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Advantages and disadvantages of implant navigation surgery. A systematic review☆

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ABSTRACT

This review elucidates the advantages and disadvantages of the different implant navigation methods to assist the precise surgical placement of dental implants. Implant navigation surgery can be classified into: dynamic and static navigation, and static navigation can further be divided into full (FG)- and half-guided (HG) implant surgery. The HG implant placement includes the drilling-guided, pilot-drill guided, and the non-computed guided approaches. In dynamic navigation, the bone drilling and the implant placement are completely tracked with a specific software; while the static navigation refers to the use of static surgical templates. The FG associated with flapless surgery and teeth/crown supported guides has demonstrated the highest accuracy, followed by the drilling and pilot HG surgery that may provide comparable results, while the non-computer HG and FH implant placement provide the least accuracy in transmitting the implant positioning from the pre-surgical planning to the patient. Additionally, flapless implant surgery is related to reduced pain, less analgesic consumption, less swelling, shorter chair-time, and reduced risk of hemorrhage while achieving greater patient satisfaction. Nevertheless, other methods such as non-computer HG and FH implant surgery procedures require more surgical experience to overcome their limitations. There is still limited evidence to support dynamic surgery, and further investigations are needed.

Contents

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1. Introduction

Navigation surgery was originally introduced in neurosurgery for conducting safer brain surgery in a minimally invasive matter (Mezger et al., 2013). While other terms such as computer-aided surgery, computer-assisted intervention, or image-guided surgery have all been interchangeably used to describe this concept, computer-assisted or navigation surgery is the most commonly used term throughout literature.

With the establishment of navigation surgery in the dental implant field, the two approaches dynamic and static navigation were introduced. Dynamic navigation through a three-dimensional (3D) software allows for the monitoring of the bone drilling and implant placement in real time during the entire length of the procedure (Block et al., 2017; D'Haese et al., 2017). While static navigation refers to the use of static surgical templates for the bone implant drilling sequence and the implant placement.

Different navigation approaches have been described which involve a wide variety of tools, devices, and technological advancements, while free-hand (FH) implant placement requires no guided stents. However, FH technique and the static navigation method, which include the full-guided (FG) and half-guided (HG) approaches, remain the most widely employed methods to date.

Many investigations have focused on implant positioning, regarding the advantages of implant restorations, adequate esthetics, proper maintenance and allowing for screw-retained prosthesis (D'Haese et al., 2017; Linkevicius et al., 2013). The soft and hard-tissue peri-implant stability with the long-term success are therefore related to the 3D positioning of implant placement (Buser et al., 2004; Tarnow et al., 2000). The accuracy of implant placement is often evaluated by the superimposed pre- and post-operative CBCT image and measurement of the deviations at the coronal or apical part of the implants along with mesio-distal and bucco-lingual discrepancies and implant axis angle deviations.

Despite the excellent results obtained with the FG navigation surgery (Bover-Ramos et al., 2018; Colombo et al., 2017; Moraschini et al., 2015; Raico Gallardo et al., 2017; Schneider et al., 2009; Sicilia and Botticelli, 2012; Van Assche et al., 2012), controversies still exist regarding its routine use (Vercruyssen et al., 2015b). Certain limitations have been attributed that render its use (full-guided static or dynamic navigation) a challenge, such as: reduction of accuracy in fully-edentulous arches compared to partially edentulous ones (Farley et al., 2013; Younes et al., 2018); reduced accuracy in bone-supported templates when compared with mucosal-supported or tooth-supported templates (Arisan et al., 2010; Vercruyssen et al., 2015b); deficient passive (inaccurate) adjustment of temporary prostheses prepared in advance for immediate loading protocols (Amorfini et al., 2017); and mouth-opening limitations, particularly in posterior areas, that may prevent the use of static surgical guides in combination with the special designed surgical drills. In addition, bone augmentation procedures require flap reflection which further limit their use in the flapless approach. However, FG implant surgery can still be employed in cases requiring flap reflection, even though a reduction in accuracy may be expected in relation to the flapless protocol if the degree of mouth opening of the patient does not hinder its use.

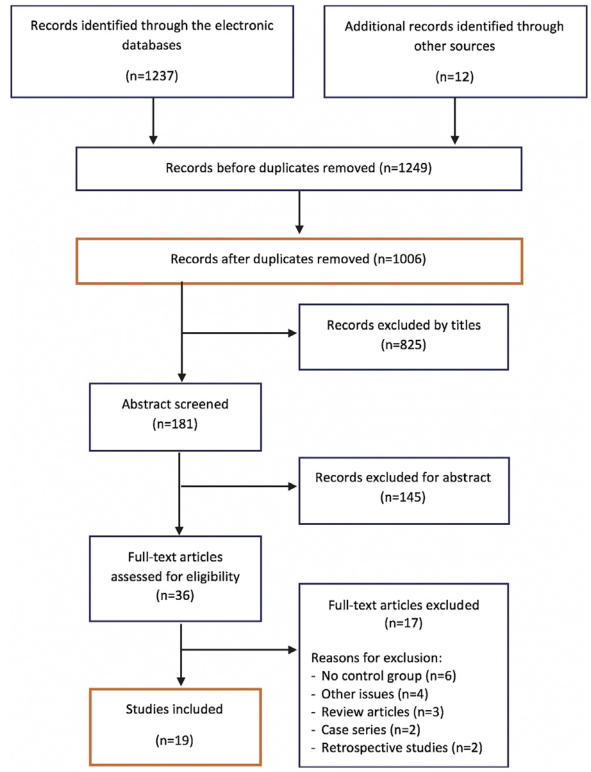

Fig. 1. Flowchart depicting the search strategy and selection process.

The aim of this review was to clearly classify the different methods to assist dental implant placement surgery in order to clarify the terminology and describe the advantages and disadvantages of each procedure in relation to transmitting the information from the pre-surgical planning to the patient.

2. Electronic literature search

This review is based on an electronic literature search of the National Library of Medicine (MEDLINE by Pubmed) and EMBASE, performed with the intention of collecting relevant information on computer-supported implant planning and guided implant surgery. We included human randomized clinical trials (RCTs), non-randomized clinical trials, ex-vivo and in-vitro studies which compared two or more navigation surgery approaches: full-guided (dynamic or static) implant navigation surgery as a test group; and half-guided implant navigation or free-hand as a control group. Contrarily, studies with no comparison group, retrospective and case series studies were excluded. The search strategy has been described in Fig. 1.

