Guided surgery for single-implant placement: A critical review

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Abstract

Objective

The objective of this review was to evaluate the scientific evidence on accuracy, as well as esthetic and clinical outcomes of single-tooth implants placed using computer-assisted, template-based surgery.

Case description

Electronic and manual literature searches of clinical studies published between January 2002 and May 2015 were carried out using specified indexing terms. Outcomes were accuracy, Pink Esthetic Score, and clinical outcomes (Implant and prosthetic survival rates, complications, and marginal bone loss).

Results

A total of 706 titles and abstracts were found during the electronic and manual searches, but 563 publications were excluded (inter-reviewer agreement $k = 0.78$). The full texts of the remaining 143 publications were evaluated. A total of 125 papers had to be excluded because they did not fulfill the inclusion criteria ($k = 0.99$). Three manuscripts were added from the reference lists of all of the selected articles. A total of 21 articles were thus selected that fulfilled the inclusion criteria of and quality assessment required for this critical review.

Conclusion

Despite the high accuracy and a cumulative survival rate of 100%, there is little evidence to support the hypothesis that there is a clinical advantage of computer-assisted, template-based implant placement over conventional treatment protocols for the placement of an implant-supported single-tooth restoration. Long-term randomized clinical trials are needed to confirm these preliminary results.

Keywords

Computer-assisted surgery, single-tooth replacement, guided surgery.

Introduction

Single-tooth replacement by means of osseointegrated dental implants may be considered a reliable treatment option for replacing missing teeth, following both immediate and early protocols.[1, 2] Periimplant soft-tissue esthetics represents one of the major aspect of implant success, particularly in the anterior maxilla, and it may be a main factor in the patient's decision on implant therapy, rather than a conventional fixed or removable dental prosthesis.[3] It is well established that sufficient bone volume and a favorable 3-D implant position are prerequisites for long-term functional and esthetic success.[3–5] However, alveolar bone resorption after tooth loss seems to be inevitable with both immediate and delayed implant placement[6] and loading.[7] Consequently, prosthetically guided implant positioning might be difficult to achieve.

In recent years, the growing interest in prosthetically guided implant placement, together with the option of fitting prostheses with immediate function, has led to the development of software that integrates the restorative treatment plan (computer-assisted) with minimally invasive (template-based) surgery,[8–12] along with reduced treatment time and postoperative discomfort.[12] Guided implant surgery using cone beam computed tomography (CBCT), virtual treatment planning software and stereolithographic surgical templates has undoubtedly been a major step toward achieving optimal 3-D implant positioning with respect to both anatomical and prosthetic parameters. Computer-assisted, template-based implant placement offers the potential for better predictability and flapless implant surgery, resulting in reduced intraoperative discomfort and postoperative morbidity.[12] It also shortens the overall surgery time.

After enthusiastic preliminary reports,[13, 14] some independent prospective studies[9, 10, 15–17] drew attention to the potential deviations of 3-D directions between virtual planning and the actual final position of the implant. This approach is technique-sensitive and perioperative complications have to be taken into account.

Although, in general, tooth-supported templates are more accurate than mucosa-supported ones,[8] the application of guided surgery to enhance single-tooth implant positioning and esthetic outcome has not been widely reported in the literature. Potential advantages of flapless implant placement in the esthetic zone may include reduced mucosal recession and maximum preservation of periimplant papillae.[5, 18, 19]

Computer-assisted, template-based implant placement may help clinicians to perform successful implant therapy avoiding elevation of large flaps or even eliminating flaps completely, causing less pain and discomfort to patients.[12] One might assume that, in the case of complex anatomy, as well as post-extraction implant placement, both patients and clinicians could benefit from computer-assisted, template-based surgery. In such advanced cases, correct estimation of the bone condition and the implant position, as well as precise drilling, according to the preoperative planning may be essential in ensuring the successful placement of an implant.

The aim of the present critical review was to evaluate the scientific literature regarding accuracy, esthetic, and clinical outcomes of single-tooth implants placed using computer-assisted, template-based surgery.

Materials and methods

The review was written according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (http://www.prisma-statement.org). The protocol of this systematic review was adapted to the PICO format (P = population/patients: patients who received single implants placed using guided surgery; I = intervention: single-implant placement using guided surgery; C = comparator/control: single-implant placement using a conventional free-hand approach; O = outcomes: accuracy, esthetics and implant survival rate).

