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Precision and Efficiency in Endodontics: Dynamic Navigation Explored - A Systematic Review and Meta-Analysis

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Abstract:

Introduction: The advent of the recent concept of "Guided Endodontics" has revolutionized the field of Endodontics, particularly with the introduction of dynamic navigation (DN). DN has shown potential not only in complex cases but also in everyday practice. **The aim of the study:** This study aimed to systematically review the application of DN for drilling in endodontics and conducted a meta-analysis to assess its accuracy and efficiency compared to conventional endodontics (free hand drilling). **Materials and Methods:** Two independent reviewers conducted a comprehensive literature search using relevant keywords in four electronic databases. The review included eligible articles that were assessed for accuracy and efficiency. Bias assessment was conducted using ROB 2 tool. **Results:** A total of 10 eligible articles were included in the systematic review and meta-analysis. The findings revealed that DN demonstrated statistically significant lower linear and angular deviations. **Conclusion:** DN proves to be a valuable, accurate, and effective modality in endodontics. It optimizes treatment outcomes even for less experienced operators and paves the way for a new era of digitalized endodontic practice.

Introduction

Endodontics is defined as the art and science that is concerned with anatomy, physiology, and pathology of pulp and peri radicular area. Successful outcomes for root canal treatment are highly dependent on accurate and precise access to the pulp system. The importance of access cavity preparation cannot be overstated. It lies in its ability to provide proper visualization, disinfection, shaping, and obturation of the root canal system, leading to effective treatment outcomes. On the other hand, adequate design plays a crucial role in providing sufficient structural integrity for successful post-endodontic restoration [1]. not only Precise drilling is a crucial parameter in access cavity preparation, but it also further extends to rather implementations such as root-end resection in surgical endodontics.

Noteworthy, modern endodontics is faced with considerable limitations. The new trend of contracted and ultra-conservative designs demands an advanced armamentarium and a high degree of precision[2]. Additionally, access through obliterated root canal space is highly challenging albeit with recent advancements in visualization and 3D imaging technologies [3]. Microscopes enable enhanced visualization of anatomical landmarks and intricate canal morphology, while, CBCT scans provide valuable information about the tooth's internal structure, aiding in the determination of optimal access points and the identification of additional canals. Although they result in great improvement, access through obliterated root canal space still may eventually result in massive dentine loss or catastrophic errors as perforations[4].

Interestingly, digital dentistry has paved the way for treatment possibilities that were previously unavailable, and the field of endodontics is no exception. The concept of guided endodontics, though not recent in implantology, is relatively new for guided drilling in endodontics. Static-guided endodontics relies on the computer-aided fabrication of 3D templates that guide the orientation and point of entry for safe drilling. The recent body of evidence supports its integration with accessing obliterated pulp space or in surgical root resection[5–9]. But the novel modality of static-guided endodontics also encountered some issues and limitations. One problem with the guide is the limitation of inter-arch space. This is particularly true in the posterior region. Another issue is the need for the fabrication of multiple guides, one for each canal due to the change of direction. The time needed for extended workflow is also another obstacle[10].

A novel approach called dynamic navigation (DN) has emerged, not only for complex cases that were prone to disastrous errors but also for routine daily practice. This system allows for real-time guidance of drilling[11]. computer aided dynamic navigation is imported from earlier implementation in implantology[12]. It utilizes stereoscopic cameras and marker spheres to determine spatial positions in relation to surrounding structures and hence, enables real-time tracking of important anatomical landmarks and facilitates accurate virtual display and precise localization and navigation in the operating room[11]. Recent published evidence suggests its clinical impact on various applications[13–15]. The objective of this study is to conduct a systematic review of the implementation of DN in endodontics, along with a meta-analysis to evaluate its accuracy and feasibility in comparison to traditional endodontic techniques.

Materials and Methods

Study design:

The review was conducted following the guidelines of Preferred Reporting Items for Systematic Reviews and Meta-Analyses “PRISMA”.

