Potential Deviation Factors Affecting Stereolithographic Surgical Guides: A Systematic Review

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Currently, the application of computer-aided design and coordinated computer-aided manufacturing in implantology allows the virtual planning of positioning the dental implants, key in the longevity of the prosthesis, related to anatomical and prosthetic considerations.1

Surgical guide systems can be divided into static or dynamic. Static surgical guides are made in the laboratory through 3-dimensional printing (prototyping) known as stereolithographic (SLA) guides or perforations in templates made on the jaw models. They are called static because they do not allow modification of the planned position during the surgical procedure. Dynamic guides use a mechanical or optical system to transfer the virtual planning to the surgical field, displaying the process on a screen in real time.

Stereolithographic guides can be single or multiple, the multitype guides are generally used with no stabilization screws, changing the guide as the drill diameter increases and have showed similar results than single type guides. Single guides use physical stops for different diameter of drills.2

Several deviations have been described in literature and therefore the aim of this study was to determine what factors are involved in accuracy of SLA-guided surgery with stereolithographic static systems.

**Objective:** The aim of this study was to review potential deviation factors in stereolithographic surgical guides for dental implantology, warnings, and limitations of the system.

**Methods:** An electronic search in databases EMBASE, the Cochrane Library, and PubMed were conducted by 3 researchers to collect information on the accuracy of static computer-guided implant placement to summarize and analyze the overall accuracy. The latter included a search for correlations between factors such as support (teeth/mucosa/bone), number of templates, use of fixation pins, jaw, template production, guiding system, and guided implant placement in articles related to guided surgery with stereolithographic static systems.

**Results:** From 761 identified articles, a total of 24 articles were reviewed, which included 2767 dental implants. Data from studies analysis had shown a mean deviation of 3.08 degrees in angular position, 1.14 at the entry point, and 1.46 at apex position. Involved deviation factors were related to planning, laboratory, and surgical phases.

**Conclusion:** Guided surgery may have a limited precision as technique, which surgeons need to be aware in the planning process. This review suggests some security measures in guided surgery process. (Implant Dent 2019;28:68–73)

**Key Words:** surgery, computer-assisted, dental implants, ambulatory surgical procedures, tomography, x-ray computed

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Implants by computer-assisted stereolithographic surgical guides independent of implant number, length, diameter, position, or angulation, into healthy bone, either screw-retained or cement-retained prosthodontic rehabilitation, according to an immediate, early, or conventional loading protocol.

For inclusion in this study, articles reporting on accuracy, implant and prosthetic failures, biological or mechanical complications were selected.

Focus question. What factors are involved in the accuracy of stereolithographic guided surgery?

Search Strategy


Studies Selection and Data Extraction. Inclusion criteria for articles were as follows: clinical studies related to guided surgery with stereolithographic static systems in patients; prospective, retrospective, randomized clinical trials, cohort, transversal and longitudinal studies about accuracy; clinical studies including at least 5 human subjects, which outcomes on angular, entry point, or apical position were specified.

Exclusion criteria were as follows: studies about zygomatic implants, post-extraction sockets, short implants, bone grafts, sinus lift, clinical cases, animals studies, in vitro, laboratory studies, reviews of literature, cranio-maxillofacial reconstructions, oncological, cleft lip-palatal, syndromes or disease patients related studies.

Two reviewers analyzed the studies independently and discussed with a third reviewer for final selection.

Risk Analysis of Bias

The quality analysis tool for the studies was QUADAS 2 (Quality assessment tool for diagnostic accuracy studies) from Bristol University, which evaluated risk of bias and applicability for patient selection, index test, reference standard, flow period, and timing.

Analysis Risk of Bias

As we can see in Figure 1, positive results were found in relation to patients selection; this could be due to most of authors agree in the basic patients conditions for guided surgery treatment. But quite opposite findings were observed in relation to index tests, as conditions and measurements differ from the studies, which avoid a meta-analysis. In general, the risk of bias was indicated as medium level.