3. Study selection

Nineteen studies were selected: 9 RCTs, 3 CT, 2 ex-vivo and 5 in-vitro studies, corresponding to a total number of 4063 implants (2315 in the FG group and 1748 in a control group).1962 implants were selected from RCTs (1221 in a FG group and 741 in a control

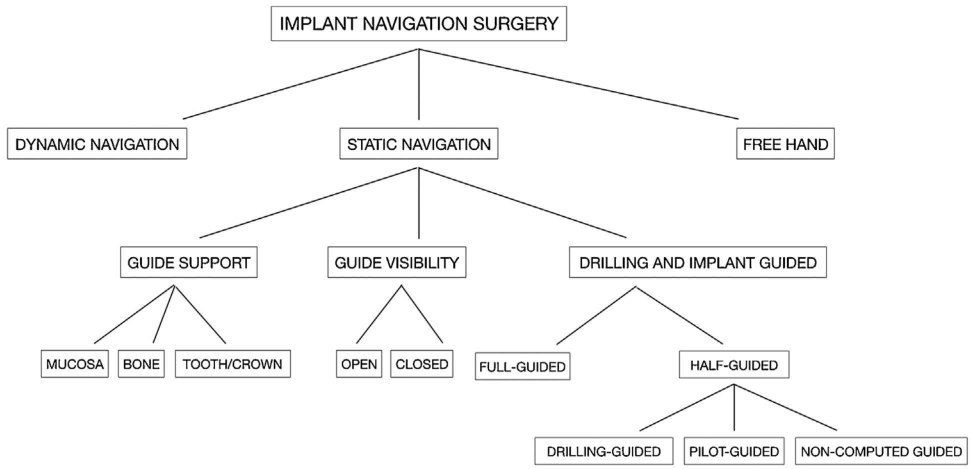

Fig. 2. Implant navigation surgery classification.

group); 1229 were from CT studies (531 in a FG group and 698 in a control group); 77 from ex-vivo studies (38 in a FG group and 39 in a control group); and 795 corresponded to in-vitro studies (525 in a FG group and 270 in a control group).

4. Implant navigation surgery classification

According to the type of navigation system, implant surgery can be classified into: dynamic and static navigation, and static navigation can further be divided into full (FG)- and half-guided (HG) implant surgery. Static navigation can also be classified based on the type of the surgical guide stents into: open and closed guided; or mucosa, bone and tooth-crown supported guided (Fig. 2).

All these different implant navigation surgery approaches rely on how the information from the pre-surgical planning to the patient is communicated during the implant placement and contain different characteristics that offer advantages or setbacks during the implant placement (Fig. 3). The information regarding the mentioned techniques that resulted from the systematic search are detailed in Tables 1 and 2.

5. Dynamic navigation

This technique is also referred to as navigation-guided surgery, involves 3D planning with cone beam computed tomograph (CBCT) exploration, and prosthetic analysis before the surgical procedure. A guided template is not used during the surgery, while with special instruments and a specific software, the bone drilling and the implant placement is completely tracked with the navigation system. The patient's anatomy and the surgical procedures are shown in real time in a 3D software.

Advantages: Dynamic navigation can improve the precision of implant placement compared to the FH method (Block et al., 2017; Brief et al., 2005; Hoffmann et al., 2005; Kramer et al., 2005), and to the pilot-drill HG surgery (Block et al., 2017; Somogyi-Ganss et al., 2015). Based on a multicenter prospective clinical study, Block and colleagues observed that the improved accuracy in terms of implant angulation is the prominent feature of using dynamic navigation when compared to HG and FH method (Block et al., 2017). The dynamic navigation software allows correct implant placement with proper parallelism, and the feedback provided by the clinician gives the possibility to modify the planned surgical approach during the surgery (Block et al., 2017).

Disadvantages: An error in the system that would affect the spatial relationship between the reference points and the patient can lead to a mistake during the drilling and implant placement (Brief et al., 2005). The need of precaution during all the steps of the surgery is mandatory to avoid an iatrogenic consequence for the patient (Somogyi-Ganss et al., 2015). A learning curve is described, and a training period is required before employment on patients (Block et al., 2017). Finally, aside from the higher cost associated with this system, and the limitations of in-vitro studies that comprise the majority of the dynamic navigation research (Brief et al., 2005; Hoffmann et al., 2005; Kramer et al., 2005; Somogyi-Ganss et al., 2015), human studies regarding its clinical application are still scarce. Thus, further clinical investigations are needed to assess the benefits of this approach, including time consumption analysis in comparison to other methods.

6. Static navigation

Static navigation uses static surgical templates during the bone implant drilling sequence and the implant placement. The surgical templates transmit the information from the pre-surgical prosthetic and surgical planning to the patient. The main inconvenience of the static navigation system is the inability to change the pre-surgical planning position during the surgery, unless the surgical approach is changed to FH technique.

The static navigation surgery can be classified according to: (1) the type of the guide support; (2) the type of surgical visibility; and (3) the type of drilling and implant placement facility.

6.1. Guide support

6.1.1. Mucosa-supported guide

Guides supported by the oral mucosa are associated to flapless surgery. If bone architecture allows for the flapless approach, a mucosa-supported guide should be the first choice in partially or fully edentulous patients. In partially edentulous patients, a combination of mucosa and tooth/crown supported guide will improve the surgical template stabilization, while in fully edentulous cases, surgical templates are supported by buccal and lingual mucosal flanges as well as the palatal mucosa (Fig. 4). Additionally, transmucosal fixation pins are often used in fully edentulous patients to better stabilize the template.

Advantages: Mucosa-supported full-guided templates offer greater accuracy than osseous-supported guides (Vercruyssen et al., 2015b), while lacking major differences (Arisan et al., 2013a; 2010). This better accuracy accompanied by mucosa-guide stents might be related to the necessity to elevate surgical flaps in osseous-supported guides that ultimately interferes with the surgical guides. Hence, mucosa-supported guides are typically

Table 1
Implant positioning accuracy data in implant navigation comparison studies.

