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Accuracy of Teledentistry in Diagnosing Dental Diseases

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Introduction

According to estimates provided by the World Health Organization (WHO), approximately50% of the world's population is affected by one form or another of oral disease. The report lists untreated dental caries (permanent and deciduous teeth), periodontal disease, and oral cancer as the most common oral health diseases [1]. The high prevalence of dental caries is primarily caused by a lack of access to dental care, a high intake of sugary foods, and poor oral hygiene. Periodontal diseases are most commonly brought on by poor oral hygiene and tobacco use. The primary risk factors for oral cancer are the consumption of tobacco, alcohol, and betel quid, which is a mixture of tobacco, areca nut, and slaked lime. Significant oral health issues are being caused by a lack of awareness of oral hygiene's importance and a lack of access to dental care, particularly in rural and underserved populations [2].

In recent years, the use of computers, telecommunications technology, digital diagnostic imaging services, devices, and software for analysis and follow-up have all seen significant technological advancements in the field of dentistry. The field of dentistry today has travelled much further than it ever could thanks to cutting-edge information technology. Not only has new information technology made it possible for dental patients who live far away from healthcare facilities or qualified dentists to have partial or complete management, but it has also improved the quality of dental patient management [3].

Tele dentistry is a combination of telecommunications and dentistry, involving the exchange of clinical information and images over remote distances for dental consultation and treatment planning [4].

In the early stages of the 1990s, teleconsultation, and telediagnosis were mostly reported in the fields of oral surgery, oral medicine, or oral pathology, and all the more as of late, different specialties have additionally integrated tele dentistry. Tele dentistry can also lower costs and improve the delivery of oral healthcare. The true benefit of tele dentistry is that it reduces health care disparities and provides better and more equitable access

to specialist oral health care services. Additionally, it has the potential to reduce the gap in access to oral healthcare that exists between urban and rural communities [3,5].The COVID-19 pandemic greatly impeded global access to dental care due to the lockdown, fear of contamination from aerosol-generating dental treatments, and the risk of contracting SARS-Cov2, necessitating the need for modification of treatment modalities [6].

Since practically all dental operations result in the release of aerosols, several advisory and regulatory dentistry organizations throughout the world have called for the COVID-19 pandemic to be treated with the utmost caution and have requested that only emergency care be offered [7]. As a result, this public health emergency has presented dentists with new challenges to provide dental care without endangering the patient's general health during the pandemic by establishing new priorities, limiting and reducing contamination risks, and improving treatment efficacy to boost productivity and effectiveness. Tele dentistry is none such tool that assisted patients through remote care as new methods, devices, and more applications of digital health have emerged [8].Analysis of the literature reveals that the accuracy of tele dentistry in detecting oral diseases largely depends on photographs taken with a smartphone camera and the capability of non-dental personnel such as community health workers and school teachers in screening and early detection [6,9].

Few studies offer convincing evidence in favour of using a reliable, accessible, less invasive, less time-consuming, and less physically and psychologically uncomfortable alternative tool for schoolchildren's dental caries screening. In a study conducted on 95 schoolchildren to detect Aries by examining photographs taken by the dentist and teachers, sensitivity and specificity were above 86% and 91% respectively. The prevalence of caries in children during a clinical dental examination was comparable to that found during a non-dental tele dentistry examination as well as a dental tele dentistry examination [6].Studies suggest that modern imaging technologies with autofluorescence imaging can identify invisible lesions in the oral cavity, and Automated tele-cytopathology analysis can be offered as a point of care, especially in areas with a shortage of qualified personnel. In a study performed for early detection of oral cancer using a mobile application capturing system, an overall sensitivity of 96.69% and specificity of 98.69% were noted [10].