Results

Flow Diagram

The initial electronic database search yielded 761 titles which were independently screened resulting in the consideration of 321 publications. Abstracts were then reviewed and the remaining 51 studies were analyzed in detail, resulting in the exclusion of 25 articles (Fig. 2). Three reviewers agreed on the classification of 24 of the studies, with an estimated kappa test of 0.75 (Table 1). Most of protocols used retention pins in the guide and flapless technique. Dental, mucosal, and bone supported guides were included, as well as multiguides without retention pins. The variability of protocols and methods used in the studies did not allow us to perform a meta-analysis; therefore, we use all data as a narrative review.

Studies’ Characteristics

The implant position on the dental arch, the use of fixation pins, and the type of surgery (with local or general anesthesia) showed no statistical significant difference for any variable.

Cassetta et al found that guide fixation (fixed vs movable), supporting arch (maxilla vs mandible), and bone density also influenced intrinsic errors, during an assessment of the clinical relevance of potential mechanical errors in stereolithographic surgical templates.

Cautions

Vercruyssen et al have described some precautions as follows: make sure optimal fit of denture; in case of total edentulous patients, the denture can be relined using a soft reline, for this matter. Register the position of the denture in relation to the bone
according to double scan procedure, with radiopaque markers of at least of 2 mm diameter.

Check the scan for movement artifacts and absence of space/air between denture and underlying soft tissues to be certain of proper fit. Cone beam computed tomography scan setting of 120 kVp, pulses of 3 to 8 mA, 8 cm scan height, and exposure time of 20 seconds reconstructed with an 0.3-mm isotropic voxel size was recommended. Regarding the radiographic techniques used, no significant differences were found. Inadequate mouth opening and high tension in the lips or cheek can make treatment more difficult and reduces the accuracy of the implant position. Especially in the canine tooth region, during drilling, the angled drill head had to be placed toward the cheeks, with the drill tip angulated toward the palate. Inaccuracies are mainly explained due to gaps between the drill, drill guide, and sleeve in the surgical template.

Potential Deviation Factors

Presurgical planning. Not all patients are candidates for guided surgery without flap detachment. It is important during planning to determine if the surgical guide will be bone, mucosal, or dental supported. The mouth opening should be evaluated as well as the length of the drills. In general, when using the surgical guide, a minimum of 35 mm of oral space is required for the surgeon to position the drills correctly in the holes of the guide: 20 mm are necessary for drill bits, 10 mm of distance between the guidewire and the cervical end of the implant, and the 5 mm thickness of the contra-angle head. Based on the amount of available bone and considering the possibility of fenestration, it is recommended a safety distance of 2 mm from anatomical structures.

The patient’s movements during scanning may affect the deviation in implant angulation. Currently, the new tomographers have reduced scanning times and these movement errors. Surgical planning may change in case of complications as template fractures during the surgery, limited primary implant stability, need for additional grafting procedures, and prosthetic misfit.

To avoid errors related to mucosal thickness, it is recommended to use a stable pressure during bite registration, during scanning, and in surgery. The amount of soft tissue and its mobility may hinder the accuracy of the guide fixation. The increase of 1 mm of mucosa increases buccolingual deviation by 0.4 mm.

The observed deviations in the posterior region have been related to the limitation of mouth opening. In this case, it may be difficult to drill long implants and the insertion of the drill bits. The length of the implant and the depth into the bone perforation has been associated to deviations.

Precision increases when the surgical guides are fixed with screws tightly in the jaws. At least 3 fixation screws are recommended in the anterior and 2 posterior regions. In case of not been possible to fix the guide with screws, it is suggested to use multiple guides avoiding micro-movements. Kalt and Gehrke report higher precision when using double guide sleeve during drilling with the first drill, the lance. Long, wide, and strong metal sleeves would give greater stability to guide.

The inappropriate use of the guides and mismatch of the drill with the guide cylinder negatively influences the precision of the implants. In addition, the prosthesis must be of sufficient thickness to allow the segmentation of the
tomographic images. If it is too thin, it does not differentiate the prosthesis edges from the air spaces.

