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Review

Investigation on the accuracy of implant surgery in dynamic navigation: metanalysis and systematic review of literature

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ABSTRACT

The object of this study was to compare, through meta-analysis, the accuracy in implant placement obtained in Dynamic Navigation (DN) with Static Navigation (SN) and with Conventional Free-Hand Surgery (CS) and to provide some useful clinical parameters to consider during the planning phase of the intervention. A meta-analysis was performed, dividing the selected studies into two groups based on the statistical technique adopted: DN *vs* CS and DN *vs* SN. The heterogeneity between the various studies was assessed with the homonymous test and quantified with I2. The results were graphically represented using a forest plot. Egger's test and funnel plot was used to investigate the "small study effect". The search was performed through the PubMed database, and the Cochrane Library database identified 448 articles. After applying the inclusion criteria, 14 articles were selected and used for quantitative synthesis (meta-analysis). From the results obtained from this meta-analysis, it can be stated that the DN mode allows for better accuracy than conventional surgery, the most used type of surgery, and is comparable to static navigation, the gold standard for accuracy.

INTRODUCTION

The rehabilitation of partial and total edentulism using osteointegrated implants is a method that has proven to be highly effective and predictable, with success rates reported in the literature that are also high in the long-term follow-up (1, 2). In order to obtain these results, the diagnostic phase of pre-surgical planning is fundamental and, if carried out correctly, reduces complications connected to implant malposition, such as an occlusal overload of the implant that can lead to a preterm failure, unsatisfactory aesthetics, in particular in the anterior sectors, and prosthetist difficulty in creating a prosthetic product (3). Complications of greater interest always linked to a malposition of the implant can be cortical perforations, lesions of adjacent teeth and damage to particular anatomical structures, such as the inferior alveolar nerve or the maxillary sinus (4).

Once the planning has been carried out, i.e. once the ideal implant position has been identified on the software, the clinician's objective is to transfer it with maximum reproducibility to the real site (transition to the surgical phase); in order to do this, there are 2 methods available:

• Analogical: CS

• Digital: Computer Assisted Surgery (CAS), also known as Computer Guided Surgery or Surgery in Navigation

This last method is divided into two modalities:

• Surgery in SN

• Surgery in DN

A distinction can be made between SN using templates (dime) and direct DN using optical transmission systems (5). The last frontier in the field of implant surgery is represented by DN, a practical aid to minimise the discrepancies between the virtually planned implant position (using special software) and the real position of the dental implant. This technique is therefore added to the other two already available in implantology: CS and SN. The following discussion will compare the accuracy of these three surgical modalities through a systematic review and meta-analysis of what is currently reported in the literature.

MATERIALS AND METHODS

The guidelines in the *Cochrane Handbook for Systematic Reviews of Interventions (the Handbook)*, version 5.1.0 of March 2011, were followed for this systematic review of the literature accompanied by meta-analysis. Furthermore, the PRISMA Statement (2015) Guidelines for reporting systematic reviews and meta-analyses were followed to realise the Materials and methods section. (6) To search for scientific publications, the online databases most used in Italy, "PubMed" and "Cochrane Library", were used. The bibliographic research was carried out from February 2021 until the end of June of the same year by a single author (M.B.).

The following filters were applied to search for publications in the online databases mentioned above:
1) publication date included in the period from 01/01/2000 to 31/06/2021;
2) articles published exclusively in English.

In addition, the research was carried out to select studies that compared the accuracy obtained from implant surgery in DN with the one obtained from other types of implant placement, such as SN and/or CS. The search strategy was based on the following terms: "Oral Implant", OR "Endosseous Implant", OR "Dental Implant", OR "Implant Placement", AND "Navigation surgery", OR "Image-guided surgery" OR "Dynamic Navigation" OR "Dynamic surgery" AND "Free-hand" OR "Conventional surgery "OR" Computer-Aided Design "OR" Static Navigation "OR" Static surgery "OR" Template " AND "Mesh " OR "custom titanium mesh" OR "custom mesh" OR "titanium mesh".

Eligibility criteria

Regarding the articles potentially includable in the review, randomised-controlled clinical trials (RCT), controlled clinical trials (CCT), cohort studies, comparative cadaver studies and comparative model studies were considered. Cadaver and model studies were included to compensate for the reduced availability of articles regarding implant placement in DN due to the recent introduction of this technique, and this was possible as no Patient-centered outcomes or other data requiring a follow-up period were assessed but only those relating to the accuracy of the system, which can also be measured in this type of studies. Studies involving pterygoid implants, zygomatic implants, orthodontic mini-screws, studies with no control and case reports were not included in the review.

As indicated by the *Cochrane Handbook for Systematic Reviews of Interventions*, the protocol for the formulation of the PICO question was adopted to outline the criteria for the inclusion of the articles, as shown below (7):

- **Population:** Only articles regarding patients, models and cadavers with partial or total edentulism to be rehabilitated with the placement of dental implants preceded by virtual planning were considered. Furthermore, the number of total implants had to be greater than or equal to 10 in the test and control groups.
- **Intervention:** The test group had to be composed of DN implant placement.
- **Comparison:** The control group had to consist of implant placement with SN surgery, the gold standard for accuracy, or with CS, the most used procedure.
- **Outcomes:** The outcomes searched for in the articles were divided into primary and secondary outcomes. The primary outcome searched was the accuracy measured by superimposition between the virtual plan and the real position of the implant and reported as one of the following parameters:
    - *angular deviation,*
    - *total apical deviation*
    - *total coronal deviation*.

In addition, the following accuracy parameters were considered secondary outcomes:

- *apical depth deviation*
- *coronal depth deviation*
- *lateral apical deviation* and *lateral coronal deviation.*

Data characteristics

Coronal and apical deviations were assessed in individual clinical trials as follows: a first CBCT is executed to allow the digital planning of the ideal implant position. After the surgery, a second CBCT is performed to evaluate the implant position. Then a superimposition of the first and second CBCT is performed to evaluate the accuracy of the surgery technique adopted (Fig. 1).

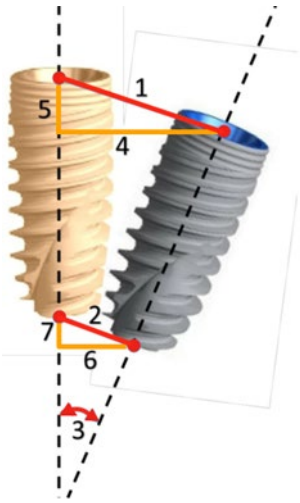

Fig. 1. *The primary outcomes are shown in red, and the secondary outcomes are shown in orange. Angular deviation (3): evaluates the amplitude of the angle formed by the axis of the positioned implant and the insertion axis of the virtual implant, expressed in degrees (°). Total apical deviation (2): is the overall distance between the center of the positioned implant apex and the center of the virtual implant apex, expressed in mm. This variable, also considering the depth and the angular deviation, is reported, in some articles, as a 3D apical distance. Total coronal deviation (1): this is the total distance between the center of the platform of the positioned implant and the center of the virtual implant platform, expressed in mm. This variable, considering also the depth and the angular deviation is reported, in some articles, as 3D coronal distance. Apical depth deviation (7): is the distance between the center of the positioned implant apex and the center of the virtual implant apex, measured along the Z axis. It is expressed in mm. Coronal depth deviation (5): is the distance between the center of the placed implant platform and the center of the virtual implant platform, measured along the Z axis and is expressed in mm. Lateral apical deviation (6): is the distance between the center of the positioned implant apex and the insertion axis of the virtual implant, measured perpendicular to the latter and is expressed in mm. Lateral coronal deviation (4): is the distance between the center of the platform of the positioned implant and the insertion axis of the virtual implant, measured perpendicular to the latter, and expressed in mm.*

Study selection

The PRISMA 2009 flow diagram guidelines were followed to select the articles (6). The titles obtained through the generic research previously explained were subsequently reviewed one by one (identification) by a single author (M.B.). At this point, the articles were selected by analysing the title and reading the abstract. In this second phase (screening), the full satisfaction of the inclusion criteria by the article in question was assessed. Therefore, studies that did not meet the inclusion criteria were excluded at this stage. Instead, the

publications in which the abstract reading was insufficient to understand if the inclusion criteria were met were included in the next phase (reading the full text (eligibility). In this way, it was possible to include only the studies that met all the criteria set out above.

Data collection process

The data of interest were extrapolated and grouped in data collection tables. The following parameters were analysed: 1) authors, year of publication, type of study; 2) test surgery modality and machinery used, comparison surgery modality; 3) the total number of patients, cadavers, models, number of test patients, cadavers, models, number of control patients, cadavers, models; 4) number of test implants, number of control implants; 5) type of edentulous test, type of edentulous control; 6) primary outcomes, secondary outcomes.

Statistical analysis

A meta-analysis was performed, dividing the selected studies into two groups based on the statistical technique adopted: DN *vs* CS and DN *vs* SN.

The meta-analysis results were expressed as standardised mean difference (SMD = Standardized Mean Difference) for the quantitative variables (Total Coronal Deviation, Coronal lateral D., Coronal depth D., Total apical D., Lateral apical D., Apical Depth D., Angular Axes D.). The extent of SMD was interpreted as mild, SMD = 0.2; medium, SMD = 0.5; and high, SMD = 0.8.

The heterogeneity between the various studies was assessed with the homonymous test and quantified with I2. The Higgins heterogeneity index (I2) describes the proportion of heterogeneity of the individual studies that cannot be explained by the sampling error and has the advantage of being intrinsically independent of the number of studies. Since the heterogeneity test was significant and/or the I2 was> 30% (8) for all the variables considered, a "random" effects statistical model was used. The combined (pooled) estimates and the related confidence intervals were calculated using Der Simonian and Laird (9). Finally, the results were graphically represented using a forest plot.

Egger's test and funnel plot were used to investigate the "small study effect" (10). As a general rule, funnel plot asymmetry tests should only be used when at least 10 studies are included in the meta-analysis. When there are fewer studies, the tests' power is insufficient to distinguish randomness from true asymmetry.
The level of statistical significance was set at 5%, and the confidence intervals (CI) were calculated at 95%. All data were analysed with the STATA Software (Version 15).

