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Current Trends in Modern Dentistry: Diagnostic Sensitivity of AI in Detecting Dental Conditions. A Systematic Review and Meta-Analysis

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Abstract

Introduction: Patient diagnosis and treatment planning are fundamental for achieving a successful and favorable treatment outcome. However, the complexity of these phases requires thorough patient evaluation and dental expertise. Modern dentistry employs various advanced digital technologies to aid dental practitioners.

Objectives: This systematic review, meta-analysis, and clinical protocol aimed to analyze the current trends in modern dentistry, focusing on optimizing diagnosis and treatment plan procedures through the incorporation of advanced digital technologies, and establishing a protocol for the use of these technologies in clinical practice.

Material and Methods: A systematic literature search was conducted on PubMed, EBSCO, and Scopus databases until February 2024. The addressed PICO question was, "How can the dentist maximize and optimize patient's diagnosis and treatment planning using current digital technologies?" In addition, a meta-analysis of the selected studies was conducted, pooling the sensitivity and specificity information of the Diagnocat® AI system regarding nine intraoral conditions, using R 3.5.1 software (R Core Team (2018)).

Results: A total of 657 articles were obtained from the initial search, of which 13 articles met the inclusion criteria. All 13 articles concluded that the advanced digital technologies studied possessed advantageous outcomes in patient diagnosis and treatment planning procedures, providing more information regarding current patient conditions and future treatment planning steps. Five of the 13 articles were included in the meta-analysis and indicated that the Diagnocat® AI system is a useful complementary diagnostic tool rather than a substitutional measure for dental practitioners.

Conclusion: This systematic review and meta-analysis provided significant data showing that advanced digital technologies, such as CAD/CAM, Modjaw®, Diagnocat®, and DSD, optimize and maximize dental practitioner capabilities during diagnosis and treatment planning procedures, thus providing significant results in favor of the hypothesis.

Keywords: Artificial intelligence; CAD/CAM; Diagnocat®; Diagnosis and treatment plan; Digital smile design; Modjaw

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Introduction

Patient diagnosis and treatment planning are considered the basic foundations for achieving a successful and favorable treatment outcome, yet such stages are highly complex and require thorough patient evaluation and dental expertise [1].

Modern dentistry and the entire medical field have been revolutionized extensively in recent decades because of rapid improvements in digital healthcare [2,3]. Compared with traditional analogue dentistry, these improvements have completely changed how dentists and the entire digital workflow occur in the patient's diagnosis and treatment planning process. Incorporating such advanced technologies is fundamental for creating precise and improved dentist-patient communication, reducing working time while minimizing dentist errors, and maximizing patient satisfaction [2-6].

Furthermore, the diagnosis and treatment planning of complex dental treatments, such as oral rehabilitation using dental implants, require comprehensive patient evaluation and functional analysis utilizing a multidisciplinary approach. Therefore, the adequate utilization of digital technologies in dental practice, from clinical, surgical, and prosthodontic aspects, can improve team communication and avoid the loss of crucial information [7].

This systematic review and meta-analysis investigated the current trends in modern dentistry and how dentists could implement such technologies in their clinics. This study focused on advanced digital technologies for diagnosis and treatment planning, including the Diagnocat® Artificial Intelligence (AI) system, Digital Smile Design (DSD), Modjaw®, and Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) systems.

The Diagnocat® AI system utilizes convolutional neural network technology, which can process large and complex images, such as dental radiographs, orthopantomography, and Cone-Beam Computed Tomography (CBCT), to optimize diagnosis and treatment planning [8,9]. DSD serves as a communication tool between the dentist and the patient, enabling the visualization of final treatment results while also allowing the dentist to design and create a treatment plan adapted to the patient's conditions and demands [10,11]. The Modjaw® device highlights the patient's occlusion during dental diagnosis and planning. The device consists of high-quality cameras that record the lower facebow and scan facial areas to produce real-time computerized jaw movement replication [12]. CAD/CAM systems have revolutionized modern dentistry by integrating advanced digital technologies to maximize patient diagnosis, treatment planning, restoration, and fabrication. CAD/CAM systems are currently utilized within the entire field of dentistry and range from data acquisition using scanners to digital design and fabrication [13].

