



ELSEVIER

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.intl.elsevierhealth.com/journals/dema

Accuracy evaluation of surgical guides in implant dentistry by non-contact reverse engineering techniques

M. Giordano^a, P. Ausiello^{b,1}, M. Martorelli^{c,*}

^a Giordano Dental Office, Caserta, Italy

^b University of Naples Federico II, School of Dentistry, Department of Restorative Dentistry Via S. Pansini 5, 80131 Naples, Italy

^c University of Naples Federico II, School of Engineering Department of Mechanics and Energetics – DiME P.le Tecchio, 80, 80125 Naples, Italy

ARTICLE INFO

Article history:

Received 11 June 2012

Accepted 18 June 2012

Available online xxx

Keywords:

Guided implant surgery

Laser scan

Dental implants

Virtual modeling

Impressions

ABSTRACT

Objective. In the paper laser scanning was used to evaluate, by indirect methods, the accuracy of computer-designed surgical guides in the oral implant supported rehabilitation of partially or completely edentulous patients.

Materials and methods. Five implant supported rehabilitations for a total of twenty-three implants were carried out by computer-designed surgical guides, performed with the master model developed by muco-compressive and muco-static impressions. For all cases the surgical virtual planning, starting from 3D models obtained by dental scan DICOM data, was performed. The implants were inserted on the pre-surgical casts in the position defined in the virtual planning. These positions were acquired by three-dimensional optical laser scanning and compared with the laser scans of the intraoral impressions taken post-operatively. **Results.** The comparison between the post-surgical implant replica positions and the positions in the pre-operative cast, for the five patients, shows a maximum distance in the range 1.02–1.25 mm, an average distance in the range 0.21–0.41 mm and a standard deviation in the range 0.21–0.29 mm.

Significance. The results of this research demonstrate accurate transfer of implant replica position by virtual implant insertion into a pre-operative cast and a post-operative cast obtained from impressioning. In previous studies the evaluation of the implant positions have required a post-surgical CT scan. With the indirect methods by laser scanning technique, proposed in the paper, this extra radiation exposure of the patient can be eliminated.

© 2012 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.

1. Introduction

The number of patients asking for fixed implant-supported rehabilitations has increased considerably in the past few years [1].

Today implant-supported reconstructions to restore the stomatognathic system, in terms of function and

esthetics, after tooth loss or aplasia, is considered to be a routine procedure with high success rates [2–6].

Historically, standard radiographic imaging techniques (intraoral and panoramic) were available for investigation of potential implant sites.

Nowadays three-dimensional computed tomography (CT) and cone beam CT (CBCT) systems allow a more reliable

* Corresponding author. Tel.: +39 81 7682470.

E-mail addresses: pietro.ausiello@unina.it (P. Ausiello), massimo.martorelli@unina.it (M. Martorelli).

¹ Tel.: +39 81 7462089.

0109-5641/\$ – see front matter © 2012 Academy of Dental Materials. Published by Elsevier Ltd. All rights reserved.

<http://dx.doi.org/10.1016/j.dental.2012.06.006>

Table 1 – Patients and distribution of the implant sites.

Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
46	12-14-16 22-24-26	14-15-16 24-25-26	32-34-36 42-44-46	32-35-42 45

**Fig. 1 – Occlusal check in extra-hard wax with radiographic stents during CT examination.**

treatment planning than when only two-dimensional data were available [7–13].

From the CT data (DICOM format – *digital imaging and communications in medicine*), the three-dimensional reconstruction of surgical sites is obtained [14]. This allows the virtual implant planning driven by restorative considerations and the successive fabrication of surgical guides by means of CAM (computer aided manufacturing) or RP (rapid prototyping) techniques.

The developments in computer-aided planning by means of the use of 3D virtual models have drastically modified the interventional possibilities in implant dentistry, changing the traditional invasive surgical protocol, with a flapless procedure eventual immediate loading [15,16].

The clinical steps involved are determined by different morphological conditions: the bone quantity and quality, the sensitive anatomical structures.

Although computer-guided implant dentistry is an upcoming technology with the potential for more predictive and less invasive implant placement, its performance has to be critically evaluated, because it is already in clinical practice.

Transfer of the virtual three-dimensional implant planning to the surgical field is the most critical point in the procedure.