Article, year	HG/FH technique stent		N (patients)		N (implants)		Edentulous		Coronal implant deviation MD (SD) in mm		Apical implant deviation MD (SD) in mm		Vertical implant deviation (SD) in mm		Apical angle implant deviation (SD) in º	
	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test
Human RCT																
Arisan et al. (2013a,b)	FG	FH	34	29	206	140	TE	TE	NA	NA	NA	NA	NA	NA	NA	NA
Farley et al. (2013)	FG	FH	10	10	10	10	SI	SI	0.63 (0.37)	1.15 (0.57)	1.11 (0.71)	1.84 (0.97)	−1.24 (0.68)	−0.17 (1.09)	3.68 (2.19)	6.13 (4.04)
Pozzi et al. (2014)	FG	FH	25	26	103	99	TE, PE	TE, PE	NA	NA	NA	NA	NA	NA	NA	NA
Vercruyssen et al. (2014a)	FG	FH/HG (plot drill)	48	12/12	212	51/51	TE	TE	NA	NA	NA	NA	NA	NA	NA	NA
Vercruyssen et al. (2014b)	FG	FH/HG (plot drill)	48	12/12	212	51/51	TE	TE	NA	NA	NA	NA	NA	NA	NA	NA
				12/12	209	51/51	TE	TE	1.38 (0.74)	2.77 (1.54)/2.97 (1.41)	1.91 (0.73)	2.91(1.52)/ 3.0(1.68)	NA	NA	3.13 (1.99)	9.92 (6.01)/8.43 (5.1)
Vercruyssen et al. (2015a,b)	FG	FH/HG (plot drill)	48	12/12	209	51/51	TE	TE	0.61 (0.54)	2.31 (1.72)/1.42 (1.09)	NA	NA	0.91 (0.71)	1.25 (0.95)/2.20 (1.44)	NA	NA
Amorfini et al. (2017)	FG	FH/HG (plot drill)	12	12	36	34	PE	PE	NA	NA	NA	NA	NA	NA	NA	NA
Younes et al. (2018)	FG	FH/HG (plot drill)	10	11/11	21	26/24	PE	PE	0.55 (0.11)	1.27 (0.11)/0.79 (0.11)	0.81 (0.21)	1.97 (0.19)/1.14 (0.2)	0.43 (0.09)	0.50 (0.09)/0.68 (0.09)	2.30 (0.92)	6.99 (0.87)/5.95 (0.87)
Human CT																
Arisan et al. (2010)	FG flapless/FG flap	FH	15/16	21	99/101	141			NA	NA	NA	NA	NA	NA	NA	NA
Arisan et al. (2013a,b)	FG flapless/FG flap	FH	12//12	27	97/72	184			NA	NA	NA	NA	NA	NA	NA	NA
Block et al. (2017)	FG DN	FH/HG (drilling guided)			219	122/373	PE	PE	0.74 (0.43)	1.19 (0.68)/ 0.80 (0.49)	0.9 (0.55)	184 (105)/1.01 (0.65)	0.76 (0.6)	1.12 (0.83)/0.89 (0.73)	2.97 (2.09)	650 (4.21)/3.43 (2.33)
Ex-vivo																
Kuhl et al. (2013)	FG	HG (drilling guided)	5	5	18	19	PE	PE	1.52 (0.61)	1.56 (0.51)	1.55 (0.74)	1.84 (0.49)	0.73 (0.38)	0.58 (0.33)	3.79 (0.93)	4.45 (1.32)
Noharet et al. (2014)	FG	HG (non-computer guided)	3	3	19	20	PE	PE	0.93 (0.65)	2.06 (1.13)	1.13 (0.89)	2.27 (1.23)	0.18 (0.46)	−0.29 (1.01)	3.9 (3.4)	9.18 (4.28)
In-vitro																
Nickenig et al. (2010)	FG	HG (non-computer guided)	10	10	23	23	PE	PE	0.9 (1.06)	2.6 (2.44)	0.9 (0.94)	2.3 (2.13)	NA	NA	4.2 (3.04)	9.8 (4.25)
Vermeulen (2017)	FG	FH	4	4	40	40	SI, PE	SI, PE	0.42	1.27	0.52	1.28	0.54	0.73	2.19	7.63
Brief et al. (2005)	DN	FH	5//5	5	30	15			0.5 (0.55)	1.35 (0.56)	0.46 (0.32)	0.84 (0.65)	NA	NA	3.16 (3.15)	4.59 (2.84)
Somogyi-Ganss et al. (2015)	FG/DG	HG (non-computer guided)			1200	400	PE	PE	0.82 (0.52)/1.14 (0.55)	1.14 (0.68)	1.14 (0.69)/1.18 (0.5)	1.74 (1.07)	1.14 (0.84)/1.04 (0.71)	0.73 (0.71)	3.54 (2.22)/2.99 (1.68)	8.95 (4.65)
Hoffmann et al. (2005)	DN	FH			112	112	TE	TE		NA		NA		NA	4.2 (1.8)	11.2 (5.6)

FG, full-guided; HG, half-guided; FH, free hand; TE, totally edentolous; PE, partially edentolous; SI, single implant.

Table 2
Advantages and disadvantages of implant navigation surgery approaches.

Implant navigation surgery		Author, year	Evidence	Advantages	Disavantages
					Lack of evidence
			In-vitro (3)		
		Brief et al. (2005)			
				Accuracy	
		Hoffmann et al. (2005) Somogyi-Ganss et al. (2015)			
Dynamic navigation					
			CT (1)	Change during surgery	Cost
		Block et al. (2017)		Flap-less <Chair-time <Pain <Swelling >Patient satisfaction	
					Cost
			RCT (7)	Accuracy	
		Arisan et al. (2010)		Flap-less	
				<Chair-time <Pain <Swelling	
Full-guided		Arisan et al. (2013a)			Planning and pre-surgical time
		Pozzi et al. (2014) Vercruyssen (2014a) Vercruyssen (2014b)	CT (1)		
				>Patient satisfaction	
		Vercruyssen et al. (2015a,b) Younes et al. (2018)			
			CT (1)	Accuracy Flap-less	
	Drilling-guided	Kuhl et al. (2013)		<Pain	Vertical implant placement
			Ex-vivo (1)	<Swelling	
		Block et al. (2017)		<Chair-time	
		Farley et al. (2013)		Accuracy	
		Vercruyssen et al. (2014a)		Flap-less	
				<Chair-time	
	Pilot-guided	Vercruyssen et al. (2014b)	RCT (7)	<Pain <Welling	Vertical implant placement
Hall guided		Vercruyssen et al., 2014a,b Vercruyssen et al. (2015a,b) Amorfini et al. (2017) Younes et al. (2018)		>Patient satisfaction	
				<Cost	
		Nickenig et al. (2010)	Ex-vivo (1)		
		Noharet et al. (2014)			<Accuracy
	Non-computed guided			<Planning time	Flap-surgery
		Somogyi-Ganss et al. (2015)	In-vitro (2)		>Pain >Swelling >Chair-time >Patient satisfaction Worse accuracy
				<Cost	Flap-surgery
		Brief et al. (2005)	RCT (7)		>Pain
					>Swelling
				<Planning time	>Chair-time
			CT (2)		
Free hand		Arisan et al. (2010)		Change during surgery >Visibility	
					>Patient satisfaction
		Arisan et al. (2013a,b) Pozzi et al. (2014) Vercruyssen et al. (2014a,b) Vercruyssen et al. (2015a, b) Hoffmann et al. (2005) Younes et al. (2018) Vermeulen (2017)	In-vitro (1)	>Cooling fluid contact	

RCT: randomized clinical trial; CT: clinical trial.