The PICO questions: How Accurate and Effective is Dynamic Navigation Compared with Conventional Free Hand Drilling in Endodontic Treatment?

Where the components of the PICO questions are as follows.

P: Teeth to undergo/in need for root canal treatment

I: drilling guided with dynamic navigation

C: free hand drilling

O: the accuracy and effectiveness of the procedures

Research Strategy:

Two independent reviewers conducted an extensive literature search until October 2021 using a combination of keywords and index terms in four distinct electronic databases, namely PubMed, Scopus, ScienceDirect, Cochrane Library and Google Scholar, as part of a thorough and comprehensive review. The combinations of search terms were “Dynamic navigation AND Endodontic*” OR “Dynamic navigation AND access cavity” OR “Guided dynamic endodontics” OR “Digital endodontics” OR “Real-time guided drilling AND Root canal” OR “Dynamic navigation AND root canal”.

Inclusion criteria:

No time restrictions

Only English articles

Articles of drilling in endodontics

Both In vitro and in vivo studies were included

All types of teeth (anterior/posterior or natural/printed) were included

studies measuring either1ry and/or 2ry intended outcomes

Exclusion criteria:

Articles in languages rather than English

Review articles

Case studies

Articles measuring other outcomes

In addition to the aforementioned databases, a manual search was conducted in the references lists of suspected studies to identify potentially eligible studies. Titles and abstracts of articles were screened independently first for exclusion of irrelevant evidence while the rest were considered for full-text reviewing and data extraction. In cases of disagreement during the study selection process, any differences were resolved through discussions until a consensus was reached.

Data extraction:

Data extraction was accomplished individually by each reviewer, Data extracted include the following; name of authors, year of publication, name of Journal, the study design, sample size, type of teeth, DN system, outcome measurements, time point at measuring, type of practitioner, point at measurements of accuracy. Measured parameters and results were observed at the end of data extraction.

Quality Assessment

Two independent reviewers evaluated the quality of the selected studies using the modified Cochrane Risk of Bias 2.0 tool for randomized trials (RoB 2)[1]. The tool assessed different domains, including the randomization process, deviations from intended interventions, missing outcome data, measurement of outcomes,

[1] McGuinness, LA, Higgins, JPT. Risk-of-bias VISualization (robvis): An R package and Shiny web app for visualizing risk-of-bias assessments. Res Syn Meth. 2020; 1- 7. https://doi.org/10.1002/jrsm.1411