The aim of this paper is to evaluate the accuracy of the surgical guides, analysing the deviations between the virtual planning and the *in vivo* location of the implants.

In the previous studies the accuracy in computer-aided implant surgery was usually evaluated by means of post-surgical CT scan to verify the implant positions [17–21].

In the paper an indirect method for the accuracy evaluation, using a laser scanning technique is described. This method allows to reduce the radiation exposure eliminating the extra radiations of post-surgical computed tomography scan.

2. Materials and methods

2.1. Patients selection

The data of five patients, three men and two women with different implant-prosthetic rehabilitative requirement, were used for this study.

Two patients had a total mandibular edentulous dentition, one patient a total maxillary edentulous dentition, one patient a single intercalated mandibular edentulous dentition and one patient a bilateral distal maxillary edentulous dentition.

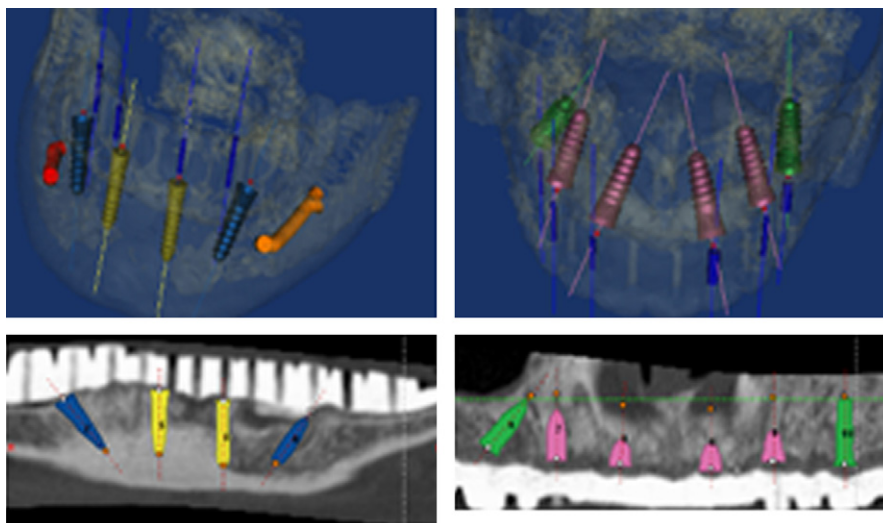
**Fig. 2 – Virtual pre-surgical planning.**



Fig. 3 – Ray set machine.

In order to preserve the keratinized gingival, in the case of thin biotype, only the patient exhibiting single intercalated edentulous dentition was rehabilitated using an approach with flap,

The mean patient age was 52 years (between 35 and 60 years). *Table 1* shows the distribution of the implant sites.

Inclusion criteria for the patients were:

- Absence of relevant systemic diseases in contradiction for osteo-integrate implant rehabilitations.
- Presence of adequate bone volumes for the implant placement without regenerative techniques.
- If smokers no more than 10 cigarettes for day.

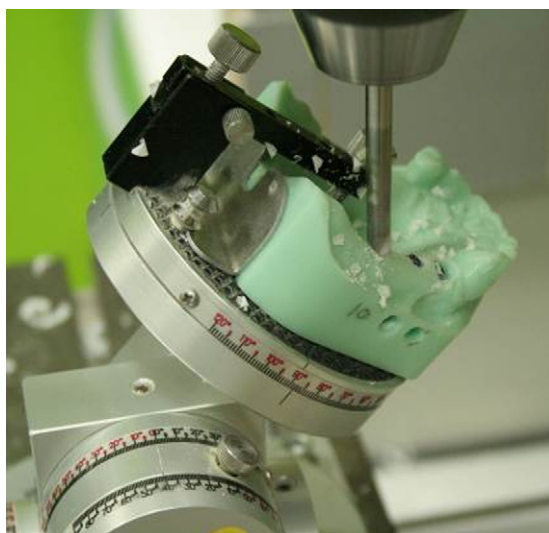


Fig. 4 – Master model is oriented and drilled to place in it the implant analogs.

