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Review Article

Overview of the Diagnostic Accuracy of Teledentistry for Dental Caries

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ABSTRACT

Significant physiological, economic, and societal burdens are brought on by dental caries. It hurts healthcare economics and life quality. This load was created by several factors. Lack of access to dental care and effective early caries identification are two of the biggest issues. One sustainable way to expand access to dental care is through teledentistry. Furthermore, teledentistry is widely employed in the recognition of dental caries. The purpose of this study was to examine the literature about the precision of caries detection using teledentistry technologies in contrast to traditional clinical assessment. The following keywords were used to search peer-reviewed literature in various databases without time limits: "Accuracy," "Dental caries," "Detection," "Diagnosis," and "Teledentistry." We found 22 pertinent papers in three primary contexts. Six of the research studies were carried out in dental clinics, and five in-vitro settings, while the remaining trials were conducted in public places, mainly schools. Comparing teledentistry for caries identification to a traditional visual dental examination, we found that it had high sensitivity and specificity. Teledentistry applications might be used to reliably diagnose dental caries. The usage of smartphones for teledentistry applications is on the rise.

Keywords: Telemedicine, Teledentistry, Caries, Diagnosis, Dental, Review

Introduction

Despite considerable global improvements in children's oral health, dental caries remain one of the most common concerns in children's health [1]. Significant physiological, psychological, economic, and social burdens are brought on by dental caries. Inadequate oral hygiene and lack of information about oral health enhance this burden, which has a detrimental impact on both healthcare economics and quality of life [2]. A lot of elements led to this burden. However, one of the primary contributory variables for this burden is the absence of effective early caries diagnosis and dental treatment access [3]. Consequently, early caries identification and treatments can help prevent or reduce pain, anxiety, and other health experiences that caries can trigger [4].

Notwithstanding its drawbacks, including subjectivity and high expense, particularly when conducting extensive surveys, the clinical visual-tactile dental examination remains the most widely used method for detecting dental caries in the clinical environment and is the gold standard for doing so [5]. The branch of dentistry known as teledentistry uses digital technologies to enable remote dental care delivery and reception. A favorable impact on the delivery and sustainability of dental treatment was demonstrated by teledentistry, which also showed remarkable promise as an alternative cost-effective strategy to expand access to dental services [6]. Over the past decade, teledentistry has grown significantly because of advancements in mobile phone technology and internet bandwidth, which have made it simpler to capture, transmit, and store digital photos [7].

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Reviewing the research on the accuracy of caries diagnosis using teledentistry technologies in comparison to traditional dental clinical examination was the goal of this study.

Materials and Methods

The different database was utilized to research the Peer-reviewed literature including PubMed, Scopus, Web of Science, Cochrane Library database, and Google Scholar with no time limits. A total of 268 studies were identified during this review. Articles that investigated the accuracy of teledentistry applications in caries detection either in a laboratory setting, public settings, or clinical situations were included. References of the included articles were also searched for additional references. Teledentistry articles in orthodontics, oral radiology, oral medicine, oral surgery, dental public health interventions, or dental traumatology were not included in this review. Articles not written in the English language were excluded. A total of 22 articles were included in this review. All the articles were reviewed by the title, abstract, and full text for relevance. The following keywords were used: "Accuracy", "Dental caries", "Detection", "Diagnosis", and "Teledentistry" to explore the existing literature.

Results and Discussion

Applications for teledentistry have been utilized for years to identify dental caries. Teledentistry's ability to identify dental caries in in-vitro, clinical, and epidemiological situations has shown increasing accuracy. Eleven of the 22 studies we found were conducted in public places, mainly schools, whereas six were conducted in dental offices or hospitals, and five were conducted in vitro **(Table 1)**.

Table 1. Summary of studies conducted inaccuracy of teledentistry examination in dental caries detection