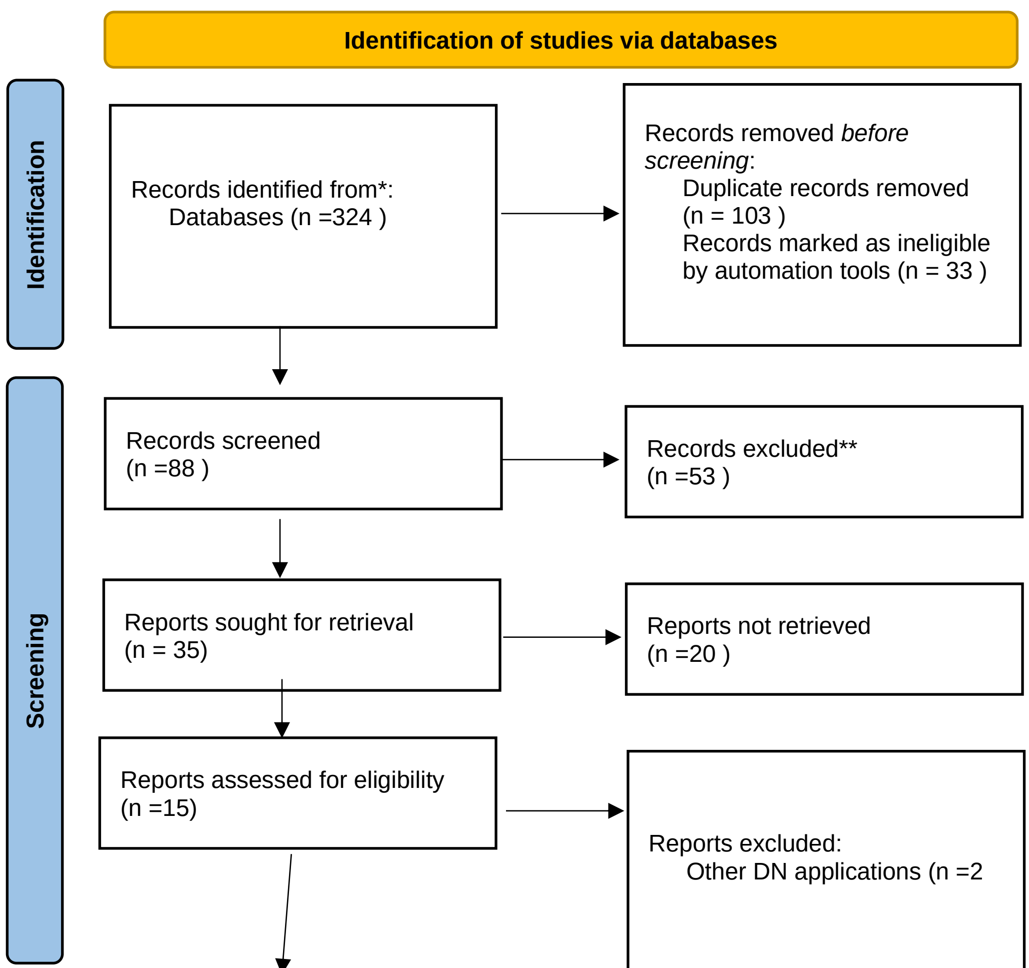
and selection of reported results. Each domain was categorized as low, unclear, or high risk of bias. When at least one domain was reported to be a high risk then the whole study was nominated as high risk, the same with unclear data.

Statistical analysis

Quantitative analyses were performed through meta-analysis[16](Comprehensive Meta-Analysis Software, version 2.2.27[17]). Continuous data were synthesized where fixed effects model was performed for various aspects as for linear deviation, and angular deviation and number of mishaps. Heterogeneity was detected by X^2. The level of significance was set at $p < 0.05$.

Results

Out of 324 screened titles, 236 titles were excluded for duplicates and irrelevant subjects, and 88 titles were included for abstract screening. The abstract screening process of 35 yielded 13 eligible articles for full-text evaluation. However, 3 case studies were excluded while only 10 articles could be considered. The PRISMA chart for data flow is shown in Figure (1).



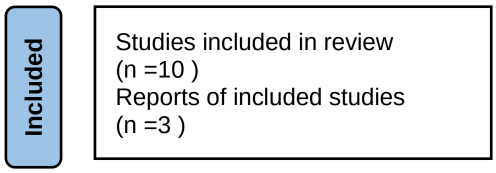


Figure (1) PRISMA data flow chart for the systematic review

Study Characteristics

The study characteristics are summarized in table (1) All the included studies were in vitro experimental studies. Half of the studies included natural teeth [18–22] and the other half utilized 3D printed synthetic teeth[23–27]. Some samples mimicked root canal obliteration with one study classifying two categories of obliteration (less than 13 mm obliteration and more than 13 mm obliteration)[18]. Most articles discussed the implementation of DNS in access cavity preparation except one article that measured its success for the removal of fiber post [20] and one for surgical root resection[18]. The outcome measured extended from measuring the accuracy of the drilling path to simply counting the number of successful attempts. Secondary outcomes included the effect of the operator´s experience and time consumed during the process and the amount of dentine removal.