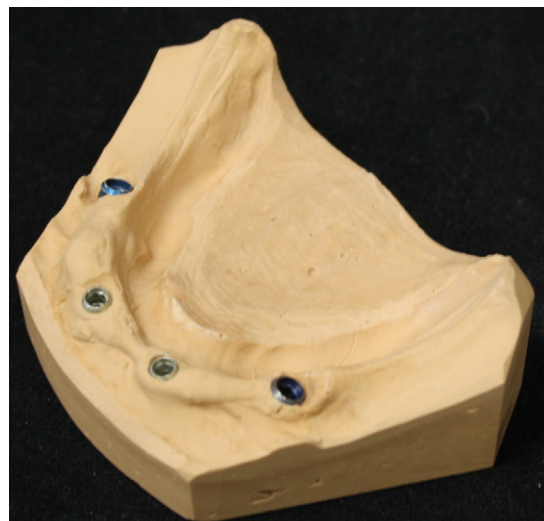


Fig. 5 – Simulation of implant surgery on pre-surgical cast.

On the basis of a panoramic radiograph, it was decided to continue the treatment-planning phase of selected patients by means of a CT scan of the maxilla that the patient carried out with radiographic stents produced from self-curing resin mixed with barium sulphate powder in a ratios of 3:1.

In order to avoid unwanted dental overlaps and to stabilize the radiographic stents during the CT examination, some stabilizers were made using extra-hard wax of 10 mm height, which patient bites between the dental arches during CT examination (*Fig. 1*).

2.2. Virtual pre-surgical planning computed tomography – based

The virtual pre-surgical planning was applied (Implant 3D software by Media Lab, Italy) to have a detailed 3D analysis in the implant placement (*Fig. 2*).

The planning was possible through the interpretation of DICOM images of the CT examination.

The virtual data were used to fabricate the surgical guides using a Ray Set machine (Biaggini Medical Devices, Italy) (*Fig. 3*) that orients, in accordance with the parameters from virtual analysis, the resin or plaster master model, in order to place in it, in a correct three-dimensional manner, the implant analogs (*Fig. 4*).



Fig. 6 – Shape acquisition of the pre-surgical cast with implant analogs.

Then both surgical stents with a resinous framework like of total removable dentures (stents for exclusive mucosal support), and surgical stents with a metal core like a skeleton (stents at the exclusive dental support) can be made.

2.3. Simulation of implant surgery on casts and reverse engineering acquisitions

From the 3D virtual planning, the data of implant positions were transferred to the master model and the analog implants were inserted and fixed in it (Fig. 5).

A reverse engineering (RE) system, D700 Scanner (by 3Shape, Denmark) was used to acquire, for each patient, the three-dimensional virtual shape of the master model with the

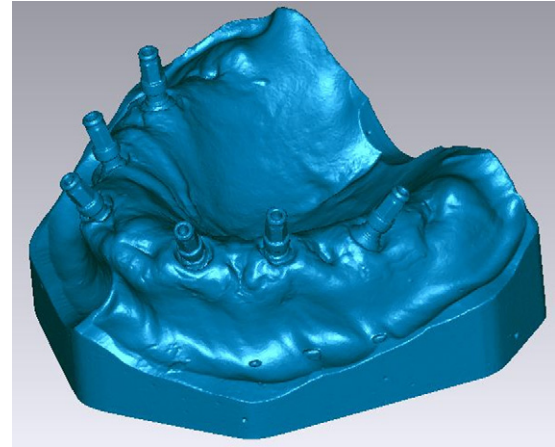


Fig. 8 – CAD model of a post-surgical cast.

Table 2 – Number and length of implants and type of surgical approach.

	Flapless	With flap
Implantlength 9 mm	1	0
Implantlength 11 mm	1	0
Implantlength 13 mm	22	1

analog (Fig. 6) with the aim to obtain the 3D CAD model, useful for the successive evaluation of the accuracy of the implants position.

2.4. Implant surgery

Twenty-three conical implants have been used with lengths between 9 and 13 mm (EXACTA WP, Biaggini Mediacal Devices).

On the basis of periodontal biotype a flapless approach was chosen, in the case of thick biotype, and an approach with flap in the case of thin biotype, in order to preserve the keratinized gingiva.

The number of implants, the length and type of surgical approach, are summarized in the Table 2.

All implants have received the provisional immediate load within 48 h post-surgery. In the case of the individual intercalated edentulous patients the prosthesis was attached through the abutment millable prosthesis screwed with a torque of 30 N cm, and using a cemented resin crown.