Search strategy

An electronic literature search was carried out with the intention of collecting relevant information about the accuracy, clinical application and esthetic outcomes of single implants placed using computer-assisted, template-based surgery. The following electronic databases were consulted: PubMed database of the U.S. National Library of Medicine, Scopus scientific abstract and citation database and the Cochrane Library. In accordance with the AMSTAR (A Measurement Tool to Assess Systematic Reviews) checklist, the grey literature in the New York Academy of Medicine Grey Literature Report was screened in order to find possible unpublished works.

The electronic databases were searched using the following MeSH (Medical Subject Headings) terms: ("Surgery, Computed/r-Assisted"[Mesh] OR "Therapy, Computed/r-Assisted"[Mesh] OR "Computer-Aided Design"[Mesh]) AND ("Dental/Oral Implants"[Mesh] OR "Dental Implants, Single-Tooth"[Mesh] OR "Dental Prosthesis, Implant-Supported"[Mesh]). Free-text terms ("Implant treatment" OR "Computed guided" OR "Single-tooth gap" OR "Guided surgery") were added to all searches.

The initial search included data from human, *ex vivo* and *in vitro* studies written in English and published between 2002 and May 2015 in refereed journals. No restrictions were implemented regarding the study design. The search included original research, clinical reports, technical notes and systematic reviews. Studies using static computer-assisted, template-based implant systems and dynamic navigation systems were included in the present review. All of the abstracts were evaluated according to established criteria on the topics of this review, in order to select relevant manuscripts for further full-text evaluation. For evaluation of randomized controlled or comparative studies, it was required that the enrolled population have at least five patients in each group. Clinical reports and technical notes were considered of interest when providing relevant scientific information on the subject. For evaluation of implant and prosthodontic survival rates, it was required that patients had been followed for at least one year after implant placement. However, no specific follow-up period was required for evaluation of surgical or prosthetic complications during implant placement/loading or for assessing patient-centered outcomes of surgery and the immediate postoperative period.

Afterward, manual searches of the reference lists of selected manuscripts were conducted, limited to the following journals: *Clinical Implant Dentistry and Related Research*, *Clinical Oral Implants Research*, *International Journal of Oral and Maxillofacial Implants*, *International Journal of Computerized Dentistry* and *European Journal of Oral Implantology*. Additionally, a new search excluding "Dental/Oral Implants, Single-Tooth" from the previously used MeSH terms was performed, followed by a manual search, in order to find single-tooth dental implants placed using computer-assisted, template-based surgery in larger cohorts of patients. The authors of each selected manuscript were contacted, if necessary, in order to obtain missing or supplementary information. Finally, the authors of the current review used personal contacts in an attempt to identify unpublished or ongoing eligible studies. Two reviewers (MT and SMM) performed the literature search independently. A third reviewer (LC) reassessed both the included and excluded studies.

The following outcome variables were defined:
- accuracy, defined as the difference in location or angulation between the computer planning and the actual position of the placed implant: deviation at the entry point, deviation at the apex, deviation in height and deviation of the axis;
- esthetic outcome: Pink Esthetic Score (PES);
- clinical outcomes: implant and prosthetic survival and success rates, any biological and biomechanical complications, and marginal bone loss.

Based on randomized controlled trials in previously published systematic reviews, the following question was addressed: Is there scientific evidence to support the hypothesis that there is a clinical advantage of using computer-assisted, template-based implant placement compared with conventional treatment protocols for the placement of an implant-supported single-tooth restoration?

Results

A total of 706 potentially relevant titles and abstracts were found during the electronic (n = 704) and manual (n = 2) searches. During the first stage of study selection, 563 publications were excluded based on their title and abstract (inter-reviewer agreement k = 0.78). For the second stage, the full texts of the remaining 143 publications were thoroughly evaluated. A total of 125 papers had to be excluded at this stage because they did not fulfill the inclusion criteria of the present review (inter-reviewer agreement k = 0.99). Three manuscripts were added from the reference lists of all of the selected full-text articles. Finally, a total of 21 articles were selected that fulfilled the inclusion criteria of and quality assessment required for this critical review.

The 21 selected studies included one *in vitro* comparative study,[20] four prospective single-cohort studies,[19, 21–23] one case series,[24] six case reports,[25–30] eight reviews of the literature,[8, 31–37] and one randomized controlled trial.[38] A diagram of the search strategy is presented in **Figure 1**.