Quality Assessment

Results of quality assessment are presented in Figure (2)

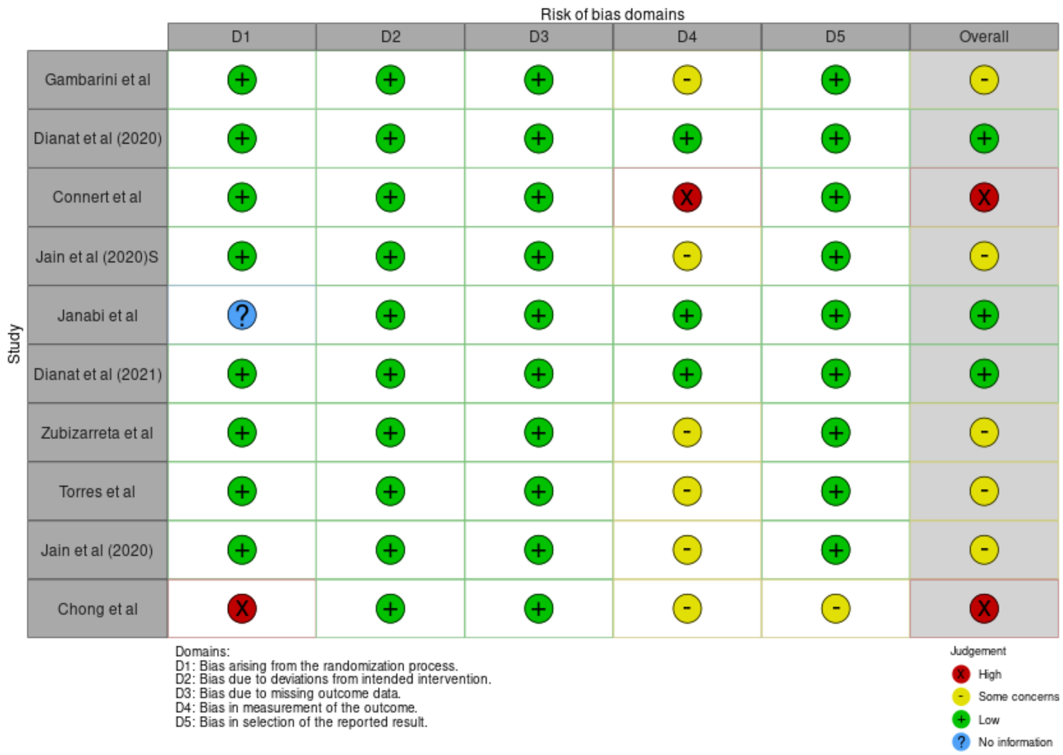


Figure (2) Risk of bias assessment using the modified RoB 2.0 tool.

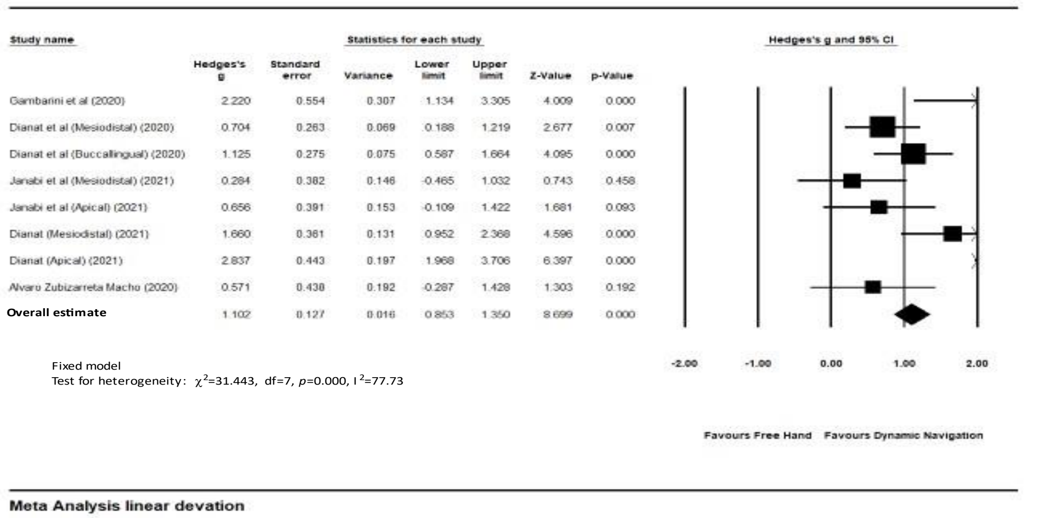
Table (1): Summery of included studies in the systematic review