Hypothesis and Objectives

Hypothesis

The hypothesis of this systematic review and meta-analysis was that the integration of current advanced digital technologies, including CAD/CAM systems, Modjaw®, DSD, and Diagnocat® AI, maximize dentist's skills in the processes of diagnosis and treatment planning.

Objectives

General objective: To evaluate, analyze, and determine the effects of CAD/CAM, Diagnocat®, DSD, and Modjaw® in the processes of diagnosis and treatment planning.

Specific objective:

1. To describe the creation of a digital workflow and a virtual patient using CAD/CAM, Diagnocat®, DSD, and Modjaw® during diagnosis and treatment planning.

2. Establish the accuracy of Diagnocat® AI system in the process of patient diagnosis.

Material and Methods

Details of the search methodology are as follows. We selected the databases, outlined the search strategy, conducted screening and paper selection, and performed statistical analysis.

This systematic review and meta-analysis was conducted in accordance with the PRISMA Guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [14].

The following structure was used to formulate the review questions:

• P (Population): Patients of all ages requiring complex diagnosis and treatment planning.

• I (Intervention): Application of CAD/CAM systems, Modjaw®, DSD, and Diagnocat® during diagnosis and treatment.

• C (Comparison): Utilization of the Diagnocat® AI system as a complementary diagnostic tool.

• O (Outcomes): Establish a digital workflow during the diagnosis and treatment planning phases.

The PICO question was "How can the dentist maximize and optimize patient's diagnosis and treatment planning using CAD/CAM systems, Modjaw®, DSD, and Diagnocat® AI?"

Eligibility criteria

The studies included had to adhere to the following criteria:

Type of study: Retrospective, observational, *in vivo* pilot, and *in vitro* studies focusing on the integration of advanced digital technologies in the field of modern dentistry for the optimization of patient diagnosis and treatment planning; articles published between January 2013 and February 2024.

Types of patients: Patients of all ages, genders, and ethnic backgrounds; patients suffering from various dental pathologies and conditions, such as periodontal diseases, dental caries, orthodontic problems, and maxillofacial and temporomandibular joint disorders.

Type of intervention: Studies that investigate the use of advanced digital technologies in modern dentistry, aid dentist diagnosis, and facilitate treatment planning for patients. Such technologies include CAD/CAM systems, AI technology in dentistry, DSD systems, CBCT, and intraoral scanners, and studies demonstrating the effectiveness of advanced digital technologies in the diagnosis and treatment planning of patients.

Types of outcomes: Studies that provided data regarding the impact of advanced digital technologies on diagnostic accuracy and treatment planning quality; studies that provided data on the efficiency of such advanced digital technologies as well as the cost-effectiveness of implicating these technologies; and studies that provided data on the complications and negative aspects of implicating advanced digital technologies in the process of diagnosis and treatment planning.

Search strategy and study selection

An extensive electronic search was performed, using the following databases: PubMed, EBSCO, and Scopus. The initial key words that were applied included: "digital smile design", "artificial intelligence", "CAD/CAM", "treatment plan", "Diagnosis", "Jaw tracking technology", "mandibular kinematics recorded", and "Modjaw". These keywords were used along with the Boolean operators 'AND' or 'OR' and an advanced digital search. This was performed in addition to searches using MeSH terms generated in PubMed to obtain suitable, wider, and more extensive search results.

The PubMed date filter was used to obtain articles published within the past 10 years (between 2013 and 2023). The search strings used for the other databases were modified using the Polyglot Search Translator Tool (https://sr-accelerator.com/#/polyglot) [15]. The final search was made on October 27th, 2023. The same search was conducted on March 2nd, 2024, to scan for any relevant new articles published recently; however, no new articles were found to significantly contribute to the results of this study; thus, the number of search results from the preliminary search remained unchanged.

