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Effect of a CAD-CAM sinus surgical template on the outcome of sinus augmentation. A systematic review

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SUMMARY

Objective. To analyze the effect of the computer-aided designed maxillary sinus surgical template (CAD-MSST) on the surgical outcome.

Materials and Methods. A systematic search was conducted in MEDLINE (PubMed), Cochrane, web of science, Scopus, and ProQuest databases as well as reference list manual search up to November 2019. After excluding irreverent studies or with a high risk of bias, detailed data, and final results of each study was extracted.

Results. Upon 426 recorded studies, five studies were eligible enough to be included during the study selection procedure and a total of 99 patients with 606 implants were evaluated. As a result of using CAD-MSST, less complication is expected during the surgical phase, in the healing period, and even after loading.

Conclusions. CAD-MSST brings the advantage of 3D display of multislice imaging with faster and more accurate manufacturing procedure. Simplification of the surgical procedure and limits invasiveness. However, the effect of delayed or immediate implant placement, or using angulated implants are the subjects recommended to be investigated in the future studies.

Keywords: computer aided design, computer guided, sinus floor augmentation, success, surgical template.

INTRODUCTION

Sufficient bone height between the alveolar crest and the maxillary sinus is needed for the insertion of a dental implant in the posterior part of the maxilla (1). With insufficient crestal height, the sinus floor membrane can be elevated that leads to alveolar bone formation. The procedure is called sinus floor elevation or sinus lifting (1).

Various complications may jeopardize the final success of sinus floor elevation. Intraoperative complications during and after sinus floor elevation are possible including bleeding, buccal flap laceration, alveolar ridge fracture, damage to the adjacent tooth root, and perforation of the Schneiderian membrane (2). 10 to 40% of cases experienced membrane damage which is the most prevalent complication in sinus floor elevation procedure. Anatomical variations in the sinus cavity and sinus walls, various thickness of the schneiderian membrane and iatrogenic conditions might be the most common contributing factors in sinus perforation (3).

Advances in the surgical procedures have been proposed to reduce the rate of complications (4-7). The introduction of multislice imaging also reduced the incidence of complications and has to be taken in to account during the planning and surgical phases (8). Cone-beam computed tomography (CBCT) can provide a 3-dimensional (3D) view for a clinician, but the practitioner is still required to visually transfer the information of the CBCT scan to the patient during surgery (8).

The use of surgical guides was firstly introduced and classified in the 1980s (9). In computer-guided implant insertion, placement of implants is guided prosthetically in a favorable position with minimal possibility of complication (10). computer guided surgical guide could also be an option for sinus floor augmentation. This type of surgical template is also called computer aided designed maxillary sinus surgical template(CAD-MSST) (Fig. 1) (11). Lower invasive procedure and decreased risk of membrane perforation and damage to superior alveolar artery are the possible advantages of sinus surgical template application over other current approaches (12). However, surgical guide

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Fig. 1. An example of a sinus surgical template (picture from Goodacre *et al.* (11) study)

templates may increase the initial cost of treatment. A placed surgical guide could limit the required accessibility for proper handling of the membrane elevation (13). As a result, using these templates might not be easy during the surgical procedure (13). As data about the effect of CAD-MSST was sparse, this review aimed to evaluate the clinical results of this technique in dental practice. The null hypothesis was that the CAD-MSST application is unnecessary and does not influence sinus elevation complications.

MATERIALS AND METHODS

This review was designed based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) checklist (14). The main question of this study was defined as follows: Do patients with the need for sinus augmentation with applying a MSST show successful clinical results. The question and search strategy of this article was designed in agreement with the general idea of other systematic reviews (15, 16).

An electronic search in PubMed/MEDLINE, Scopus, Embase, ProQuest, and Web of science along with references of selected studies for full-text review was conducted until November 2020 with MeSH and non-MeSH selected keywords (Table 1). Records were exported to a reference management software (Endnote X8; Thomson Reuters) and after the removal of duplicates, remained studies were checked for title/abstract analysis by two independent reviewers (A.D. and A.M). Subsequently, the same reviewers (A.D. and A.M) evaluated the full text of selected studies for eligibility according to inclusion and exclusion criteria (Table 2). In cases of disagreement, 2 reviewers discussed the article to reach the same consensus. The following data were extracted from the included studies: study year, study type, study objectives, number of patients, template manufacturing protocol, the surgical approach for implant placement, measurements conducted in each study, outcomes (sinus complications during and after surgery, implant survival/failure or success rate, and implant marginal bone loss), and follow up duration. The extracted data were entered into a spreadsheet (Microsoft Excel 2007) afterward.