Paper name	author	Journal /year	Study design	DN system	Sample types	Problem to solve	Sample size	Number of operators	outcomes
Precision of Dynamic Navigation to Perform Endodontic Ultraconservative Access Cavities: A Preliminary In Vitro Analysis	Gambarini et al	J Endod 2020	In vitro	Navident	Artificial teeth Upper first molar	UCAC NB: until localization of MB1	20 n=10	One skilled operator	1-Precision 2-time
Accuracy and Efficiency of a Dynamic Navigation System for Locating Calcified Canals	Dianat et al	J Endod 2020	Ex vivo	X Gide	Human single rooted teeth in cadaver jaws	Calcified canals 0-13 mm ,More than 13 mm	60 root canals n=30	2 operators	1-accuracy 2-reduced dentine thickness 3-time 4-Number of mishaps and unsuccessful attempts
Dynamically Navigated versus Freehand Access Cavity Preparation: A Comparative Study on Substance Loss Using Simulated Calcified Canals	Jain et al	J Endod 2020	In vitro	Navident	Printed upper and lower central incisors	Canal calcification	40 Upper & Lower n=20	One operator (2nd year endodontic resident)	1-accuracy 2-time
Real time guided endodontics with a miniaturized dynamic system versus conventional free hand endodontic access cavity preparation:substance loss and procedure time	Connert et al	J Endod 2021	In vitro	DENACAM Mini-navident	Printed teeth	Access cavity preparation of partial calcified canals	12 models Total 72 teeth n=36	2 years exp & 12 years experienced operator	1-substance loss (by volume) 2-time Per method, per operator

3-Dimentional accuracy of dynamic navigation technology in locating calcified canals	Jain et al	J Endod . 2020	In vitro	Navident	3 sets 84 printed teeth	Accessing the calcified canals in anterior & posterior teeth	Root canals=138	One operator Board certified endodontist	Accuracy 2D & 3D
Accuracy and efficiency of 3-dimentional dynamic navigation system for removal of fiber post from root canal treated teeth	Janabi et al	J Endod . 2021	Ex vivo	X-Guide	Natural single rooted teeth with post&core in cadaver maxilla	Removal of fiber post	26 n=13	One experienced operator	1-accuracy 2-time 3-total change in tooth volume
Computer-aided dynamic navigation: a novel method for guided endodontics	Chong &Makdissi	Quintessence int 2019	In vitro	Navident	Extracted teeth	Locating the canals	Root canals=46	One experienced operator	Number of successful and unsuccessful attempts
Accuracy and efficiency of guided root end resection using a dynamic navigation system:a human cadaver study	Dianat et al	Int J endod 2021	Cadaver study	X-Guide	Natural teeth in cadaver jaws	Root end resection	40 roots n=20	One operator	1-Accuracy(global platform and apex deviations,angular deflection) 2-time 3-number of mishaps
Accuracy of computer-Aided Dynamic Navigation Compared to Computer Aided static Procedure for Endodontic Access Cavities: An In Vitro Study	Zubizarreta-Macho et al	J Clin Med 2020	In vitro study	Navident	Natural single rooted	Compare DN to SN and FH in access cavity preparation	30 teeth n=10	One operator	Accuracy (angular deflection, horizontal deviation)
Dynamic navigation: a laboratory study on accuracy and potential use of guided root canal treatment	Torres et al	Int J endod 2021	In Vitro study	Navident	3-D printed teeth	Sever pulp obliteration	168 access cavities	3 operators	Accuracy (deviation at entry, apical deviation, vertical deviation, angular deviation and total deviation)