RESULTS

Study selection and description

The search through the PubMed database identified 437 articles; instead, the search through the Cochrane Library database identified 21 articles. After eliminating the duplicates, 448 publications were obtained. A single operator (M.B.) viewed all these 448 titles and selected 347 abstracts to be read to assess whether or not they comply with the topic of interest. After the screening phase, 320 articles were removed. The 27 papers that tested positive for eligibility were investigated by reading the full text to assess whether they adhered to the inclusion criteria and, consequently, their possible use in the systematic review and meta-analysis. After reading the text, it was possible to exclude 13 jobs (Table I). From the initial research, 14 articles were selected: 14 were used for the qualitative synthesis (systematic review of the literature), and 14 were used for quantitative synthesis (meta-analysis). Following the *PRISMA 2009 guidelines*, a flow chart was constructed summarising the study selection procedure (Fig. 2). It is always important to mention and consider the

possibility and the risk of bias in the included studies. The general characteristics of the 14 studies included in the quantitative synthesis were collected and summarised in the following table (Table II). Five clinical studies were identified (11-15), 1 study on the anatomical specimen (16) and 8 in vitro studies (4, 17-23).

Table I. *Articles excluded with motivation.*

Author Year	Reason for exclusion
Pellegrino et al.	2019 Absence of control
Stefanelli L. et al.	2019 Absence of control
Widmann et al.	2010 Absence of control
Kim et al.	2015 Absence of control
Golob Deeb J. et al.	2019 Absence of control
Emery et al.	2016 Absence of control
Sun et al.	2019 Absence of control
Ma L. et al.	2019 N. implants test/control < 10, DS not reported
Jokstad A. et al.	2018 Accuracy not reported or not comparable
Herklotz I. et al.	2017 Accuracy not reported or not comparable
Mischkowski R. et al	2016 Accuracy not reported or not comparable
Kramer F. et al.	2004 Accuracy not reported or not comparable
Sießegger M. et al.	2001 Accuracy not reported or not comparable

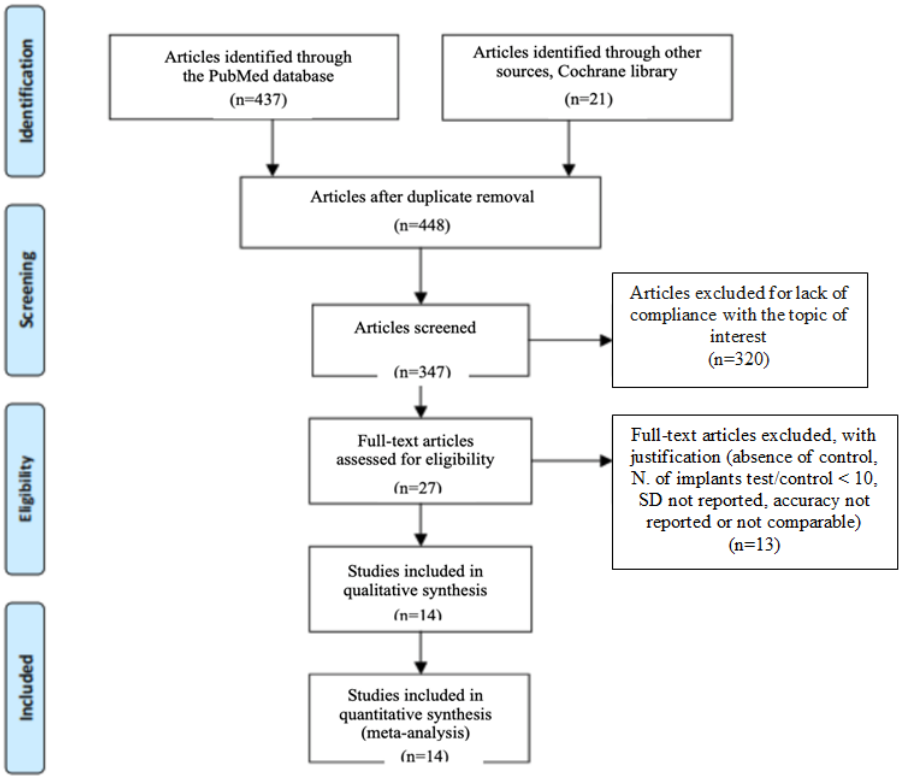

Fig. 2. *PRISMA flow chart.*

Table II. *General characteristics of the included studies.*

Author, Year	Study type	Surgical technique adopted		N(patients)		N(implants)		Edentulous type	
		Test	Control	Test	Control	Test	Control	Test	Control
HUMAN (VIVO)									
Kaewsiri, 2019	Human RCT	DN (IRIS-100)	SN	30	30	30	30	PE	PE
Block, 2017	Human CT	DN(X-Guide, full guide) DN(X-Guide, partial guide)	CS	tot 478		219 373	122	PE PE	PE PE
Yimarj P 2020	RCT parallel	DN(Iris-100)	SN (VisiJet MP200)	Tot 30		30	30	Partial (two neighboring implants)	Partial (two neighboring implants)
Sun 2020	Non-RCT	DN(AqNavi)	- sCAIS - d+sCAIS Freehand	NR		32	32 32 32	NR	NR
Aydemir 2020	Split-mouth RCT	DN(Navident)	Freehand	15	15	43	43	Partial (posterior bilateral edentulism)	Partial (posterior bilateral edentulism)
EX VIVO (CADAVER)									
Ruppin, 2008	Ex Vivo (human cadaver mandibles)	DN (RoboDent) DN (Artma Virtual Patient)	SN	tot20 (20 human cadaver mandibles)		40 40	40	TE-PE TE-PE	TE-PE
VITRO (MODEL)									
Mediavilla Guzman 2019	in vitro study (Polyurethane model)	DN(Navident)	SN(NemoStudio® / ProJet 6000)	10 models	10 models	20	20	Total	Total
Zhou 2020	in vitro study (Resin 3D printed model)	DN (Yizhimei)	sCAIS (VisiJet M3)	10 models	10 models	40	40	Partial	Partial
Jorba-Garcia 2019	in- vitro study (Resin model)	DN (NaviDent)	CS	3 models	3 models	18	18	PE	PE
Chen CK, 2018	In vitro study (Plaster model)	DN (AQ Navi SNS)	SN CS	10 models	10 models 10 models	50	50 50	PE	PE PE
Somogyi-Ganss, 2014	In vitro study	DN (NaviDent)	CS SN (Strauman GS) SN (Simplant SG) SN (Nobel Guide)	50	50 50 50 50	400	400 400 400 400	PE	PE PE PE PE
Kang, 2014	In vitro study	DN (CBYON Suite System), zona canini DN (CBYON Suite System), zona molari	SN	10	10	20 20	20 20	TE TE	TE TE
Hoffmann, 2005	In vitro study	DN (Vector Vision Compact)	CS	8	8	112	112	TE	TE
Brief, 2005	In vitro study	DN (RoboDent) DN (DenX IGI System)	CS	5 5	5	15 15	15	PE PE	PE

DN: Dynamic Navigation, SN: Static Navigation, CS: Conventional Surgery PE: partially edentulous TE: totally edentulous
NR: not reported, dCAIS dynamic computer – aided implant surgery, sCAIS static computer – aided implant surgery

All the studies included analysed the implant positioning in DN as a test intervention; in particular, 1 of these studies used and evaluated two DN systems as a test; 1 divided the test group based on the site of insertion in canine and molar position and 1 study divided the test group, based on the method of insertion, between Full and Partial Guide. If control intervention is considered, only 6 studies represented implant placement in SN, 5 studies by CS) and 3 by SN and CS.

Considering the total number of implants inserted and divided into the 3 groups used in the subsequent meta-analysis, the data concerning 1517 implants in the DN test group, 1482 implants in the SN control group and 792 implants in the CS control group were collected.

In almost all the articles considered, the type of edentulism treated was exclusive of the partial type, with the exception of 3 in vitro studies which performed the insertion of implants in models characterised by total edentulism. In the remaining studies, it was not possible to separate the number of partial edentulous ones from the total edentulous ones.

Results of the individual studies

This paper examined the following primary outcomes resulting from the implant placement: total coronal deviation, total apical deviation and angular deviation. The secondary outcomes considered are coronal lateral deviation, coronal depth deviation, apical lateral deviation and apical depth deviation.

Primary outcomes

The total coronal deviation parameter was analysed in 8 studies, 4 clinical (11-13, 15) and 4 in vitro (4, 17, 18, 19). The total apical deviation was analysed in 11 studies, 5 clinical (11-15) and 6 in vitro (4, 17, 1-20, 23).

The angular deviation parameter was analysed in all included studies (4, 11-23). The primary outcomes were grouped in the table below (Table III).

Table III. *Primary outcomes.*

Author, Year	Study Type	Surgery type		N(implants)		Mean Total Coronal Deviation (SD); mm		Mean Total Apical Deviation (SD); mm		Mean Angular Deviation (SD); °	
		Test	Control	Test	Control	Test	Control	Test	Control	Test	Control
HUMAN (VIVO)											
Kaewsiri, 2019	Human RCT	DN	SN	30	30	1,05 (0,44)	0,97 (0,44)	1,29 (0,5)	1,28 (0,46)	3,06 (1,37)	2,84 (1,71)
Block, 2017	Human CT	DN f DNp	CS	219 373	122	1,16 (0,59) 1,31 (0,68)	1,78 (0,77)	1,29 (0,65) 1,52 (0,78)	2,27 (1,02)	2,97 (2,09) 3,43 (2,33)	6,5 (4,21)
Yimarj P 2020	RCT parallel	DN	SN	30	30	1,24 (0,39)	1,04 (0,67)	1,58 (0,56)	1,54 (0,79)	3,78 (1,84)	4,08 (1,69)
Sun 2020	Non-RCT	DN	- sCAIS - d+sCAIS Freehand	32	32 32 32			1,25 (0,09)	1,49 (0,08) 0,98 (0,19) 1,89 (0,09)	3,24 (0,36)	4,54 (0,29) 2,20 (0,38) 6,12 (0,12)
Aydemir 2020	Split-mouth RCT	DN	Freehand	43	43	1,01 (0,07)	1,70 (0,13)	1,83 (0,12)	2,51 (0,21)	5,59 (0,39)	10,04 (0,83)
EX VIVO (CADAVER)											
Ruppin, 2008	Ex Vivo (human cadaver mandibles)	DN DN	SN	40 40	40					8,1 (4,6) 8,1 (4,9)	7,9 (5)
VITRO (MODEL)											
Mediavilla Guzman 2019	in vitro study (Polyurethane model)	DN	SN	20	20	0,85 (0,48)	0,78 (0,43)	1,18 (0,60)	1,20 (0,48)	4,00 (1,41)	2,95 (1,48)
Zhou 2020	in vitro study (Resin 3D printed model)	DN	sCAIS	40	40	0,4 (0,41)	1,15 (0,34)	0,34 (0,33)	1,37 (0,38)	0,97 (1,21)	2,6 (1,11)
Jorba-Garcia 2019	in- vitro study (Resin model)	DN	CS	18	18	1,29 (0,46)	1,50 (0,58)	1,33 (0,5)	2,26 (1,11)	1,6 (1,3)	9,7 (5,2)
Chen CK, 2018	In vitro study (Plaster model)	DN	SN CS	50	50 50	1,07 (0,48)	1,02 (0,46) 1,44 (0,56)	1,35 (0,55)	1,5 (0,79) 2,00 (0,79)	4,45 (1,97)	6,02 (3,71) 9,26 (3,62)
Somogyi-Ganss, 2014	In vitro study	DN	CS SN 1 SN 2 SN 3	400	400 400 400 400			1,71 (0,61)	2,32 (1,18) 1,71 (0,86) 1,46 (0,76) 1,91 (0,94)	2,99 (1,68)	8,95 (4,65) 3,31 (1,86) 3,09 (1,9) 4,24 (2,66)
Kang, 2014	In vitro study	DNc DNm	SNc SN m	20 20	20 20					12,37 (4,18) 8,97 (3,83)	6,72 (3,41) 3,9 (2,44)
Hoffmann, 2005	In vitro study	DN	CS	112	112					4,2 (1,8)	11,2 (5,6)
Brief, 2005	In vitro study	DN 1 DN 2	CS	15 15	15			0,6 (0,2) 0,94 (0,4)	1,89 (0,8)	2,12 (0,78) 4,21 (4,76)	4,59 (2,84)