Fig. 1

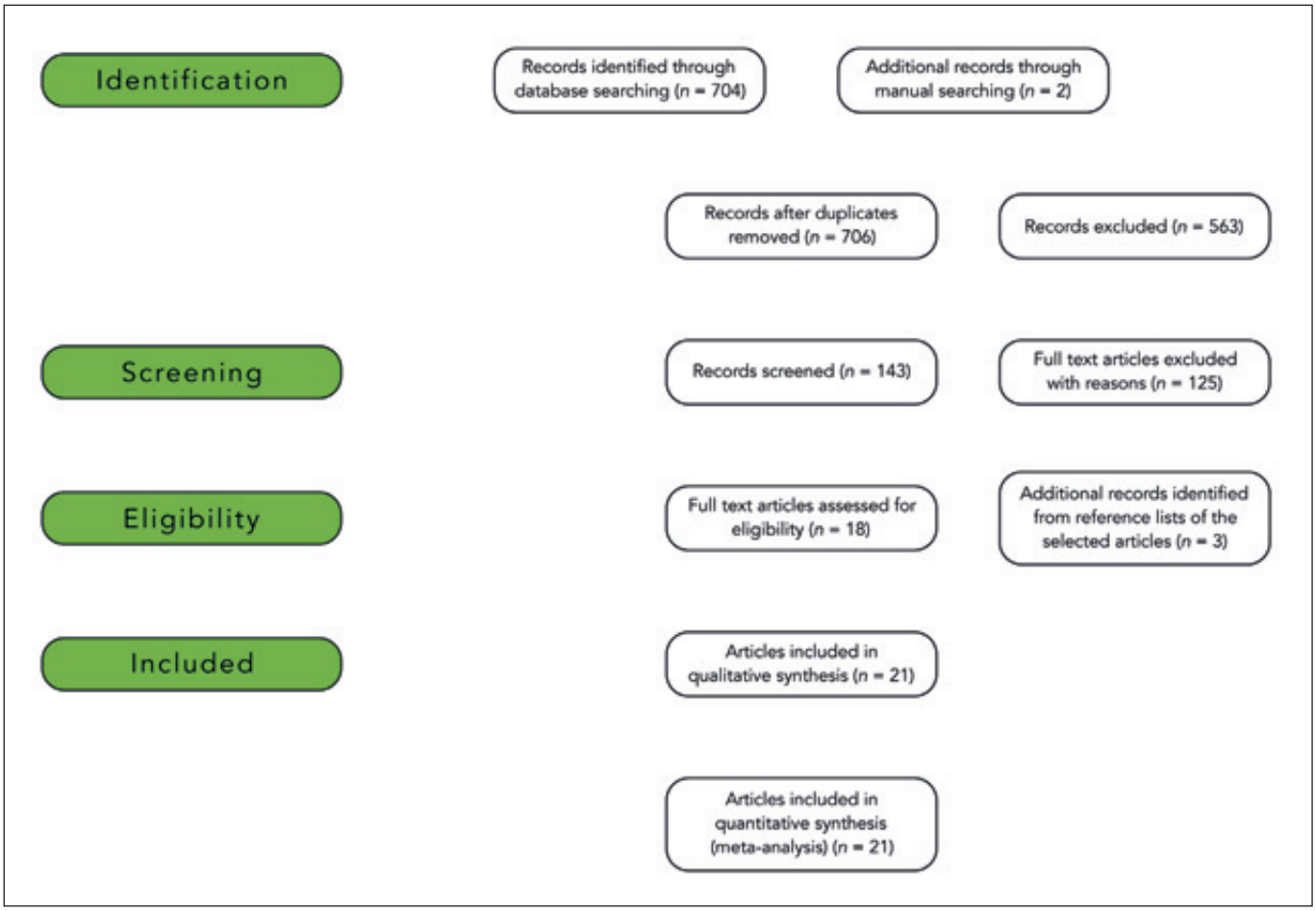

Fig. 1
Diagram of the search strategy.

