Review Article

ACCURACY OF TELEDENTISTRY IN DENTAL CARIES DETECTION - A LITERATURE REVIEW

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ABSTRACT

Dental caries causes significant physiological, financial, and social burden. It negatively affects the quality of life and healthcare economics. Many factors contributed to the creation of this burden. Amongst the most significant is the lack of efficient early caries detection and access to dental care. Teledentistry is an effective approach to increase access to dental services sustainably. Additionally, teledentistry is being used extensively in dental caries detection. This review aimed to review the literature about the accuracy of caries detection through teledentistry applications compared to traditional clinical examination. Peer-reviewed literature was searched in different databases with no time limits using the keywords: "Accuracy", "Dental caries", "Detection", "Diagnosis", "Teledentistry" to explore the literature. We identified 22 relevant studies in 3 main different settings. Five studies were carried out in in-vitro settings, while six studies in dental clinics, and the remaining were carried out in public settings, mainly schools. Our review revealed that the teledentistry for caries detection has good sensitivity and specificity when compared to traditional visual dental examination. Dental caries detection could be carried out reliably through teledentistry applications. It can be noticed that there is an ascending trend in smartphone use in teledentistry applications.

Key words: Telemedicine, Teledentistry, Caries, Diagnosis, Dental, Review.

Introduction

Regardless of tremendous improvement in children's oral health worldwide, dental caries is still considered one of the most extensive health problems in children [1]. Dental caries cause a significant physiological, psychological, financial, and social burden. This burden increases when there is inadequate knowledge about oral health and failure to practice good oral hygiene which negatively affects the quality of life and healthcare economics [2]. Many factors contributed to this burden. However, lacking efficient early caries detection and access to dental care contribute significantly to the risk factors of this burden [3]. Therefore, early detection of caries coupled with early intervention can help avoid or minimize pain, anxiety, and negative health experiences that may be caused by caries [4].

The clinical visual-tactile dental examination is the gold standard to detect dental caries in the clinical setting and is still the most commonly used approach for caries detection despite its limitations such as subjectivity and high cost especially with large-scale surveys [5]. Teledentistry is the field of dentistry that helps to receive and provide dental services remotely using digital platforms. Teledentistry showed promising potential as an alternative cost-effective approach to increase access to dental services and showed a positive effect on the delivery and sustainability of dental care [6]. The practice of teledentistry has been greatly expanded over the past decade with both improvements in internet bandwidth and improvements in mobile phone technology, making the capture, transmission, and storage of digital images easier [7].

This review aimed to review the literature about the accuracy of caries detection through teledentistry applications compared to traditional dental clinical examination.

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", "Teledentistry" to explore the existing literature.

Results and Discussion

Teledentistry applications have been used for a long time to detect dental caries. Dental caries detection through teledentistry showed improving accuracy among different research settings; in-vitro, clinical, and epidemiological. We identified 22 studies, five studies were carried out in in-vitro settings, while six studies were carried out in dental clinics or hospitals and the remaining eleven studies were carried out in public settings, mainly schools **(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, Z. Jones, R. S. (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, M. *et al.* (2016)	Australia	University dental clinic	Smartphone	In vivo	WHO protocol	Oral examination (registered dental practitioner)
9	Estai, M. (2017)	Australia	University dental clinic	Smartphone	In vivo	WHO protocol	Visual examination
10	Kohara, E. K. *et al.* (2018)	Brazil	University clinic & lab	Smartphone + DSLR camera	In vivo & In vitro	ICDAS	Visual examination
11	AlShaya, M. S. (2020)	Saudi Arabia	Clinic	Smartphone	In vivo	WHO criteria	Visual tactile evaluation
12	Patterson, S. (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, K. C. (2017)	India	Urban health center	Intraoral camera	In vivo	dmft/DMFT	Clinical examination
20	Purohit, B. M. (2017)	India	Outreach health centers	Smartphone video recording	In vivo	DMFT	Visual tactile examination

21	T, S. *et al*. (2017)	India	School	Intraoral camera	In vivo	dmft	Visual examination
22	Estai, M. (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; decayed, filled primary teeth. dfs; decayed, the filled surface of primary teeth. Deft; decayed, extracted, filled primary teeth. dmft; decayed, missing, filled primary teeth. DFT; filled permanent teeth, decayed, DMFT; decayed, missing, filled permanent teeth.

Teledentistry in in-vitro settings

In the early 2000s, initial attempts were made to explore the intraoral cameras' ability in occlusal surfaces caries detection. Still, photographs and video recordings were compared to the in-vitro histologic examination (the gold standard in in-vitro studies). It showed moderate sensitivity which meant that the intraoral camera can be used to detect occlusal caries remotely. However, caution was advised since there were some false-negative results [8, 9].

A decade later, more advanced intraoral cameras were introduced. Consequently, more research explored their ability to help in detecting caries on occlusal surfaces. The sensitivity and specificity increased up to 80% as reported by multiple studies [10-12]. Those studies showed promising results with the International Caries Detection and Assessment System (ICDAS) of occlusal caries classification system although their ability to determine the lesion depth was limited. These in-vitro studies paved the way for teledentistry caries detection applications; therefore, more research was carried out exploring its scalability in clinical and public settings.