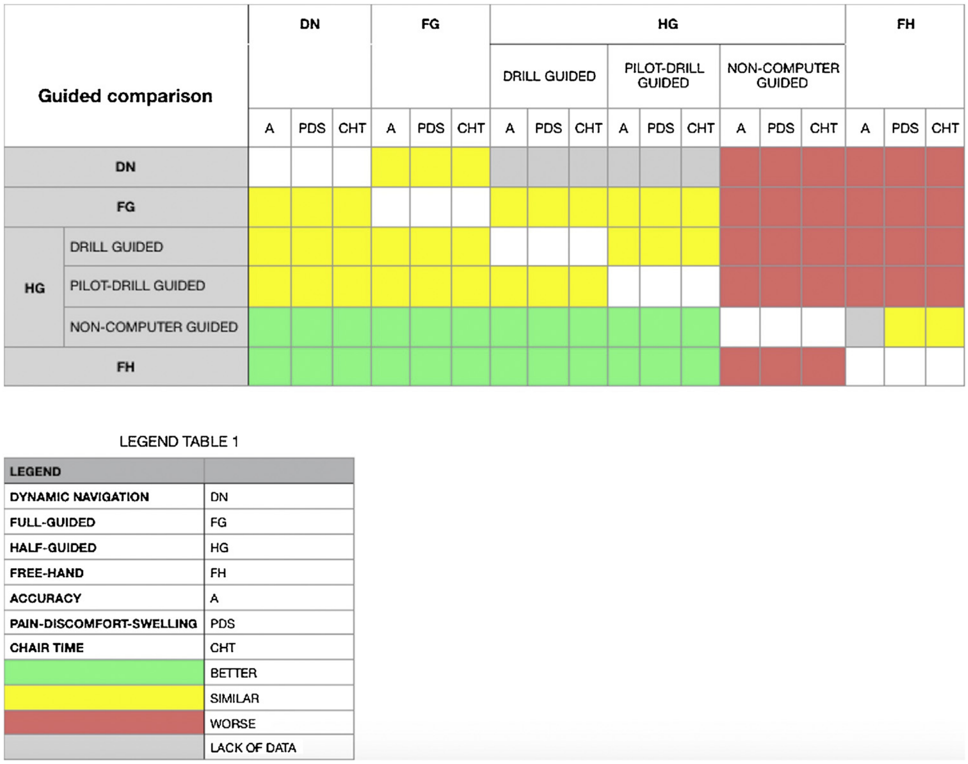

Fig. 3. Implant navigation approach comparison.

Fig. 4. Closed mucosa-supported full-guided template (Limaguide system. Innovacion Dental SL. Barcelona, Spain).

associated with flapless surgery, which is associated with lower post-operative pain, swelling, and the lowest patient morbidity (Arisan et al., 2010; Farley et al., 2013). This procedure also involves the highest patient satisfaction (Amorfini et al., 2017; Pozzi et al., 2014) and a significant reduction in chair-time compared to flap surgery (Arisan et al., 2013a; Vercruyssen et al., 2014b).

Disadvantages: Flapless surgery avoids bone augmentation procedures that reduce the amount of cases where it can be utilized. Additionally, soft-tissue augmentation procedures would have to be limited to the tunnel approach. Additional obstacles may involve the 3D surgical guide stabilization in an edentulous arch as compared to a partially edentulous patient, as well as utilizing an intraoral scanner due to reduced anatomical landmarks (Farley et al., 2013; Younes et al., 2018). However, advancements in digital technology are slowly overcoming these challenges (Vercruyssen et al., 2015b).

6.1.2. Bone-supported guide

In this method, the surgical guide is supported by the bone surface which requires reflection of a full-thickness flap. They are indicated in cases with bone deficiencies, where bone augmentation procedures are indicated, or with areas with anatomical limitations.

Advantages: The main advantage of this approach is to facilitate bone augmentation procedures to overcome anatomical insufficiencies if indicated. Open flap surgery allows direct visual contact to the bone architecture, to anatomical structures such as the mental nerve, to the lateral wall of the maxillary sinus or to the external bone limits of the nasal cavity.

Disadvantages: Flap surgery is associated with an increase in patient morbidity, greater post-operative pain, higher analgesic consumption, postoperative swelling, and longer chair-time (Arisan et al., 2013a; Vercruyssen et al., 2014b). Therefore, it also results in lower patient satisfaction compared to mucosa or tooth-supported guides (Amorfini et al., 2017; Pozzi et al., 2014).

6.1.3. Tooth/crown supporter guide

The remaining teeth or crowns are used for enhancement of stabilization of the guide templates in partially edentulous patients (Figs. 5–7). Mucosa or bone support can be applied simultaneously as well. Transitional implants can also be used to enhance stabilization of the surgical guides as an alternative approach in fully edentulous patients.

Advantages: Partially edentulous patients allow for better surgical guide support than fully edentulous patients, due to the usage of the remaining teeth for additional stabilization. According to the systematic review of Raico Gallardo et al., the tooth-supported guides offered more accuracy than bone or mucosa-supported guides (Raico Gallardo et al., 2017). Consequently, tooth/crown

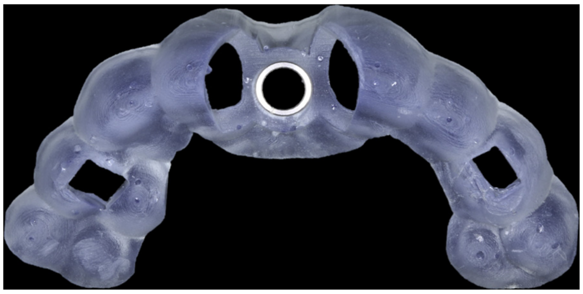

Fig. 5. Closed tooth-supported full-guided template (Formlabs, Form 2 3D printer. Formlabs Inc. Somerville, USA; Blue Sky Bio, Grayslake, USA).