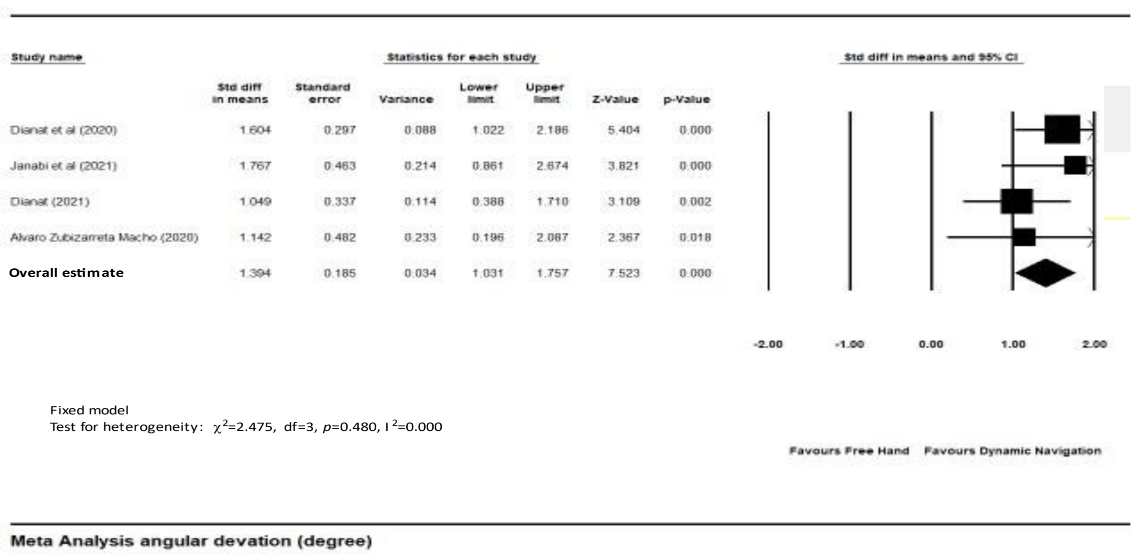
Qualitative assessment Meta-analysis

Qualitative assessment was performed through Meta-analysis of relevant studies with common measured outcomes. Data synthesis was presented as forest blot (Figures 3-5).
Regarding linear deviation, DN demonstrated statistically lower linear deviation than free hand , mean difference=1.102,95%CI(0.853,1.35),p=0.
The same was shown for angular deviation as the DN showed statistically lower angular deviation, mean difference=1.394,95%CI(1.031,1.757),p=0.
The number of successful attempts was in favor for dynamic navigation. The overall estimates were 0.2 (odds ratio), CI(0.06-0.8) , P=0.02.



Study name	Hedges's g	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Gambarini et al (2020)	2.220	0.554	0.307	1.134	3.305	4.009	0.000
Dianat et al (Mesiodistal) (2020)	0.704	0.263	0.069	0.188	1.219	2.677	0.007
Dianat et al (Buccallingual) (2020)	1.125	0.275	0.075	0.587	1.664	4.095	0.000
Janabi et al (Mesiodistal) (2021)	0.284	0.382	0.146	-0.465	1.032	0.743	0.458
Janabi et al (Apical) (2021)	0.656	0.391	0.153	-0.109	1.422	1.681	0.093
Dianat (Mesiodistal) (2021)	1.660	0.361	0.131	0.952	2.368	4.596	0.000
Dianat (Apical) (2021)	2.837	0.443	0.197	1.968	3.706	6.397	0.000
Alvaro Zubizarreta Macho (2020)	0.571	0.438	0.192	-0.287	1.428	1.303	0.192
Overall estimate	1.102	0.127	0.016	0.853	1.350	8.699	0.000