A few researchers believe that a dentist can perform a time-effective and reliable tele screening of the oral soft and hard tissues using only approximations of true color intraoral scans obtained using IOS (Trios, 3Shape). A study conducted with IOS revealed sensitivity and specificity values of 61% and 39% for gingivitis and 67% and 33% for periodontitis, respectively[11].Sensitivity and specificity explain the diagnostic ability of a test to correctly identify diseased and non-diseased respectively. They are independent of disease prevalence which refers to the probability of disease in a specific population at a given time and summary receiver operating characteristics (SROC) analysis is used to evaluate the predictive power for diagnosis. Reviews have been published on the reliability of tele dentistry in detecting oral cancer, gingivitis, and dental caries in both children and adults. There have not been any published literature reviews that assess the efficacy of teledentistry in identifying oral disorders as a whole, to the best of my knowledge. This article aims to evaluate the literature and information on the effectiveness of Teledentistry as a tool to detect the most prevalent conditions affecting oral health.

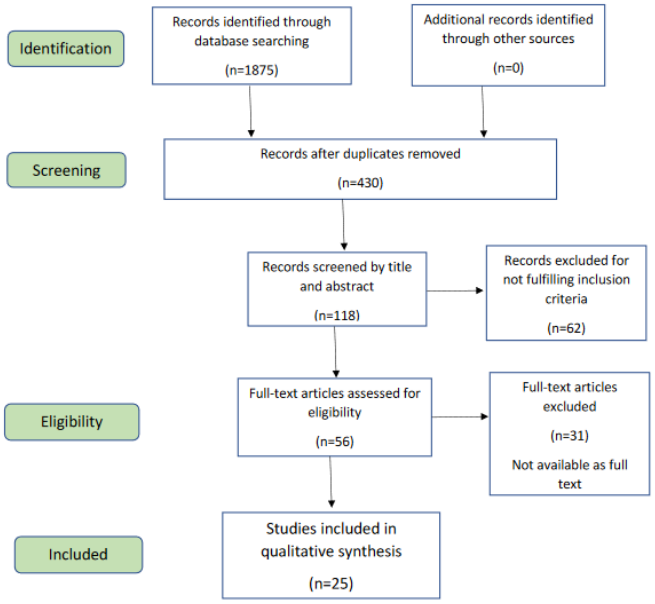

Figure 1: Showing Flowchart of Literature Search and Selection Criteria

Table 1 presents an overview of the descriptive features of all included studies. The included articles were published between 2014 and 2023 and were conducted in 11 different countries. Out of these 25 articles, eight studies [4,8,12,16,17,20,24,25] were carried out in India, three studies [15,18,30] in Brazil, two studies each in Saudi Arabia [6,14], Australia [16,19], Thailand [20,31], China [22,23], and Malaysia [27,29], and one each in Italy [12], Iran[7], Switzerland [11], and the United States [26]. 10 studies [6,12,7,13,14,15,16,17,18,19] assessed the diagnostic efficacy of Teledentistry for detecting dental caries; 5 studies [20,21,11,22,23] focused on gingivitis, and 10 studies [24,25,26,27,28,29,30,31,9,32] examined oral malignancies. All studies involved human participants and the number of participants ranged from 6 to 3445.Most of the studies [6,12,7,13,14,17,18,24,27,9,32] used Smartphone cameras to capture intraoral photographs. In addition, six studies [20,21,11,22,26,31] employed intraoral scanners, while two studies [15,23] collected photos using professional digital cameras. Four studies [16,19,29,30] developed mobile phone applications for image acquisition, storage, and transmission of records to the server. Two studies [25,28] developed a smartphone-based intraoral dual-modality imaging platform to screen oral cancer. Video recordings of the oral cavity were gathered along with images in two studies [21,30] that are included in this review and one study [13] completely relied on videographic examination. Clinical dental examinations conducted by experienced dentists, pedodontists, prosthodontists, periodontists, oral medicine experts, oral oncology specialists, and dental students served as the gold standard for reference in the majority of the research. Varied examiners carried out an assessment of the images and videos gathered to determine the accuracy of teledentistry. Teledentistry examinations were performed by oral healthcare specialists like oral medicine specialists in seven studies [24,25,26,27,28,29,31] and pedodontists in one study [14]. Dental students performed virtual examinations in one study [7]. Mothers [17], prison health volunteers (PHV) [20], and community health workers (CHW)[9] were trained to perform oral screening, image analysis, and diagnosis in three different studies.