DN: Dynamic Navigation, SN: Static Navigation, CS: Conventional Surgery PE: partially edentulous TE: totally edentulous; NR: not reported, dCAIS dynamic computer – aided implant surgery, sCAIS static computer – aided implant surgery, c: canines, m: molars

Secondary outcomes

The lateral coronal deviation parameter was analysed in a total of 6 studies, 1 clinical (12), 1 on an anatomical piece (16) and 4 in vitro (18, 20, 21, 23). The coronal depth deviation parameter was analysed in 2 studies, 1 clinical (12) and 1 in vitro (21).

The apical lateral deviation parameter was analysed in 4 studies, 1 clinical (12) and 3 in vitro (20, 21, 23). The apical depth deviation parameter was analysed in a total of 7 studies, 2 clinical (12, 14), 1 on an anatomical piece (16) and 4 *in vitro* (18, 20, 21, 23). The secondary outcomes were grouped in the table below (Table IV).

Table IV. *Secondary outcomes.*

Author, Year	Study Type	Surgery type		N(implants)		Mean coronal lateral deviation (SD); mm		Mean coronal depth deviation (SD); mm		Mean apical lateral deviation (SD); mm		Mean apical depth deviation (SD); mm	
		Test	Control	Test	Control	Test	Control	Test	Control	Test	Control	Test	Control
HUMAN (VIVO)													
Kaewsiri, 2019	Human RCT	DN	SN	30	30								
Block, 2017	Human CT	DN f DNp	CS	219 373	122	0,74 (0,43) 0,8 (0,49)	1,19 (0,68)	0,76 (0,6) 0,89 (0,73)	1,12 (0,83)	0,9 (0,55) 1,01 (0,65)	1,84 (1,05)	0,78 (0,6) 0,9 (0,74)	1,1 (0,82)
Yimarj P 2020	RCT parallel	DN	SN	30	30								
Sun 2020	Non-RCT	DN	- sCAIS - d+sCAIS Freehand	32	32 32 32							0,73 (0,13)	1,00 (0,15) 0,52 (0,20) 1,42 (0,25)
Aydemir 2020	Split-mouth RCT	DN	Freehand	43	43								
EX VIVO (CADAVER)													
Ruppin, 2008	Ex Vivo (human cadaver mandibles)	DN DN	SN	40 40	40	1,0 (0,5) 1,2 (0,6)	1,5 (0,8)					0,6 (0,3) 0,8 (0,7)	0,6 (0,4)
VITRO (MODEL)													
Mediavilla Guzman 2019	in vitro study (Polyurethane model)	DN	SN	20	20								
Zhou 2020	in vitro study (Resin 3D printed model)	DN	sCAIS	40	40								
Jorba-Garcia 2019	in- vitro study (Resin model)	DN	CS	18	18	0,85 (0,41)	1,26(0,66)					0,88 (0,47)	0,57(0,33)
Chen CK, 2018	In vitro study (Plaster model)	DN	SN CS	50	50 50								
Somogyi-Ganss, 2014	In vitro study	DN	CS SN 1 SN 2 SN 3	400	400 400 400 400	1,14 (0,55)	1,14 (0,68) 0,9 (0,48) 0,76 (0,54) 0,81 (0,55)			1,18 (0,56)	1,74 (1,07) 1,19 (0,62) 0,99 (0,64) 1,24 (0,8)	1,04 (0,71)	0,73 (0,71) 1,05 (0,86) 1,1 (0,79) 1,27 (0,86)
Kang, 2014	In vitro study	DNc DNm	SNc SN m	20 20	20 20	2,06 (1,43) 3,03 (1,81)	0,73(0,41) 0,68 (0,44)	1,14 (1,25) 0,76 (0,84)	0,47(0,34) 0,32 (0,25)	2,76 (1,03) 3,31 (2,07)	2,03(0,97) 1,08 (0,77)	1,42 (1,01) 1,96 (0,93)	1,52(1,31) 0,52 (0,52)
Hoffmann, 2005	In vitro study	DN	CS	112	112								
Brief, 2005	In vitro study	DN 1 DN 2	CS	15 15	15	0,35 (0,17) 0,65 (0,58)	1,35 (0,56)			0,47 (0,18) 0,68 (0,31)	1,62 (0,68)	0,32 (0,21) 0,61 (0,36)	0,84 (0,65)

DN: Dynamic Navigation, SN: Static Navigation, CS: Conventional Surgery PE: partially edentulous TE: totally edentulous NR: not reported, dCAIS dynamic computer – aided implant surgery, sCAIS static computer – aided implant surgery, c: canines, m: molars

Clinical outcomes

Before dealing with the section regarding quantitative synthesis to extrapolate clinical data that can be valid as a reference during the planning phase of an intervention in DN, a further investigation was made where the overall mean and standard deviation of all studies included in the systematic review were calculated. The

overall mean and standard deviation of DN are shown in the following table, divided into primary and secondary outcomes. (Table V).

Table V. *Accuracy of dynamic navigation.*

Primary outcomes	Mean (SD)
Total Coronal Deviation	1,04 (0,44)
Total apical deviation	1,25 (0,45)
Axis angular deviation	4,7 (2,27)
Secondary outcomes	Mean (SD)
Lateral coronal deviation	1,18 (0,7)
Coronal depth deviation	0,89 (0,86)
Lateral apical deviation	1,47 (0,76)
Apical depth deviation	0,91 (0,56)

Quantitative synthesis of the results

A quantitative comparison for the accuracy of implant placement was performed through a meta-analysis of each of the 7 primary and secondary outcomes evaluated.

Forest plot graphs were extrapolated from the meta-analysis for a simpler graphical interpretation. In addition, where possible, or where the number of studies allowed their realisation, the Egger test was also performed accompanied by the graphical representation through a funnel plot to investigate the "small study effect".

The results of the statistical tests accompanied by the reference graphs are shown in the section below, divided by parameter. In order to facilitate the interpretation, the results relating to the comparison between DN and CS were highlighted in blue, and those between DN *vs* SN in yellow.

Total coronal deviation

For the total coronal deviation, the statistical analysis shows that there is a high difference (SMD = -1.650), statistically significant ($p < 0.001$), in favor of DN in comparison with CS. From the comparison of DN *vs* SN, a slight difference emerges (SMD = -0.234) in favor of DN, but this difference does not reach statistical significance ($p = 0.576$) (Table VI).

Table VI. *Total coronal deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Aydemir (2020)	-6.609	-7.694	-5.524	8.00
Chen CK (2018)	-0.709	-1.114	-0.305	10.40
Jorba-Garcia (2019)	-0.401	-1.061	0.259	9.63
Block (2017)	-0.668	-0.877	-0.460	10.78
Block (2017)	-0.940	-1.172	-0.707	10.75
Sub-total				
D+L pooled SMD	-1.650	-2.509	-0.791	49.56
DN vs SN				
Chen CK (2018)	0.106	-0.286	0.499	10.43
Zhou (2020)	-1.991	-2.530	-1.453	10.03
Mediavilla (2019)	0.154	-0.467	0.774	9.76
Yimarj P (2020)	0.365	-0.146	0.875	10.11
Kaewsiri (2019)	0.182	-0.325	0.689	10.12
Sub-total				
D+L pooled SMD	-0.234	-1.055	0.586	50.44
Overall				
D+L pooled SMD	-0.933	-1.527	-0.339	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	113.91	4	0.000	96.5%	0.8741
DN vs SN	52.99	4	0.000	92.5%	0.8074
Overall	192.50	9	0.000	95.3%	0.8400

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 3.77	p = 0.000
DN vs SN	z= 0.56	p = 0.576
Overall	z= 3.08	p = 0.002

Total coronal deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* SN comparison and the lower portion the DN *vs* CS comparison, it can be seen that the test, the DN, is favoured in comparison with the CS and comparable to the SN, although presenting a very slight difference, however not significant (Fig. 3).