Teledentistry in clinical settings

In 2009, Elfrink *et al*. compared both intraoral cameras and conventional single-lens reflex cameras to the visual examination in the pediatric dentistry clinic. They encouraged the use of intraoral photographs in the clinical and epidemiological studies based on their findings that found their sensitivity and specificity of assessing caries were 85.5% and 83.6% respectively [13].

Since 2016, Estai and his team in Australia have had a multi-study teledentistry project on detecting caries using smartphones. They investigated the feasibility of dental assistants in photographs acquisition in comparison to the clinical unaided visual examination done by a general dentist according to the WHO caries classification system [1]. In the beginning, they proofed the concept with an exploratory study. Five adult participants have been visually examined and 30 intraoral photographs were taken for them, five for each. The results showed sensitivity and specificity of 57% and 100% respectively. This indicates that the proposed system for screening can be a valid and reliable alternative to traditional visual clinical oral examination [14].

After that, they scaled it up with one hundred patients of different ages and recruited a dental assistant to do the teledentistry examination of the intraoral photographs. They pointed out that the intraoral photographs have sensitivity and specificity of 60% and 97%, respectively, compared to the clinical visual examination [15].

Moreover, they conducted another study to compare intraoral photographs taken by a dental assistant to the clinical unaided visual examination, while the teledentistry examination of the intraoral photographs was still done by a dentist. Interestingly, they found 60% sensitivity which is similar to the results of the previous study where the teledentistry examination was done by the dental assistant [16]. Occlusal caries shows an acceptable level of detection from photographs taken by a smartphone camera related to the traditional visible oral evaluation which is a low-cost and reliable alternative screening tool in dental clinics. In addition, the results of the last two studies showed the cost-effectiveness for the use of non-dentist personnel in the teledentistry applications, since the dental assistant role in this project was as effective as the dentist, however, it is less costing.

AlShaya *et al*. (2020) explored the reliability of mobile phone teledentistry in caries detection in 57 children in their mixed dentition. Intraoral photographs were taken by a trained dentist then distributed to 6 pediatric dentists through a Google Drive link in an attempt to detect caries from intraoral photographs. The authors compared the results collected from the dentists to the chairside dental caries examination (gold standard). Their findings showed an average of around 80% sensitivity and specificity. They also found that their model was more reliable in primary teeth than the permanent ones [17].

Teledentistry in public settings

In 1998, at the University of Alberta Telehealth Centre, a study was conducted comparing traditional visual dental screening in schools with the teledentistry examination of intraoral photographs. First, they examined 137 primary schoolchildren with the visual dental examination using the deft/DMFT indices (Deft; Extracted, filled primary teeth, decayed, DMFT; missing, decayed, filled permanent teeth). After two months, they carried out the intraoral photographing with an intraoral camera and compared the caries detection ability through the photographs. As a pilot study, teledentistry showed a range of agreement between 89% and 100% which were perfect agreement [18].

Telehealth centers were established in six inner-city primary

schools and seven child-care centers in Rochester, NY. The teledentistry 2006 project complemented the existing telehealth model focusing to evaluate the ubiquity of dental caries in pre-school children enrolled in urban child-care centers. Utilizing an intraoral camera, teleteeth assistants recorded digital images of children's teeth and sent the images to a pediatric dentist. The first findings of the project showed that teledentistry was a useful scheme for detecting active dental caries; mainly early childhood caries (ECC). The author also found that utilizing this technology made it probable for few children attending inner-city child-care centers to have their teeth evaluated at an early age [19].

In 2007, from the above-mentioned project at Rochester, a pilot study was conducted to assess the reliability of using intraoral cameras and telehealth communication technology to screen preschool children for oral disease, in particular ECC. They found that no statistical difference between means of tooth decay detected from the intraoral photographs and the visible evaluation. While the evaluation has more sensitivity than the clinical examination (gold standard), they re-evaluated the teeth clinically and confirmed the caries presence. Thus, recommending that the intraoral camera is a viable and likely to be a cost-effective alternative to oral examination for carries evaluation, especially ECC in preschool children [20].

Early Head Start is a project in some states in the United States that aims to provide education and promote the general development of children below five years of age.

Early Head Start inner-city children centers enrolled children to Expand the Rochester teledentistry project.

Kopycka-Kedzierawski *et al*. (2008) showed that teledentistry could help screen dental caries. Examining 162 children in an inner-city center, they found that over half of the children in this young age group had ECC and that most of whom had never been to a dentist.