Sn.	Author/Year	Place of study	Sample size	Diagnosis	Person conducting remote diagnosis	Method of detection	Conclusion
1.	AlShaya M et al., (2022) [6]	Saudi Arabia	95	Dental caries	Dentist	Intraoral photographs	Teledentistry has acceptable accuracy for caries detection with photographs taken by smartphone camera in schoolchildren compared to traditional clinical dental examination
2.	Zotti F et al., (2022) [12]	Italy	43	Dental caries	Experienced dentist	intraoral home photographs	The cross-sectional observational clinical study showed good potential for telediagnosis of caries (TD), which proved to be a feasible method to combine with routine caries diagnosis in daily preventive dentistry practice.
3.	Golsanamloo O et al., (2022) [7]	Iran	20	Dental caries	40 Dental students (2 dental students for each patient)	Intraoral photographs obtained by a high-quality mobile phone camera	The diagnostic sensitivity and specificity for clinical and virtual treatment plans showed no significant differences between virtual (mobile phone teledentistry) and clinical examination.
4.	Purohit BM et al., (2016) [13]	India	139	Dental caries	2 trained and calibrated examiners	Video recording of the oral cavity	This study provides evidence that teledentistry may be used as an alternative screening tool for the assessment of dental caries and is viable for remote consultation and treatment planning.
5.	AlShaya MS et al., (2018) [14]	Saudi Arabia	57	Dental caries	6 pediatric dentists	mobile phone camera	Mobile phone teledentistry offers acceptable reliability for the initial diagnosis of caries in children. The use of teledentistry without radiographs is not as accurate as clinical examination.
6.	Morosini I AC et al., (2014) [15]	Brazil	102	Dental caries	2 distant consultants	professional digital camera	Adolescent inmates could benefit from oral health screening using digital photography. Teledentistry appears to
7.	Estai M et al., (2015) [16]	Australia	6	Dental caries	2 offsite dentists	Android application	This trial shows that teledental screening has the potential to be utilized as a valid and reliable screening tool to identify high-risk individuals with decay and can allow onsite practitioners to triage referrals in a timely manner and treat more patients.
8.	Kale S et al., (2019) [17]	India	100	Dental caries	100 mothers	smartphone photographic	Following dental health education, it can be concluded that mothers are in a better position to diagnose their child's dental status through smartphone-based photographs.

9.	Kohara EK et al., (2018) [18]	Brazil	15	Dental caries	2 Examiners	smartphone images	Performing diagnoses based on photographic images provided by cameras is feasible, and the diagnosis is accurate in distinguishing sound enamel surfaces from extensive (cavitated) lesions.
10.	Estai M et al., (2017) [19]	Australia	100	Dental caries	2 charters (offsite dentists)	image acquisition Android App	The mobile teledentistry approach has shown the potential to detect occlusal caries from photographs taken by a smartphone camera with an acceptable diagnostic performance compared to traditional face-to-face screening.
11.	Santipipat C et al., (2023) [20]	Thailand	152	Gingivitis	PHV (prison health volunteers)	intraoral camera (IOC)	Teledentistry facilitates dentists in conducting dental disease screening programs for prisoners. Using the IOC, the dentists achieved acceptable diagnostic accuracy in identifying the possible dental treatment needs
12	Pentapati KC et al., (2017) [21]	India	62	Gingivitis	Calibrated dental examiner	Intra-oral camera	The intra-oral camera was shown to be a reliable tool to identify common oral diseases.
13.	Steinmeier S et al., (2020) [11]	Switzerland	10	Gingivitis	Remote examiners (experienced general practitioners)	intraoral scan	The remote examination using IOS was effective in detecting dental findings, whereas periodontal conditions could not be assessed with the same accuracy. Still, remote assessment of IOS would allow a time-efficient screening and triage of patients.
14.	Chiu S et al., (2022) [22]	China	40	Gingivitis	3 trained dentists	intraoral camera	The use of a calibrated intraoral camera to assess the gingival status, and operation of the camera in polarization mode to assess the margins of full-crown restorations, are feasible and effective diagnostic aids that could facilitate the development of teledentistry.
15.	Guo S et al., (2021) [23]	China	31Z	Gingivitis	2 trained dentists	Intraoral digital photograph examination (IDPE)	The feasibility of caries status assessment via IDPE is promising. Digital oral health evaluation merits further clinical consideration.
16.	Birur NP et al., (2019) [24]	India	3445	Oral cancer	Remote oral medicine specialist	mobile phone imaging	The trained CHWs can aid in identifying oral potentially malignant disorders and can be utilized in oral cancer screening programs.

