Accuracy of Digital vs Conventional Implant Impression Approach: A Three-Dimensional Comparative In Vitro Analysis

Kinga Basaki, DMD, MSc, FRDC(C)¹/Hasan Alkumru, DDS, MSc, PhD, FRDC(C)²/Grace De Souza, DDS, MSc, PhD³/Yoav Finer, DMD, MSc, PhD, FRDC(C)⁴

**Purpose:** To assess the three-dimensional (3D) accuracy and clinical acceptability of implant definitive casts fabricated using a digital impression approach and to compare the results with those of a conventional impression method in a partially edentulous condition. **Materials and Methods:** A mandibular reference model was fabricated with implants in the first premolar and molar positions to simulate a patient with bilateral posterior edentulism. Ten implant-level impressions per method were made using either an intraoral scanner with scanning abutments for the digital approach or an open-tray technique and polyvinylsiloxane material for the conventional approach. 3D analysis and comparison of implant location on resultant definitive casts were performed using laser scanner and quality control software. The inter-implant distances and inter-implant angulations for each implant pair were measured for the reference model and for each definitive cast (n = 20 per group); these measurements were compared to calculate the magnitude of error in 3D for each definitive cast. The influence of implant angulation on definitive cast accuracy was evaluated for both digital and conventional approaches. Statistical analysis was performed using t test (α = .05) for implant position and angulation. Clinical qualitative assessment of accuracy was done via the assessment of the passivity of a master verification stent for each implant pair, and significance was analyzed using chi-square test (α = .05). **Results:** A 3D error of implant positioning was observed for the two impression techniques vs the reference model, with mean ± standard deviation (SD) error of 116 ± 94 μm and 56 ± 29 μm for the digital and conventional approaches, respectively (P = .01). In contrast, the inter-implant angulation errors were not significantly different between the two techniques (P = .83). Implant angulation did not have a significant influence on definitive cast accuracy within either technique (P = .64). The verification stent demonstrated acceptable passive fit for 11 out of 20 casts and 18 out of 20 casts for the digital and conventional methods, respectively (P = .01). **Conclusion:** Definitive casts fabricated using the digital impression approach were less accurate than those fabricated from the conventional impression approach for this simulated clinical scenario. A significant number of definitive casts generated by the digital technique did not meet clinically acceptable accuracy for the fabrication of a multiple implant–supported restoration. Int J Oral Maxillofac Implants 2017;32:792–799. doi: 10.11607/jomi.5431

**Keywords:** dental implants, dental impression techniques, digital impression, dimensional measurement accuracy, intraoral scanner, three-dimensional imaging

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1Prosthodontics Faculty Lecturer, Prosthodontics and Restorative Dentistry, Faculty of Dentistry, McGill University, Montreal, Quebec, Canada.
2Assistant Professor, Prosthodontics, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.
3Assistant Professor, Restorative Dentistry, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.
4Yoav Finer, Prosthodontics, George Zarb/Nobel Biocare Chair in Prosthodontics, Faculty of Dentistry, University of Toronto, Toronto, Ontario, Canada.

Correspondence to: Dr Kinga Basaki, McGill University, 1281A Gilford St, Montreal, QC, H2J 1R3, Canada.
Email: kinga.baskai@gmail.com
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An accurate impression and definitive cast are fundamental to a successful outcome in any prosthodontic rehabilitation. This remains true for implant-supported prostheses, for which impression techniques have been directly adapted from traditional prosthodontics. An essential first step in the fabrication process is the accurate three-dimensional (3D) capture and transfer of the implant position from the mouth to the definitive cast via an impression.¹ An inaccurate impression results in an inaccurate definitive cast, making it impossible to fabricate a prosthesis that is appropriately related to the 3D position of the implant(s) in the patient’s mouth. The resultant prosthesis misfit can lead to potential...
biomechanical complications due to excessive stress within the prosthesis and bone-implant-prosthesis interface.2–5 Because osseointegrated implants have approximately one-tenth the movement allowance of teeth,6 they have a very limited capacity to compensate for discrepancies in prosthetic framework fit. It is therefore critical that an implant impression and resultant definitive cast be as accurate as possible in order to fabricate a successful implant-supported prosthesis.

