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Review

THE ACCURACY OF STATIC COMPUTER-GUIDED DENTAL IMPLANT SURGERY FOR THE PROSTHETIC REHABILITATION OF PARTIALLY OR TOTAL EDENTULOUS PATIENTS: A NARRATIVE REVIEW

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ABSTRACT

The purpose of this paper is to review the literature on the accuracy of static computer-guided surgery in implantology, starting from a summary of the evolution of implant-placement guidance systems and the importance of correctly positioning dental implants. Subsequently, we consider both the mean and the maximum deviations reported by recently published papers to assess the overall accuracy of such systems. The mean linear deviation is reported to be in the 1-1.63 mm range at the coronal centre of the implant or its apex, while the mean angular deviation is stated to be around 5-6°, suggesting greater precision of static computer-guided surgery if compared to free-hand positioning. At last, the need to better distinguish the factors influencing results is highlighted.

KEYWORDS: *implant, computer, guided, dentistry, accuracy, placement*

INTRODUCTION

Surgical and prosthetic protocols based on the principles of osseointegrated implants are an essential rehabilitation element among the therapeutic options available for totally and partially edentulous patients. In its infancy, the founding principle guiding the therapeutic success of implant dentistry was the achievement of the osseointegrative process, defined by Brånemark (1) as the intimate anatomical congruence between the living and remodelling bone and a biocompatible alloplastic component that transfers functional loads to the bone, in the absence of soft tissues at the interface. This goal

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remains essential but is no longer the clinician's primary concern since osseointegration has accelerated in its advent and made qualitatively more predictable. In summary, it can be asserted that the initial search for reproducible success based on osseointegration has been supplanted by the desire to grant long-term stability to oral implants.

According to the literature (2), success in implantology depends on many factors, the role of which varies concerning the study considered. For instance, a review by Jung and colleagues (3) reported an average survival rate for implant-supported single crowns after 5 years of 96.8%; the incidence rate of biological complications was 7-9%, and the incidence rate for the most common technical complication, namely the loosening of the screw, amounted to 12.7%. Among the risk factors for dental implant failure, the literature reports elements related to the patient, aspects related to the implant, the prosthetic design, and the operator (2). A group of elements often considered fundamental to achieving long-lasting success are the occlusal ones, all of which reflect a correct prosthetic design and a concordant implant placement. Starting from the evidence that implant success depends on the congruity of the prosthetic planning carried out, the concept of prosthetically-driven implantology unfolds. This term indicates the logic according to which the implant position must not be chosen on the maximum bone availability but rather be planned to achieve the best aesthetic-functional results in the long term (4).

In the original method of prosthetically-driven implantology (5), the operative plan started with mounting the jaws models on the articulator and realising a diagnostic wax-up, which is clinically validated by a mock-up. Once an adequate result was achieved, a radiological template containing a radiopaque material representing the chosen prosthetic axis was created; the patient was then subjected to a 2D radiological examination so that the clinician could choose the implant position on visual guidance. The further evolution of these methods has seen the introduction of the first surgical guides, made according to the "Double purpose templates" protocol. The subsequent advent of an inexpensive and low-dose 3D imaging technology, such as CBCT, allowed the distortion limits of orthopantomography to be overcome. In contrast, the subsequent introduction of many software able to reproduce 3D radiographic data previously printed on 2D films allowed the clinician to place implants in a virtual environment.

Despite the great revolution offered by these imaging techniques, a problem remained unsolved: the methods discussed until now were more a visual guidance than a strict surgical guide since transferring the plan *in vivo* still presented some major issues; in other words, the possibility to reproduce *in vivo* the designated location for implants was still strongly operator dependent. In this regard, a study by Payer (6) analysed which factors influenced the angular deviation of free-hand positioned implants compared to the initially planned position, reporting as the most significant element of the surgeon's experience. This difficulty was solved by the introduction of CAD/CAM technologies, which were first used to realise precise jaws models with milling techniques and then to produce surgical guides through stereolithography.