17	Song B et al., (2018) [25]	India	190	Oral cancer	Remote specialists	A smartphone-based intraoral dual-modality imaging platform	To improve the accuracy, AFI and WLI information was fused into one three- channel image. The performance with fused data is better than using either white light or autofluorescence image alone.
18	Nguyen J et al., (2023) [26]	USA	189	Oral cancer	Oral medicine specialist	remote intraoral camera	This study demonstrated that a novel low-cost, smartphone-based telehealth platform consisting of an intraoral camera and custom software application can be utilized to perform synchronous remote specialist intraoral examinations that provide similar levels of diagnostic accuracy as in-person diagnosis.
19.	Haron N et al., (2017) [27]	Malaysia	16	Oral cancer	2 oral medicine specialists	Mobile Phone Imaging	This study provides evidence that teledentistry can be used for communication between primary care and OMS and could be readily integrated into clinical settings for patient management.
20.	Uthoff RD et al., (2018) [28]	India	99	Oral cancer	A remote specialist	A smartphone- based, dual-modality imaging system	The initial feedback on the smartphone-based, dual-modality imaging system is positive, with both the remote specialist and CNN achieving high values of sensitivity, specificity, PPV, and NPV compared to the on-site specialist gold standard.
21	Haron N et al., (2021) [29]	Malaysia	355	Oral cancer	Offsite oral healthcare specialist	a mobile phone application called MeMoSA®	Referral decisions made through MeMoSA® is highly comparable to clinical examination demonstrating it is a reliable telemedicine tool to facilitate the identification of high-risk lesions for early management.
22.	Gomes MS et al., (2017) [30]	Brazil	55	Oral cancer	2 trained examiners	mobile application (app) for oral cancer screening	Mobile apps including videos and data collection interfaces could be an interesting alternative in oral cancer research development.
23.	Vetchaporn S et al., (2021) [31]	Thailand	34	Oral cancer	Oral medicine specialist	intraoral camera with fluorescent aids	Validity and reliability for the screening of dysplasia in OPMDs were higher than the autofluorescence method.

24.	Thampi V et al., (2022) [9]	India	1200	Oral cancer	Community health workers (CHW) & dentists	oral cancer screening mobile application	The findings of this study suggest the feasibility of training community health workers to perform oral cancer screening in a low- or middle-income country.
25.	Vinayagamoorthy K et al., (2019) [32]	India	131	Oral cancer	2 examiners	Mobile phone camera imaging	There was a substantial agreement between the diagnosis based on clinical examination and WhatsApp images.

Table 1: Showing Descriptive Study Characteristics of Included Studies [6,7,9,11-32].

Tables 2, 3, and 4 display the sensitivity and specificity values reported by the included studies for dental caries, gingivitis, and oral cancer respectively.