They recommended that teledentistry might be a possibly productive means of high-risk analysis in pre-school children for early signs of ECC [21]. Furthermore, Kopycka-Kedzierawski and Billings (2013) sought to validate the established protocols of the Rochester teledentistry program to screen for ECC in preschool children. Two hundred ninety-one children were randomized into two groups: group 1 received a traditional, visual-tactile examination, while group 2 received a teledentistry examination, then follow up-examinations at 6 and 12 months for both groups. Their results suggested no statistical difference between the mean dfs (decayed, filled surface of primary teeth) of the clinical examinations and the teledentistry examination when screening for ECC in preschool children. The data further indicated that color printouts of teeth with cavities granted to parents of children who accepted teledentistry screenings endorsed oral healthcare usage. Parents in the teledentistry group stated that they were motivated by the photos to make an appointment with a dentist [22].

Amavel *et al*. (2009) proposed the utilize of existing inexpensive imaging devices such as smartphones instead of cameras or intraoral scanners. Evaluating the effectiveness of actual phone cameras to capture images of dental caries in kindergarten children, they found that their model was dependable with high sensitivity (94%), and mild specificity (52%). They recommended, based on their findings, that distant diagnosis of children's dental complications based on mobile phone photographs constituted a valid ability [23].

In 2013, Boye *et al*. conducted a cross-sectional study to compare caries detection on intraoral photographs with the visual dental examination (gold standard) in primary school children. Their outcomes showed 90% reliability and 85% sensitivity of the teledentistry evaluation. Therefore, it was concluded that teledentistry intraoral photographs examination can provide an alternative diagnostic utility with the advantages of bias decrease, remote scoring, and archiving [24].

Moreover, Morosini *et al*. (2014) dental caries in a cohort of 102 Brazillian juvenile offenders were aimed in a study to determine whether teledentistry was valid. They evaluated the DMFT index through intraoral photographs examination compared to clinical examination. The intraoral photographs were taken by digital camera and were uploaded to cloud service then examined by a dental consultant. The teledentistry evaluation sensitivity ranged from 48% to 73% and the and specificity was 98% to 97% which makes teledentistry a reliable alternative to the traditional oral evaluation [25].

While most of the published literature on the effectiveness of teledentistry in diagnosing dental caries comes from the United States, there is emerging data from developing nations such as India. Pantapati *et al*. (2017) used an intraoral camera to record videos of intraoral tissues in children visiting urban health centers in addition to the clinical examination of dental caries. The DMFT scores were significantly higher with intraoral videos compared to the clinical examination. They assessed the validity of the teledentistry intraoral photographs examination by visually re-evaluating children detected to have caries abrations on photographs that were not detected visually earlier.

Their outcomes indicated ideal reliability (93.55 agreement with Kappa value of 0.714) and affirmative association ($r = 0.876$, $p < 0.001$) between the mean DMFT of teledentistry evaluation compared to the visible clinical evaluation [26]. This is similar to the outcomes of, previously mentioned, Kopycka-Kedzierawski *et al*. (2007) where the teledentistry examination had higher sensitivity than the clinical examination [20].

Moreover, Purohit *et al*. (2017) desired to estimate the reliability of the video-graphic arrangement as a tool to picture dental caries among 12-year-old schoolchildren in a rural region of India. The study included 159 children and found that teledentistry evaluation has 86% sensitivity and 58% specificity compared to clinical examination when screening for dental caries. They recommended that teledentistry may be utilized as a substitute screening tool for dental caries and is possible for distant deliberation and treatment planning [27]. In another study from India, Subbelexmi *et al*. (2017) examined the accuracy and viability of utilizing teledentistry for the screening and diagnosis of dental caries in children between the ages of three to six years. Using mobile phone-based photographs for 318 children, they concluded that effective screening for ECC in young children was probable with digital images generated in a school surrounding, thus flagging the way for the application of teledentistry as compelling means for the diagnosis of dental caries [28].

More recently, Estai *et al*. proposed a comprehensive teledentistry project to improve dental health in school children. They investigated the ability of teledentistry examination to detect dental caries through smartphone cameras compared to visual dental examination in school children. Although they found that the mean dft/DFT (decayed, filled primary and permanent teeth respectively) scores for the photographic method have less sensitivity and specificity than the visual dental examination, the difference was not statistically significant. Therefore, they concluded that the photographic method had acceptable accuracy and diagnostic ability, especially with primary dentition and young children [29, 30].

In 2015, Ines Meurer *et al*. (2015) found in their review that there were proportionate outcomes between photographic and visible inspection techniques [31]. Furthermore, Estai *et al*. (2018) reported comparable results between teledentistry and clinical examination in a review exploring the diagnostic accuracy of teledentistry in the identification of dental caries. Although heterogeneity of the reviewed studies made generalization difficult, it was found in the review that teledentistry demonstrated acceptable diagnostic performance in the identification of dental caries [32].

The verdicts of this review and the accuracy confirmed the teledentistry to detect caries which is compatible with the results of previous reviews. Moreover, this review included studies that were missed by previous reviews or published afterward.

Conclusion

Based on this literature review, it can be concluded that dental caries detection could be carried out reliably through teledentistry applications. The results of dental examinations were comparable between the intraoral photographs and the traditional visual dental examination. Although there is ascending trend in smartphone use in teledentistry applications, the diversity in technologies and equipment used in the previous literature obligates more standardized and reproducible teledentistry applications, especially in epidemiologic oral surveys.

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