The current computer-guided surgery protocols include both fully and partially computer-guided surgery. In these techniques, the information obtained from overlapping a digital wax-up with a 3D radiological model is used to virtually position the implant, creating the best compromise between the patient's anatomy and a good prosthetic rehabilitation. Then, later, a stereolithographic template is produced presenting sleeves of known diameter, inclination, angle and position, and fixed in place thanks to mucous, dental or bone support.

This study aims to review the literature looking for papers assessing the accuracy, thanks to which such systems can potentially facilitate the clinician to obtain the planned implant position intraoperatively.

MATERIALS AND METHODS

This paper tries to answer the question: "Does the use of computer-guided surgery in implant dentistry, being either a full or a partially guided protocol, allows the clinician to reproduce the virtually planned implant position *in vivo* precisely?".

The concept of "accuracy" in computer-guided surgery is intended as the level of congruence that exists between the virtually planned implant position and the post-operative one (7). The parameters that are taken into account to define the accuracy are the following four: the linear discrepancy, measured in millimetres, between the coronal centre of the placed implant and its planned position, the linear discrepancy, measured in millimetres, between the apical centre of the placed implant and its planned position, the deep/height divergence, measured in millimetres, between the coronal centre of the placed implant and its planned position and, lastly, the angular deviation between the two implants' main axis. The variations mentioned above may be due to summing errors occurring in all phases: the acquisition of data through CBCT, the correct positioning of the radiological template, the correct segmentation of the models, the production of the template both by manual manufacturing or through CAD/CAM methods, the intraoral fixation of the template and the accuracy of the used sleeves.

In early 2016, a search was performed through the PubMed engine, using as a query string: '("dental implants" OR "tooth implant" OR "oral implants") AND ("guided surgery" OR "computer-guided surgery" OR "computer-assisted surgery" OR "image-guided surgery") AND "accuracy" AND "Dentistry" [Mesh]'. This query produced 111 results, dated from 2002 to 2015. Subsequent inclusion criteria were: being published in a journal with at least a Q2 ranking, according to the "Scimago Journal & Country Rank" engine, and having a study design among reviews and systematic reviews. At the end of the first phase, 9 studies were chosen.

Afterwards, an independent reviewer assessed each result's relevance, first analysing its title and abstract and then proceeding with a full-reading review when the first two were deemed appropriate. Since some studies shared the same data, only the most comprehensive was included. This protocol led to selecting 6 studies, 3 being systematic reviews and 3 being narrative reviews.

Vercruyssen et al. (8) analysed the accuracy of implant placement both under the guidance of laboratory-fabricated templates and by CAD/CAM methods, focusing mainly on maximum deviations rather than the mean values, as is usually the case. Concerning stereolithographic techniques, 31 studies were considered. The technologies analysed were heterogeneous and included NobelGuide®, Simplant®, Med3D®, ImplantMaster®, Cadimplant® and others.

The same paper, based on 2 *ex vivo* models and 8 *in vivo* studies, reports that the Litorim/NobelGuide® system has a maximum linear discrepancy at the entry point of 1.4mm (mean 0.8mm and SD = 0.3mm), a maximum linear deviation at the apex of 1.5mm (mean 0.9mm and SD = 0.3mm) and a maximum axis deviation of 3.8° (mean 1.8° and SD = 1.0°). Furthermore, the Simplant® system has a maximum axis deviation of 12.2° and a maximum linear deviation measured at the apex of 7.7mm. A maximum deviation measured at the apical level of 6.4mm and a maximum angular deviation of 21.0° is reported for the Surgicase® system. Finally, it is argued that, since these represent the limit values available in the literature, it is appropriate to consider the current error level for the most used static computer-guided surgery systems, close to the 1-1.5mm range.