Studies were evaluated by a modified version of meta-analysis of statistics assessment and review instrument (MAStARI) (17) (Table 3). Risk of bias was qualified based on the obtained score: (-9 to -3 (low), -3 to 3 (medium), 4 to 9 (high quality)).

RESULTS

Among 426 potentially relevant records, 161 was remained to be checked for title/abstract analysis. Of 12 selected studies for full-text analysis, only 5 fulfilled the eligibility criteria (Fig. 2). Demographic factors, measurements, and outcomes of the included studies have been demonstrated (Table 4 and 5). A total of 99 patients with 606 implants were included in this study. Due to the heterogeneity of the included studies (like study design, implant system, applied techniques and outcome measurements), no meta-analysis could be conducted. All of the finally selected studies were included in a moderate or high-quality group according to the MAStARI checklist. The most common reasons for bias in overall studies was lack of randomization.

Table 1. Key-words used in this study based on PICO question

Searching strategy	(“sinus elevation" OR "sinus augmentation" OR “sinus floor Augmentation[MeSH Term]”) AND ("computer-guided" OR "guided surgery" OR "model surgery" OR "surgical template" OR " surgical guide" OR "3D printing " OR "Computer-Aided Design[MeSH]") AND ("complication" OR "failure" OR "success" OR "survival" OR "satisfaction" OR "cost" OR "time" OR "acceptance" OR "discomfort" OR "trauma" OR " perforation" OR "advantages" OR "disadvantages" OR "functional" OR "ease of elevation” OR “adaptation” OR “ease of Grafting” OR “Surgical area view” OR “Prolong surgery” OR “view of surgical area” OR “Immobility” OR “Primary stability”)

Table 2. Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
• English language studies • Studies with the use of a surgical template for sinus lifting procedure • Studies with implant placement after sinus lifting procedure	• Studies with teeth auto-transplantation after sinus lifting. • Repeatedly published studies. • Studies qualified with “very High” or “High” risk of bias. (Minor score of <10)