The accuracy of teledentistry for detecting dental caries was evaluated in ten studies [6,12,7,13,14,15,16,17,18,19] with a total of 677 participants. Reported sensitivity values ranged from 57% to 90.65% with an average sensitivity of 74.4% and specificity values from 58% to 100% with an average specificity of 92%. Estai M et al., [16] demonstrated the lowest sensitivity, whereas AlShaya M et al., [6] demonstrated the highest sensitivity. The lowest specificity was demonstrated by Purohit BM et al., [13] and the highest specificity was demonstrated by Estai M et al., [16] as shown in Table 2.

Study (Year)	Sensitivity (%)	Specificity (%)	Accuracy (%)	Others
AlShaya M et al., (2022) [6]	90.65	95.7	>90	PPV, NPV
Zotti F et al., (2022) [12]	74	99.1	_	PPV, NPV
Golsanamloo O et al., (2022) [7]	76.44	92.9	_	Kappa
Purohit BM et al., (2016) [13]	86	58	_	PPV, NPV
AlShaya MS et al., (2018) [14]	79.1	85.9	_	kappa
Morosini I AC et al., (2014) [15]	73	98	95	PPV, NPV, kappa
Estai M et al., (2015) [16]	57	100	_	Kappa
Kale S et al., (2019) [17]	88.3	98.3	96	PPV, NPV
Kohara EK et al., (2018) [18]	58	95.1	_	Kappa
Estai M et al., (2017) [19]	60 – 63	96 -99	96	PPV, NPV, Kappa

Table 2: Showing Summary of the Statistical Results of the Included Studies on Dental Caries.

*PPV: Positive prediction values; NPV: Negative predictive values

Five studies [20,21,11,22,23] with a total of 295 participants evaluated the accuracy of teledentistry for assessing gingival status. Reported sensitivity values ranged from 59.5% to 100% with an average sensitivity of 82.6% and specificity values from 39% to 100% with an average specificity of 67.4%. Guo S et al., [23] demonstrated the lowest sensitivity, whereas Santipipat C et al., [20] demonstrated the highest sensitivity. The lowest specificity was demonstrated by Steinmeier S et al., [11] and the highest specificity was demonstrated by Santipipat C et al., [20] as shown in **Table 3.**

Study (Year)	Sensitivity (%)	Specificity (%)	Accuracy (%)	Others
Santipipat C et al., (2023) [20]	100	100	_	PPV, NPV
Pentapati KC et al., (2017) [21]	98	72.7	_	Kappa
Steinmeier S et al., (2020) [11]	61	39	_	_
Chiu S et al., (2022) [22]	94.7	52.3	_	Kappa
Guo S et al., (2021) [23]	59.5	73.1	77.4	PPV, NPV, Kappa

Table 3: Showing Summary of the Statistical Results of the Included Studies on Gingivitis.

*PPV: Positive prediction values; NPV: Negative predictive values

Ten studies [24,25,26,27,28,29,30,31,9,32] with a total of 5714 participants evaluated the accuracy of teledentistry for screening oral cancers. Reported sensitivity values ranged from 81.3% and 98.4% with an average sensitivity of 90% and specificity values from 58% and 100% with an average specificity of 86.4%. Haron N et al., [27] demonstrated the lowest sensitivity, whereas Vinayagamoorthy K et al., [32] demonstrated the highest sensitivity. Vinayagamoorthy K et al., [32] demonstrated the lowest specificity, whereas Haron N et al.,

[27] demonstrated the highest specificity as shown in **Table 4.**

Few studies also reported accuracy, kappa scores, positive predictive values (PPV), and negative predictive values (NPV) in addition to sensitivity and specificity.