SN	Author	Country	Setting	Technology/ type of imaging/ equipment	In-vitro/ in-vivo	Scoring system	Reference/ Gold standard
1	Forgie *et al*. (2003)	United Kingdom	Hospital	Video and photograph, intraoral camera	In vitro	Created by the authors	Histology evaluation
2	Erten *et al*. (2005)	Turkey	Not reported	Photograph, intraoral camera	In vitro	ERK scale	Histology evaluation
3	Boye *et al*. (2012)	United Kingdom	University oral health unit	Photograph; intraoral camera	In vitro	BASCD	Histology evaluation
4	Gomez *et al*. (2013)	United Kingdom	Oral care center	Photograph, intraoral camera	In vitro	ICDAS	Histology evaluation
5	Van Hilsen and Jones (2013)	USA	University lab	Photograph, DSLR camera	In vitro	CAMBRA	Histologic evaluation
6	Elfrink *et al*. (2009)	Netherlands	Dental practice	Photograph, intraoral camera	In vivo	dft	Visual examination (pediatric dentists)
7	Estai *et al*. (2016)	Australia	Dental practice	Smartphone	In vivo	WHO protocol	Visual examination (general dentist)
8	Estai *et al.* (2016)	Australia	University dental clinic	Smartphone	In vivo	WHO protocol	Oral examination (registered dental practitioner)
9	Estai (2017)	Australia	University dental clinic	Smartphone	In vivo	WHO protocol	Visual examination
10	Kohara *et al*. (2018)	Brazil	University clinic and lab	Smartphone + DSLR camera	In vivo and In vitro	ICDAS	Visual examination
11	AlShaya (2020)	Saudi Arabia	Clinic	Smartphone	In vivo	WHO criteria	Visual tactile evaluation
12	Patterson (1998)	Canada	Primary schools	Intraoral camera	In vivo	deft/DMFT	Visual evaluation
13	Kopycka-Kedzierawski *et al*. (2007)	USA	Childcare center	Intraoral camera	In vivo	dfs	Visual Evaluation (general dentist)

14	Kopycka Kedzierawski (2008)	USA	Kindergartens	Intraoral camera	In vivo	dfs	No comparison (to screen the prevalence of caries only)
15	Amavel *et al*. (2009)	Portugal	Kindergartens	DSLR camera	In-vivo	Created by the authors	Visual evaluation (general dentist)
16	Boye *et al*. (2013)	United Kingdom	Primary school	Intraoral camera	In vivo	DMFT/dft	Visual evaluation (general dentists)
17	Kopycka Kedzierawski (2013)	USA	Kindergartens	Intraoral camera	In vivo	dfs	Visual tactical evaluation (pediatric dentist)
18	Morosini *et al*. (2014)	Brazil	Juvenile detention facility	DSLR camera	In vivo	DMFT	Visual evaluation
19	Pentapati *et al.* (2017)	India	Urban health center	Intraoral camera	In vivo	dmft/DMFT	Clinical examination
20	Purohit *et al.* (2017)	India	Outreach health centers	Smartphone video recording	In vivo	DMFT	Visual tactile examination
21	Subbalekshmi *et al*. (2017)	India	School	Intraoral camera	In vivo	dmft	Visual examination
22	Estai (2021)	Australia	School	Smartphone	In vivo	dft/DFT	Visual examination

Colors explanation: Yellow; in vitro setting, Orange; Dental setting, Gray; public setting

Abbreviations: DSLR: Digital Single-Lens Reflex. ERK: Ekstrand, Ricketts, and Kidd scale. BASCD: British Association for the Study of Community Dentistry. ICDAS: International Caries Detection and Assessment System. CAMBRA: Caries Management by Risk Assessment. WHO: World Health Organization. dft; decaying and filled primary teeth. dfs: decaying, the filled surface of primary teeth. Deft; decaying, removed, and filled primary teeth. Decaying, missing, or filled primary teeth. DFT: filled permanent teeth, decaying DMFT: decaying, missing, and filled permanent teeth.

Teledentistry in in-vitro settings

The potential of intraoral cameras to detect caries on occlusal surfaces was first investigated in the early 2000s. However, in-vitro histologic inspection (the gold standard in in-vitro investigations) was contrasted with photos and videos. Because of its modest sensitivity, the intraoral camera may be employed to remotely diagnose occlusal caries. However, because some of the findings were falsely negative, concern was urged [8, 9].

More sophisticated intraoral cameras were released ten years later. As a result, another study investigated their potential to aid in the detection of caries on occlusal surfaces. According to several investigations, the sensitivity and specificity rose to 80% [10-12]. Despite their limited capacity to ascertain the depth of the lesion, those studies demonstrated encouraging outcomes using the International Caries Detection and Assessment System (ICDAS) of the occlusal caries categorization system. Since teledentistry caries detection applications were made possible by these in-vitro experiments, more study was conducted to examine their scalability in both clinical and public contexts.

Teledentistry in clinical settings

Elfrink *et al*. [13] examined the visual inspection in a pediatric dental clinic using intraoral cameras and traditional single-lens reflex cameras. Based on their results, which showed that intraoral pictures had a sensitivity of 85.5% and a specificity of 83.6% in detecting caries, they recommended their use in clinical and epidemiological investigations [13].