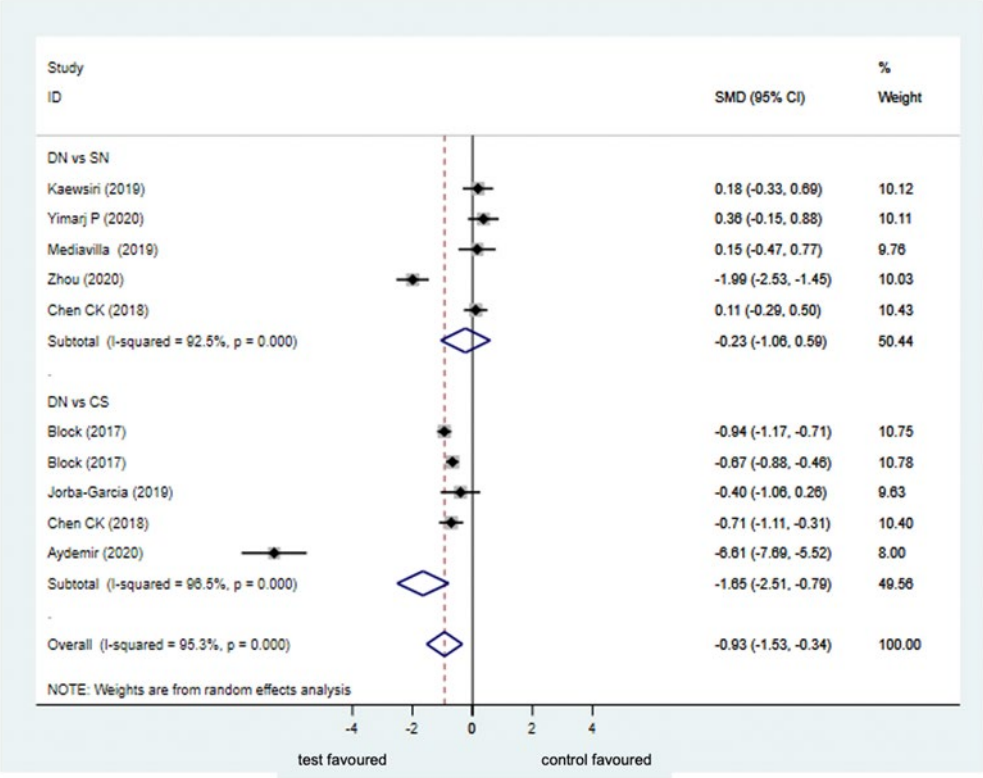

Fig. 3. *Total coronal deviation, forest plot.*

Total apical deviation

For the total apical deviation, the statistical analysis shows that there is a high difference (SMD = -1.919), statistically significant ($p < 0.001$), in favor of DN in comparison with conventional surgery. From the comparison of DN *vs* SN, a moderate difference emerges (SMD = -0.556) in favor of DN, reaching statistical significance ($p = 0.008$) (Table VII).

Table VII. *Total apical deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Block (2017)	-1.222	-1.462	-0.982	6.17
Block (2017)	-0.887	-1.099	-0.676	6.20
Sun (2020)	-7.111	-8.455	-5.767	3.53
Aydemir (2020)	-3.976	-4.711	-3.241	5.12
Jorba-Garcia (2019)	-1.080	-1.782	-0.378	5.20
Chen CK (2018)	-0.955	-1.369	-0.541	5.88
Somogyi-Ganss (2014)	-0.649	-0.792	-0.507	6.27
Brief (2005)	-2.212	-3.133	-1.291	4.61
Brief (2005)	-1.502	-2.319	-0.685	4.90
Sub-total				
D+L pooled SMD	-1.919	-2.482	-1.355	47.88
DN vs SN				
Kaewsiri (2019)	0.021	-0.485	0.527	5.69
Yimarj P (2020)	0.058	-0.448	0.565	5.69
Sun (2020)	-2.819	-3.516	-2.121	5.22
Mediavilla-Guzman (2	-0.037	-0.657	0.583	5.41
Zhou (2020)	-2.894	-3.525	-2.263	5.39
Chen CK (2018)	-0.220	-0.614	0.173	5.92
Somogyi-Ganss (2014)	0.000	-0.139	0.139	6.27
Somogyi-Ganss (2014)	0.363	0.223	0.503	6.27
Somogyi-Ganss (2014)	-0.252	-0.392	-0.113	6.27
Sub-total				
D+L pooled SMD	-0.556	-0.969	-0.143	52.12
Overall				
D+L pooled SMD	-1.220	-1.601	-0.840	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	177.38	8	0.000	95.5%	0.6313
DN vs SN	181.71	8	0.000	95.6%	0.3465
Overall	560.92	17	0.000	97.0%	0.5960

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 6.67	p = 0.000
DN vs SN	z= 2.64	p = 0.008
Overall	z= 6.29	p = 0.000

Total apical deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* CS comparison and the lower portion the DN *vs* SN comparison, it can be seen that the test, the DN, is favoured in comparison with the CS and also favoured in comparison with the SN, with statistical significance in both comparisons (Fig. 4).

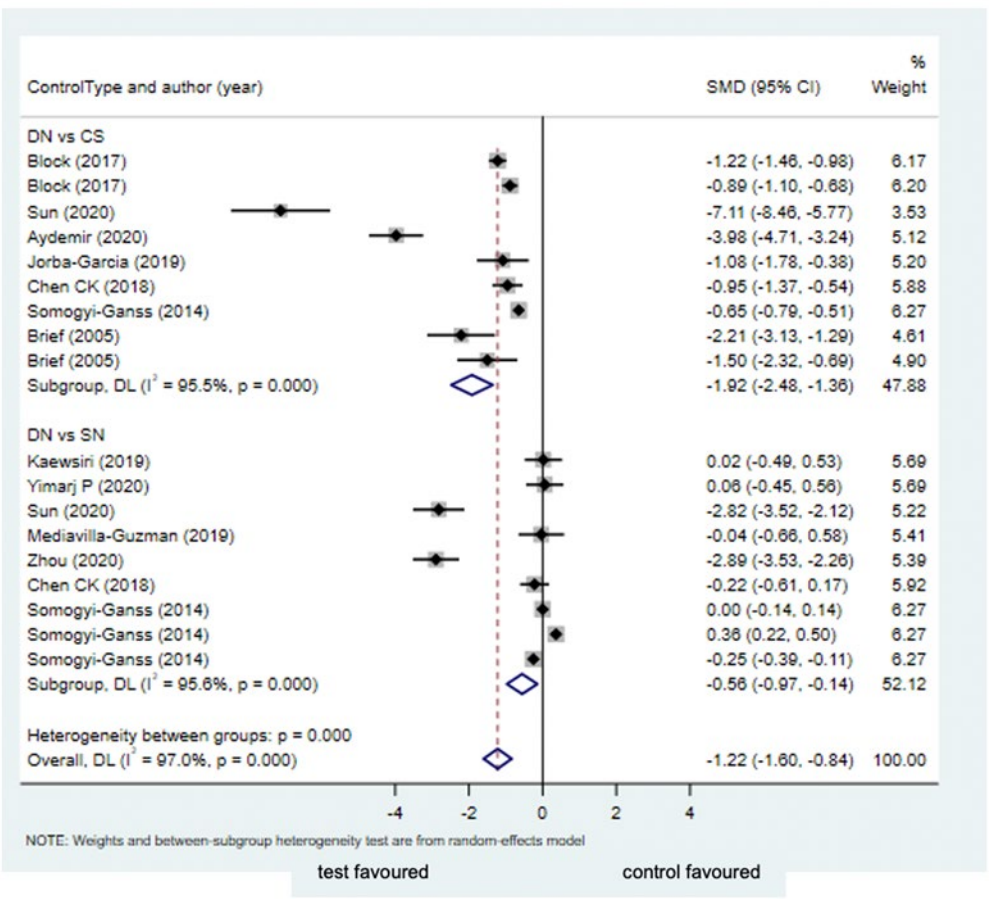

Fig. 4. *Total apical deviation, forest plot.*

Axis angular deviation

For the angular deviation of the axes, the statistical analysis shows that there is a high difference (SMD = -2.269), statistically significant (p <0.001), in favor of DN in comparison with conventional surgery. From the comparison of DN *vs* SN, a slight difference emerges (SMD = -0.199) in favor of DN, but this difference does not reach statistical significance (p = 0.239) (Table VIII).

Table VIII. *Axis angular deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs SN				
Kaewsiri (2019)	0.142	-0.365	0.649	4.50
Yimarj P (2020)	-0.170	-0.677	0.337	4.50
Sun (2020)	-3.977	-4.831	-3.123	3.94
Ruppin (2008)	0.042	-0.397	0.480	4.58
Ruppin (2008)	0.040	-0.398	0.479	4.58
Mediavilla Guzman (2	0.726	0.085	1.367	4.30
Zhou (2020)	-1.404	-1.894	-0.913	4.52
Chen CK (2018)	-0.529	-0.927	-0.130	4.63
Somogyi-Ganss (2014)	-0.181	-0.319	-0.042	4.84
Somogyi-Ganss (2014)	-0.056	-0.194	0.083	4.84
Somogyi-Ganss (2014)	-0.562	-0.703	-0.421	4.84
Kang (2014)	1.481	0.778	2.185	4.20
Kang (2014)	1.579	0.865	2.293	4.18
Sub-total				
D+L pooled SMD	-0.199	-0.529	0.132	58.44
DN vs CS				
Block (2017)	-1.168	-1.406	-0.930	4.78
Block (2017)	-1.056	-1.271	-0.842	4.80
Sun (2020)	-10.733	-12.685	-8.781	2.17
Aydemir (2020)	-6.862	-7.983	-5.742	3.46
Jorba-Garcia (2019)	-2.137	-2.965	-1.310	3.98
Chen CK (2018)	-1.651	-2.106	-1.196	4.56
Somogyi-Ganss (2014)	-1.705	-1.867	-1.543	4.83
Hoffmann (2005)	-1.683	-1.988	-1.378	4.73
Brief (2005)	-1.186	-1.966	-0.406	4.07
Brief (2005)	-0.097	-0.813	0.619	4.17
Sub-total				
D+L pooled SMD	-2.269	-2.850	-1.688	41.56
Overall				
D+L pooled SMD	-1.073	-1.460	-0.686	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs SN	186.57	12	0.000	93.6%	0.3069
DN vs CS	223.40	9	0.000	96.0%	0.7433
Overall	800.09	22	0.000	97.3%	0.7992

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs SN	z= 1.18	p = 0.239
DN vs CS	z= 7.65	p = 0.000
Overall	z= 5.44	p = 0.000

Axis angular deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* SN comparison and the lower portion the DN *vs* CS comparison, it can be seen that the DN test is favoured in comparison with the CS and comparable to the SN, although presenting a very slight difference, however not significant. Furthermore, it can be observed that the difference between DN and SN remains minimal and negligible both by analysing the data as a whole and in individual studies, except for the data reported by Kang et al. and Sun et al. (14, 21), which differ considerably from the other data reported (Fig. 5).