In Fig. 7 implant surgery is shown.

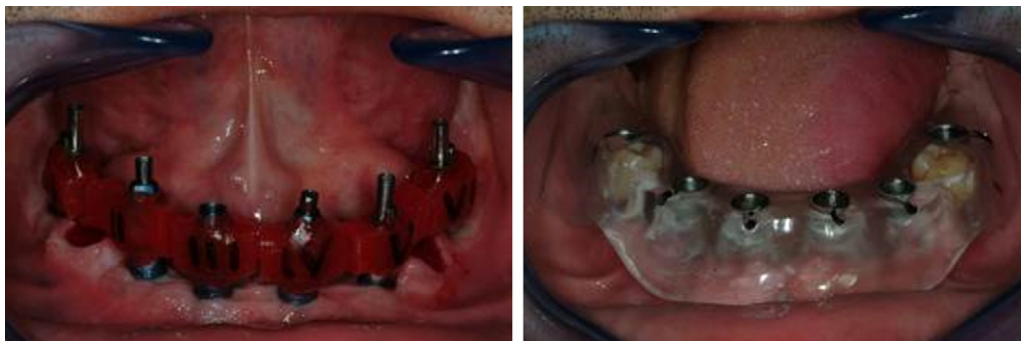


Fig. 7 – Implant surgery.