The search in PubMed, EBSCO, and Scopus was performed with the following search string: (((((artificial intelligence AND dentistry AND diagnocat)) OR ((cad/cam system AND dentistry AND diagnosis AND treatment plan))) OR ((modjaw AND jaw tracking technology))) OR ((Modjaw AND mandibular kinematics recorded))) OR (digital smile design).

The searches were performed individually using different databases to obtain the desired articles on the use of advanced technological products to aid dentists in patient diagnosis and treatment planning.

Selection process of studies

The obtained studies were filtered based on titles, abstracts, and full texts. The first stage involved scanning the titles of different articles and eliminating those that did not meet the selection criteria or were found to be irrelevant based on the title. Duplicate articles found in the four databases were manually excluded. The second stage involved a thorough reading of the abstract, objectives, methodology, conclusions, and discussion. The selection criteria were then applied, and articles that did not comply with the criteria were removed. Finally, the third stage included further screening and filtering of studies based on full-text information and gathering of relevant data. Studies on steps performed beyond diagnosis and treatment planning were excluded, as were digital technologies that were not considered significant milestones in diagnosis and treatment planning procedures. We excluded all clinical case reports, case series, and literature reviews to include articles that were considered to be the most relevant, consistent, and unbiased in this systematic review. Any disagreements regarding selected studies were discussed and resolved by the reviewers. Subsequently, the degree of agreement among the selected studies from the second and third stages was calculated using Cohen's kappa test.

Data extraction

A table was created to emphasize the most relevant information required. The parameters in the table include the article's title, authors, year of publication, sample size (if documented), type of technology/study, results, and outcomes of the diagnosis and treatment plan. Regarding the results indicated for each article, the main factor considered was the additional patient information provided by the studied technology that may be helpful for diagnosis and treatment plan processes.

For the meta-analysis, the data extracted from the articles included the number of total assessments, specificity, and sensitivity of each study regarding the diagnostic accuracy of the Diagnocat® AI system in the detection of missing teeth, caries and periapical lesions, dental fillings, endodontically treated teeth, underfilled canals, overfilled canals, voids in the canal filling, and periodontal bone loss.

Data synthesis

To summarize and compare the various results and variables of the different studies, a meta-analysis was done to analyze and evaluate the obtained data. This meta-analysis was performed to determine the accuracy of the AI system in the process of patient diagnosis by assessing and detecting nine intraoral conditions: Missing teeth, caries, periapical lesions, fillings, endodontically treated teeth, underfilled canals, overfilled canals, voids in the canal filling, and periodontal bone loss. The researchers conducted an exhaustive systematic review of the literature, with the final number of studies was 13 studies. Of these, eight articles incorporated AI technology, and of those eight articles, only some reported data on the sensitivity to detect the nine previously mentioned intraoral conditions. Sensitivity and specificity rates were considered primary outcomes. For sensitivity and specificity, the raw rate was estimated using a random-effects model with the corresponding Z-statistics, p-values, and 95% confidence intervals. A restricted maximum likelihood estimator was used. A heterogeneity analysis was carried out, Cochran's Q test was applied, and the I^2 index was calculated, representing the amount of between-study variability compared to total variability. Expressed as a percentage, it ranges from 0% to 100%. <25%, 25%-75%, >75% associated with low, medium, and high levels of heterogeneity, respectively. Wilson's correction was applied to papers reporting extreme rates (0% or 100%) to estimate the heterogeneity statistics. Funnel plots and Egger's tests were used to assess the publication bias. The significance level was set at 5% ($\alpha=0.05$). The software used was R 3.5.1 (R Core Team (2018). R: Language and environment for statistical computing. R Foundation for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/).

Quality and risk of bias assessment

The five studies included in the meta-analysis were analyzed using a descriptive study of the variables. The risk of bias was evaluated to examine the methodological quality of the included studies. As all the articles included in the meta-analysis were retrospective, a single quality assessment scale was applied using The Quality Assessment and Diagnostic Accuracy Tool-2 scoring system (QUADAS-2)*.