Vercruyssen et al. (9) sought proof of accuracy when using CAD/CAM methods in computer-guided implantology, selecting for their narrative review 31 studies performed both *in vitro*, *ex vivo*, and *in vivo*. The technologies considered were heterogeneous; the most common were StentCad®, NobelGuide® and Simplant®. The authors report an average deviation measured at the entry point of 0.9mm, with peaks of 4.5mm, an average deviation measured at the apex of 1.3mm, with peaks of 7.1mm, and an average axis deviation of 3.5°, with peaks of 21.2°.

Schneider et al. (10) carried out a systematic review based on a total of 321 sites (50 *in vitro*, 116 *ex vivo* and 155 *in vivo*) obtained from 8 articles about the accuracy of implant placement. Both manually produced guides (48 sites) and stereolithographic ones (275 sites), including NobelGuide®, Simplant®, StentCad® e Med3D®, were considered.

Regarding the linear deviation measured at the entry point, a value of 1.07mm (95% CI = 0.76-1.22mm) is reported, with differences that depended on the type of study considered: in the *in vitro* study (50 sites), the value was 0.90mm, in cadaver studies (116 sites) the value was 1.04mm and in *in vivo* studies (155 sites) the value was 1.16mm. Similarly, no significant differences are reported in the extent to which the measure refers to the implant site or the implant itself, whether the guide was manually made or depending on the type of stabilisation used. The mean linear deviation measured at the apex is 1.63mm (95% CI = 1.26-2.00mm). Again, no particular differences are indicated concerning the variables mentioned above. The average error in depth/height is reported only in two studies, both performed on cadavers: in the case of manually manufactured guides, the value was 0.28mm, and in the case of stereolithographic guides, it amounted to 0.60mm, with an average value of 0.43mm (95% CI = 0.12mm-0.74mm). Information about the mean angular deviation is reported in all the studies considered, and the mean value was 5.26° (95% CI = 3.94-6.58°).

In 2012, Van Assche et al. (11) conducted a systematic review on the accuracy of implant placement using 10 computer-guided surgery systems, including NobelGuide®, SurgiGuide® and Med3D®. The paper was based on a sample of 279 patients and 19 studies: 2 performed *in vitro*, 5 *ex vivo* and 12 *in vivo*. The mean deviation measured at the entry point is set at 0.99mm, with a range of variability of 0.0-6.5mm; the mean deviation measured at the apex is set at 1.24mm, in a range 0.0-6.9mm, the mean angular deviation detected was 3.81°, ranging from 0.00 to 24.9°, and, lastly, the mean deviation in verticality is reported to be 0.46mm, variable between -2.33mm and 4.2mm. In addition, the authors agreed to report the number of templates used as a statistically significant element of variability, although there are not enough RCTs to assert their role.

Sicilia et al. (12) produced the third EAO consensus report on computer-guided implantology, analysing its accuracy and advantages. The work is based on the previously cited Van Assche et al. paper (9), to which it adds a contextualisation stemming from the current scientific knowledge on the accuracy of these systems. The third EAO consensus report states a mean deviation value at the entry point of 1.09mm, an average deviation at the apex of 1.28mm, a mean vertical deviation of 0.5mm and an average angular deviation of 3.9°. The study concludes that it is reasonable to expect an average horizontal deviation of 1.2mm and a deviation in the vertical direction of 0.5mm while using static computer-guided surgery, even though peaks of deviation up to 6mm have been reported.

D'Haese et al. (7) analysed 31 *in vitro*, *ex vivo* and *in vivo* studies to conduct a systematic review concerning the accuracy and indications of static computer-guided surgery. The software used was heterogeneous and included NobelGuide® and Simplant®. In *in vitro* studies, both an average deviation at the entry point of 0.9mm and a mean deviation at the apex of 1.00mm are reported; in cadaver studies, a mean deviation at the entry point of 1.3mm is detected, an average deviation at the apex of 0.9mm and an average axis deviation of 3.9° are also stated. The authors conclude that it is appropriate to expect a mismatch between the planned and the actual implant's position, even when adopting these technologies, and therefore the clinician should maintain at least 2mm of distance from the anatomical structures to be preserved.