All current conventional impression techniques result in some degree of error, manifested as displacement of the implant analogs in the definitive cast compared with the true intraoral positioning of the implants.7–9 Variables that have been shown to influence implant impression accuracy include impression material selection,10–12 tray selection,13 impression approach,9,14 implant angulation,15,16 and the inherent fit of impression components.17,18 While numerous studies have evaluated and compared existing implant impression techniques, research to date does not support one single impression technique as superior to all others.9

The advent of digital technology gives clinicians the option to use intraoral scanners in place of conventional impression techniques. The use of digital impressions eliminates the need for traditional impression materials, making the procedure technique potentially more comfortable for patients while decreasing error from analog techniques.19,20 Digital impressions have the capacity to simplify the impression procedure, reduce chair time, and ease communication between the clinician and the laboratory.19,21,22 Several in vitro studies have compared traditional impression procedures with digital impression approaches, yet there remains a lack of consensus regarding the accuracy and clinical acceptability of digital techniques.23–26 The scanning abutments body used in the present study (Straumann CARES Mono Scanbody system, Straumann) is one of several commercially available digital implant impression systems that allow the clinician to obtain an implant-level impression utilizing a specialized scanning abutment and an intraoral scanning device such as the iTero scanner (iTero, Align technology). The iTero intraoral scanner captures the 3D location of the scan abutment via intraoral images using parallel confocal imaging and transmits this data to a centralized milling center to produce definitive casts that are used by laboratory technicians to fabricate prostheses. While validated for conventional prosthodontic restorations,27,28 relatively limited research has been conducted in its application with implant-supported restorations that require higher accuracy.

The aim of the current study was to evaluate the accuracy and clinical acceptability of definitive casts generated from digital implant-level impressions using a scanning abutment body (Straumann Mono Scanbody, Straumann) in combination with an iTero intraoral scanner (iTero, Align technology) and to compare this technique with conventional implant-level impressions on a simulated patient. The hypotheses were: (1) definitive casts fabricated using the digital approach would be clinically acceptable and equivalent to those using the conventional approach, and (2) implant angulation would not affect the accuracy of the definitive cast with either technique.

MATERIALS AND METHODS

Reference Model Fabrication
A custom reference model representing a clinical situation of mandibular bilateral posterior edentulism was fabricated from heat-cured methyl methacrylate with soft tissue analog over the implant sites and lingual undercuts where appropriate to best simulate a realistic clinical scenario (Fig 1a). Two implants (Bone Level Implant, Straumann) were placed in each posterior segment, with narrow crossfit (3.3 mm) and regular crossfit (4.1 mm) implants in the first premolar and molar positions, respectively. Implants on the right side were placed parallel with the vertical plane, and implants on the left side were angulated 10 and 30 degrees off the vertical plane with a convergence angle of 20 degrees to simulate non-ideal placement (Fig 1b).

Implant Impressions and Definitive Casts Fabrication
Based on previous studies,24,29 a mean vector magnitude error (VME) between implant centerpoints was anticipated at 30 µm. Based on the selected non-inferiority
limit of 60 μm, at a significance level (α) of 0.05, a power of 80%, and with a standard deviation of outcome of 50 μm, a sample size of 10 impressions per group was selected. Ten impressions of the simulated patient were taken using each technique. For the conventional approach, implant-level impressions were taken of the reference model using standardized custom trays and implant transfer copings (Impression post for open-tray, Straumann) (Fig 2). Custom trays were fabricated from light-cured methacrylate resin (Triad, Dentsply) with four soft tissue stops and an opening over each implant site, allowing access for the open-tray impression technique and ensuring predictable orientation. Visual and tactile verification of proper seating of impression copings were performed before final definitive impressions were taken with polyvinyl siloxane (PVS) material (Aquasil Ultra Monophase DECA, Caulk Tray Adhesive). All impressions were poured with vacuum mixed type IV dental stone (Silky-Rock, Whipmix Corp) using a two-part silicone index (Lab-Putty, Coltene/Whaledent) to standardize material volume.