Study (Year)	Sensitivity (%)	Specificity (%)	Accuracy (%)	Others
Birur NP et al., (2019) [24]	84.7	97.6	_	PPV, NPV
Song B et al., (2018) [25]	85	88.7	86.9	_
Nguyen J et al., (2023) [26]	94.8	62.5	92.1	_
Haron N et al., (2017) [27]	81.3	100	_	Kappa
Uthoff RD et al., (2018) [28]	88.75	87.65	_	PPV, NPV
Haron N et al., (2021) [29]	94	95.5	_	Kappa

Gomes MS et al., (2017) [30]	91	90.5	90.9	PPV, NPV, Kappa
Vetchaporn S et al., (2021) [31]	87.5	84.6	_	PPV, NPV
Thampi V et al., (2022) [9]	96.69	98.69	98.29	PPV, NPV
Vinayagamoorthy K et al., (2019) [32]	98.4	58	96.8	PPV, NPV, Kappa

Table 4: Showing Summary of the Statistical Results of the Included Studies on Oral Cancer.

*PPV: Positive prediction values; NPV: Negative predictive values

Discussion

The aim of this review is to summarize the existing evidence on the diagnostic accuracy of teledentistry and to compare its accuracy in diagnosing dental caries, gingivitis, and oral cancers collectively to a traditional clinical examination as a gold standard. A total of 6686 participants from 25 eligible studies were included in this review. Telediagnosis overall had good diagnostic accuracy. All the included studies found teledentistry examination comparable to the traditional clinical examination when screening for dental caries, gingival status, and oral malignancies.

Clinical dental exams served as the reference standard for all the studies. For the 25 studies included in this review, the overall sensitivity and specificity for the teledentistry system were observed to be 82.4% and 84.8% respectively. The highest sensitivity values were observed while screening for oral cancer and the highest specificity while screening for dental caries. Whereas the lowest sensitivity was observed for dental caries and the lowest specificity for assessing gingival status.

Kale S et al., [17]; Santipipat C et al., [20]; Thampi V et al., [9] evaluated the accuracy of teledentistry in diagnosing dental diseases by employing mothers [17], prison health volunteers (PHV) [20] and community health workers (CHW) [9] respectively, following dental health education and training. The accuracy of diagnosis in these studies showed strong agreement with that of dentist diagnosis, suggesting the feasibility of training mothers, PHV, and CHW to perform dental disease screening for better patient management. These studies did highlight the need for additional training of non-dental personnel to ensure that all aspects of the oral cavity were captured accurately and at the appropriate angles.

Telediagnosis of caries was shown to be less accurate than clinical examination in the diagnosis of early-stage enamel caries since the lesion has not yet undergone a significant change in appearance [12,18]. Dental radiographic examinations are essential for identifying early and inter-proximal carious diseases, and since teledentistry cannot employ radiographs, diagnostic accuracy may be compromised [14,19]. Studies that recorded photographs using smartphone cameras noted poor image quality owing to the camera's resolution, blurring, over-saturation, illumination, flash, and exposure time, particularly while examining gingival conditions.

In comparison to smartphone cameras, intra-oral scanners have the extra benefit of being able to take photographs without the use of retractors, reflectors, or other tools. The intraoral camera with fluorescent aids utilized in three trials [25,28,31] has shown to be effective mainly in older persons who have limited mouth opening, as the intraoral component of the

device is tiny and works in dark environments owing to its own light source.

The teledentistry system makes it easier for researchers to obtain data by facilitating electronic data gathering. It also enables remote consultation and offers geo-tagging for high- risk groups to help with oral cancer monitoring [24,9]. As a practical way to provide basic oral screening in locations with limited resources, teledentistry helps close the gap between dental specialists and rural communities.

Conclusion

The study findings provide evidence to strongly support the fact that teledentistry can be used as a reliable and feasible alternative to conventional clinical examinations for screening oral conditions. Further, it is excellent for addressing oral health requirements in remote locations and reducing healthcare disparities. Additionally helps prevent excessive referral of healthy individuals to oral cancer specialists. For detecting oral diseases, teledentistry consistently showed high sensitivity and specificity values. Thus, it can be concluded that teledentistry can serve as a valuable adjunct for diagnosing dental diseases. The development and use of more affordable methods of collecting high-quality pictures for improved diagnosis must be the focus of future study.

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