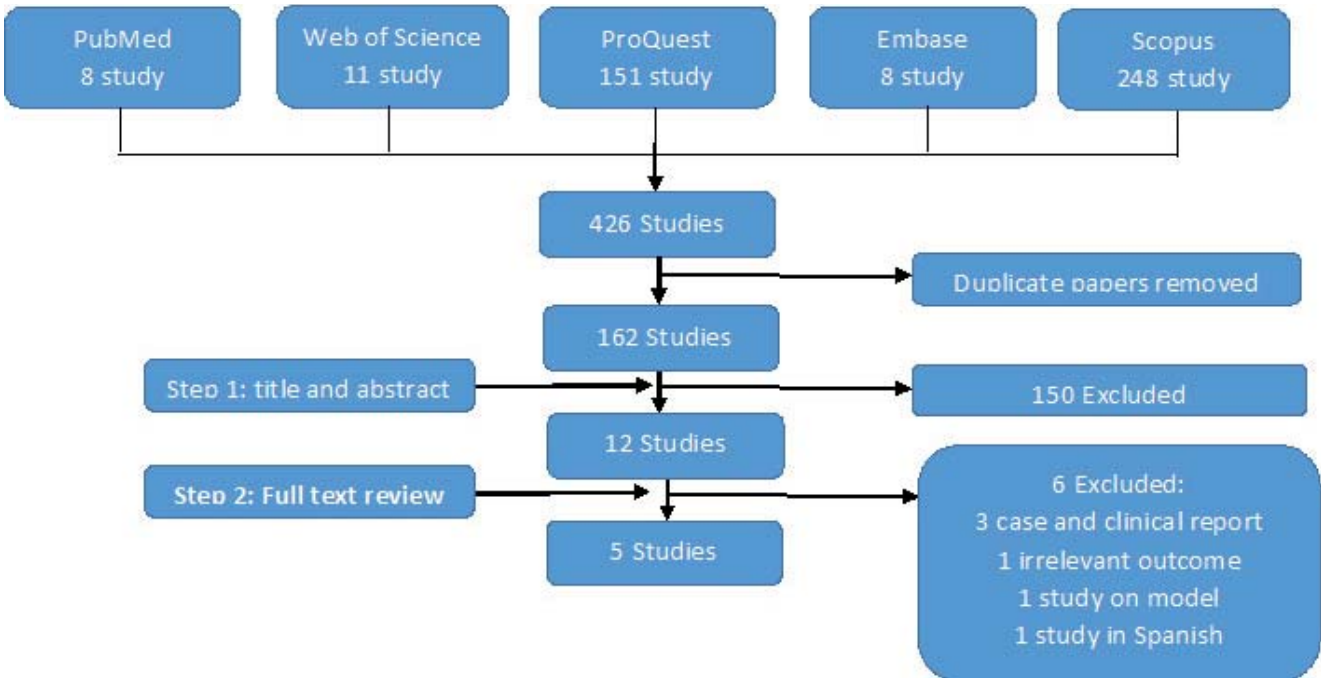

Fig. 2. Study selection according to the PRISMA checklist. PRISMA, Preferred Reporting Items for Systematic reviews and Meta-analyses.

In Zaniol *et al.* study (18), 50% of participants undergone a second surgical procedure for implant placement. All of the other studies used one-stage surgery with placement of implants simultaneously after grafting (except one patient in Kocyiğit *et al.* (19) study) (18-21). Only in one of these 5 studies, immediate loading after implant placement was applied (17).

CT examination in four studies (17, 18, 20, 21) and CBCT in two studies (17, 19) was used to construct a three-dimensional model for each patient. One study used a surgical stent to guide graft placement and immediate implant insertion simultaneously in close sinus lifting procedure (17).

Two studies followed patients for almost 3 years (17, 18). These studies investigated factors like marginal bone loss (MBL), and implant and prosthesis survival rates after sinus lifting with surgical templates. MBL from baseline to 1 year after implant insertion was not much different between studies (0.47 mm and 0.33 mm); this similarity was also present after 3 years (0.63 mm and 0.57 mm) (17, 18). One study followed the implants until implant exposure (21) and 2 studies were cross-sectional (19, 20). The survival rate in the two studies was found to be more than 90% after 3 years (100%and 98.53%) while using MSST (17, 18). However prosthetic survival rate was reported to be 100% that means prosthesis is still functional, although it may contain some defects.

Surgical complication explained only in three studies (19-21). Sinus perforation risk was reported to

Table 3. Risk of bias assessment for selected studies

MAStARI Criteria	Zaniol *et al.* (18)	Kocyiğit *et al.* (20)	Pozzi1 *et al.* (9)	Engelke *et al.* (22)	Osman *et al.* (21)
1. Is the study based on a random or pseudorandom sample?	-1	-1	-1	-1	-1
2. Are the criteria for inclusion in the sample clearly defined?	1	1	1	1	1
3. Are confounding factors identified and strategies to deal with them stated?	1	1	1	1	1
4. Are outcomes assessed using objective criteria?	1	1	1	1	1
5. If comparisons are being made, was there sufficient description of the groups?	0	1	0	0	1
6. Is follow-up carried out over a sufficient time period?	1	1	1	1	1
7. Are the outcomes of people who withdrew described and included in the analysis	0	-1	1	0	1
8. Are outcomes measured in a reliable way?	1	1	1	1	1
9. Is appropriate statistical analysis used?	0	0	0	0	0
Sum	**4**	**4**	**5**	**4**	**6**

1=Yes, -1=No, 0=Not applicable. Risk of bias for cohort studies assessed by using MAStARI critical appraisal tools. MAStARI, Meta-Analysis of Statistics and Review Instrument.

be around 5% in two studies (20, 21) and 9.3% in the other study (19). The incidence of sinus lifting procedure with conventional methods was reported to be 25-42% in previous studies (3).

Two studies investigated patients' satisfaction after surgery (17, 18). In Zaniol study (17), all patients healed without problem after a low window sinus lift and reported a good (45%) or excellent (55%) level of satisfaction concerning post-surgical side effects (pain and swelling). In the first week after implant placement, a low level of pain was reported in Pozzi *et al.* study (mean score: 3.17±1.82 – using a 0-10 numbered scale) (18).