Figure (3): Forest plot meta-analysis of linear deviation



Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Dianat et al (2020)	1.604	0.297	0.088	1.022	2.186	5.404	0.000
Janabi et al (2021)	1.767	0.463	0.214	0.861	2.674	3.821	0.000
Dianat (2021)	1.049	0.337	0.114	0.388	1.710	3.109	0.002
Alvaro Zubizarreta Macho (2020)	1.142	0.482	0.233	0.196	2.087	2.367	0.018
Overall estimate	1.394	0.185	0.034	1.031	1.757	7.523	0.000

Figure (4): Forest plot meta-analysis of angular deviation

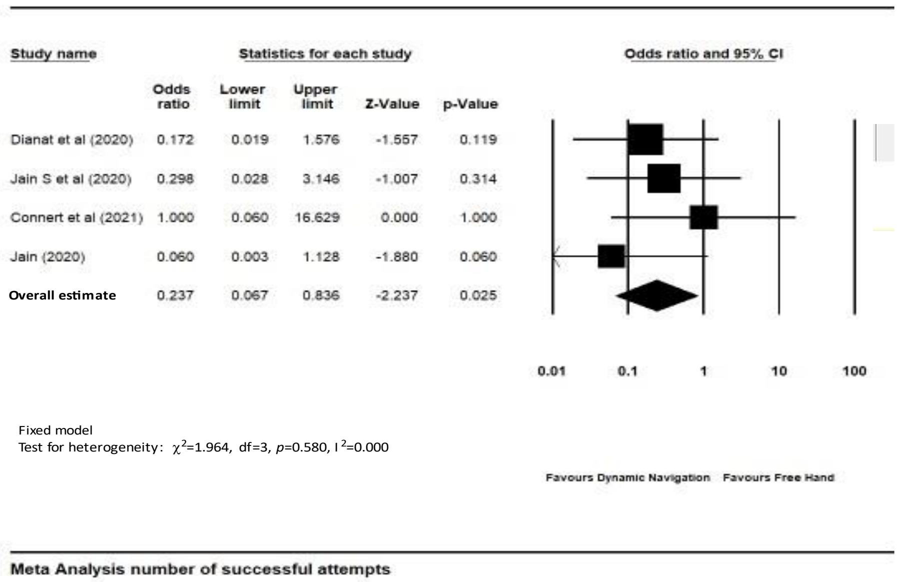


Figure (5): Forest plot meta-analysis of number of successful attempts

Discussion:

The accuracy of drilling is crucial in different aspects of endodontics. This includes and is not limited to the accuracy of access cavity preparation. Dynamic navigation can provide a precision computer-guided drilling path in accordance with preplanned design with the help of its sophisticated algorithm and imported 3d image(11). Accurate drilling aids in minimal dentine removal with maximum preservation of sound tooth structure. This concedes also with the modern trend of ultra-conservative designs for accessing pulp space like Truss, Ninja, or orifice-oriented designs(28). The problem of challenging obliterated pulp space could be successfully addressed through dynamic guided drilling. The same issue is contributed when safety is the priority for surgical root-end resection. In fact, static guided drilling is more readily available and could be more effective to prevent the operator from deviating from the proposed drilling path due to its restricting features like sleeves. However, DN excels static guided due to an easier, simpler, and more predictable procedure that could be accomplished in a single visit(15).

Unfortunately, serious impediments to the promising technology are present owing to limitations within the accuracy of 3D data acquisition through CBCT(29). Human factor limitations also contribute to imperfections due to hand tremors or lack of coordination. Thus, this review was conducted to systemically review available and relevant evidence in the literature to address the degree of accuracy of DN-guided drilling as compared to conventional manual drilling. The review also was concerned with how effective the new modality is.