Results

A total of 657 articles were obtained from the initial search: PubMed (n=265), Scopus (n=223), and EBSCO (n=169). Prior to screening, 255 duplicate articles were manually removed, leaving 402 articles for screening. Of these publications, 96 were retrieved and considered potentially eligible after screening by title (196 articles) and abstract (110 articles). The full texts were obtained, and the exclusion criteria were applied. A total of 96 articles were evaluated in depth, and the reasons for excluding 83 articles are presented in the flowchart below (Figure 1). Ultimately, 13 articles met the inclusion criteria and were included in this systematic review. The k-value for inter-examiner agreement on the inclusion of studies was 0.91, indicating almost perfect agreement according to the Landis and Koch criteria.

The meta-analysis produced nine models based on the raw sensitivity and specificity rates of the selected articles corresponding to the individual diagnostic assessment criteria: Missing teeth, caries, periapical lesions, fillings, endodontically treated teeth, underfilled canals, overfilled canals, voids in the canal filling, and periodontal bone loss. The results demonstrated the individual raw sensitivity rate, overall sensitivity rate, individual raw specificity rate, and overall specificity rate (Tables 1-3).

Critical analysis of the meta-analysis

This meta-analysis provides a useful overview of the capabilities of

Table 1: Sensitivity of the meta-analysis.

Condition	Autor, year	Data modality	Number of assessments (n)	Raw sensitivity outcomes (p)	Overall sensitivity rate	Mean raw proportion (WMP)	Standard error (SE)	95% confidence interval (CI)	Z test (p-value)	I² index	Cochrane's Q statistic (p-value) for heterogeneity	Egger's test (p-value)	Funnel's plot and data interpretation
Missing teeth	Bayrakdar et al., 2021 (24)	CBCT	n=508	p=0.953	0.945 (95% CI: 0.903-0.988)	0.945	0.022	0.903 0.988	<0.001***	0.973	<0.001***	<0.001***	Z p-value <0.001 is not relevant because this is a test testing if p=0%, sensitivity rates are extremely different from 0. The heterogeneity associated to the model is high (I2=97.3%) and statistically significant. It seems that Orhan et al., 2023 could be a relevant source of heterogeneity. The funnel's plot revealed a high level of asymmetry (p<0.001)
	Zadronzy et al., 2022 (25)	Panoramic	n=960	p=0.961									
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.982									
	Orhan et al., 2023 (23)	Panoramic	n=404	p=0.878									
Caries	Zadronzy et al., 2022 (25)	Panoramic	n=960	p=0.445	0.512 (95% CI: 0.293-0.731)	0.513	0.112	0.294 0.733	<0.001***	0.99	<0.001***	0.188	High heterogeneity (I^2=99.0%) and statically significant. All three papers reported remarkably different values (in spite of the remarkable asymmetry, there was not enough evidence of significance (p=0.188).
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.729									
	Orhan et al., 2023 (23)	Panoramic	n=404	p=0.360									
Periapical lesions	Zadronzy et al., 2022 (25)	Panoramic	n=805	p=0.390	0.658 (95% CI: 0.396-0.920)	0.658	0.134	0.396 0.920	<0.001***	0.995	<0.001***	0.467	The heterogeneity associated to the model is high (I^2=99.5%) and statistically significant. All four papers reported remarkably different values.
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.838									
	Orhan et al., 2023 (23)	Panoramic	n=81	p=0.469									
	Orhan et al., 2020 (27)	CBCT	n=153	p=0.928									
filling	Zadronzy et al., 2022 (25)	Panoramic	n=805	p=0.832	0.893 (95% CI: 0.811-0.976)	0.893	0.042	0.811 0.976	<0.001***	0.979	<0.001***	0.013*	The heterogeneity associated to the model is high (I^2=97.9%) and statistically significant. All three papers reported remarkably different values
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.972									
	Orhan et al., 2023 (13)	Panoramic	n=541	p=0.874									
Endodontically treated teeth	Zadronzy et al., 2022 (25)	Panoramic	n=805	p=0.872	0.890 (95% CI: 0.806-0.974)	0.89	0.043	0.806 0.974	<0.001***	0.975	<0.001***	0.027*	The heterogeneity associated to the model is high (I^2=97.5%) and statistically significant. All three papers reported remarkably different values
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.968									
	Orhan et al., 2023 (23)	Panoramic	n=184	p=0.821									
Underfilled canals	Zadronzy et al., 2022 (25)	Panoramic	n=109	p=0.609	0.678 (95% CI: 0.624-0.731)	0.678	0.027	0.624 0.731	<0.001***	0.423	0.183	0.642	The heterogeneity associated to the model is moderate (I2=42.3%) and not statistically significant. No significance regarding publication bias was concluded (p=0.642)
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.698									
	Orhan et al., 2023 (23)	Panoramic	n=60	p=0.700									
Overfilled canals	Zadronzy et al., 2022 (25)	Panoramic	n=109	p=0.455	0.630 (95% CI 0.382-0.878)	0.63	0.127	0.382 0.878	<0.001***	0.939	<0.001***	0.949	The heterogeneity associated to the model is high (I^2=93.9%) and statistically significant. All three papers reported remarkably different values. Great variability associated to Orhan et al., 2023 due to its extremely small sample size. No significant publication bias was concluded
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.783									
	Orhan et al., 2023 (23)	Panoramic	n=3	p=0.667									