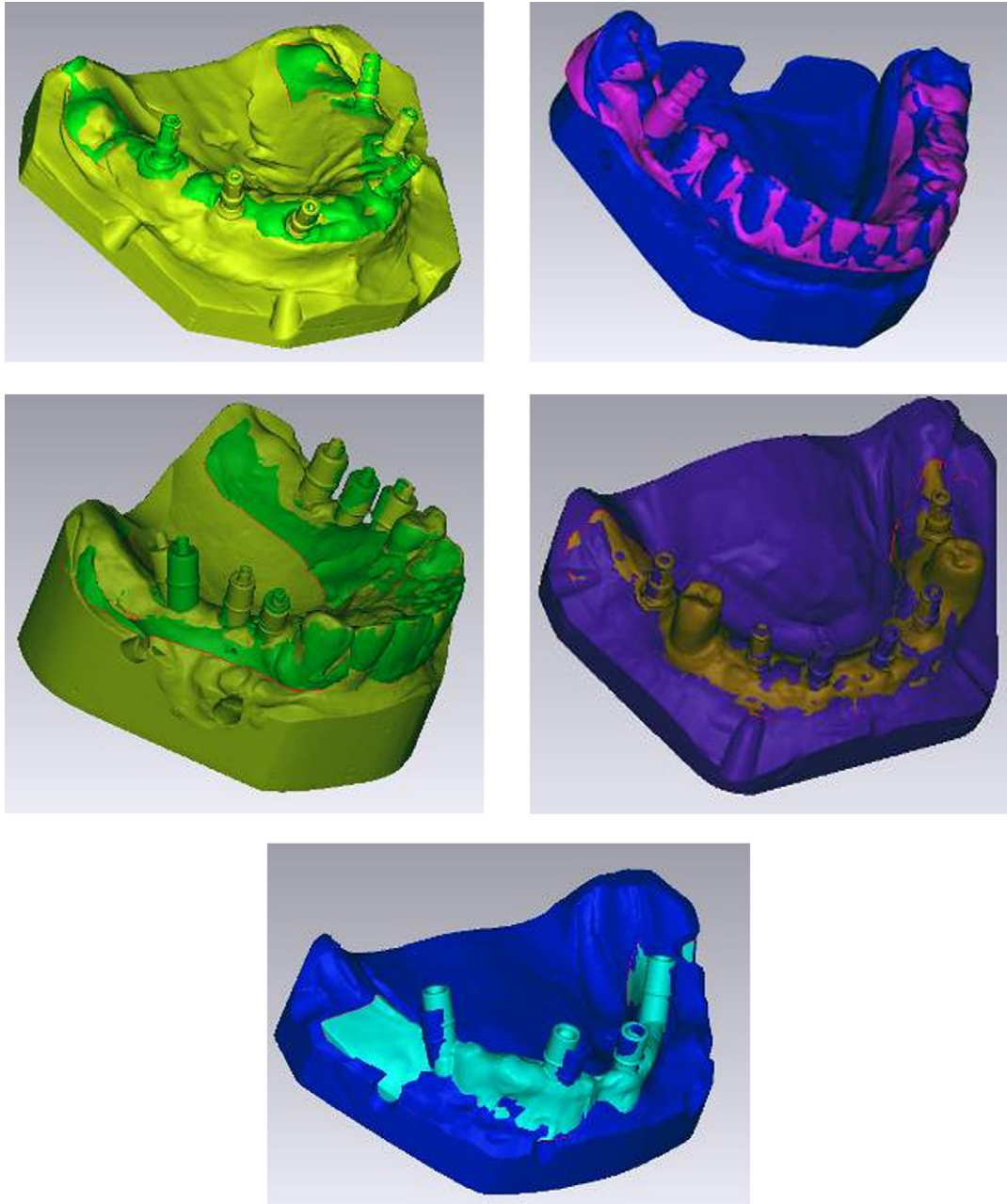


Fig. 9 – CAD models alignment.

2.5. Laser scans of post-surgical casts

For each patient, a post-surgical cast was realized.

The three-dimensional shape of these casts was acquired by means of 3Shape's D700 Scanner and the 3D CAD models (Fig. 8), useful for the accuracy evaluation of the implants position, were obtained.

3. Results

To evaluate the accuracy of the computer-designed surgical guides, the comparison between CAD models obtained

starting from laser scans of the pre- and post-surgical casts, for each one of the five patients, was carried out.

To obtain the alignment (Fig. 9) and the analysis of the deviations between the CAD models, the analysis tools of Geomagic software (by Raindrop Geomagic, USA) was applied. The results are shown in Fig. 10.

The deviation statistics are summarized in Table 3.

These data clearly show that the standard deviation is within 0.29 mm.

Fig. 10c and e shows, for the implants of gray color, a significantly deviation between the positions of these implants pre- and post-surgery, but this one because intentionally the implant surgeon, during surgery, forced the implant along the