For the digital approach, implant impressions of the simulated patient were taken using one-piece polymer scanning abutments (Straumann CARES Mono Scanbodies, Straumann) and an intraoral scanning device (iTero intraoral scanning device, Cadent iTero, Align technology) (Fig 3). The resultant stereolithic (STL) files were approved and sent to the fabrication center (San Jose, California), where precision-milled polyurethane casts were fabricated for each impression. Corresponding implant analogs (NC and RC Reposition analog, Straumann) were manually inserted into the milled definitive casts and secured with cyanoacrylate resin (Scotch super glue, 3M ESPE).

### 3D Scanning and Measurement of Casts

The reference model and each of the 20 definitive casts were scanned using a 3D laser measuring machine (D810 3D scanner, 3Shape), which has a reported accuracy of 8 μm and has been used reliably for similar measurements in multiple recent studies. The scans were performed with high-precision custom scanning abutments (Elos Accurate Scan Bodies, Elos Medtech) attached to the implant analogs. The scan files (STL format) were then imported into a quality control software (Convince, 3Shape) for analysis. The centerpoints of the scanning abutments were located by extracting the intersection of the cylinder axis with the top plane of the scanning abutment, and this point was used as a reference for implant position to calculate vector magnitudes between the two implant sites in each quadrant using x, y, and z centerpoint coordinate system data (Fig 4). The inter-implant distances, as well as inter-implant angulations per implant pair, were calculated for the reference model and each definitive cast, and these measurements were subsequently compared to assess the magnitude of error in three dimensions.
Assessment of Definitive Cast Accuracy Using a Clinically Relevant Approach

The accuracy of definitive casts was further compared using a simulated clinical approach via a verification stent. A master verification stent for each side of the reference model was fabricated using non-engaging temporary implant cylinders (Post for temporary restoration bridge, Straumann) splinted with resin (Pattern Resin LS, GC Corporation); the stents were sectioned and reattached on the reference model to ensure passivity (Fig 5). Clinical assessment of passivity (P = passive; NP = nonpassive) was made via visual and tactile verification (alternate finger pressure technique) using the master verification stent for each implant pair from the same side of the definitive casts.

Data Analysis and Statistics

The 3D distance between implant analog centerpoints was calculated for each implant pair per quadrant using

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**Fig 4** Measurement methodology. (a) Digital scan of cast with Elos scanning abutments (Elos) in place. (b) Selection of scanning abutment cylinder-plane intersection point with 3D Vector illustrated. (c) 3D coordinate system establishment. (d) Angle measurement.

**Fig 5** Verification jig stent fabricated on reference cast, sectioned and luted.
the formula: $3D \text{ vector magnitude} = (x + y + z)^{\frac{1}{2}}$. The VME was calculated for each implant pair by comparing its respective 3D vector magnitude to the respective measurement on the reference model. Inter-implant angulations, measured using the cylinder long axis of the scanning abutments, were further calculated for each implant pair and compared to the reference model to obtain implant angulation errors.

The mean VME and mean angulation error were calculated for both impression approaches to reflect the accuracy of the generated definitive casts compared to the reference model. To compare the accuracy of the digital vs conventional impression approach, a t test (unpaired, two-tailed) was used to compare mean VME and inter-implant angulation difference between the two techniques. To further analyze whether implant placement angulation affected the accuracy of the impression technique, a paired t test was used to compare VME between angulated and non-angulated sides within each impression technique group. Chi-square test was used to compare the categorical data obtained from the verification jig stent testing. All statistical analysis was performed using SPSS software (SPSS v.17, SPSS Inc). $P < .05$ was considered significant.

## RESULTS

### Evaluation of Measurement Methodology

The reference value calculated on the reference model from five consecutive scans showed an average deviation of 7.0 μm for inter-implant vector magnitude and an average deviation of 0.03 degrees for inter-implant angulation. This precision in measurement was consistent with the manufacturer’s claim for the laser scanner and was within an acceptable range for this study.

### 3D Error

Both impression techniques resulted in casts with some degree of error when compared to the simulated patient (Table 1). When the 3D error (VME) of implant analog positioning in definitive casts was compared, the mean ± SD error of the conventional impression group ($56 ± 29 \mu m$, range 15–111 μm) was significantly lower ($P = .011$) than that of the digital impression group ($116 ± 94 \mu m$, range 21–298 μm) (Fig 6).