Voids in the canal filling	Zadronzy et al., 2022 (25)	Panoramic	n=109	p=0.800	0.591 (95% CI: 0.242-0.940)	0.591	0.178	0.242 0.940	<0.001***	0.988	<0.001***	0.233	The heterogeneity associated to the model is high (I^2=98.8%) and statistically significant. All three papers reported remarkably different values. Non-significance publication bias was concluded (p=0.233).
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.733									
	Orhan et al., 2023 (23)	Panoramic	n=50	p=0.230									
Periodontal bone loss	Zadronzy et al., 2022 (25)	Panoramic	n=805	p=0.801	0.857 (95% CI: 0.764-0.949)	0.857	0.047	0.764 0.949	<0.001***	0.98	<0.001***	<0.001***	The heterogeneity associated to the model is high (I^2=98.0%) and statistically significant. All three papers reported remarkably different values. Despite including only three papers, the level of asymmetry was very high, concluding publication bias (p<0.001)
	Ezhov et al., 2021 (26)	CBCT	n=1346	p=0.949									
	Orhan et al., 2023 (23)	Panoramic	n=607	p=0.818									

Table 2: Specificity of the meta-analysis.

Condition	Autor, year	Data modality	Number of assessments (n)	Raw specificity outcomes (p)	Overall specificity rate	Mean raw proportion (WMP)	Standard error (SE)	95% confidence interval (CI)	Z test (p-value)	I^2 index	Cochrane's Q statistic (p-value) for heterogeneity	Egger's test (p-value)	Funnel's plot and data interpretation
Missing teeth	Zadronzy et al. [25]	Panoramic	n=960	p=0.981	0.970 (95% CI: 0.942-0.997)	0.97	0.014	0.942 0.997	<0.001***	94.9%	<0.001***	0.398	The heterogeneity associated to the model is high (I^2=94.9%) and statistically significant. The Funnel's plot did not reveal asymmetry (p=0.398).
	Ezhov et al. [26]	CBCT	n=1346	p=0.941									
	Orhan et al. [23]	Panoramic	n=404	p=0.986									
Caries	Zadronzy et al. [25]	Panoramic	n=805	p=0.982	0.988 (95% CI: 0.978-0.998)	0.988	0.005	0.978 0.998	<0.001***	72.0%	0.022*	0.223	The heterogeneity associated to the model is moderate (I^2=72.0%) and not statistically significant. The Funnel's plot did not reveal asymmetry (p=0.223).
	Ezhov et al. [26]	CBCT	n=1346	p=0.995									
	Orhan et al. [23]	Panoramic	n=141	p=0.981									
Periapical lesions	Zadronzy et al. [25]	Panoramic	n=805	p=0.981	0.989 (95% CI: 0.978-0.999)	0.989	0.005	0.978 0.999	<0.001***	70.0%	0.023*	0.601	The heterogeneity associated to the model is moderate (I^2=70.0%) but statistically significant. The Funnel's plot did not reveal asymmetry (p=0.601).