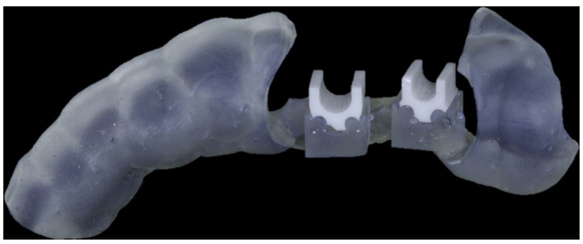

Fig. 6. Open tooth-supported half-guided template (Formlabs, Form 2 3D printer. Formlabs Inc. Somerville, USA; Blue Sky Bio, Grayslake, USA).

Fig. 7. Closed tooth-supported non-computer half-guided template (Vacuum, Machine III, Keystone Industries, New Jersey, USA).

supported guides in combination with mucosa-supported guides in flapless FG surgeries provide the highest accuracy in 3D implant positioning between the pre-surgical planning and the final implant placement (Farley et al., 2013; Raico Gallardo et al., 2017; Vermeulen, 2017; Younes et al., 2018). Additionally, tooth/crown supported templates can offer all the advantages of mucosa or bone-supported guides when applied.

Disadvantages: If reflection of a flap is required, it can interfere with the surgical guides and reduce the transmission of the implant positioning accuracy (Arisan et al., 2010). Therefore, pre-surgical planning is recommended to avoid flap interferences.

6.2. *Guide visibility*

6.2.1. *Closed guides*

Closed guide stents cover the entire surgical field and do not allow visibility of the bone or the mucosa during the bone drilling sequence and the implant placement (Figs. 4, 5 and 7). They are more restrictive than open guide stents and most frequently used in FG surgery.

Advantages: Drills and implants fully drive through the surgical template, avoiding possible modification of bone drilling during the surgery.

Disadvantages: Satisfactory outcomes depend on the pre-surgical planning and on the efficacy of the type of guide system used, since the wrong drilling sequence or implant mis-positioning are not detected when closed-templates are employed. Closed guides do not allow cooling fluid to come in direct contact with the drills during bone preparation, which can raise the bone temperature and possibly compromise the healing (Boa et al., 2016; Liu et al., 2018).

6.2.2. *Open guides*

Open guides have an open access located on the buccal side of the template that allows a buccal view of the surgical field and direct visual control of the bone and the mucosa during the bone drilling sequence and implant placement (Fig. 6).

Advantages: Drills and implants can be fully or partially driven through the surgical template. Some pre-surgical errors or guided system inaccuracies can be overcome as a result of the direct visual control on the bone and mucosa during the drilling and implant placement. Hence, a hard or soft-tissue defect can be detected and corrected. Finally, open guides allow better contact of the cooling fluid with the drills, reducing the temperature during bone preparation (Boa et al., 2016; Liu et al., 2018).

Disadvantages: Desirable outcomes depend on the pre-surgical planning and on the efficacy of the guided system used, although an increasing potential positioning error is due to the open guided systems being a less restrictive method.

6.3. *Drilling and implant placement*

6.3.1. *Full-guided (FG)*

They are also known as guided-surgery or computer-guided surgery. FG static navigation involves CBCT exploration, 3D planning, and prosthetic analysis before a computer-guided template is obtained to perform a guided implant placement (Figs. 4 and 5). The computer-stent guides the entire surgical procedure, the drilling bone preparation, and the implant placement. Oftentimes, FG accompanies a flapless surgery, considering that 3D planning and computer-guided templates provide sufficient information for avoiding flaps. A flapless surgery requires sufficient bone volume and enough keratinized mucosa to avoid regenerative procedures. If insufficient bone or keratinized mucosa is present, a flap surgery is highly recommended along with a FG implant surgery to perform bone regeneration and avoiding punch incisions for maintaining maximum keratinized mucosa.

Advantages: Accuracy is one of the major advantages of a full-guided implant surgery. Several randomized clinical trials confirm that FG surgery offers the highest accuracy in transmission of the implant positioning from the pre-surgical planning to the patient (Farley et al., 2013; Vercruyssen et al., 2015a; 2014a; Younes et al., 2018). According to the clinical prospective study of Arisan et al. (2013b), the lowest implant positioning error occurred with single-implant and FG mucosa-supported guides (6%), compared to FH (88%). Additionally, it was concluded that a FG implant placement results in significantly less interproximal emerging error than FH technique.

Moreover, when enough bone and keratinized mucosa are present, FG is the most accurate method for performing a flapless surgery, that can also benefit from a shorter chair-time compared to the FH method (Arisan et al., 2013b Pozzi et al., 2014; Vercruyssen et al., 2014b), or to pilot-drill HG surgery (Amorfini et al., 2017; Arisan et al., 2013a Pozzi et al., 2014; Vercruyssen et al., 2014b); significantly reducing the postoperative discomfort, pain, swelling, and analgesic consumption (Amorfini et al., 2017; Arisan et al., 2010; Pozzi et al., 2014; Vercruyssen et al., 2015a; Younes et al., 2018). Therefore, FG in combination with flapless surgery has shown better patient satisfaction scores based in the Oral Health Impact Profile (OHIP) and visual analog scale (VAS) scales compared to HG and FH techniques (Amorfini et al., 2017; Pozzi et al., 2014), and it is associated with reduced hemorrhages during and after the surgical procedure (Amorfini et al., 2017; Arisan et al., 2010; Pozzi et al., 2014; Vercruyssen et al., 2015a). Finally, FG implant surgery allows for a more predictable temporary restoration over dental implants, and less time required in adaptation of temporary crowns in immediate loading protocols (Amorfini et al., 2017).

Disadvantages: Full-guided templates determine the bone drilling and implant placement but removes the possibility to change anything during surgery. 3D-planning skills are needed and any error in pre-surgical planning or within the guided-system will result in a wrong implant positioning. Thus, surgical experience is highly recommended to prevent this inconvenience and overcome any inaccuracy.

Ultimately, the cost of FG surgery is higher, especially in comparison with the FH technique where no templates are used (Ravida et al., 2018).