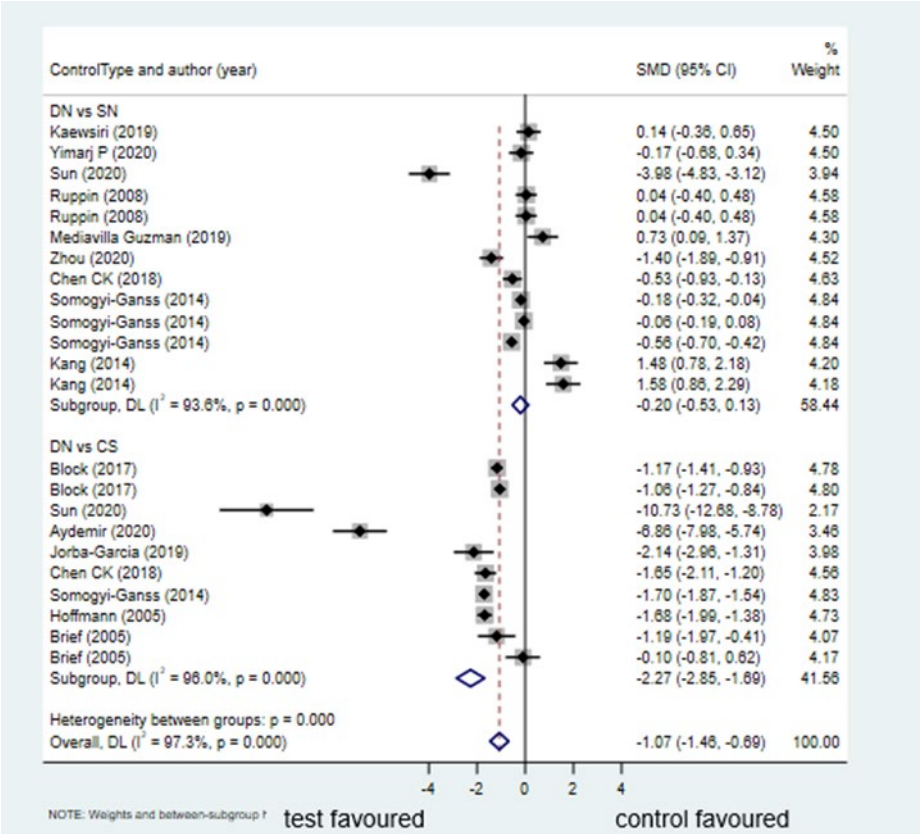

Fig. 5. *Axis angular deviation, forest plot.*

The presence of the "small study effect" was investigated using the funnel plot and the Egger test:

- Funnel plot axis angular deviation, DN *vs* CS comparison (Fig. 6).
- Funnel plot axis angular deviation, DN *vs* SN comparison (Fig. 7).
  - Since the p = 0.148, the presence of "small-study effects" is excluded from the comparison between DN and CS. (Table IX).
  - Since p = 0.840, the presence of "small-study effects" is excluded from the comparison between DN and SN. (Table X).

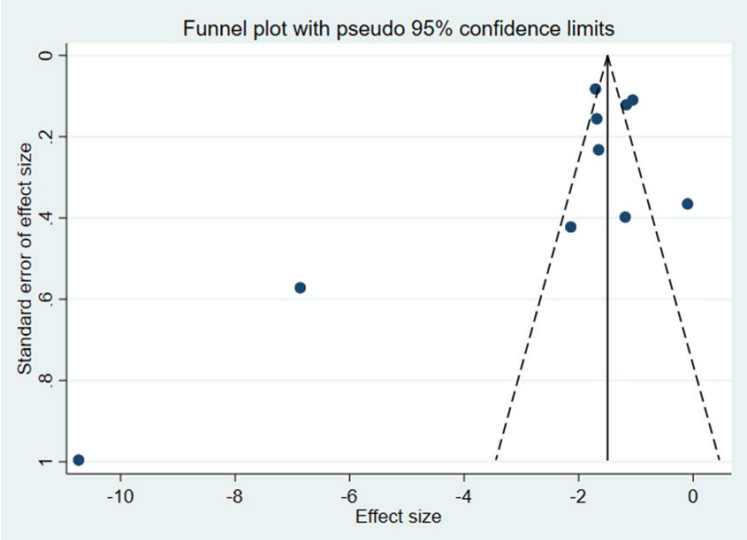

Fig. 6. *Funnel plot axis angular deviation, DN vs CS comparison.*

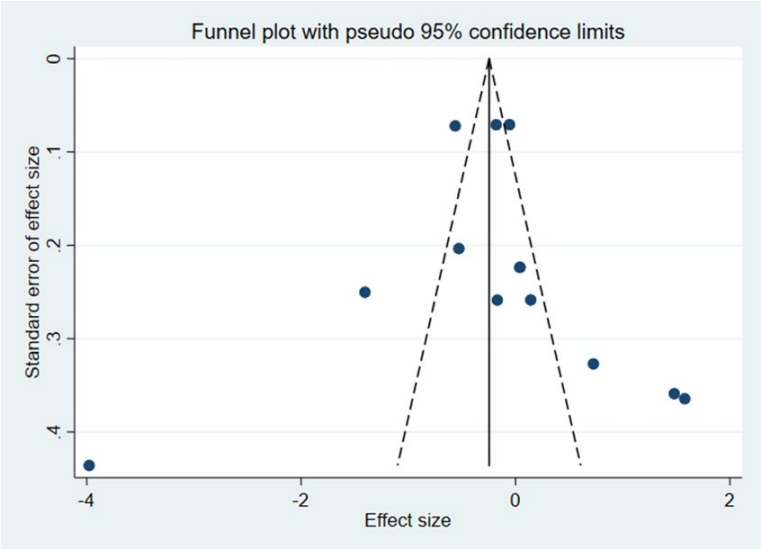

Fig. 7. *Funnel plot axis angular deviation, DN vs SN comparison.*

Table IX. *Since the p = 0.148, the presence of "small-study effects" is excluded in the comparison between DN vs CS.*

```
. ***CHECKING PUBLICATION BIAS WITH EGGER'S TEST FOR DN vs CS
. *table (P VALUE)
. metabias _ES _seES if ControlType=="DN vs CS",  egger

Note: data input format theta se_theta assumed.

Egger's test for small-study effects:
Regress standard normal deviate of intervention
effect estimate against its standard error

Number of studies =  10                              Root MSE      =   4.598
```

Std_Eff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
slope	-.9547596	.4109467	-2.32	0.049	-1.902405	-.0071148
bias	-4.062364	2.53608	-1.60	0.148	-9.910575	1.785846

```
Test of H0: no small-study effects          P = 0.148
```

Table X. *Since p = 0.840, the presence of "small-study effects" is excluded in the comparison between DN vs SN.*

```
. ***CHECKING PUBLICATION BIAS WITH EGGER'S TEST FOR DN vs SN
. *table (P VALUE)
. metabias _ES _seES if ControlType=="DN vs SN",  egger

Note: data input format theta se_theta assumed.

Egger's test for small-study effects:
Regress standard normal deviate of intervention
effect estimate against its standard error

Number of studies =  13                              Root MSE      =   4.11
```

Std_Eff	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
slope	-.2887218	.2567526	-1.12	0.285	-.8538305	.2763869
bias	.3977745	1.925844	0.21	0.840	-3.840979	4.636528

```
Test of H0: no small-study effects          P = 0.840
```

Coronal lateral deviation

For the lateral coronal deviation, the statistical analysis shows a high difference (SMD = -0.867), statistically significant (p = 0.001), in favor of DN compared to conventional surgery. From the comparison of DN *vs* SN, a moderate difference emerges (SMD = 0.449) in favor of SN, reaching statistical significance (p = 0.006) (Table XI).

Table XI. *Coronal lateral deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Block (2017)	-0.844	-1.075	-0.614	8.57
Block (2017)	-0.718	-0.928	-0.509	8.62
Jorba-Garcia (2019)	-0.746	-1.423	-0.069	6.84
Somogyi-Ganss (2014)	0.000	-0.139	0.139	8.75
Brief (2005)	-2.416	-3.372	-1.461	5.58
Brief (2005)	-1.228	-2.012	-0.443	6.34
Sub-total				
D+L pooled SMD	-0.867	-1.358	-0.376	44.70
DN vs SN				
Ruppin (2008)	-0.750	-1.203	-0.296	7.82
Ruppin (2008)	-0.424	-0.868	0.019	7.86
Somogyi-Ganss (2014)	0.465	0.324	0.605	8.75
Somogyi-Ganss (2014)	0.697	0.554	0.840	8.75
Somogyi-Ganss (2014)	0.600	0.458	0.742	8.75
Kang (2014)	1.264	0.583	1.946	6.82
Kang (2014)	1.784	1.046	2.522	6.55
Sub-total				
D+L pooled SMD	0.449	0.129	0.768	55.30
Overall				
D+L pooled SMD	-0.133	-0.503	0.238	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	77.56	5	0.000	93.6%	0.3037
DN vs SN	70.89	6	0.000	91.5%	0.1437
Overall	352.23	12	0.000	96.6%	0.4030

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 3.46	p = 0.001
DN vs SN	z= 2.75	p = 0.006
Overall	z= 0.70	p = 0.483

Coronal lateral deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* CS comparison and the lower portion the DN *vs* SN comparison, it can be seen that the test, the DN, is very favored in comparison with the CS but disadvantaged when compared to the SN, with statistical significance in both comparisons (Fig. 8).

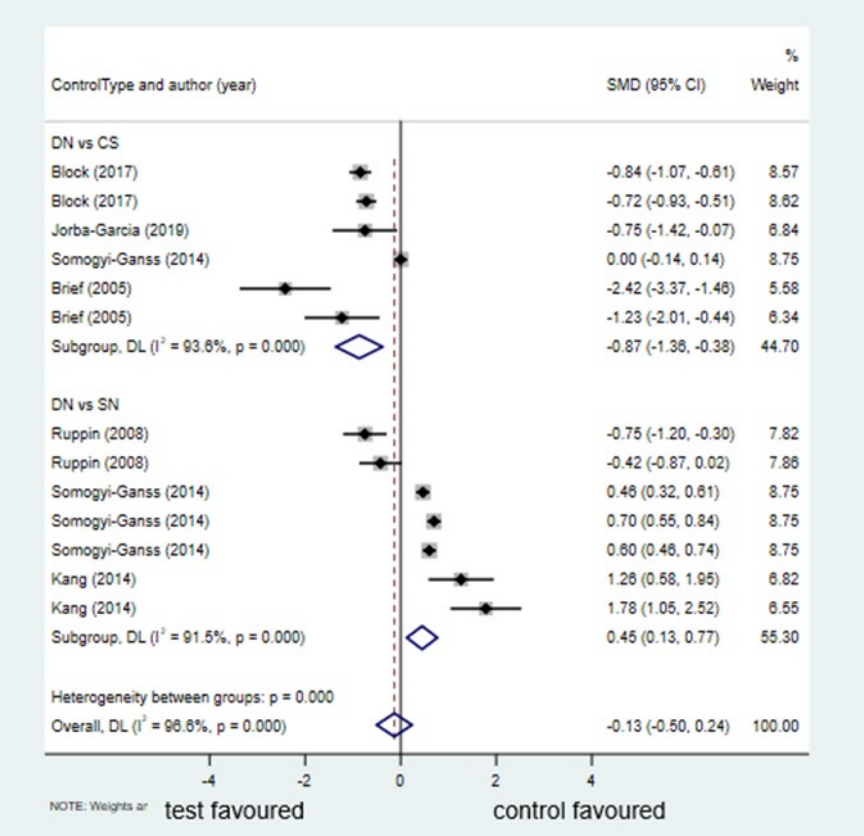

Fig. 8. *Coronal lateral deviation, forest plot.*

Coronal depth deviation

For the coronal depth deviation, the statistical analysis shows that there is a moderate difference (SMD = -0.408), statistically significant (p <0.001), in favor of DN in comparison with conventional surgery. From the comparison of DN *vs* SN, a moderate difference emerges (SMD = 0.721) in favor of SN, and this difference reaches statistical significance (p = 0.002) (Table XII).