	Ezhov et al. [26]	CBCT	n=1346	p=0.995									
	Orhan et al. [23]	Panoramic	n=81	p=0.987									
Filling	Zadronzy et al. [25]	Panoramic	n=805	p=0.987	0.984 (95% CI: 0.970-0.997)	0.984	0.007	0.970 0.997	<0.001***	87.5%	0.007**	0.002**	The heterogeneity associated to the model is high (I^2=87.5%) and statistically significant. The Funnel's plot revealed publication bias (p=0.002).
	Ezhov et al. [26]	CBCT	n=1346	p=0.992									
	Orhan et al. [23]	Panoramic	n=541	p=0.967									
Endodontically treated teeth	Zadronzy et al. [25]	Panoramic	n=805	p=0.994	0.994 (95% CI: 0.991-0.997)	0.994	0.002	0.991 0.997	<0.001***	0.1%	0.389	0.171	The heterogeneity was total (I^2=0.1%). The Funnel's plot revealed asymmetry (p=0.171).
	Ezhov et al. [26]	CBCT	n=1346	p=0.995									
	Orhan et al. [23]	Panoramic	n=184	p=0.981									
Underfilled canals	Zadronzy et al. [25]	Panoramic	n=109	p=1.000	0.994 (95% CI: 0.990-0.998)	0.994	0.002	0.990 0.998	<0.001***	0.0%	0.755	0.833	The homogeneity associated to the model was absolute (I^2=0.0%). The Funnel's plot revealed symmetry (p=0.833).
	Ezhov et al. [26]	CBCT	n=1346	p=0.994									
	Orhan et al. [23]	Panoramic	n=60	p=0.990									
Overfilled canals	Zadronzy et al. [25]	Panoramic	n=109	p=1.000	0.997 (95% CI: 0.994-1.000)	0.997	0.002	0.994 1.000	<0.001***	0.0%	0.943	0.817	The homogeneity associated to the model was absolute (I^2=0.0%). The Funnel's plot revealed symmetry (p=0.817).
	Ezhov et al. [26]	CBCT	n=1346	p=0.997									
	Orhan et al. [23]	Panoramic	n=3	p=1.000									
Voids in the canal filling	Zadronzy et al. [25]	Panoramic	n=109	p=0.942	0.984 (95% CI: 0.958-1.000)	0.984	0.013	0.958 1.000	<0.001***	75.3%	0.053	0.124	The heterogeneity associated to the model is moderate-high (I^2=75.3%) and marginally significant (p=0.053). The Funnel's plot revealed symmetry (p=0.124).
	Ezhov et al. [26]	CBCT	n=1346	p=0.996									
	Orhan et al. [23]	Panoramic	n=50	p=0.992									

Periodontal bone loss	Zadronzy et al. [25]	Panoramic	n=805	p=0.847	0.917 (95% CI: 0.847-0.986)	0.917	0.036	0.847 0.986	<0.001***	97.9%	<0.001***	<0.036*	The heterogeneity associated to the model is high (I²=97.9%) and significant. The Funnel's plot revealed asymmetry.
	Ezhov et al. [26]	CBCT	n=1346	p=0.966									
	Orhan et al. [23]	Panoramic	n=607	p=0.935									

Table 3: Details regarding the stu.

