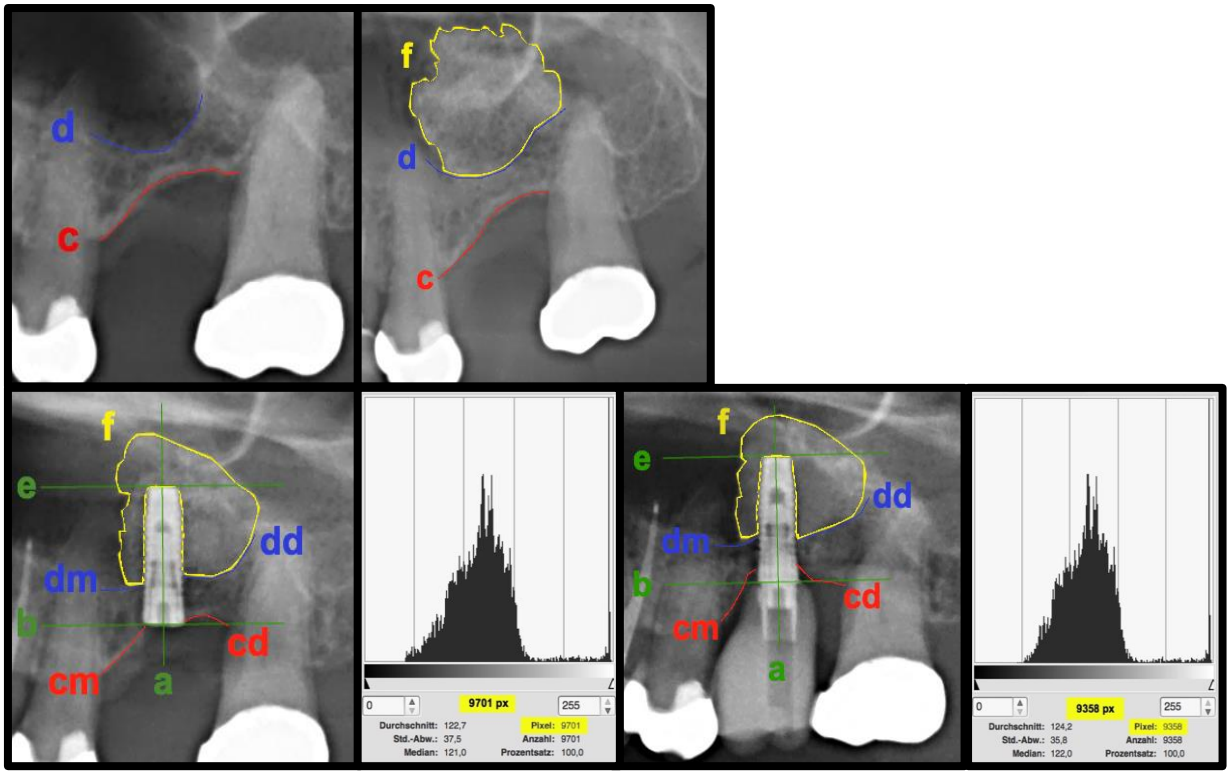


Fig. Group II;
A: Initial situation. B: Situation direct after sinus floor augmentation. C: Situation direct after implantation. D: Histogram direct after implantation.
E: Situation 6 months after implantation. F: Histogram 6 months after implantation.

Table 1 Types and locations of implants used in this study

Patient number	Group 1/2	Number of implants	Quadrant 1/2	Implant position	Residual bone height (mm)	Implant 1 (mm)	Implant type	Implant 2 (mm)	Implant type	Implant 3 (mm)	Implant type
1	1	1	2	25	2.9	10 × 3.25	OC 2				
2	1	1	1	15	5.1	10 × 3.25	T3 NPSPW				
3	1	2	1	15/16	6.5	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
4	1	1	1	15	4.4	10 × 4	OC 2				
5	1	2	2	26/27	8.2	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
6	1	2	2	26/27	4.0	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
7	1	3	2	24/25/26	9.9	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW
8	1	2	2	25/26	4.9	11.5 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
9	1	2	2	25/26	3.3	10 × 4/3	T3 NPSPW	8.5 × 4/3	T3 NPSPW		
10	1	1	2	25	4.4	10 × 4/3	T3 PW				
11	2	1	1	16	3.4	11.5 × 4/3	T3 PW				
12	2	2	2	25/26	4.4	10 × 4/3	T3 PW	8.5 × 4/3	T3 PW		
13	2	2	2	24/26	4.2	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
14	2	2	1	15/16	3.8	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
15	2	2	1	15/16	4.9	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
16	2	2	2	25/26	5.7	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
17	2	2	1	15/16	5.0	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
18	2	1	2	26	2.8	10 × 3.25	T3 NPSPW				
19	2	2	2	25/26	6.3	10 × 3.25	T3 NPSPW	10 × 3.25	T3 NPSPW		
20	2	2	2	25/26	6.9	10 × 4/3	T3 PW	8.5 × 4/3	T3 PW		
21	2	2	1	14/15	5.1	11.5 × 4/3	T3 PW	10 × 4/3	T3 PW		
22	2	2	2	25/26	5.1	10 × 4/3	T3 PW	10 × 4/3	T3 PW		

OC 2, Osseotite Certain 2; T3 NPSPW, T3 Non-Platform switched parallel wall; T3 PW, T3 parallel wall implant (mm) = length and diameter

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