Table XII. *Coronal depth deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Block (2017)	-0.521	-0.746	-0.296	29.68
Block (2017)	-0.304	-0.510	-0.099	30.01
Sub-total				
D+L pooled SMD	-0.408	-0.620	-0.195	59.69
DN vs SN				
Kang (2014)	0.731	0.090	1.373	20.14
Kang (2014)	0.710	0.070	1.350	20.17
Sub-total				
D+L pooled SMD	0.721	0.268	1.174	40.31
Overall				
D+L pooled SMD	0.045	-0.431	0.520	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	1.95	1	0.163	48.6%	0.0114
DN vs SN	0.00	1	0.963	0.0%	0.0000
Overall	23.20	3	0.000	87.1%	0.1851

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 3.77	p = 0.000
DN vs SN	z= 3.12	p = 0.002
Overall	z= 0.18	p = 0.854

Coronal depth deviation, forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* CS comparison and the lower portion the DN *vs* SN comparison, it can be seen that the test, the DN, is favoured in comparison with the CS but disadvantaged if compared to SN, with statistical significance in both comparisons (Fig. 9).

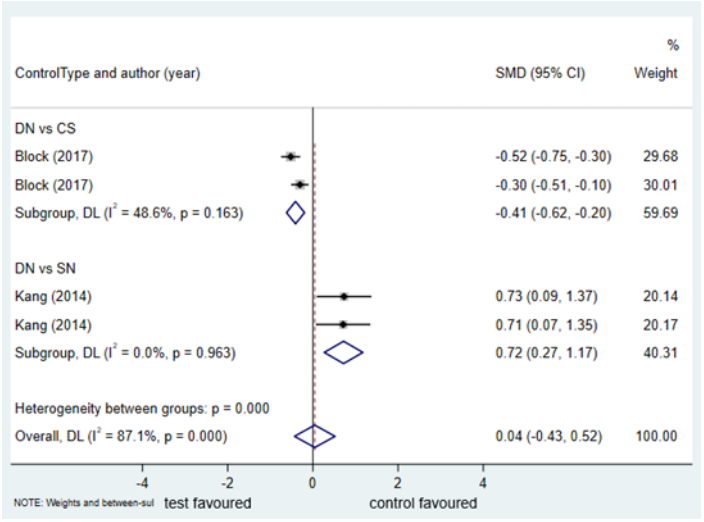

Fig. 9. *Coronal depth deviation, forest plot.*

Lateral apical deviation

For the lateral apical deviation, the statistical analysis shows that there is a high difference (SMD = -1.216), statistically significant (p <0.001), in favor of DN in comparison with conventional surgery. From the comparison of DN *vs* SN, a slight difference emerges (SMD = 0.289) in favor of SN, and this difference reaches statistical significance (p = 0.048) (Table XIII).

Table XIII. *Lateral apical deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Block (2017)	-1.226	-1.466	-0.986	11.10
Block (2017)	-1.081	-1.296	-0.866	11.19
Somogyi-Ganss (2014)	-0.656	-0.798	-0.513	11.40
Brief (2005)	-2.312	-3.250	-1.375	7.07
Brief (2005)	-1.779	-2.633	-0.925	7.57
Sub-total				
D+L pooled SMD	-1.216	-1.603	-0.829	48.32
DN vs SN				
Somogyi-Ganss (2014)	-0.017	-0.156	0.122	11.41
Somogyi-Ganss (2014)	0.316	0.177	0.455	11.40
Somogyi-Ganss (2014)	-0.087	-0.226	0.052	11.41
Kang (2014)	0.730	0.089	1.371	8.91
Kang (2014)	1.428	0.730	2.126	8.55
Sub-total				
D+L pooled SMD	0.289	0.003	0.576	51.68
Overall				
D+L pooled SMD	-0.419	-0.818	-0.019	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	33.90	4	0.000	88.2%	0.1402
DN vs SN	36.53	4	0.000	89.1%	0.0773
Overall	293.37	9	0.000	96.9%	0.3596

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 6.16	p = 0.000
DN vs SN	z= 1.98	p = 0.048
Overall	z= 2.05	p = 0.040

Lateral apical deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* CS comparison and the lower portion the DN *vs* SN comparison, it can be seen that the test, the DN, is favoured in comparison with the CS but disadvantaged if compared to SN, with statistical significance in both comparisons (Fig. 10).

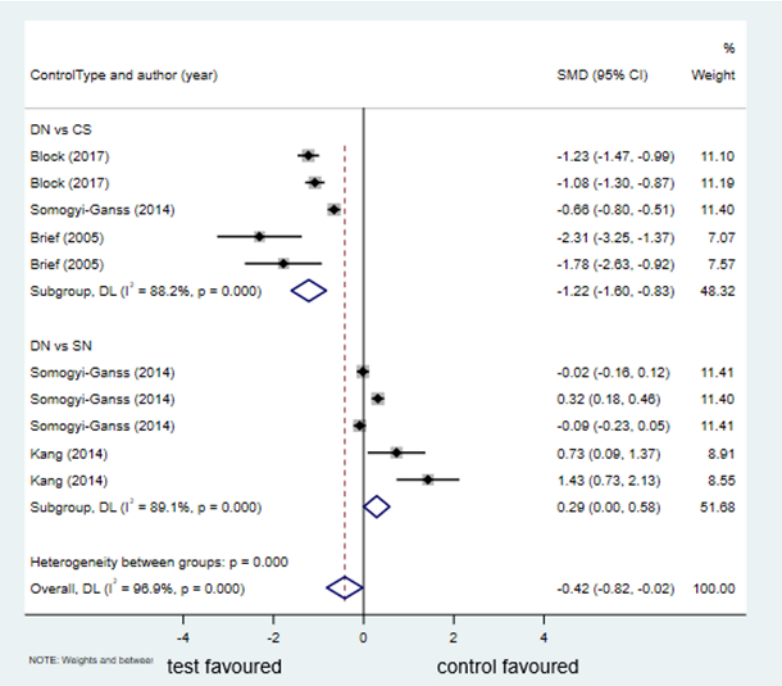

Fig. 10. *Lateral apical deviation, forest plot.*

Apical depth deviation

For the apical depth deviation, the statistical analysis shows a moderate difference (SMD = -0.577) with borderline statistical significance (p = 0.055) in favor of DN compared to conventional surgery. From the comparison of DN *vs* SN, a slight difference emerges (SMD = -0.065) in favor of DN, and this difference does not reach statistical significance (p = 0.673) (Table XIV).

Table XIV. *Apical depth deviation.*

Study	SMD	[95% Conf.	Interval]	% Weight
DN vs CS				
Block (2017)	-0.466	-0.690	-0.242	7.88
Block (2017)	-0.263	-0.468	-0.058	7.94
Sun (2020)	-3.463	-4.245	-2.681	5.00
Jorba-Garcia (2019)	0.763	0.085	1.441	5.55
Somogyi-Ganss (2014)	0.437	0.296	0.577	8.13
Brief (2005)	-1.077	-1.846	-0.307	5.06
Brief (2005)	-0.438	-1.163	0.287	5.30
Sub-total				
D+L pooled SMD	-0.577	-1.167	0.013	44.85
DN vs SN				
Sun (2020)	-1.924	-2.519	-1.328	6.00
Ruppin (2008)	0.000	-0.438	0.438	6.88
Ruppin (2008)	0.351	-0.091	0.793	6.86
Somogyi-Ganss (2014)	-0.013	-0.151	0.126	8.14
Somogyi-Ganss (2014)	-0.080	-0.219	0.059	8.14
Somogyi-Ganss (2014)	-0.292	-0.431	-0.152	8.13
Kang (2014)	-0.085	-0.706	0.535	5.86
Kang (2014)	1.911	1.157	2.665	5.14
Sub-total				
D+L pooled SMD	-0.065	-0.366	0.236	55.15
Overall				
D+L pooled SMD	-0.260	-0.537	0.017	100.00

Test(s) of heterogeneity:

	Heterogeneity statistic	degrees of freedom	P	I-squared**	Tau-squared
DN vs CS	149.27	6	0.000	96.0%	0.5567
DN vs SN	76.21	7	0.000	90.8%	0.1429
Overall	228.90	14	0.000	93.9%	0.2406

** I-squared: the variation in SMD attributable to heterogeneity)

Note: between group heterogeneity not calculated;
only valid with inverse variance method

Significance test(s) of SMD=0

DN vs CS	z= 1.92	p = 0.055
DN vs SN	z= 0.42	p = 0.673
Overall	z= 1.84	p = 0.066

Apical depth deviation: forest plot

Observing the forest plot, of which the upper portion concerns the DN *vs* CS comparison and the lower portion the DN *vs* SN comparison, it can be seen that the test, the DN, is favoured in comparison with the CS and comparable to SN, although presenting a very slight difference, however not significant (Fig. 11).