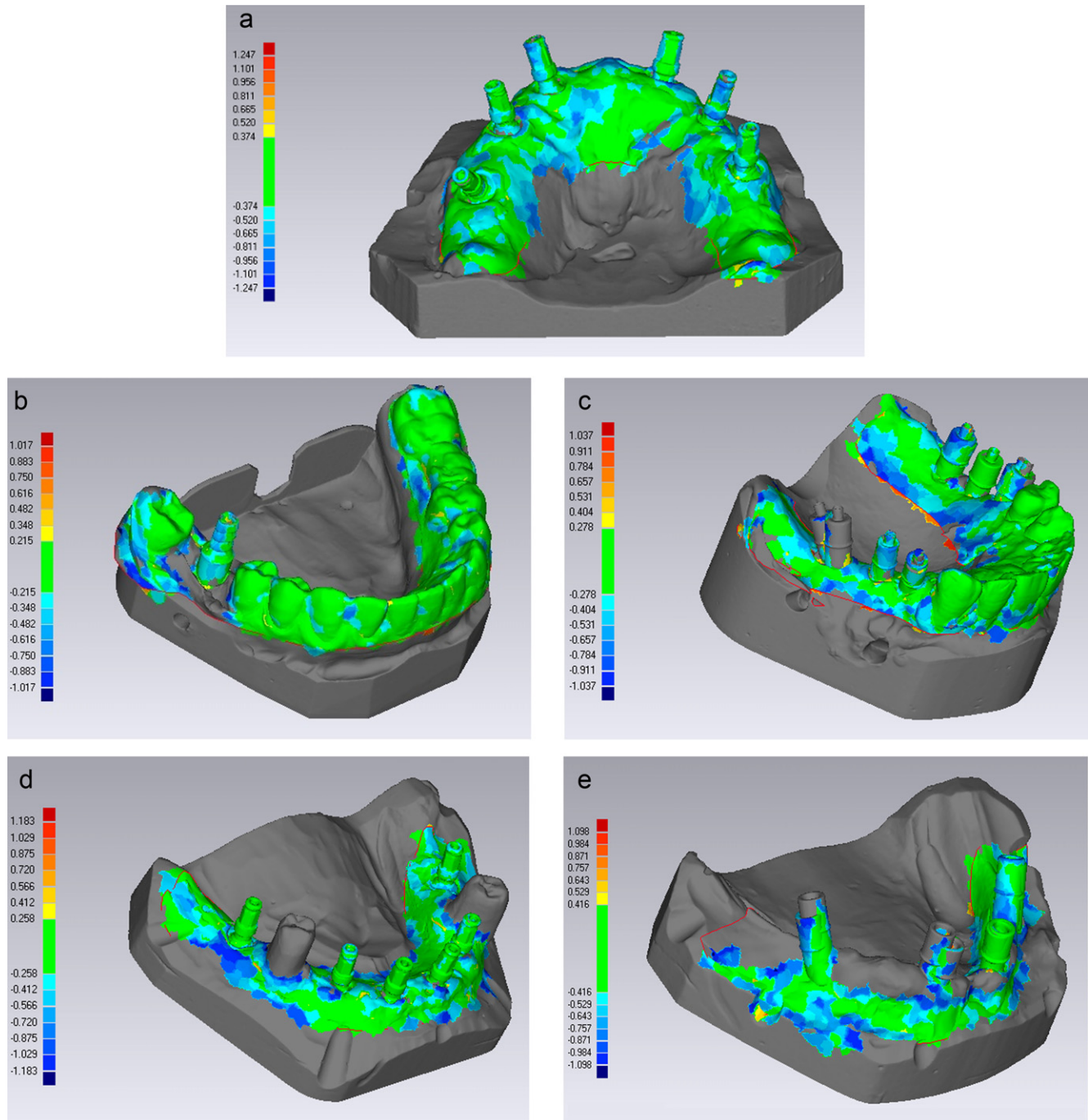


Fig. 10 – CAD models comparison.

cortical areas expressly weakened during the preparation of the site finalized to the increase of the maxillary sinus.

4. Discussion

The esthetic and functional success of osseo-integrated implant oral rehabilitation is strictly dependent on correct pre-operative planning.

Prior to use of Virtual Prototyping in Dentistry, such planning has been carried out exclusively with the aid

of two-dimensional X-ray images or with images from three-dimensional examinations, but examined exclusively on film by transillumination by means of a diaphanoscope.

The use of Virtual Prototyping in the implant dentistry field, starting from CT data, it is possible to plan very detailed surgery in a virtual environment. So it is possible pre-operatively, with three-dimensional virtual analysis, to insert implants in the most strategically valid locations, carefully considering the availability of bone from both a quantitative and qualitative point of view. Also the choices of the surgeon in a virtual environment can be guided by biomechanical and

Table 3 – Deviation statistics.

Case study	Parameter	Value (mm)
Patient 1 (6 implants)	Maximum distance	1.246861
	Average distance	0.374294
	Standard deviation	0.253309
Patient 2 (1 implant)	Maximum distance	1.016909
	Average distance	0.214762
	Standard deviation	0.210133
Patient 3 (6 implants)	Maximum distance	1.037237
	Average distance	0.277666
	Standard deviation	0.239729
Patient 4 (6 implants)	Maximum distance	1.182534
	Average distance	0.258454
	Standard deviation	0.240632
Patient 5 (4 implants)	Maximum distance	1.098204
	Average distance	0.415527
	Standard deviation	0.291825

prosthetic assessments, as this aspect of oral osseointegrated rehabilitation appears to be fundamental.

Various authors [21–23] affirm that the accuracy obtainable in implant positioning, by means of computer-aided procedures, is superior to that obtained by a freehand approach.

However this outcome is closely dependent on the accuracy with which the data are transferred pre-operatively from the virtual planning to the master model.

In this regard, special consideration must be given to the positioning of the implant analogs on the pre-operative master model. With the Ray Set technique, the implant analogs are not positioned with the aid of stereolithographic surgical guides, but it is the machine itself that, after having properly oriented the model according to the spatial coordinates from the virtual planning, allows the dental technician to position implant analogs correctly oriented and with the right depth.

In this study the comparison between the pre- and post-surgical implant positions, for five patients, showed a standard deviation within 0.29 mm.

In reference to this correspondence between the pre- and post-surgical master models it is important to consider the type of under-preparation of the implant site. In fact, in order to increase the implant primary stability, a fundamental requirement to have osseo-integration, the implant sites were under-prepared with one or two steps in function of bone density. Therefore a greater proportion of under-preparation will imply a greater deviation between the pre- and post-surgical casts.