DISCUSSION

There is extensive literature on the accuracy offered by static computer-guided surgery, although it is difficult to carry out a thorough analysis since different systems have different levels of precision and samples are very often mixed. The importance of assessing the accuracy of implant placement when adopting such procedures is exacerbated in protocols that provide for immediate loading since the prosthetic device is based on the planned implant position rather than its post-operative one, and in the flapless protocols since it is no longer possible to visualise all the bony and soft tissues properly.

In order to understand the relevance of the previously reported values, it is necessary to compare them with the results of freehand-placed implants: a study by Nickenig et al. (13) compared the results detected *in vivo* with free-hand positioning to those obtained under computer aid on 23 implants. In the free-hand positioning scenario, an average deviation measured at the entry point of 2.4-3.5mm is detected, compared to 0.9mm in the case of guided surgery, an average deviation measured at the apex of 2.0-2.5mm, against 0.6-0.9mm in the case of guided surgery, and a mean axis deviation of 10.4°, against the 4.2° of guided surgery, are also reported. In light of those values, it is evident that computer-guided surgery presents more precise and predictable results than free-hand positioning. However, the persistence of a certain margin of error obliges the clinician not to exempt himself from the usual surgical considerations.

The literature agrees that due to this residual error, it is reasonable to consider a safety margin of 2mm (7) as the deviation is generally 1-1.5mm (8), mainly developed in the vertical direction rather than in the horizontal plane (9). This level of error makes guided surgery superior in terms of accuracy compared to free-hand insertion, especially for what concerns less experienced operators. According to Vercruyssen (9), this residual error is to be found in the poor preparation of the implant site (hesitating in the persistence of obstacles that prevent the complete descent of the implant), in the resilience offered by soft tissues in case of flapless surgery, in the sub-optimal management of radiographic information (a guide reconstruction with too low grey values will be too thick and will thus result in a misfit on the alveolar process), or in the wrong stabilisation of the guide and its eventual deformation during the operating phase. There are no reported differences in accuracy related to whether surgery involves the upper jaw or the lower one.

A second crucial aspect of the success of computer-guided surgery is to be found in the stabilisation of the guide. On the topic of the variation in precision ascribable to the type of support given to the surgical guide, Van Assche et al. (11) reported a slightly better accuracy for tooth-supported guides than those with mucous support, probably attributable to the resilience offered by soft tissues. On the other hand, the bone support sine stabilisation utilising mini-implants seems, according to Vercruyssen (9), even less precise than the mucous support, despite the differences being usually reduced.

CONCLUSION

The current narrative review has considered papers published up to 2015 dealing with the ability of static computer-guided surgery to reproduce the planned implant position.

In light of the data analysed, it can be concluded that a certain error when using computer-guided surgery in implant dentistry is still present, albeit significantly lower than with free-hand insertion. The mean error in the studies mentioned above, whether *in vitro*, *ex vivo* or *in vivo*, is included within the 1-1.6mm range of linear deviation at the entry point/apex and within the range of 5-6° in terms of angular deviation. In addition, it is possible to assert that tooth and mucosal-supported guides are more accurate compared to guides relying on bone support without mini-implants. At the same time, there is no significant difference concerning the treated jaw, the surgeon's experience in free-hand positioning and the computer-guided surgery system employed.

In conclusion, one should note the difficulty in comparing different studies due to their heterogeneity, thus preventing us from gathering precise information on the accuracy of each system. Furthermore, clinicians should also remember that the literature is far from affirming the undisputed superiority of computer-guided implantology over conventional procedures regarding safety, results, morbidity and efficiency, mainly when the latter is performed by experienced surgeons (14).

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