Technology	Details	Indication of use
Modjaw®	Modjaw, Villeurbanne, France	Situations requiring additional information regarding patient's dynamic occlusion in a complex and extensive prosthodontic treatment
Diagnocat®	Diagnocat, Inc., San Francisco, USA	Supplemental technology that maximizes dentists' skills in complex diagnosis and treatment planning procedures

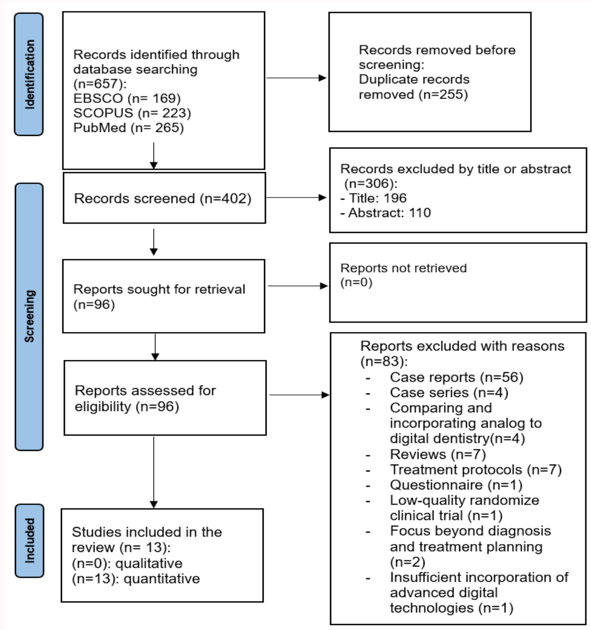

Figure 1: The scheme followed in the selection of articles is based on the PRISMA flow chart.

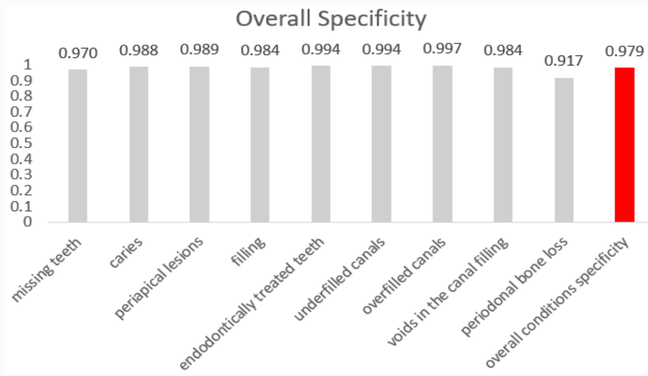

Figure 2: Graph of the overall specificity and sensitivity (B) of the various conditions.

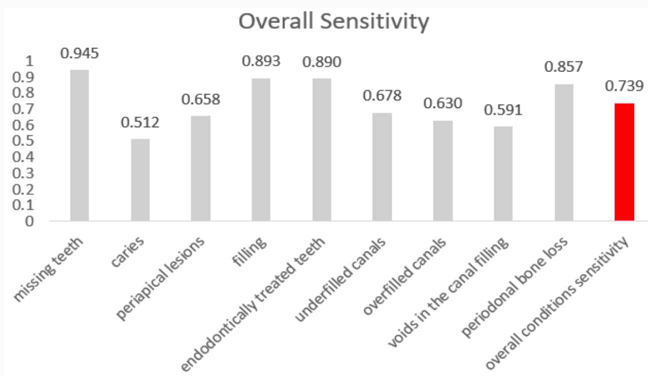

Figure 3: Graph of the overall sensitivity of the various conditions.

the Diagnocat® system in patient diagnosis. It calculates the accuracy of the system in detecting the nine intraoral conditions based on their sensitivity and specificity. The analysis revealed the strengths and limitations of this technology, indicating the necessity for a thorough overall assessment.

The Diagnocat® system demonstrated an excellent overall specificity rate of 0.979 (Figure 2), indicating a high capability to correctly rule out the presence of intraoral conditions and supporting its reliability in identifying healthy individuals. In contrast, the overall sensitivity rate of 0.739 revealed a moderate capacity to correctly identify positive cases by intraoral conditions (Figure 3). Although this might imply a reasonable capacity to detect intraoral conditions, there is still room for improvement, particularly in conditions with meager overall sensitivity rates, such as dental caries diagnosis (0.512).

The marked heterogeneity and variability of values across the included studies highlight issues regarding the consistency, applicability, and validity of Diagnocat® performance. Components such as the study design, sample size, and potential biases of each study might have contributed to the observed discrepancies.