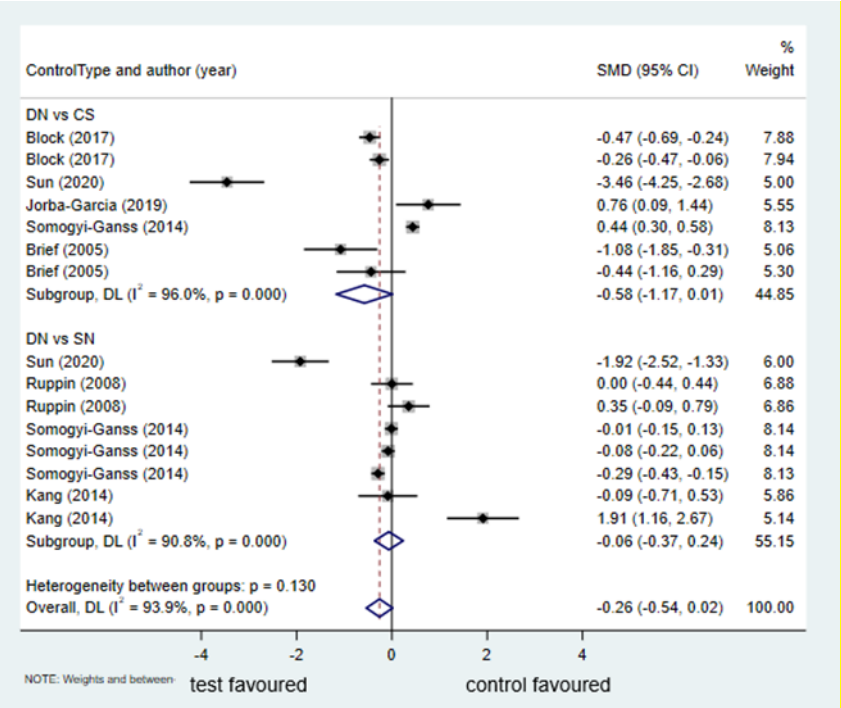

Fig. 11. *Apical depth deviation, forest plot.*

Summary of meta-analysis results

In almost all the meta-analyses, heterogeneity was found between the studies, partly reflecting the variability of the surgical experiences.

Concerning primary outcomes, using a DN method allows for significantly better accuracy than conventional surgery; compared to SN; however, two slight differences are not statistically significant, and a moderate difference that is statistically significant, all in favor of DN.

Regarding secondary outcomes, DN is significantly more accurate than conventional surgery but less than SN, except for the apical depth deviation in comparison with static navigation, which has minimal and no significant differences (Table XV).

Table XV. *Summary of meta-analysis results, statistically significant differences are shown in bold.*

	DN vs SN		DN vs CS	
	SMD, 95%CI (p)	**I2 (p)**	**SMD, 95%CI (p)**	**I2 (p)**
PRIMARY OUTCOMES				
Total coronal deviation	-0.234, -1.055; 0.586 (p=0.576)	**92.5% (p= 0.000)**	**-1.650, -2.509; -0.791 (p=0.000)**	**96.5% (p= 0.000)**
Total apical deviation	**-0.556, -0.969; -0.143 (p= 0.008)**	**95.6% (p=0.000)**	**-1.919, -2.482; -1.355 (p= 0.000)**	**95.5% (p=0.000)**
Axis angular deviation	-0.199, -0.529; 0.132 (p= 0.239)	**93.6% (p=0.000)**	**-2.269, -2.850; -1.688 (p=0.000)**	**96.0% (p=0.000)**
SECONDARY OUTCOMES				
Linear coronal deviation	**0.449, 0.129; 0.768 (p=0.006)**	**91.5% (p=0.000)**	**-0.867 -1.358; -0.376 (p=0.001)**	**93.6% (p=0.000)**
Coronal depth deviation	**0.721, 0.268; 1.174 (p=0.002)**	0.0% (p=0.963)	**-0.408, -0.620; -0.195 (p=0.000)**	48.6% (p= 0.163)
Linear apical deviation	**0.289, 0.003; 0.576 (p=0.048)**	**89.1% (p=0.000)**	**-1.216, -1.603; -0.829 (p=0.000)**	**88.2% (p=0.000)**
Apical depth deviation	-0.065, -0.366; 0.236 (p=0.673)	**90.8% (p=0.000)**	**-0.577, -1.167; 0.013 (p=0.055)**	**96.0% (p=0.000)**

DISCUSSION

From the results obtained from this meta-analysis, it can be stated that the DN mode allows for better accuracy than conventional surgery, the most used type of surgery, and is comparable to SN, the gold standard for accuracy.

DN vs CS

Compared with CS, surgery in DN presents notable and significant differences in all the parameters taken into consideration.

In more detail, slight differences are found in the results obtained from CS in the two different clinical and model study settings, which appears to be slightly more accurate in model studies than at a clinical level. This difference can be traced back and explained by the fact that in the experimental setting, mainly due to the absence of saliva, blood, and soft tissue encumbrance, the notch on the drill used as a reference during the osteotomy is more easily identifiable.

DN vs SN

When considering the primary outcomes from the comparison with SN, the data show that DN has better accuracy. The total apical deviation shows a moderate difference in favor of DN and reaches statistical significance, while the total coronal deviation and the axis angular deviation show slight differences in favor of DN, but neither of them reaches statistical significance.

Regarding the different types of studies (clinical, anatomical preparation, and model studies), in all three primary outcomes, there is some agreement in the results of the different types of studies, with some exceptions (14, 17, 21).

Kang et al. (21), in regards to the axes angular deviation, clearly differs from the other studies with a clear difference in favor of SN (values comparable to the other studies for SN, the worst among all studies included for DN). However, the discrepancy between the study by Kang and the other studies, included manifesting itself in the test (DN) and being negligible as regards the control (SN), may be partly justified by the systematics used for DN, which is not among those available on the market and therefore presumably still in the experimentation phase. In some studies, the discrepancy could be attributed to the systematics used (14, 17).

In secondary outcomes, compared with SN, the data show that SN has better accuracy. The coronal lateral deviation presents a moderate difference in favor of the SN and reaches statistical significance, the coronal depth deviation presents a high difference in favor of the SN and reaches statistical significance, the apical lateral deviation presents a slight difference in favor of SN and reaches statistical significance. In contrast, the apical depth deviation presents a slight difference in favor of DN but does not reach statistical significance.

Since the primary outcomes favour DN while the secondary outcomes favour SN, it can be concluded that overall, DN and SN have comparable accuracy.

Furthermore, the fact that secondary outcomes show better accuracy for static navigation must be analysed, taking into consideration that the data derive mainly from anatomical preparation studies and in vitro studies and little from clinical studies since secondary outcomes were considered in only one clinical study, and detail only the apical depth. The almost total absence of the clinical component in the analysis of secondary outcomes may explain the reason for the difference found with the primary ones.

The accuracy of SN strictly depends on the stability of the surgical guide, which in turn depends on the type of edentulousness from the supporting tissue, the movements of the muscle compartment, and the thickness and resilience of the supporting tissues (24, 25). All conditions in model studies, no matter how much you try to recreate and reproduce them, do not negatively affect the performance of this navigation mode, thus resulting in better accuracy than in anatomical preparation studies and clinical studies (26). However, exactly the opposite happens for DN; considering DN, this trend not only does not manifest itself but also presents an opposite trend; by comparing the weighted averages obtained on the model and in the clinical setting, a better accuracy emerges in favor of clinical studies in all the parameters considered except for the total coronal deviation (Table XVI).

Table XVI. *Comparison of Dynamic Navigation results divided by study type.*

	Total coronal deviation, mm	Total apical deviation, mm	Axis angular deviation, °	Lateral coronal deviation, mm	Coronal depth deviation, mm	Lateral apical deviation, mm	Apical depth deviation, mm
CLINICAL	1.23 (0.59)	1.45 (0.65)	3.41 (2)	0.78 (0.47)	0.84 (0.68)	0.97 (0.61)	0.85 (0.66)
ANATOMICAL PREPARATION	-	-	8.1 (4.75)	1.1 (0.55)	-	-	0.7 (0.5)
VITRO	0.86 (0.46)	1.50 (0.56)	3.6 (1.85)	1.21 (0.62)	0.95 (1.05)	1.30 (0.62)	1.05 (0.7)
OVERALL	1.17 (0.57)	1.47 (0.61)	3.75 (2.1)	0.98 (0.54)	0.85 (0.70)	1.12 (0.61)	0.92 (0.67)

Comparison of DN results divided by study type

The fact that in DN, the clinical data are better than the model studies can be partly explained by the fact that the clinical studies are recent and therefore report the data of systematic DNs updated and tested over time than those used in experimental settings on a model, which may still be in the process of being perfected or even prototypes. It should also be considered that using these DN systematics in the clinical setting is reserved for operators who have usually completed extra-clinical training before using them on the patient. This condition is not necessary for experimental settings based on the model and in which it can therefore be assumed that the inexperience in the use of these systematic DNs adversely affects the performance detected, in fact, the existence of a learning curve in the use of DN has been demonstrated, with statistically significant differences between the measurements obtained in the first and subsequent surgical interventions (12, 27) (Table XVI).

CONCLUSIONS

Although this meta-analysis has limitations due to the small number of articles in the literature regarding this recent surgical technique and also due to the high heterogeneity obtained by including anatomical preparation studies and model studies, we can conclude that further clinical studies, possibly RCTs, are needed in order to make a comparison characterised by greater statistical power and better homogeneity (28-30).

Despite these limitations, based on the foregoing sections, it can be stated that the introduction and use of a DN system in implantology represents a predictable and reliable surgical technique (31-33) (Table XVI).

Compared to CS, which is still the most widespread implant placement modality, DN allows for greater accuracy, which potentially translates into a lower number of intra-operative complications and more optimal prosthetic management, simplifying its steps and reducing the need to use complex and unexpected solutions that would lead to an increase in costs and times (34-37).

When using DN, a safety distance of at least 2 mm from the surrounding anatomical structures must be established and considered in the design phase, as for Static Navigation (38, 39); this is because DN while allowing a high reduction of the discrepancy detected between virtual planning and real positioning, has a residual margin of error (40-42).

Compared with SN, currently the gold standard in terms of accuracy, DN allows you to obtain overlapping results whose possible differences, found mainly in the secondary outcomes, remain slight and insignificant (43, 44).

This minimal difference in favor of SN is, however, entirely compensated by the many advantages introduced by DN; first of all, the enormous flexibility of use which, not being constrained by a rigid template (typical instead of SN), allows the surgeon the possibility to modify the rehabilitation project in the intra-operative phase and to manage the peri-implant tissues in the most suitable way for the patient's clinical situation (45, 46).

In conclusion, although further studies are necessary to validate the cost-benefit ratio, the possible extension of operating times must also be carried out for the reasons just expressed, DN is proposed, when available, as the system of the first choice in implantology, combining in a single instrument the indispensable versatility offered by CS with the accuracy typical of SN (47, 48).

Conflicts of Interest

All the Authors confirm no conflict of interest or financial support.