**Surgical**

Confirm that the guide is well positioned and stable in the jaw. Look for areas of tension or possible interference in the adaptation of the guide. Difficulties may arise in positioning the surgical guide. After anesthetic infiltration, wait around 10 minutes and massage the infiltrated area to prevent edema from interfering with the adaptation of the guide. During the infiltration of anesthesia, the gingiva undergoes local volume increase.

Be aware of micro-movements that may arise during drilling, especially in cases of free end and total edentulous. It is important to fix and support the guide, and it is even possible to fix the guide with temporary implants. Keep the drill parallel and centered relative to the guide cylinder.

Torques larger than 50 N were related to guide fracture. However, avoid excessive pressure, in this case, remove the guide for the last millimeters of insertion of the implant. The fracture of the surgical guide can be avoided by increasing the space between the teeth or implants and the guide cylinder, maintaining the required thickness of the material.

Even when all perforations are made with a surgical guide, the deviation can occur when the implant is inserted manually at the end of the procedure. The depth of the implant placed with guided surgery can also vary from the planning, depending on the system employed.

The vertical dimension depends on the level of the bone crest, but in aesthetic cases, it is advisable to detach the flap for visual control. Walton et al have suggested that professional training and experience influences the accuracy of guided surgery.

**DISCUSSION**

Until 2011, limited information about accuracy of implant placement of the maxilla of fully edentulous patients was given. This study includes articles from 2012 to 2017, which reduces the risk of bias obtaining more homogenic data.

Vercruysen et al evaluating computer-assisted surgery in totally edentulous patients with surgical guides supported on mucosal or bone, found a mean vertical deviation of 0.9 ± 0.8 mm (range: 0.0–3.7 mm) and 0.9 ± 0.6 mm (range: 0.0–2.9 mm) in a horizontal direction. The overall mean deviation for the guided surgery in mesio-distal direction was 0.6 ± 0.5 mm (range: 0.0–2.5 mm) and 0.5 ± 0.5 mm (range: 0.0–2.9 mm) in buccolingual direction. These results are within the values found in this study, which are less than reported by Tahmasseb et al in a meta-analysis of the accuracy of 1.12 mm (maximum of 4.5 mm) at the entry point measured in 1530 implants and 1.39 mm at the apex (maximum of 7.1 mm), 3.5 degrees (95% CI 3.0–4.1), with a maximum of 21.2; similar values were found in meta-analysis of Van Assche et al. Pettersson et al investigated 25 fully edentulous patients in 15 patients receiving implant in their upper jaw, 5 or 6 implants were placed, showing a mean 3-dimensional deviation for “implant tip” of 1.05 mm (range: 0.25–2.63 mm), a mean deviation for

**Table 2. Characteristics of Included Studies and Resume of Data Extraction**

<table>
<thead>
<tr>
<th>Author</th>
<th>Angle (graus)</th>
<th>Entry (mm)</th>
<th>Apex (mm)</th>
<th>Implants (n)</th>
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<td>BL/MD</td>
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<td>0.60</td>
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<td>2.42</td>
<td>2.84</td>
<td>20</td>
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<td>Vercruysen et al 2014</td>
<td>3.00</td>
<td>1.40</td>
<td>1.60</td>
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<tr>
<td>Cassetta et al 2013(c)</td>
<td>4.88</td>
<td>1.52</td>
<td>1.97</td>
<td>111</td>
</tr>
<tr>
<td>Sun et al 2015</td>
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<tr>
<td>Sun et al 2015(b)</td>
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<td>1.48</td>
<td>1.80</td>
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<td>0.89</td>
<td>1.08</td>
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<tr>
<td>Cassetta et al 2014(a)</td>
<td>4.33</td>
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<td>—</td>
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<td>—</td>
<td>—</td>
<td>129</td>
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<tr>
<td>Platzer et al 2013</td>
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<td>0.27</td>
<td>0.28</td>
<td>15</td>
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<tr>
<td>Mean</td>
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<td>1.14</td>
<td>1.46</td>
<td>85.28</td>
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</table>
“shoulder” of 0.80 mm (range: 0.10–2.68 mm), a mean “angular deviation” of 2.31 degrees (range: 0.24–6.96 degrees), and a mean “depth deviation” of −0.06 mm (range: −1.65 to 2.05 mm). Higher deviations were seen at the implant apex, as major control of the drill guide is at the entry point, leaving a relative small gap for the tip movement.