The multi-study teledentistry research that Estai and his colleagues in Australia have been working on since 2016 focuses on using smartphones to identify dental caries. The WHO caries classification system was used to compare the clinical unassisted visual assessment performed by a general dentist with the viability of dental assistants in taking pictures [1]. Initially, exploratory research was conducted to validate the idea. After a visual examination, 30 intraoral photos were obtained of five adult participants, five of each. The results indicated a 57% sensitivity and a 100% specificity. This suggests that the suggested screening method might be a valid and dependable substitute for the conventional visual clinical oral assessment [14].

They then increased the number of patients to one hundred of varying ages and hired a dental assistant to do the intraoral photo teledentistry assessment. When comparing to the clinical visual examination, they noted that the intraoral photos had a sensitivity of 60% and a specificity of 97% [15].

Additionally, they carried out a second trial in which they compared intraoral photos obtained by a dental assistant to the clinical unassisted visual assessment. However, a dentist still performed the teledentistry inspection of the intraoral photos. Remarkably, they discovered 60% sensitivity, which is comparable to the findings of the earlier study in which the dental assistant performed the teledentistry examination [16]. As a cost-effective and dependable alternative screening technique utilized in dental offices, smartphone camera images may be used to identify occlusal caries to a sufficient degree in comparison to the traditional visual oral examination. Also, since the dental assistant job in this project was equally successful as the dentist's but less costly, the results of the first two studies showed that using non-dentist personnel in teledentistry applications was cost-effective.

In their 2020 study, AlShaya *et al*. [17] investigated the accuracy of mobile phone teledentistry in detecting dental caries in 57 children with mixed dentition. Six pediatric dentists were given access to intraoral photos via a Google Drive connection after a qualified dentist took them to identify cavities in the images. The chairside dental caries examination (gold standard) was compared to the results obtained from the dentists. They found that their sensitivity and specificity were on average about 80%. Their approach has also been shown to be more accurate for primary teeth than permanent ones [17].

Teledentistry in public settings

A research study comparing teledentistry inspection of intraoral photos with standard visual dental screening in schools was carried out in 1998 at the University of Alberta Telehealth Centre. They started by doing a visual dental examination on 137 elementary school students using the deft/DMFT indices (deft: missing, decaying, filled permanent teeth; DMFT: extracted, filled primary teeth, rotted). Two months later, they used an intraoral camera to take intraoral photos, and they compared the photos' capacity to identify caries. Teledentistry's pilot research revealed an agreement range of 89-100%, which was an exact match [18].

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A pilot research study was carried out in 2007 as part of the aforementioned Rochester initiative to evaluate the efficacy of screening preschoolers for oral illness, namely ECC, utilizing intraoral cameras and telehealth communication technologies. They discovered no statistically significant difference between the visual assessment and the means of tooth decay observed in the intraoral photos. Although the assessment was more sensitive than the clinical test (gold standard), they reassessed the teeth clinically and verified the existence of caries. Therefore, it is suggested that the intraoral camera is a practical and probably affordable substitute for oral examination in the assessment of comorbidities, particularly ECC in children in preschool [20].

Some U.S. states have implemented Early Head Start, a program designed to educate and advance the overall development of children under five.

The Rochester teledentistry initiative was expanded by enrolling children from Early Head Start inner-city centers. Teledentistry may be useful in screening for dental caries, as demonstrated by Kopycka-Kedzierawski *et al*. [21]. After examining 162 kids in an inner-city location, they discovered that the majority of them had never visited a dentist and that more than half of them had ECC.

They suggested that teledentistry might be a potentially useful method of high-risk analysis for early indications of ECC in preschool-aged children [21]. Additionally, Kopycka-Kedzierawski and Billings [22] aimed to verify the Rochester teledentistry program's established procedures for screening children in preschool for ECC. Two hundred and ninety-one children were randomly assigned to one of two groups. Group 1 underwent a conventional, visual-tactile assessment, while Group 2 underwent a teledentistry assessment. Both groups subsequently underwent follow-up exams at six and twelve months. Their findings indicated that while screening for ECC in preschool-aged children, there was no statistically significant difference between the mean dfs (decayed, filled surface of primary teeth) of the clinical tests and the teledentistry assessment. The findings also showed that parents of children who underwent teledentistry tests were more likely to use oral healthcare when they received color printouts of teeth with cavities. In the teledentistry group, parents said that the pictures encouraged them to schedule a dental visit [22].

