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

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\section*{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

\section*{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.

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

Table 1 – Patients and distribution of the implant sites.

<table>
<thead>
<tr>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
<th>Patient 4</th>
<th>Patient 5</th>
</tr>
</thead>
</table>

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 postsurgical 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.
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.

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).
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 analogs (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 Medical 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.

<table>
<thead>
<tr>
<th>Implant length</th>
<th>Flapless</th>
<th>With flap</th>
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<tbody>
<tr>
<td>9 mm</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>11 mm</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>13 mm</td>
<td>22</td>
<td>1</td>
</tr>
</tbody>
</table>

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.
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 Geo-magic 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
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

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

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