DISCUSSION

When a surgeon wants to place implants and encounters an insufficient bone height in the posterior maxilla, sinus floor augmentation is an inevitable procedure. Depending on the bone volume, this procedure could become more invasive in a procedure called "open sinus lift" (22). The risk of complications occurrence along with this procedure, and even after that is significant (23). As a result, the application of a new method for the reduction of this risk must be taken into consideration. This Review focused on the potential advantages of the CAD-MSST to help the surgeons and patients experience an easier and less problematic surgery.

Zaniol *et al.* (17) proposed a new approach for open sinus elevation using a CAD-CAM surgical template. Reduction in sinus membrane perforation risk and post-surgical discomfort were observed in this study. As a result, this study stated that the low window technique along with surgical guide fabrication could play an important role in achieving successful results.

In Osman *et al.*'s study (20) , computer-guided sinus floor elevation through lateral window approach with simultaneous implant placement was compared to a non-guided approach. For the first group with a surgical template, only one sinus membrane perforation occurred while it was three for the control group. This study also stated that along with a reduction in operating time and sinus membrane perforation, surgical templates allow the clinicians to use cortical septa and thus providing

Table 4. Description of demographic factors and used methods and materials in the included studies

Author (Year)	Study type	Objective	Number of patients	Template manufacturing protocol	Surgical approach of implant placement
Zaniol *et al.* (2018) (18)	retrospective	safety and effectiveness of low window technique by application of the surgical guide	22 patients (10 women and 12 men; mean age: 59.06± 8.6 years old),79 imp	CT or CBCT scan performed and a surgical guide manufactured by 3D printing	1stage (13 p, 36 imp)/ 2 stage (15 p, 43 imp)
Osman *et al.* (2017) (21)	Cross-sectional	comparing the efficacy of cad cam surgical guide in the reduction of sinus perforation in sinus floor elevation compared to the standard technique	15 patients(6 women,9 men; mean age:47 years old),20 imp	multi-slice CT scan was digitalized and then printed using fused deposition modeling technology	1 stage
Pozzi *et al.* (2014) (19)	cohort	A novel technique for minimally invasive transcrestal sinus grafting with immediate implant placement and immediate loading by surgical template	66 patients(38 women,28 men; mean age 51.3 years),136 implant(40 mono lateral,26 bilateral)	CT before(2 times; double-scan protocol), fabrication of a stereolithographic-generated surgical template through software planning program	1 stage+immediate loading
Kocyiğit *et al.* (2013) (20)	cohort	use of preoperative model surgery and a maxillary sinus surgical template(MSST) in maxillary sinus augmentation using a lateral approach	10 patients (4 women,6 men; /age: 45-65 years),27 imp, 5 with maxillary sinus surgical template (MMST) + implant surgical guide and 5 with surgical implant guide only	CBCT used to construct a three-dimensional model and MMST and stereolithographic surgical guide were constructed using a prototyping machine	1 stage(except for 1 patient)
Engelke *et al.* (2005) (22)	Case series	use of endoscopic flapless sinus floor augmentation coupled with CT assisted 3D planning and surgical template fabrication for implant placement	6patients (21 imp:18Xive/3 Semados)	CT scan and virtual implant planning in the program were performed and a surgical stent was printed	1 stage

P – patient; Imp – implant.

more supports to the placed implants. In this study, in contrast with the other investigated studies, no graft material was used to fill the created space. However, all of the implants were completely osseointegrated at the time of prosthetic loading. Prolonged pain, edema, or postoperative infection was not reported in any of the patients.

Pozzi *et al.* (18) describes a new procedure for flapless transcrestal maxillary sinus floor augmentation using computer-guided planning with the use of a surgical template in combination with expander condensing osteotomy. No biological or mechanical complications or prosthetic failures occurred during the follow-ups. Moreover, the mean MBL during the first year and 3 years follow up was in a normal range like Zaniol study (17). All patients reported low levels of pain and periodontal parameters were normal. Cumulative implant survival rate was 98.53% at 3 years, prosthetic survival rates were 100% and only 3 porcelain chippings were reported in 3 years.