To these considerations it has to be added that in the case in which the implant site preparation is finalized to the increase of the maxillary sinus by crestal way, the final position of the implant will be significantly different by that one defined in the virtual planning (as it is clearly shown in Fig. 10c and e for the implants of gray color), and this because the implant has been intentionally forced along the cortical areas expressly weakened during the preparation of the site.

The depth of the implant analogs in the master model is determined by measuring the thickness of the mucosa of the patient in the virtual design phase. Therefore it is not the stent that determines the position of the implants, but it is

the position of the latter which allows the construction of the surgical stent.

This aspect is crucial, because the technician can perform customizations at the request of the surgeon if, for periodontal reasons, it is preferable to support and protect the access flaps.

Another very effective aspect, has been the technique of muco-compressive impressions performed on the edentulous jaw to eliminate the error arising from the mucosal resiliency itself. With this approach, it has become unnecessary to use an endosseous anchor-pin to stabilize the surgical stent. In fact, in all cases considered in this study, the surgical stent was greatly stabilized by exploiting the exclusive mucosal support.

This technique makes the surgery less invasive and offers the patient a smoother post-operative recovery.

However other factors can affect the accuracy with which data are transferred from the virtual to the surgical environment. Widmann, Pettersson et al. [21,22] consider that the thickness of the engraving, the patient's movements and the scanning parameters can generate inaccuracies during image acquisition.

Furthermore, human error remains an uncontrollable factor which can contribute to some additional imprecision.

5. Conclusions

In the paper an indirect approach, for the accuracy evaluation of computer-designed stents in Implant Dentistry, using a non-contact active RE technique, was considered.

The results show, in the transfer of implant position from the 3D virtual planning to the patient, a standard deviation in the range 0.21–0.29 mm.

In the prosthetic field, standard deviations within 0.29 mm are not negligible and this is why the temporary restoration was carried out after appropriately detected a post-surgery master impression with rigid splinting of the implant transfers.

Instead in the surgery, standard deviations within 0.29 mm are absolutely negligible.

Therefore computer-designed surgical guides represent a valuable aid for the implant surgeon. He can perform, by virtual planning, using the instrument for transfer of implant coordinates and by techniques of muco-static and muco-compressive impressions, a minimally invasive implant surgery and biomechanically and prosthetically guided.

Acknowledgements

The authors gratefully acknowledge the Jonata laboratory (Caserta, Italy) and eng. Angelo Salamini (Sintesi Sud – Ariano Irpino, Italy) for their useful technical support.

REFERENCES

- [1] Bornstein MM, Halbritter S, Harnisch H, Weber HP, Buser D. A retrospective analysis of patients referred for implant placement to a specialty clinic: indications, surgical procedures and early failures. *International Journal of Oral & Maxillofacial Implants* 2008;23:1109–16.