Discussion

Through a comprehensive evaluation of the included articles and a meta-analysis of the accuracy of the Diagnocat® system, the information was integrated to establish the effects of each selected technology on the patient diagnosis and treatment planning process. Diagnosis and treatment planning by dental practitioners are crucial for successful treatment and patient satisfaction. Thus, the implementation of additional measures capable of optimizing and maximizing the capabilities of dental practitioners has immense effects and must be examined thoroughly.

Across all 13 studies included in this systematic review, three analyzed the application of Modjaw® technology, all of which indicated that patient diagnosis was positively influenced and patient data acquisition was improved by demonstrating Modjaw® device accuracy *in vivo* [16] and *in vitro* [17]. The Modjaw® device presented a level of precision similar to that of an industrial-grade scanner for capturing the vertical intermaxillary relationship, with an accuracy of 11 mm. In addition, it exhibited commendable consistency in recording the real hinge axis of patients, as well as enhanced accuracy in capturing the maxillomandibular relationship in a centric relation.

The Modjaw® was found to be particularly helpful in complex and extensive prosthodontic treatments [16,17].

Two studies analyzed the incorporation of DSD into patient treatment planning. Both studies found DSD to be an effective prosthetic design method that encouraged favorable results, improved the virtual patient, and optimized the digital workflow technique [18,19]. Furthermore, both articles illustrated that either 2D or 3D DSD technology aids in treatment planning, resulting in adequate clinical results and improving treatment success by aiding the dental practitioner in visualizing and understanding the treatment, as well as improving dentist-patient communication, ultimately resulting in higher patient satisfaction [18,19].

Concerning the meta-analysis, there was moderate to high significance in favor of the hypothesis that applying the Diagnocat® system maximizes dentists' skills in the diagnosis and treatment planning processes. In addition, according to the meta-analysis and the overall specificity and sensitivity obtained, Diagnocat® provides the dental practitioner a valuable complementary tool in the phases of patient diagnosis and treatment planning. It also serves as a supplemental technological advancement rather than a substitute for the dental practitioner's intraoral and complete patient examination because of the lack of total accuracy and variability in the results regarding the different intraoral conditions.

Similarly, considering the results of Orhan et al. (2022), Orhan et al. (2023), and Orhan et al. (2021), the Diagnocat® system presented various diagnostic capabilities, including assessment of the pharyngeal airway, which is a significant aspect in patients with obstructive sleep apnea; assessment of osseous changes in the mandibular condyle; and detection of impacted third molars [20-22].

Therefore, it can be concluded that across studies, the utilization of advanced digital technologies, including Modjaw®, DSD, CAD/CAM, and Diagnocat®, maximizes and optimizes the skills of dentists in the stages of patient diagnosis and treatment planning. In addition, it showed that the Modjaw® system provides additional accurate information regarding patients' dynamic occlusal conditions, provides additional patient data that facilitate more successful treatment planning, and demonstrates the dependency of the Modjaw® system on the CAD/CAM software digital intraoral scan. Similarly, 3D DSD has exhibited satisfactory and adequate clinical results, aiding dental practitioners during the treatment planning stage, which also depends on the presence of a CAD/CAM program from which the treatment design takes place. As a result, both the Diagnocat® and Modjaw systems provide an accurate and reliable source of additional patient data and information regarding both dynamic and intraoral conditions, which serve as crucial factors for patient treatment planning using 3D DSD and CAD/CAM systems.

Conclusion

General objective

- This systematic review and meta-analysis successfully analyzed the effects of CAD/CAM, Diagnocat®, DSD, and Modjaw®, which aid dental practitioners in optimizing diagnosis and treatment plan processes.

Specific Objective

- A digital workflow and a virtual patient using CAD/CAM, Diagnocat®, DSD, and Modjaw® were created for the diagnosis and treatment planning phases.
- The meta-analysis provided significant results (overall specificity of 0.979 and overall sensitivity of 0.739) in favor of the utilization of the Diagnocat® AI system as a complementary diagnostic tool.

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