Accuracy of computer-assisted, template-based surgery for implant-supported single-tooth restorations

There are no *in vivo* randomized controlled trials in the scientific literature that report on the accuracy of computer-assisted, template-based implant placement compared with a free-hand approach for the treatment of a single-tooth gap. Three *in vivo* prospective studies, and one randomized controlled trial reported the 3-D accuracy of 65 implants placed using computer-assisted, template-based surgery.[19, 22, 23, 38] All of the data are summarized in **Table 1**. Farley et al., in a split-mouth, randomized controlled trial, reported that computer-assisted, template-based implant placement was more accurate than conventional guides, but only for coronal horizontal distances.[38] One *in vitro* comparative study (80 implants) reported the 3-D accuracy of single-tooth implants placed using navigated implant surgery compared with conventional implant placement.[20] Kramer et al. compared *in vitro* the accuracy of conventional (n = 40) versus navigated (n = 40) implant placement.[20] For each group, identical maxillary casts were used to place implants for single-tooth replacement of either the left central incisor (n = 20) or the right canine (n = 20). The authors concluded that variation in implant position, angulation and depth was reduced for implants that were placed using the navigation protocol.[20]

In a prospective study, Behneke et al. analyzed the factors that may influence the transfer accuracy of CBCT-derived, laboratory-based surgical guides for implant placement in partially edentulous patients.[22] Nineteen implants were placed to restore a single-tooth gap in 19 partially edentate patients. The accuracy of computer-assisted, template-based implant placement was evaluated using the image fusion technique. Measurements were done to calculate linear and angular deviations between virtually planned and actually placed implants. A relevant improvement of the accuracy could be achieved by final drilling or implant placement

Table 1
In vivo accuracy of computer-assisted, template-based surgery for implant-supported single-tooth restorations (mean ± standard deviation).

Table 1

Study	No. of implants	Entry point in mm (range in mm)	Apex point in mm (range in mm)	Angle in ° (range in °)
Behneke et al.[22, †]	19	0.21 ± 0.16 (0.01–0.92)	0.32 ± 0.34 (0.03–0.59)	1.35 ± 1.11 (0.07–3.33)
Fürhauser et al.[19, ‡]	27	0.84 ± 0.44 (0–1.6)	1.16 ± 0.69 (0–2.6)	2.7 ± 2.6 (0–12.7)
Ersoy et al.[23, §]	9	0.74 ± 0.4	1.66 ± 0.28	3.71 ± 0.93
Farley et al.[38, °]	10	1.45 ± 0.06 (0.50–2.67)	1.82 ± 0.6 (0.60–2.69)	3.68 ± 2.19 (0.78–7.98)

* Implant 3D software (med3D, Heidelberg, Germany).
** NobelClinician (Nobel Biocare, Zurich, Switzerland).
§ Stent Cad (Media Lab, La Spezia, Italy).
° iDent software (iDent Imaging, Ft. Lauderdale, Florida, U.S.).

with template guidance in both single-tooth gap and reduced residual dentition cases. A mean error of 0.21 ± 0.16 mm (range of 0.01–0.92 mm) at the entry point and of 0.32 ± 0.34 mm (range of 0.03–0.59) at the apex, and 1.35 ± 1.11° (range of 0.07–3.33°) of apex radial deviation were reported for single-tooth gap surgery.[22] The amount of coronal, apical and angular deviation was about half of that reported by Vasak at al. using the NobelGuide system for the rehabilitation of partially edentulous maxillae and mandibles, although all maximal deviations measured in both clinical studies were within the safety margins recommended by the planning software manufacturer.[10]

According to a recent systematic review and meta-analysis of computer-assisted, template-based implant surgery for different types of edentulism, the clinician should consider a mean error of 1.12 mm at the entry point and of 1.39 mm at the apex.[35] However, the same report indicates that the clinician should be aware that maximal deviations of 4.5 mm and 7.1 mm, respectively, have been reported—which is clinically relevant.[35] These average deviations are slightly higher than those reported by Fürhauser et al. using stereolithographic templates for the rehabilitation of single-tooth implants in the anterior maxilla (the mean deviation between planned and actual implant position measured 0.84 ± 0.44 mm at the implant shoulder [range of 0.0–1.6 mm] and 1.16 ± 0.69 mm at the implant apex [range of 0.0–2.6 mm]).[19] Mean angular deviation was 2.7 ± 2.6° (range of 0.0–12.7°) and was significantly correlated to apical deviation, but not to inaccuracy at the implant shoulder.