Due to improvement in technology and techniques, we found less mean deviations in a review of publications from 2012 to 2017 comparing to publications from 1996 to 2011 as reviewed by Van Assche et al.28

Fewer deviations were observed in cases of unitary implants, with mesial and distal dental support, a mean of 0.21 ± 0.16 mm at the cervical level, 0.32 ± 0.34 mm at the apex, and 1.35 ± 1.11 degrees. The deviation is greater when the support is unilateral or in free end.29

The posterior edentulous spaces have a negative influence on guided surgery, due to the support of the guide at one end only. However, an important factor in the accuracy of guided surgery is the fixation and support of the guide. One solution is to fix the guide with temporal implants.22

The depth of the implant placed with guided surgery can also vary from the planning, depending on the system employed. Naziri et al22 investigated different systems of guided surgery in partial edentulous patients, placing a total of 246 implants, of which 2 implants were 3 mm under planning. Comparing guided surgery systems showed that the accuracy of implant placement decreases with increasing implant length. In this same study, the greatest deviation observed in implant placement was 16.6 degrees. This considerable deviation was due to the first 2 perforations made with the surgical guide and the last without it, free hand.

Implant angulation can be affected by the difficulty of drilling, especially in long implants, by positioning long drills in the limited opening of the mouth. This is evidenced by the fact that significant deviations related to implant length in the distal mesio sense have been observed. Implants smaller than 11 mm were recommended for guided surgery and with minimum perforations possible.22

The friction of the drill with the bone and the surgical guide may interfere with the accuracy of the guide. The use of titanium sleeves to direct the drill during drilling increases guide deflections. Thus, it can also influence bone strength in drill orientation during drilling.14

Laederach et al29 observed significant differences when comparing different systems of stereolithographic guides, suggesting that the system and the protocol used influence the accuracy of the implants. The shape of the tip of the drill facilitates the sliding during the first millimeters of the drilling, acquiring stability with the sinking and greater contact with the bone. The use of plexiglas increases the error due to material resistance and the use of parallel cylinders is better than tapered cylinders.

Regardless of the tomographic equipment, the scanner protocol is more important than the device itself. To improve accuracy, a high-definition protocol is required.30

Vercruyssen et al31 reported deviations from the surgical guide in guided surgery of 1.4 mm with a range of 0.3 to 3.7 at cervical level, at the apical level was 1.6 mm (0.2–3.7), and in inclinations was 3 degrees (0.2–16 degrees). Similar results were found in this review (Table 2); however, it is possible that even with the technological developments and the use of more precise equipment, the stereolithography technique has reached a limit of association of factors specific to the technique.

Also, D’Haese et al1 investigated the accuracy of implant placement in the maxilla of 13 fully edentulous patients. A total of 78 implants were placed using mucosa-supported surgical templates. Accuracy evaluation showed a mean tip deviation of 1.13 mm (range: 0.32–3.01 mm), a mean shoulder deviation of 0.91 mm (range: 0.29–2.45 mm), and a mean angular deviation of 2.60 degrees (range: 0.16–8.86 degrees).

CONCLUSION

The increased accuracy and benefits of implants drilling that guided surgery represents for the professional and patient is indisputable. However, surgical guides are not yet free of risks and complications; even with the improvement of techniques and instruments, the deviations of the implants remain a challenge for the surgeon. It is important to keep in mind the factors related to deviations and risks to take preventive measures.

ROLES/CONTRIBUTIONS

By Authors


DISCLOSURE

The authors claim to have no financial interest, either directly or indirectly, in the products or information listed in the article.

REFERENCES


11. Pomares C, Pomares Puig C. A retrospective study of edentulous patients rehabilitated according to the “all-on-four” or the “all-on-six” immediate function concept using flapless computer-guided implant surgery. Eur J Oral Implantol [Internet]. 2010;3:155–163.