6.3.2. Half-guided (HG)

This approach which has also been referred to as partial-guided surgery, which may involve prosthetic and pre-surgical planning with CBCT exploration (3D) and cast-model planning (3D). Although 3D radiological planning is preferred, a 2D radiological imaging can also be utilized. A computer-fabricated or non-computer-fabricated surgical stent can be used in different approaches: drilling-guided, pilot-drill guided or non-computer guided.

6.3.2.1. Drilling guided. A surgical guide is used during all drilling bone sequence. Once the implant is placed, the surgical guide is then removed (Fig. 6).

Advantages: The drilling guided has similar advantages to FG approach. Block et al. (2017), in a clinical prospective study, and Kuhl et al. (2013) in an in vitro study, found similar results in terms of accuracy when comparing FG and drilling guided implant placement surgery. On the contrary, when comparing positioning accuracy to FH implant placement, drilling guided implant placement showed significantly better accuracy (Aaboud et al., 2017). The difference between drilling guided and FG surgery is the direct visual contact with the implant and the surrounding tissues during drilling-guide implant insertion thanks to the FH implant placement.

Disadvantages: The vertical implant position is not guide controlled during the implant placement (Noharet et al., 2014). This lack of control may be particularly significant with self-tapping implant designs in bone types III and IV.

6.3.2.2. Pilot-drill guided. It has also been termed first-drill guided surgery. This technique only requires the surgical guide during the pilot drilling bone sequence. Thus, after the pilot drill is used, the surgical guide is removed.

Advantages: The pilot-drill guided surgery allows bone drilling modifications after the first-drill is used. Any error in pre-surgical planning or in the guided-system will not lead to a wrong implant positioning. According to a randomized cadaver study, only slightly less accurate results were obtained when utilizing the Pilot-drill guided system compared to the FG (Kuhl et al., 2013). However, randomized clinical trials confirm the increased precision of pilot-drill guides compared to the FH system (Farley et al., 2013; Vercruyssen et al., 2015a; Younes et al., 2018).

Disadvantages: After the pilot-drill guide is used, FH surgery is performed. Overall, according to randomized clinical trials, pilot-drill guided surgery demonstrates less accuracy when compared to FG surgery (Farley et al., 2013; Vercruyssen et al., 2015a; 2014a; Younes et al., 2018). Surgical experience is required to prevent implant mispositioning as the final 3D position is FH guided and vertical implant positioning is not controlled.

6.3.2.3. Non-computer guided. A surgical non-computer fabricated template is used during the bone drilling phase and sometimes even at the implant placement. This surgical stent is produced from the 3D planning, which requires a CBCT or XR exploration, and a cast-model analysis. Usually, a wax-up or a temporary prosthesis serves as a reference for building a thermoplastic radiological stent that will be converted into a surgical stent (Fig. 7).

Advantages: It is easy to perform both in the clinic and in the lab and requires less cost than computer-guided systems, including dynamic navigation, full and half-guided static navigation systems. Guides are usually open or transparent, offering open-guide advantages. They oftentimes allow modification during the bone drilling sequence and during the implant placement. They also provide better implant positioning accuracy than the free-hand approach (Noharet et al., 2014).

Disadvantages: Less accurate than FG, drilling-guide or pilot-guide stents (Block et al., 2017; Noharet et al., 2014; Younes et al., 2018). Additionally, during the surgical procedure non-computer fabricated templates have shown less stability than computer ones, increasing the difficulty of implant placement. Hence, surgical experience in implant placement is recommended to achieve adequate results.

6.3.3. Free-hand guided

It is also known as conventional surgery and mental or brain-guided surgery. Although 3D planning is highly recommended, a pre-surgical planning may or may not involve CBCT exploration. Surgical templates are not used during bone drilling and during the implant placement.

Advantages: This commonly used method requires less pre-surgical laboratory and clinical preparation. It offers the greatest surgical view during treatment without using any devices that can interfere with direct vision to the implant bed and surrounding tissues. It allows best contact of cooling fluids to the drills, resulting in better bone temperature control (Boa et al., 2016; Liu et al., 2018).

According to randomized clinical trials, peri-implant parameters commonly used to monitor tissue healing such as marginal bone loss, bleeding on probing, probing deep, plaque index and gingival index, have not shown additional benefits when the full- or half guided techniques were employed compared to the free-hand method (Colombo et al., 2017; Moraschini et al., 2015; Pozzi et al., 2014; Vercruyssen et al., 2014b). In addition, as no radiological or surgical templates are required, FH implant surgery is associated with the least amount of cost compared with the other techniques. Lastly, no scientific evidence has demonstrated that either of the guided methods (whether FG, HG, or FH) are related to occurrence of prosthetic complications, or implant survival rates (Arisan et al., 2010; Laleman et al., 2016; Pozzi et al., 2014; Schneider et al., 2009; Voulgarakis et al., 2014).

Disadvantages: The FH implant surgery offers the least amount of accuracy in conveying the prosthetic and pre-surgical planning to the patient. This has been confirmed by many studies (Amorfini et al., 2017; Arisan et al., 2013b, 2010; Block et al., 2017; Farley et al., 2013; Kuhl et al., 2013; Nickenig et al., 2010; Noharet et al., 2014; Pozzi et al., 2014; Somogyi-Ganss et al., 2015; Vercruyssen et al., 2015a; Vermeulen, 2017; Younes et al., 2018). Implant mispositioning associated with FH implant placement is frequent, affecting 88% of the implants according to Arisan et al. (2013b). Hence, surgical experience is highly recommended to overcome this limitation. Additionally, FH implant surgery is linked to flap elevation that is associated to increase patient morbidity, more post-operative pain and swelling (Arisan et al., 2010; Farley et al., 2013), reduced patient satisfaction (Amorfini et al., 2017; Pozzi et al., 2014), longer chair-time (Arisan et al., 2013a; Pozzi et al., 2014; Vercruyssen et al., 2014b) and a higher risk for intra- and post-operative hemorrhages (Arisan et al., 2010). Furthermore, the probability of bacteremia in a conventional patient using flap surgery and FH implant placement approach has been shown to be 3 times greater than when pre-forming a flapless surgery and FG implant placement (Arisan et al., 2013a).