There was no statistically significant difference in error between parallel (right) and angled (left) implants within either the conventional ($P = .65$) or digital groups ($P = .64$) (Fig 6). For the conventional approach the mean

<table>
<thead>
<tr>
<th>Cast no./Implant pair</th>
<th>Conventional impression VME (μm)</th>
<th>Digital impression VME (μm)</th>
<th>Verification stent passivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td>98.29</td>
<td>58.00</td>
<td>P</td>
</tr>
<tr>
<td>1B</td>
<td>92.57</td>
<td>103.12</td>
<td>NP</td>
</tr>
<tr>
<td>2A</td>
<td>45.50</td>
<td>27.46</td>
<td>P</td>
</tr>
<tr>
<td>2B</td>
<td>81.20</td>
<td>204.44</td>
<td>NP</td>
</tr>
<tr>
<td>3A</td>
<td>52.31</td>
<td>99.21</td>
<td>P</td>
</tr>
<tr>
<td>3B</td>
<td>16.52</td>
<td>78.98</td>
<td>P</td>
</tr>
<tr>
<td>4A</td>
<td>89.31</td>
<td>33.43</td>
<td>P</td>
</tr>
<tr>
<td>4B</td>
<td>49.05</td>
<td>23.24</td>
<td>P</td>
</tr>
<tr>
<td>5A</td>
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</tr>
<tr>
<td>5B</td>
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</tr>
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<td>252.52</td>
<td>NP</td>
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<td>10A</td>
<td>15.22</td>
<td>293.51</td>
<td>NP</td>
</tr>
<tr>
<td>10B</td>
<td>24.17</td>
<td>298.26</td>
<td>NP</td>
</tr>
</tbody>
</table>

Mean ± SD 55.6 ± 29.6 116.4 ± 94.6*
A = parallel side; B = angled side; P = passive; NP = nonpassive. *$P < .05$.  

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**Table 1  Vector Magnitude Error and Verification Stent Passivity Measured for Each Implant Pair on Definitive Casts from Both the Conventional and Digital Impression Approaches**

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± SD VME of the parallel side was 58 ± 32 µm, and the angled side VME was 53 ± 28 µm; for the digital approach the parallel side VME was 109 ± 93 µm, and the angled side VME was 123 ± 100 µm.

Inter-Implant Angulation
The mean ± SD inter-implant angulation difference was not statistically significant between conventional (0.46 ± 0.32 degrees) and digital impression (0.48 ± 0.28 degrees) groups (P = .83).

Verification Stent Assessment
There were significant differences in passivity of the verification stents between the conventional and digital definitive casts, with acceptable fit of 18 out of 20 casts and 11 out of 20 casts for the conventional and digital methods (P = .01), respectively.

DISCUSSION
The present study was designed to evaluate the accuracy of definitive casts generated from a fully digital implant-level impression system and to compare the results to casts fabricated from a conventional implant impression technique using a simulated clinical scenario. The reference model, with bilateral edentulous areas, was intended to simulate a realistic clinical situation often restored with dental implants. Different implant sizes were selected to restore the premolar and molar regions to reflect possible clinical decisions, and implants were placed slightly angulated and convergent on the left side to mimic a non-ideal clinical situation and to allow for the examination of the influence of the secondary variable of implant angulation.

While the results demonstrated that both the conventional and digital impression approaches had some degree of inaccuracy in reproducing the exact implant orientations of the reference model, the definitive casts from the digital system were significantly less accurate. For the purpose of the study, definitive casts with error less than 60 µm in implant positioning were considered clinically acceptable, as this measurement approximates the minimum error that can be detected in a clinical setting. The average 3D error for the conventional impression technique (56 µm) was found to be within the clinically acceptable range and in agreement with previously published studies, which have reported errors ranging from 20 to 89 µm using similar measurement techniques. Conversely, the digital impression technique resulted in an overall 3D inter-implant error measurement of 116 µm, which was both in excess of the defined error limit of 60 µm and demonstrated a significantly greater error and variability than the conventional implant impression technique. The numeric data were supported by the clinical assessment, as there was a significantly better fit of the verification jig stent on conventional definitive casts, which demonstrated passive fit for 18 out of the 20 casts, than for those fabricated from the digital approach, which only had 11 out of the 20 casts showing passive fit. The data thus supported the rejection of the primary hypothesis.