A retrospective study by Ersoy et al. on the 3-D accuracy of nine single-tooth implants placed by guided implant surgery reported a mean error of 0.74 ± 0.40 mm at the implant neck and 1.66 ± 0.28 mm at the apex and an angular deviation of 3.71 ± 0.93°.[23] No minimum and maximum deviations were reported for the implant-supported single-tooth restorations. The authors reported a statistically significantly higher accuracy between single and both partially and edentulous patients, in favor of single-tooth gap restorations.

A possible explanation of these results was recently published in a systematic review and meta-analysis by Tahmaseb et al., who reported that the tooth-supported guides tended to be slightly more accurate than mucosa- or mucosa- and pin-supported guides.[35] These results are also in accordance with those of the third EAO Consensus Conference on computer-guided implant therapy and soft- and hard-tissue aspects, that tooth- and mucosa-supported templates can give more accurate results than bone-supported templates.[8]

Esthetic outcomes of implant-supported single-tooth restorations performed using computer-assisted, template-based surgery

There are no *in vivo* randomized controlled trials in the literature that report esthetic outcomes of computer-assisted, template-based implant placement compared with free-hand surgery for the treatment of single-tooth gaps. In a prospective study, Fürhauser et al. reported the 3-D accuracy of 27 single-tooth implants placed for delayed replacement of maxillary incisors, using stereolithographic templates.[19] The es-

thetic outcomes were evaluated using the PES.[39] In this study, the mean deviation between the planned and actual implant position was calculated by superimposition of postoperative CBCT scans, with a mean follow-up of 2.3 years. The authors found that the 3-D inaccuracy is low in guided implant surgery, but that it may significantly compromise the implant esthetics in the anterior maxilla. Particularly, deviations toward the buccal side ≥ 0.8 mm resulted in significantly worse implant esthetics (median PES of 9.5) compared with more accurate implant positions (median PES of 13).[19] These results confirm the hypothesis that the 3-D implant position has an important influence on the esthetic outcome. A positioning of the implant that is too buccal may result in an increased crown length compared with the contralateral tooth and in midfacial recession over time.

Clinical outcomes of implant-supported single-tooth restorations performed using computer-assisted, template-based surgery

There are no *in vivo* randomized controlled trials in the literature that report the survival or success rates of implants placed using computer-assisted, template-based surgery compared with free-hand surgery for the treatment of single-tooth gaps. One randomized controlled trial, and four *in vivo* prospective studies[19, 21–23, 38] treating single-tooth gaps were identified. In two studies[19, 21] NobelClinician Software (Nobel Biocare, Gothenburg, Sweden) was used. In the other three studies, Implant 3D software (med3D, Heidelberg, Germany),[22] Stent Cad (Media Lab, La Spezia, Italy),[23] and iDent software (iDent Imaging, Ft. Lauderdale, Florida, U.S.)[38] were used.

A total of 125 single implants were placed in 123 patients (18–68 years old). In all five studies, no implant failed, resulting in a cumulative survival rate of 100%.[19,21–23,38] A mean follow-up period was reported only in two studies,[19, 21] ranging from 12 to 52 months.

Conclusion

Despite the high accuracy and a cumulative survival rate of 100%, there is little evidence to support the hypothesis that there is a clinical advantage of computer-assisted, template-based implant placement over conventional treatment protocols for the placement of an implant-supported single-tooth restoration.

- Single implants placed using computer-assisted, template-based surgery are associated with higher accuracy than single implants placed using a navigation system.
- Tooth-supported templates used to treat cases of partial edentulism provide more accurate results than do mucosa-supported templates used in completely edentulous patients.
- Tooth-supported templates for implant-supported single-tooth restorations provide even more accurate results than those for partially edentulous patients.
- Clinicians should inform patients that computer-assisted, template-based surgery implies greater planning time and additional costs. However, the higher cost should be analyzed in terms of cost-effectiveness and in light of the reduction of surgery time and postoperative pain and swelling, as well as the possible increased accuracy.
- The avoidance of critical anatomical structures, as well as the esthetic and functional advantages, with prosthodontically driven implant positioning must also be considered.
- Long-term randomized clinical trials and future reviews of literature on the topic of single-tooth replacement with implants are needed.

Competing interests

This review was performed at the request of the Foundation for Oral Rehabilitation. This foundation is an independent international initiative that unites professionals from various disciplines to improve oral health care and support humanitarian leadership. The study was self-supported and the authors declare no competing interests.

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