REFERENCES

1. Moraschini V, Poubel LAC, Ferreira VF, Barboza ESP. Evaluation of survival and success rates of dental implants reported in longitudinal studies with a follow-up period of at least 10 years: A systematic review. Int J of Oral and Maxillofac Surg 2015; 44(3):377–88.
2. Pjetursson BE, Thoma D, Jung R, Zwahlen M, Zembic A. A systematic review of the survival and complication rates of implant-supported fixed dental prostheses (FDPs) after a mean observation period of at least 5 years. Clin Oral Implants Res 2012; 23(suppl 6):22–38.
3. Hämmerle CHF, Tarnow D. The etiology of hard- and soft-tissue deficiencies at dental implants: A narrative review. J Clin Periodontol 2018; 45(Suppl 20):S267–S277.
4. Mediavilla Guzmán A, Riad Deglow E, Zubizarreta-Macho Á, Agustín-Panadero R, Hernández Montero S. Accuracy of Computer-Aided Dynamic Navigation Compared to Computer-Aided Static Navigation for Dental Implant Placement: An In Vitro Study. J Clin Med 2019; 8(12):2123.
5. Herklotz I, Beuer F, Kunz A, Hildebrand D, Happe A. Navigation in implantology. Int J Comput Dent 2017; 20(1): 9–19.
6. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. PLoS Med 2009; 6(7):e1000097.
7. Milner KA, Cosme S. The PICO Game: An Innovative Strategy for Teaching Step 1 in Evidence-Based Practice. Worldviews Evid Based Nurs 2017; 14(6):514–516.
8. Higgins JPT, Thompson SG. Quantifying heterogeneity in a meta-analysis. Stat Med 2002; 21(11):1539–58.
9. DerSimonian R, Laird N. Meta-analysis in clinical trials. Control Clin Trials 1986; 7(3):177–88.
10. Egger M, Smith GD, Schneider M, Minder C. Bias in meta-analysis detected by a simple, graphical test. BMJ 1997; 315(7109):629–34.
11. Kaewsiri D, Panmekiate S, Subbalekha K, Mattheos N, Pimkhaokham A. The accuracy of static *vs*. dynamic computer-assisted implant surgery in single tooth space: A randomised controlled trial. Clin Oral Implants Res 2019; 30(6):505–514.
12. Block MS, Emery RW, Cullum DR, Sheikh A. Implant Placement Is More Accurate Using Dynamic Navigation. J Oral and Maxillofac Surg 2017; 75(7):1377–1386.
13. Yimarj P, Subbalekha K, Dhanesuan K, Siriwatana K, Mattheos N, Pimkhaokham A. Comparison of the accuracy of implant position for two-implants supported fixed dental prosthesis using static and dynamic computer-assisted implant surgery: A randomised controlled clinical trial. Clin Implant Denti Relat Res 2020; 22(6):672–678.
14. Sun TM, Lee HE, Lan TH. Comparing accuracy of implant installation with a navigation system (NS), a laboratory guide (LG), NS with LG, and free-hand drilling. Int J Environ Res Public Health 2020; 17(6):2107.

15. Aydemir CA, Arısan V. Accuracy of dental implant placement via dynamic navigation or the free-hand method: A split-mouth randomised controlled clinical trial. Clin Oral Implants Res 2020; 31(3):255–263.
16. Ruppin J, Popovic A, Strauss M, Spüntrup E, Steiner A, Stoll C. Evaluation of the accuracy of three different computer-aided surgery systems in dental implantology: Optical tracking *vs*. stereolithographic splint systems. Clin Oral Implants Res 2008; 19(7):709–16.
17. Zhou M, Zhou H, Li SY, Zhu YB, Geng YM. Comparison of the accuracy of dental implant placement using static and dynamic computer-assisted systems: an in vitro study. J Stomatol Oral Maxillofac Surg 2021; 122(4):343-348.
18. Jorba-García A, Figueiredo R, González-Barnadas A, Camps-Font O, Valmaseda-Castellón E. Accuracy and the role of experience in dynamic computer guided dental implant surgery: An in-vitro study. Med Oral Patol Oral Cir Bucal 2019; 24(1):e76–e83.
19. Chen CK, Yuh DY, Huang RY, Fu E, Tsai CF, Chiang CY. Accuracy of Implant Placement with a Navigation System, a Laboratory Guide, and Freehand Drilling. Int J Oral Maxillofac Implants 2018; 33(6):1213–1218.
20. Somogyi-Ganss E, Holmes HI, Jokstad A. Accuracy of a novel prototype dynamic computer-assisted surgery system. Clin Oral Implants Res 2015; 26(8):882–890.
21. Kang SH, Lee JW, Lim SH, Kim YH, Kim MK. Verification of the usability of a navigation method in dental implant surgery: In vitro comparison with the stereolithographic surgical guide template method. J Cranio-Maxillofac Surg 2014; 42(7):1530–5.
22. Hoffmann J, Westendorff C, Gomez-Roman G, Reinert S. 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 2005; 16(5):609–14.
23. Brief J, Edinger D, Hassfeld S, Eggers G. Accuracy of image-guided implantology. Clin Oral Implants Res 2005; 16(4), 495–501.
24. Tahmaseb A, Wu V, Wismeijer D, Coucke W, Evans C. The accuracy of static computer-aided implant surgery: A systematic review and meta-analysis. Clin Oral Implants Res 2018; 29(Suppl 16):416–435.
25. Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer Technology Applications in Surgical Implant Dentistry: A Systematic Review. Int J Oral Maxillofac Implants 2014; 29(Suppl):25–42.
26. Bover-Ramos F, Viña-Almunia J, Cervera-Ballester J, Peñarrocha-Diago M, García-Mira B. 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 2018; 33(1):101–115.
27. Stefanelli L, DeGroot B, Lipton D, Mandelaris G. Accuracy of a Dynamic Dental Implant Navigation System in a Private Practice. Int J Oral Maxillofac Implants 2019; 34(1):205–213.
28. Barone A, Toti P, Bertossi D, Marconcini S, De Santis D, Nocini PF, Iurlaro A, Alfonsi F, Covani U. Gene Expression of Human Mesenchymal Stem Cells Cultured on Titanium Dental Implant Surfaces. J Craniofac Surg 2016; 27(3):712-7.
29. Bertossi D, Fiorino P, Corega C, Sbricoli L, De Santis D, Donadello D, Ricciardi G, Luciano U, Bressan E, Pardo A, Albanese, M, Zangani A. Cone-beam volumetric imaging in craniofacial medicine. Minerva Stomatol 2019; 68 (4):200-212.
30. Corega C, Vaida L, Festila DG, Rigoni G, Albanese M, D'Agostino A, Nocini PF, Bertossi D, Pardo A, Marconcini S, Gelpi F. Blood levels of interleukins in patients with ameloblastoma. Minerva Stomatol 2013; 62:23-26.
31. Bertossi D, Nocini R, Luciano U, et al. Piezoelectric surgery inserts *vs* conventional burst: a clinical investigation. J Biol Regul Homeost Agents 2018; 32(2 Suppl 2):15-19.
32. Corega C, Vaida L, Festila DG, et al. The benefits of Quercitin for dentistry and maxillofacial surgery: a systematic review [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.
33. De Santis D, Graziani P, Castellani R, et al. A New Radiologic Protocol and a New Occlusal Radiographic Index for Computer-Guided Implant Surgery. J Craniofac Surg 2016; 27(5):e506-10.
34. Genovesi AM, Lorenzi C, Lyle DM, et al. Periodontal maintenance following scaling and root planing. A randomised single-center study comparing minocycline treatment and daily oral irrigation with water [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.

35. Lombardo G, Pardo A, Signoretto C, Signoriello A, Simeoni E, Rovera A, Nocini PF. Hyperbaric oxygen therapy for the treatment of moderate to severe periodontitis: a clinical pilot study. Undersea Hyperb Med 2020; 47 (4):571-580.
36. Corega C, Vaida L, Festila DG, et al. Dental white spots associated with bulimia nervosa in orthodontic patients [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.
37. De Santis D, Sinigaglia S, Pancera P, et al. An overview of guided bone regeneration. J Biol Regul Homeost Agents 2019; 33(1 Suppl. 1):49-53.
38. Gelpi F, Romoli L, D'Arienzo D, et al. Lateral periodontal cyst (LPC) mimicking periodontal socket in a young patient: Report of a case and review of the literature [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.
39. Lombardo G, Signoretto C, Corrocher G, et al. A topical desiccant agent in association with ultrasonic debridement in the initial treatment of chronic periodontitis: A clinical and microbiological study. New Microbiol 2015; 38(3):393-407.
40. De Santis D, Sinigaglia S, Pancera P, et al. An overview of socket preservation. J Biol Regul Homeost Agents 2019; 33(1 Suppl. 1):55-59.
41. Lombardo G, Signoriello A, Corrocher G, Signoretto C, Burlacchini G, Pardo A, Nocini PF. A topical desiccant agent in association with manual debridement in the initial treatment of peri-implant mucositis: A clinical and microbiological pilot study. Antibiotics (Basel) 2019; 8(2):82.
42. Marconcini S, Barone A, Perrini N, et al. Conservative treatment of unicystic odontogenic keratocyst by piezosurgery approach. A case report [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.
43. Nocini PF. De Santis D, Ferrari F, Bertele GP. A Customised Distraction Device for Alveolar Ridge Augmentation and Alignment of Ankylosed Teeth.Int J Oral and Maxillofa Implants 2004; 19(1):133-44.
44. Pardo A, Signoriello A, Signoretto C, et al. Detection of periodontal pathogens in oral samples and cardiac specimens in patients undergoing aortic valve replacement: A pilot study. J Clin Med 2021; 10(17):3874
45. Marconcini S, Genovesi AM, Marchisio O, et al. In vivo study of titanium healing screws surface modifications after different debridment procedure [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.
46. Pedullà E, Plotino G, Scibilia M, et al. Cyclic fatigue comparison among endodontic instruments with similar cross section and different surface coating. Minerva Stomatol 2019; 68(2):67-73.
47. Pellegrino G, Taraschi V, Zacchino A, Ferri A, Marchetti C. Dynamic navigation: a prospective clinical trial to evaluate the accuracy of implant placement. Int J Comput Dent 2019; 22(2):139–147.
48. Ricci M, Marchisio O, Genovesi AM, et al. Comparison between oscillating-twisting rotating of brush head *vs* a characteristic sweeping bristles motion on reducing oral inflammation [published online ahead of print, 2014 Jan 14]. Minerva Stomatol 2014.