Studies examining conventional open-tray impression techniques have shown that the accuracy of definitive casts can be influenced by multiple factors. Inaccuracy can be introduced due to the machining tolerance of the transfer coping, the deformation of the impression material due to polymerization shrinkage, and the setting dimensional change of dental stone. With a digital impression system, different factors may affect the final accuracy of the definitive cast. The iTero scanner uses confocal laser scanning and a processing software that recognizes and geometrically rebuilds an object from a scanning point cloud using a registration algorithm. Any error within this digitization process would be reflected as error within the resultant definitive casts. Inherent inaccuracies of fit of the commercially available scan abutments, which range from 11 to 39 µm based on machining tolerance, may also contribute to recorded errors. Further inaccuracy may have been introduced during the milling process of the polyurethane definitive casts or could be the result of potential dimensional changes of this material in response to the ambient environment, which have been previously evaluated as ranging from 0.2% to 1.3%. Any variability in the manual positioning of the implant analogs into the prefabricated guidance sockets in the final casts would also have contributed to the recorded inaccuracy within the digital impression approach.
There remains a lack of consensus among studies examining the accuracy of digital implant impressions. Several recent studies comparing digital vs conventional implant impressions have found a greater error using the digital approach. Lin et al. specifically examined the accuracy of models fabricated from conventional and iTero digital impressions and concluded that the digital pathway, with mean errors ranging from 158 to 328 μm, was significantly less accurate. However, some studies have found equivalent accuracy between digital and analog impression techniques. Abdel-Azim et al. found equivalent error for full complete arch impressions when measuring the marginal fit of final prostheses fabricated either using analog technique or a complete CAD/CAM digital approach. While Lee et al. concluded that the accuracy of the digital method was equivalent to the conventional method when examining overall cast accuracy, they did find a statistically significant difference in vertical implant placement between the two approaches. A recent study examining the accuracy of Straumann scanbody with the TRIOS scanner found no difference when compared to two conventional impression approaches, however, the authors compared digitized analog casts to the digital impression–generated STL files and not actual fabricated casts.

The errors in digital impression accuracy reported in the above studies range from a mean of 38 to 328 μm. The variation in recorded error may be attributed to the differences in study design, measurement methodology, and the inherent differences of various digital impression systems. A recent study evaluating the accuracy of three intraoral scanners for implant impressions in vitro reported a significant difference between scanners, with an average error for the iTero scanner of 65.8 ± 55 μm for inter-implant distance and 0.38 ± 0.25 degrees for angulation. This lower error measurement may be a reflection of the fact that the authors performed measurements on digital files and not actual physical definitive casts fabricated using a digital approach, thus reducing potential factors that could affect overall accuracy of the system. The latter studies also imply that the manufacturing mode of the definitive cast in the digital system could be a major factor in the system’s overall accuracy. While some systems offer the option to directly fabricate restorations from a digital impression via a CAD/CAM approach, the fabrication of physical definitive casts remains a common practice with most digital impression systems, so measurement of the accuracy of these casts is clinically relevant and allows for a direct comparison of the different approaches and systems.

Implant placement angulation did not have a significant influence on definitive cast accuracy within either the digital or conventional impression approach. Previous studies have hypothesized that increased implant angulation can cause an increased strain within implant material leading to its deformation, with the resultant error correlated to the degree of angulation. For a digital impression approach, where material strain is not a concern, several studies have indeed not found an effect of implant angulation on digital impression accuracy. The lack of statistically significant influence of implant angulation on impression accuracy in the current study corroborates these several previous findings for the digital approach, while the lack of influence on the error in conventional approach could be potentially explained by the moderate angulation, choice of the impression material, and implant connection type.