- [2] Aglietta M, Siciliano VI, Zwahlen M, Bragger U, Pjetursson BE, Lang NP, et al. A systematic review of the survival and complication rates of implant supported fixed dental prostheses with cantilever extensions after an observation period of at least 5 years. *Clinical Oral Implants Research* 2009;20:441–51.
- [3] Jung RE, Pjetursson BE, Glauser R, Zembic A, Zwahlen M, Lang NP. A systematic review of the 5-year survival and complication rates of implant-supported single crowns. *Clinical Oral Implants Research* 2008;19:119–30.
- [4] Pjetursson BE, Tan K, Lang NP, Bragger U, Egger M, Zwahlen M. A systematic review of the survival and complication rates of fixed partial dentures (FPDs) after an observation period of at least 5 years. *Clinical Oral Implants Research* 2004;15:667–76.
- [5] Hammerle CH, Jung RE, Feloutzis A. A systematic review of the survival of implants in bone sites augmented with barrier membranes (guided bone regeneration) in partially edentulous patients. *Journal of Clinical Periodontology* 2002;29(Suppl. 3):226–31, discussion 232–23.
- [6] Pjetursson BE, Bragger U, Lang NP, Zwahlen M. Comparison of survival and complication rates of tooth-supported fixed dental prostheses (fdps) and implant-supported fdps and single crowns (scs). *Clinical Oral Implants Research* 2007;18(Suppl. 3):97–113.
- [7] Jacobs R, Adriansens A, Verstreken K, Suetens P, van Steenberghe D. Predictability of a three-dimensional planning system for oral implant surgery. *Dento-Maxillo-Facial Radiology* 1999;28:105–11.
- [8] Aranyarachkul P, Caruso J, Gantes B, Schulz E, Riggs M, Dus I, et al. Bone density assessments of dental implant sites: 2. Quantitative cone beam computerized tomography. *International Journal of Oral and Maxillofacial Implants* 2005;20:416–24.
- [9] Bolin A, Eliasson S, von Beetzen M, Jansson L. Radiographic evaluation of mandibular posterior implant sites: correlation between panoramic and tomographic determinations. *Clinical Oral Implants Research* 1996;7:354–9.
- [10] Gray CF, Redpath TW, Bainton R, Smith FW. Magnetic resonance imaging assessment of a sinus lift operation using reoxidised cellulose (Surgicel) as graft material. *Clinical Oral Implants Research* 2001;12:526–30.
- [11] Gahleitner A, Podesser B, Schick S, Watzek G, Imhof H. Dental CT and orthodontic implants: imaging technique and assessment of available bone volume in the hard palate. *European Journal of Radiology* 2004;7:257–62.
- [12] Ausiello P, Franciosa P, Martorelli M, Watts DC. Numerical fatigue 3D-FE modelling of indirect composite-restored posterior teeth. *Dental Materials* 2011;27(5):423–30, <http://dx.doi.org/10.1016/j.dental.2010.12.001>.
- [13] Ausiello P, Franciosa P, Martorelli M, Watts DC. Mechanical behavior of post-restored upper canine teeth: A 3D FE analysis. *Dental Materials* 2011;27(12):1285–94, <http://dx.doi.org/10.1016/j.dental.2011.09.009>.
- [14] Parel SM, Triplett RG. Interactive imaging for implant planning, placement, and prosthesis construction. *Journal of Oral and Maxillofacial Surgery* 2004;62:41–7.
- [15] Avramppou M, Mericske-Stern R, Blatz MB, Katsoulis J. Virtual implant planning in the edentulous maxilla: criteria for decision-making of prosthesis design. *Clinical Oral Implants Research* 2012;1–8, <http://dx.doi.org/10.1111/j.1600-0501.2011.02407.x>.
- [16] Katsoulis J, Pazera P, Mericske-Stern R. Prosthetically driven, computer-guided implant planning for the edentulous maxilla: a model study. *Clinical Implant Dentistry & Related Research* 2009;11:238–45.
- [17] Horwitz J, Zuabi O, Machtei EE. Accuracy of a computerized tomography-guided template-assisted implant placement system: an in vitro study. *Clinical Oral Implants Research* 2009;20:1156–62.
- [18] Schneider D, Marquardt P, Zwahlen M, Jung RE. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. *Clinical Oral Implants Research* 2009;20(Suppl. 4):73–86.
- [19] Van Assche N, van Steenberghe D, Guerrero ME, Hirsch E, Schutyser F, Quirynen M, et al. Accuracy of implant placement based on pre-surgical planning of three-dimensional cone-beam images: a pilot study. *Journal of Clinical Periodontology* 2007;34:816–21.
- [20] Vasak C, Watzek G, Gahleitner A, Strbac G, Schemper M, Zechner W. Computed tomography-based evaluation of template (NobelGuide™)-guided implant positions: a prospective radiological study. *Clinical Oral Implants Research* 2011;22:1157–63.
- [21] Widmann G, Bale RJ. Accuracy in computer-aided implant surgery – a review. *International Journal of Oral and Maxillofacial Implants* 2006;21:305–13.
- [22] Pettersson A, Komiyama A, Hultin M, Nasström K, Klinge B. Accuracy of virtually planned and template guided implant surgery on edentate patients. *Clinical Implant Dentistry Related Research* 2010;(May), <http://dx.doi.org/10.1111/j.1708-8208.2010.00285.x> [Epub ahead of print].
- [23] Stumpel LJ. Deformation of stereolithographically produced surgical guides: an observational case series report. *Clinical Implant Dentistry Related Research* June 2012;14(3):442–53. Article first published online: 11 FEB 2010.