Kocyiğit *et al.* (19) evaluated the benefits of preoperative model surgery and the use of MSST in sinus floor augmentation. Stereolithographic models constructed by using CBCT images were divided into 2 groups. In the first group, templates were designed for implant placement and sinus elevation simultaneously, but in the second group, only implants were placed. An oral questionnaire was distributed asking surgeons about the effectiveness of using MSST. The use of an MMST was found to be effective concerning adaptation, window preparation, ease of elevation, reduction of perforation risk, and stability during the procedure. However, the use of MMST was also observed to prolong surgery, and restrict the view of the surgical area. Overall, model surgery considered an acceptable and effective method for sinus elevation surgeries (87.5% agreement). MMST tends to be an effective tool for locating an appropriate entrance to the sinus cavity and safe elevation of the sinus membrane and effectively grafting the sinus floor.

The use of CT-scan designed surgical templates combined with endoscopy application was investigated in Engelke and Capobianco's study (21). Endoscopy can help the surgeon to localize the apical part of the implant in bony housing, control the amount of augmentation material around the implant, and verifying the complete seating of healing abutment on the fixture. Surgical template application based on CT images also lets the clinicians avoid the invasion of critical anatomic structures during surgery, limit the incision and undermining for implant placement and make flapless surgery approach with a lower risk of bone resorption possible. Finally, in this study, all of these modifications in the sinus floor elevation procedure allow the placement of implants in the prosthetically defined position and improve the quality of surgery while avoiding mentioned complications.

Limitations of this study can be the type of studies included and different outcome measurements in each study, short term follow-ups, and different methods of surgery between studies that make the comparison between studies difficult. Discrimination between the effect of delayed or immediate implant placement on subsequent complications and comparison of various outcomes between conventional sinus lifting, stent-based sinus floor augmentation, or angulated implant placement in the form of well-designed RCTs is recommended for future studies.

Table 5. Measurements, outcomes, and duration of follow up of studies included

Author (year)	Measurements/outcome	Follow up
Zaniol *et al.* (2018) (18)	MBL: Baseline to 1 year : 0.48 mm ± 0.43 mm (range, 0.1–1.3 mm) Annual bone loss after : 0.05 mm ± 0.06 mm (range, 0.0–0.2 mm)implant survival rate: 100%/prosthetic survival rate:100%	>24 month/ 38.4±13.2 month
Osman *et al.* (2017) (21)	Computer guided: 1 sinus perforation, non-guided: 3 sinus perforation, bleeding: 1.	Not described
Pozzi *et al.* (2014) (19)	MBL: Baseline to 1 year:0.33±0.36; 1 to 2 year:0.1±0.19; 2 to 3 year:0.08±0.01; baseline to 3 year: 0.51±0.29; implant survival rate: 98.53 (95% CI: 0.96-1.005)/prosthetic survival rate:100%.	3 years/36-52 months, mean – 43.96
Kocyiğit *et al.* (2013) (20)	Finding of the questionnaire given to surgeons immediately after procedure: use of an MSST was found to be effective concerning adaptation (62.5%), window preparation (87.5%), ease of elevation (95.9%), ease of grafting (95.9%), reduction of perforation risk (91.7%), and immobility during the procedure (62.5%). However, the use of an MSST was also observed to prolong surgery (100%) and restrict the view of the surgical area (79.2%). Overall, the model surgery was found to be an effective means of preparing for actual sinus elevation surgery (87.5%).	3, 6, 10 days after surgery
Engelke *et al.* (2005) (22)	1 sinus perforation, 1 narrow replaced with wide imp(primary stability), 1 implant replaced with satellite imp (primary stability),1 implant slightly deviated from the planned position, 1 implant failed before loading(not osseointegrated).	until implant exposure (7-12 month after surgery)

MBL: marginal bone loss, Imp: implant.

CONCLUSIONS

Based on the findings of this systematic review, the following conclusions were drawn:

1. A combination of lateral window technique and surgical template application seems to be a beneficial protocol while placing an implant in reduced bone height in the posterior maxilla.
2. limitation of invasion to the anatomical structures, soft tissue preservation, locating an appropriate entrance to the sinus cavity, safer membrane elevation, and providing a suitable substructure for prosthetically driven implant placement are the most important outcomes of surgical guides application during surgery. Low patient morbidity was the main post-surgical advantage.
3. Although the surgical guide application might limit the surgeon's field of view, prolong the surgery and costs more, because of its effect on a decrease in complications especially sinus membrane perforation and other advantages, in the future, it can become an essential step in sinus lifting procedure.

STATEMENT OF CONFLICTS OF INTEREST

The authors state no conflict of interest.

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