The measurement of impression accuracy for the present study was done by measuring the relative distortion of each definitive cast, as reflected by a change in inter-implant distance and angulation. A relative distortion was favored over an absolute distortion measurement, as this approach does not rely on external reference points having to be transferred to each definitive cast, which can introduce additional confounding variables. A limitation arising from this technique, however, was that measurements could not be provided for individual direction of error, horizontal (x, y axes) or vertical (z axis). It was thus not possible to evaluate whether there was greater inaccuracy in a specific direction, or whether the error in a particular axis had more influence on the passivity of fit as verified clinically using the verification jig stent. Previous studies have suggested that there is a smaller tolerance in horizontal or vertical misfit, which may explain why the measured vector magnitude error did not always correlate with the degree of misfit of the verification jig stent.

Further evaluation of the reliability and accuracy of this digital impression approach must be undertaken in both a laboratory and a clinical setting. While current success of the system based on market feedback is promising, the findings in this study indicate that the current digital impression approach may not yet be as accurate as conventional implant-level impressions to create definitive casts for a multi-unit, implant-supported restoration. Clinicians, therefore, must carefully evaluate the inherent advantages and disadvantages of the technique and ultimately interpret the clinical significance of any error on an individual basis.

CONCLUSIONS

Within the limitations of the present in vitro study, the digital impression approach produced less accurate definitive casts than the conventional approach. Both 3D analysis and clinical evaluation of definitive casts concluded that a significant portion of those from the digital approach could not be regarded as clinically acceptable. Implant angulation did not have an effect on overall cast accuracy.
ACKNOWLEDGMENTS

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REFERENCES

The following article is JOMI Online exclusive. The full text is available at www.quintpub.com

Biomechanical Three-Dimensional Finite Element Analysis of Single Implant–Supported Prostheses in the Anterior Maxilla, with Different Surgical Techniques and Implant Types

Fellippo Ramos Verri, DDS, MSc, PhD/Joel Ferreira Santiago Jr, DDS, MSc, PhD/
Daniel Augusto Faria Almeida, DDS, MSc, PhD/Victor Eduardo de Souza Batista, DDS, MSc/
Cleidiel Aparecido Araujo Lemos, DDS, MSc/
Caroline Cantieri Mello, DDS, MSc/Eduardo Piza Pellizzer, DDS, MSc, PhD

Purpose: The aim of this study was to use three-dimensional finite element analysis to analyze the stress distribution transferred by single implant–supported prostheses placed in the anterior maxilla using different connections (external hexagon, internal hexagon, or Morse taper), inclinations of the load (0, 30, or 60 degrees), and surgical techniques for placement (monocortical/conventional, bicortical, or bicortical with nasal floor elevation). Materials and Methods: Nine models representing a bone block of this region were simulated by computer-aided design software (InVesalius, Rhinoceros, SolidWorks). Each model received one implant, which supported a cemented metalloceramic crown. Using FEMAP software, finite elements were discretized while simulating a 178-N load at 0, 30, and 60 degrees relative to the long axis of the implant. The problem was solved in NEI Nastran software, and postprocessing was performed in FEMAP. Von Mises stress and maximum principal stress maps were made. Results: The von Mises stress analysis revealed that stress increased with increasing inclination of the load, from 0 to 30 to 60 degrees. Morse taper implants showed less stress concentration around the cervical and apical areas of the implant. The bicortical technique, associated or not with nasal floor elevation, contributed to decreasing the stress concentration in the apical area of the implant. Maximum principal stress analysis showed that the increase in inclination was proportional to the increase in stress on the bone tissue in the cervical area. Lower stress concentrations in the cortical bone were obtained with Morse taper implants and the bicortical technique compared with other connections and surgical techniques, respectively. Conclusion: Increasing the inclination of the applied force relative to the long axis of the implant tended to overload the peri-implant bone tissue and the internal structure of the implants. The Morse taper connection and bicortical techniques seemed to be more favorable than other connections or techniques, respectively, for restoring the anterior maxilla. Int J Oral Maxillofac Implants 2017;32:e191–e198. doi:10.11607/jomi.5472

Correspondence to: Dr Fellippo Ramos Verri, Department of Dental Materials and Prosthodontics, UNESP - Univ Estadual Paulista, José Bonifácio St, 1193, Araçatuba, São Paulo 16015-050, Brazil. Fax: +55 – 1836363296. Email: fellippo@gmail.com

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