7. Conclusions

The FG associated with flapless surgery and teeth/crown supported guides has demonstrated the highest accuracy, followed by the drilling and pilot HG surgery which may provide comparable results, while non-computer HG and FH implant placement provide the least accuracy. Additionally, flapless surgery is related to reduced pain, less analgesic consumption, less swelling, shorter chair-time, and reduced risk of hemorrhage while achieving greater patient satisfaction. Furthermore, FG implant surgery requires less time for adapting the temporary restorations over the implants. Other methods such as non-computer HG and FH implant surgery procedures require more surgical experience to overcome their limitations, although FG approach requires 3D-planning skills and surgical experience is also recommended to overcome any error in the pre-surgical planning. Finally, there is still limited evidence to support dynamic surgery, and therefore, further investigations are needed.

Disclosure

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.aanat.2019.04.005.

References

Aaboud, M., Aad, G., Abbott, B., Abdallah, J., Abdinov, O., Abeloos, B., et al., 2017. Measurement of the prompt J/[Formula: see text] pair production cross-section in pp collisions at [Formula: see text] TeV with the ATLAS detector. Eur. Phys. J. C Fields 77 (2), 76, http://dx.doi.org/10.1140/epjc/s10052-017-4644-9, Epub 2017 Feb 7.

Amorfini, L., Migliorati, M., Drago, S., Silvestrini-Biavati, A., 2017. Immediately loaded implants in rehabilitation of the Maxilla: a two-year randomized clinical trial of guided surgery versus standard procedure. Clin. Implant Dent. Relat. Res. 19 (2), 280–295, http://dx.doi.org/10.1111/cid.12459.

Arisan, V., Bolukbasi, N., Oksuz, L., 2013a. Computer-assisted flapless implant placement reduces the incidence of surgery-related bacteremia. Clin. Oral Investig. 17 (9), 1985–1993, http://dx.doi.org/10.1007/s00784-012-0886-y.

Arisan, V., Karabuda, C.Z., Mumcu, E., Ozdemir, T., 2013b. Implant positioning errors in freehand and computer-aided placement methods: a single-blind clinical comparative study. Int. J. Oral Maxillofac. Implants 28 (1), 190–204, http://dx.doi.org/10.11607/jomi.2691.

Arisan, V., Karabuda, C.Z., Ozdemir, T., 2010. Implant surgery using bone- and mucosa-supported stereolithographic guides in totally edentulous jaws: surgical and post-operative outcomes of computer-aided vs. standard techniques. Clin. Oral Implants Res. 21 (9), 980–988, http://dx.doi.org/10.1111/j.1600-0501.2010.01957.x.

Block, M.S., Emery, R.W., Cullum, D.R., Sheikh, A., 2017. Implant placement is more accurate using dynamic navigation. J. Oral Maxillofac. Surg. 75 (7), 1377–1386, http://dx.doi.org/10.1016/j.joms.2017.02.026.

Boa, K., Barrak, I., Varga Jr., E., Joob-Fancsaly, A., Varga, E., Piffko, J., 2016. Intraosseous generation of heat during guided surgical drilling: an ex vivo study of the effect of the temperature of the irrigating fluid. Br. J. Oral Maxillofac. Surg. 54 (8), 904–908, http://dx.doi.org/10.1016/j.bjoms.2016.06.004.

Bover-Ramos, F., Vina-Almunia, J., Cervera-Ballester, J., Penarrocha-Diago, M., Garcia-Mira, B., 2018. Accuracy of implant placement with computer-guided surgery: a systematic review and meta-analysis comparing cadaver, clinical, and in vitro studies. Int. J. Oral Maxillofac. Implants 33 (1), 101–115, http://dx.doi.org/10.11607/jomi.5556.

Brief, J., Edinger, D., Hassfeld, S., Eggers, G., 2005. Accuracy of image-guided implantology. Clin. Oral Implants Res. 16 (4), 495–501, http://dx.doi.org/10.1111/j.1600-0501.2005.01133.x.

Buser, D., Martin, W., Belser, U.C., 2004. Optimizing esthetics for implant restorations in the anterior maxilla: anatomic and surgical considerations. Int. J. Oral Maxillofac. Implants 19 (Suppl), 43–61.

Colombo, M., Mangano, C., Mijiritsky, E., Krebs, M., Hauschild, U., Fortin, T., 2017. Clinical applications and effectiveness of guided implant surgery: a critical review based on randomized controlled trials. BMC Oral Health 17 (1), 150, http://dx.doi.org/10.1186/s12903-017-0441-y.

D'Haese, J., Ackhurst, J., Wismeijer, D., De Bruyn, H., Tahmaseb, A., 2017. Current state of the art of computer-guided implant surgery. Periodontol 2000 73 (1), 121–133, http://dx.doi.org/10.1111/prd.12175.

Farley, N.E., Kennedy, K., McGlumphy, E.A., Clelland, N.L., 2013. Split-mouth comparison of the accuracy of computer-generated and conventional surgical guides. Int. J. Oral Maxillofac. Implants 28 (2), 563–572, http://dx.doi.org/10.11607/jomi.3025.

Hoffmann, J., Westendorff, C., Gomez-Roman, G., Reinert, S., 2005. Accuracy of navigation-guided socket drilling before implant installation compared to the conventional free-hand method in a synthetic edentulous lower jaw model. Clin. Oral Implants Res. 16 (5), 609–614, http://dx.doi.org/10.1111/j.1600-0501.2005.01153.x.

Kramer, F.J., Baethge, C., Swennen, G., Rosahl, S., 2005. Navigated vs. conventional implant insertion for maxillary single tooth replacement. Clin. Oral Implants Res. 16 (1), 60–68, http://dx.doi.org/10.1111/j.1600-0501.2004.01058.x.

Kuhl, S., Zurcher, S., Mahid, T., Muller-Gerbl, M., Filippi, A., Cattin, P., 2013. Accuracy of full guided vs. Half-guided implant surgery. Clin. Oral Implants Res. 24 (7), 763–769, http://dx.doi.org/10.1111/j.1600-0501.2012.02484.x.

Laleman, I., Bernard, L., Vercruyssen, M., Jacobs, R., Bornstein, M.M., Quirynen, M., 2016. Guided implant surgery in the edentulous maxilla: a systematic review. Int. J. Oral Maxillofac. Implants 31 (Suppl), s103–s117, http://dx.doi.org/10.11607/jomi.16suppl.g3.

Linkevicius, T., Puisys, A., Vindasiute, E., Linkeviciene, L., Apse, P., 2013. Does residual cement around implant-supported restorations cause peri-implant disease? A retrospective case analysis. Clin. Oral Implants Res. 24 (11), 1179–1184, http://dx.doi.org/10.1111/j.1600-0501.2012.02570.x.