Amavel *et al*. [23] suggested using already available, low-cost imaging equipment, such as smartphones, rather than intraoral scanners or cameras. When they tested how well real phone cameras captured pictures of dental caries in kindergarteners, they discovered that their model was reliable with a modest specificity of 52% and a high sensitivity of 94%. Based on their research, they suggested that using mobile phone photos to diagnose dental issues in youngsters remotely was a legitimate method [23].

Using a cross-sectional study, Boye *et al*. [24] compared the visual dental examination (gold standard) with intraoral photos for detecting caries in elementary school students. According to their findings, the teledentistry evaluation had an 85% sensitivity and 90% reliability. Thus, the conclusion was that teledentistry intraoral picture inspection can offer a different diagnostic tool with the benefits of remote scoring, archiving, and reduced bias [24].

Furthermore, Morosini *et al*. [25] conducted a study to assess the validity of teledentistry by examining dental caries in a sample of 102 juvenile offenders from Brazil. By comparing intraoral photo inspection to clinical examination, they assessed the DMFT index. A dental professional reviewed the intraoral photos after they were taken using a digital camera and sent to a cloud server. The sensitivity and specificity of the teledentistry assessment varied from 48-73% and 97-98%, respectively, making it a dependable substitute for the conventional oral examination [25].

Although the United States has produced the majority of the published research on the diagnostic efficacy of teledentistry, evidence from other countries like India is starting to surface. In addition to doing a clinical evaluation for dental caries, Pentapati *et al*. [26] utilized an intraoral camera to capture films of intraoral tissues in children who were attending urban health facilities. When intraoral recordings were used instead of clinical examinations, the DMFT ratings were noticeably higher. By visually reevaluating children who had caries aberrations on photos that had not previously been visually noticed, they evaluated the validity of the teledentistry intraoral pictures evaluation.

According to their results, there was a positive correlation (r = 0.876, p and lt; 0.001) and flawless dependability (93.55 agreement with Kappa value of 0.714) between the mean DMFT of the teledentistry assessment and the visual clinical assessment [26]. Kopycka-Kedzierawski *et al*. [20] observed that the teledentistry assessment was more sensitive than the clinical examination, and these results are similar to their findings [20].

Additionally, Purohit *et al*. [27] aimed to assess the videographic arrangement's dependability as a tool for visualizing dental cavities in 12-year-old students in a rural area in India. The research, which involved 159 youngsters, discovered that when it comes to screening for dental caries, teledentistry assessment had 86% sensitivity and 58% specificity when compared to clinical assessment. They suggested that teledentistry might be used as an alternative method of dental caries screening and that it could be used for remote treatment planning and discussion [27]. The accuracy and feasibility of using teledentistry for the screening and diagnosis of dental caries in children aged three to six years was investigated by Subbalekshmi *et al*. [28] in another Indian research. Utilizing mobile phone-based photos of 318 kids, they concluded that digital photos taken in a school setting were likely to be an effective way to screen for ECC in young children, paving the way for the use of teledentistry as a powerful tool for dental caries diagnosis [28].

To enhance schoolchildren's oral health, Estai *et al*. more recently suggested a complete teledentistry effort. They contrasted visual dental examinations with teledentistry examinations to see if the former could identify dental decay using smartphone cameras. They discovered that the photographic method's mean dft/DFT (decayed, filled primary, and permanent teeth, respectively) scores were less sensitive and specific than those of the visual dental assessment; nevertheless, the effect was not statistically significant. As a result, they concluded that the photographic approach's accuracy and diagnostic capacity were adequate, particularly for young infants and primary dentition [29, 30].

In their 2015 assessment, Ines Meurer *et al*. [31] discovered that the results of visual and photographic examination methods were proportional. Furthermore, Estai *et al*. [32] found that teledentistry and clinical assessment produced comparable results in a review that looked at the diagnostic precision of teledentistry in the identification of dental caries. Despite generalization being difficult because of the heterogeneity of the examined trials, the review found that teledentistry shows good diagnostic efficacy for the diagnosis of dental caries [32].

The findings of this evaluation and the accuracy validated the teledentistry to identify caries, which is comparable with the findings of earlier reviews. Furthermore, this evaluation included research that was omitted by earlier reviews or released thereafter.

Conclusion

The conclusion drawn from this assessment of the literature is that teledentistry apps might be used to accurately diagnose dental caries. When comparing the intraoral photos to the conventional visual dental checkup, the results were similar. Even if smartphone use for teledentistry applications is on the rise, the variety of tools and technology employed in earlier research necessitates more standardized and repeatable teledentistry applications, particularly in epidemiologic oral surveys.

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