Accuracy is interpreted differently by authors. It was expressed in terms of global platform deviations, angular deviations, linear deviations at the point of entry, linear deviations at the cervical level, and in different directions as buccolingual or mesiodistal directions. three studies measured 3D deviation and expressed accuracy as volumetric deviations(18,20,24). The rest of the studies measured 2D linear deviations. This heterogeneity in measurements could be to some extent confusing to the reader, so only two parameters were selected namely linear deviations and angular deviations. Both can reflect the accuracy of drilling in a clear predictable way. In addition, they are the most common among most studies. The modality of DN demonstrated statistically lower linear deviation than free hand, mean difference=1.102,95%CI (0.853,1.35). The estimate effect for angular deviation was 1.394,95% CI (1.031,1.757) which revealed statistically significant lower deflection than freehand drilling. This is of the highest clinical impact as it may reflect on the incidence of perforations due to incorrect angulation(30). The revealed higher degree of accuracy agreed with Wei et al who demonstrated a low degree of accuracy deviation for all parameters(31). It is worth mentioning that in endodontics, the highest degree of accuracy is crucial, and even slight changes in a tenth of mm would lead to major errors in contrast to navigated implantology which would accommodate a higher range of errors.

Another perspective for system accuracy is the determination of the number and percentage of procedural errors or mishaps. This perspective was highlighted by jain et al(25), Dianat et al(18) and Connert et al(27). The qualitative assessment of the data revealed an overall estimate of the odds ratio of 0.2 in favor of dynamic navigation over the freehand technique. On the other hand, Chong et al conducted an experiment trial in 2019 counting the number of mishaps and incomplete canal localization. In 29 teeth, authors successfully localized 41 canals and failed to find 5 out of total of 46 canals(22). These mishaps could be attributed to technical aspects such as the recognition of the drill tag by the optical tracking system.

Regarding effectiveness, the review sheds light on factors such as time consumed, amount of dentine removed, and finally differences among different levels of experience. Preserving the maximum amount of tooth structure dramatically affects its structural integrity and fracture resistance(32). In 2020, a study of Jain et al was dedicated to quantitatively comparing volumetric changes in tooth structure in both techniques of dynamic navigation or conventional drilling. The authors concluded association of significantly less amount of tooth substance loss with DN in maxillary teeth while differences in mandibular ones were comparable(25). These findings were also supported by the results of Jabani et al who noticed a significantly less volumetric loss of tooth structure in DN as well as the results of Connert et al (20).

The level of experience of the operator was discussed by three studies[19,26,27]. Torres et al evaluated the effect of DN when employed by three operators with different levels of experience, a final-year student and an endodontic specialist with five and 30 years of experience. Results showed that there was no statistical difference in the number of successfully localized canals among the different levels of experience (success rates reported as 91%,93% and 95% respectively)[26]. In agreement with these results, both Connert et al demonstrated nonsignificant differences between experienced and less experienced operators regarding the amount of tooth structure loss in contrast to the conventional method[27].

The most obvious shortcoming of the work described here is that all included articles were in vitro studies utilizing either natural or synthetic printed teeth. This includes an inherent limitation of low level of evidence and results could change when conducted in clinical settings owing to patient movements or view to the motion tracking stereo camera restrictions. Nevertheless, published evidence proved slight difference between model and clinical trials with no statistical significance[31].

Conclusion:

In conclusion, despite some limitations, this systematic review and meta-analysis provide valuable insights into the use of dynamic navigation for guided drilling in endodontics, with a specific focus on accuracy and feasibility. The findings demonstrate that dynamic navigation techniques hold great promise in enhancing the precision and reliability of drilling procedures during endodontic treatments compared to free-hand drilling.

Recommendations:

In light of the low level of evidence provided by in vivo and Ex vivo studies, randomized controlled trials are in demand to augment the conclusions of DN accuracy and effectiveness in clinical settings.

Conflict of interest:

The authors declared no conflict of interest

Acknowledgment:

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