Liu, Y.F., Wu, J.L., Zhang, J.X., Peng, W., Liao, W.Q., 2018. Numerical and experimental analyses on the temperature distribution in the dental implant preparation area when using a surgical guide. J. Prosthodont. 27 (1), 42–51, http://dx.doi.org/10.1111/jopr.12488.

Mezger, U., Jendrewski, C., Bartels, M., 2013. Navigation in surgery. Langenbecks Arch. Surg. 398 (4), 501–514, http://dx.doi.org/10.1007/s00423-013-1059-4.

Moraschini, V., Velloso, G., Luz, D., Barboza, E.P., 2015. Implant survival rates, marginal bone level changes, and complications in full-mouth rehabilitation with flapless computer-guided surgery: a systematic review and meta-analysis. Int. J. Oral Maxillofac. Surg. 44 (7), 892–901, http://dx.doi.org/10.1016/j.ijom.2015.02.013.

Nickenig, H.J., Wichmann, M., Hamel, J., Schlegel, K.A., Eitner, S., 2010. Evaluation of the difference in accuracy between implant placement by virtual planning data and surgical guide templates versus the conventional free-hand method – a combined in vivo – in vitro technique using cone-beam CT (Part II). J. Craniomaxillofac. Surg. 38 (7), 488–493, http://dx.doi.org/10.1016/j.jcms.2009.10.023.

Noharet, R., Pettersson, A., Bourgeois, D., 2014. Accuracy of implant placement in the posterior maxilla as related to 2 types of surgical guides: a pilot study in the human cadaver. J. Prosthet. Dent. 112 (3), 526–532, http://dx.doi.org/10.1016/j.prosdent.2013.12.013.

Pozzi, A., Tallarico, M., Marchetti, M., Scarfo, B., Esposito, M., 2014. Computer-guided versus free-hand placement of immediately loaded dental implants: 1-year post-loading results of a multicentre randomised controlled trial. Eur. J. Oral Implantol. 7 (3), 229–242.

Raico Gallardo, Y.N., da Silva-Olivio, I.R.T., Mukai, E., Morimoto, S., Sesma, N., Cordaro, L., 2017. Accuracy comparison of guided surgery for dental implants according to the tissue of support: a systematic review and meta-analysis. Clin. Oral Implants Res. 28 (5), 602–612, http://dx.doi.org/10.1111/clr.12841.

Ravida, A., Barootchi, S., Tattan, M.A., Saleh, M.H.A., Gargallo-Albiol, J., Wang, H.L., 2018. Clinical outcomes and cost effectiveness of computer-guided versus conventional implant-retained hybrid prostheses: a long-term retrospective analysis of treatment protocols. J. Periodontol. 89 (9), 1015–1024, http://dx.doi.org/10.1002/JPER.18-0015, Epub 2018 Aug 13.

Schneider, D., Marquardt, P., Zwahlen, M., Jung, R.E., 2009. A systematic review on the accuracy and the clinical outcome of computer-guided template-based implant dentistry. Clin. Oral Implants Res. 20 (Suppl. 4), 73–86, http://dx.doi.org/10.1111/j.1600-0501.2009.01788.x.

Sicilia, A., Botticelli, D., 2012. Computer-guided implant therapy and soft- and hard-tissue aspects. The Third EAO Consensus Conference 2012. Clin. Oral Implants Res. 23 (Suppl. 6), 157–161, http://dx.doi.org/10.1111/j.1600-0501.2012.02553.x.

Somogyi-Ganss, E., Holmes, H.I., Jokstad, A., 2015. Accuracy of a novel prototype dynamic computer-assisted surgery system. Clin. Oral Implants Res. 26 (8), 882–890, http://dx.doi.org/10.1111/clr.12414.

Tarnow, D.P., Cho, S.C., Wallace, S.S., 2000. The effect of inter-implant distance on the height of inter-implant bone crest. J. Periodontol. 71 (4), 546–549, http://dx.doi.org/10.1902/jop.2000.71.4.546.

Van Assche, N., Vercruyssen, M., Coucke, W., Teughels, W., Jacobs, R., Quirynen, M., 2012. Accuracy of computer-aided implant placement. Clin. Oral Implants Res. 23 (Suppl. 6), 112–123, http://dx.doi.org/10.1111/j.1600-0501.2012.02552.x.

Vercruyssen, M., Cox, C., Coucke, W., Naert, I., Jacobs, R., Quirynen, M., 2014a. A randomized clinical trial comparing guided implant surgery (bone- or mucosa-supported) with mental navigation or the use of a pilot-drill template. J. Clin. Periodontol. 41 (7), 717–723, http://dx.doi.org/10.1111/jcpe.12231.

Vercruyssen, M., De Laat, A., Coucke, W., Quirynen, M., 2014b. An RCT comparing patient-centred outcome variables of guided surgery (bone or mucosa supported) with conventional implant placement. J. Clin. Periodontol. 41 (7), 724–732, http://dx.doi.org/10.1111/jcpe.12257.

Vercruyssen, M., Coucke, W., Naert, I., Jacobs, R., Teughels, W., Quirynen, M., 2015a. Depth and lateral deviations in guided implant surgery: an RCT comparing guided surgery with mental navigation or the use of a pilot-drill template. Clin. Oral Implants Res. 26 (11), 1315–1320, http://dx.doi.org/10.1111/clr.12460.

Vercruyssen, M., Laleman, I., Jacobs, R., Quirynen, M., 2015b. Computer-supported implant planning and guided surgery: a narrative review. Clin. Oral Implants Res. 26 (Suppl. 11), 69–76, http://dx.doi.org/10.1111/clr.12638.

Vermeulen, J., 2017. The accuracy of implant placement by experienced surgeons: guided vs freehand approach in a simulated plastic model. Int. J. Oral Maxillofac. Implants 32 (3), 617–624, http://dx.doi.org/10.11607/jomi.5065.

Voulgarakis, A., Strub, J.R., Att, W., 2014. Outcomes of implants placed with three different flapless surgical procedures: a systematic review. Int. J. Oral Maxillofac. Surg. 43 (4), 476–486, http://dx.doi.org/10.1016/j.ijom.2013.10.024.

Younes, F., Cosyn, J., De Bruyckere, T., Cleymaet, R., Bouckaert, E., Eghbali, A., 2018. A randomized controlled study on the accuracy of free-handed, pilot-drill guided and fully guided implant surgery in partially edentulous patients. J. Clin. Periodontol., http://dx.doi.org/10.1111/jcpe.12897.