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The accuracy of teledentistry in caries detection in children – A diagnostic study

Mohammad AlShaya[1,2], Deema Farsi[1], Nada Farsi[3] and Najat Farsi[1]

Abstract

Introduction: : The increasing burden of dental caries and the lack of effective dental caries screening protocols in non-dental settings, such as schools, demand an innovative and cost-effective approach. Teledentistry is the field of dentistry that combines telecommunication with health records and digital imaging to improve access to dental care and help in epidemiological surveys. This study aimed to assess the accuracy of non-dentist teledentistry in caries detection compared with the clinical dental examination of a sample of 5–10-year-old schoolchildren.

Methods: A calibrated dentist examined schoolchildren aged 5–10 years old. The dentist and two teachers took intraoral photographs for each child, using a smartphone. The photographs were concealed; therefore, the dentist assessed the three sets of photographs blindly two weeks after the clinical examination. Accuracy was measured to compare the teledentistry examination with the clinical dental examination.

Results: The mean DMFT of primary teeth was 3.38, 3.42, and 3.17 upon clinical examination, dental-teledentistry examination (findings of photographs taken by a dentist), and non-dental teledentistry (findings of photographs taken by teachers), respectively. The mean DMFT of permanent teeth was 0.75, 0.69, and 0.65 upon clinical examination, dental-teledentistry examination, and non-dental teledentistry examination, respectively. In primary teeth, dental teledentistry and non-dental teledentistry examinations showed 95 and 98.3 sensitivity and 94.3 and 91.4 specificity, respectively. In permanent teeth, dental teledentistry and non-dental teledentistry examinations showed 80.8 and 88.5 sensitivity and 94.1 and 96.1 specificity, respectively.

Conclusions: Teledentistry has acceptable accuracy for caries detection in schoolchildren compared to a clinical dental examination.

Keywords

Dental caries, telemedicine, smartphone, school, Saudi Arabia

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Introduction

For decades, dental caries have continued to be one of the most prevalent health problems in children, although there has been a significant improvement in children's oral health.[1] The early diagnosis of caries, coupled with early intervention, can help avoid or minimize pain, anxiety, and negative health experiences that might be caused by caries.[2]

In Saudi Arabia, the prevalence of caries has not decreased over the last 20 years. The prevalence is estimated to be 80% in primary teeth, while it increased from around 70% to 80% in permanent teeth.[3,4] Moreover, Aldawood et al. pointed out in their study that parents had little knowledge about the timing of seeking dental care for their children.[5] A recent study in Jeddah, Saudi

[1]Pediatric Dentistry Department, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia
[2]Ministry of Health, Jeddah, Saudi Arabia
[3]Dental Public Health Department, Faculty of Dentistry, King Abdulaziz University, Jeddah, Saudi Arabia

Corresponding author:
Mohammad AlShaya, Pediatric Dentistry Department, Faculty of Dentistry, King Abdulaziz University, Jeddah 23235, Saudi Arabia.
Email: dr_shaya@hotmail.com

Arabia, found that 25% of the children recruited had never visited a dentist.[6] The access to dental care is most hindered by the cost and a lack of time, as well as a lack of transportation options.[7] In addition, the dental workforce tends to be limited in peripheral regions, while it is concentrated in Riyadh, Makkah, and the Eastern province.[8–10] Moreover, access to dental care was highly disrupted globally by the COVID-19 pandemic due to the lockdown, fear of contamination from aerosol-generating dental procedures, and the risk of contracting SARS-Cov2.[11–13]

Teledentistry is a promising field of dentistry that combines telecommunication with health records and digital imaging, to allow for the exchange of health information, improve access to dental care, and help in epidemiological surveys.[14] Teledentistry has the potential to overcome issues related to limited access to dental services, income, a lack of time, and shortages in the dental workforce, and ultimately aid in early caries detection.[15] Furthermore, teledentistry can be beneficial for communication between dental care providers and in addressing urgent cases that need immediate dental intervention.[14] In addition, teledentistry has reduced referral times and improved access to dental care in various emergent situations.[16] For instance, in a teledentistry model, oral screening performed by non-dentist care providers increased the capacity of dental care.[17] Moreover, Park et al. examined the imaging devices in different dental situations that might affect the quality of the image and found that a mobile phone-based camera can give good diagnostic quality and is very easy to handle and use.[18] In addition, the smartphone-based teledentistry model has been proven to be reliable and is easily accepted by parents.[19] Recently, in line with all these advances, the American Academy of Pediatric Dentistry (AAPD) issued a policy about teledentistry, recognizing the fact that it can help facilitate access to dental care.[20]

In Saudi Arabia, Alawwad and his colleagues pointed out that around 54% of dentists in Abha have positive attitudes toward practicing teledentistry in the future; they also recommended the integration of teledentistry into dental education, particularly at the central government level, through legislation.[21] Moreover, the National Transformation Program, which is an essential part of the Saudi Vision 2030, calls for the transformation of healthcare through the following objectives: increasing access to health services; improving the quality and efficiency of healthcare services; and promoting the prevention of health risks.[22] The document of the National Transformation Program established many initiatives to achieve these objectives; one of them is the E-health initiative, which is based on utilizing technologies to increase access to healthcare, such as telemedicine and teleconsultations. Fortunately, this initiative is becoming a reality through the establishment of the Saudi Telehealth Network, which is an initiative provided by the National Health Information Center (NHIC),[23] as well as the Saudi Arabia Telemedicine Policy, which was released jointly by the Saudi Health Council (SHC) and the National Health Information Center (NHIC).[24] Furthermore, the Saudi National Initiative on Prevention of Dental Caries implemented the utilization of the educational workforce to aid in the prevention of dental caries.[25]

In light of the Saudi Vision 2030 and with the massive transformations in healthcare demanded by the COVID-19 pandemic, this study aimed to assess the accuracy of non-dentist teledentistry in caries detection compared with that of a clinical dental examination in a sample of 5–10-year-old schoolchildren.

Methodology

The Standards for Reporting of Diagnostic Accuracy Studies (STARD) statement[26] was followed to expand the completeness and transparency of this diagnostic accuracy study.

Study setting and participants' recruitment

All potentially eligible children at a primary private school in Jeddah were invited to participate. Ninety-five of those children were recruited to participate in the study between March and June 2021. Access to the school was arranged with the school principal through direct communication. The parents of the targeted children were asked for their permission to recruit their children in the study by means of a written consent form sent by the school, which also included the purpose of the study and a description of the research.

Dental examinations of the children's primary and permanent teeth were performed, and the eligibility criteria were the following:

- Children between 5 and 10 years old
- Whose parents signed the consent form
- And who accepted the oral examination and photography

Children with the following conditions were excluded: the use of a fixed orthodontic device; severe fluorosis; hypoplasia; fractured anterior teeth; or a serious systemic disease (Figure 1).

Clinical dental examination

Oral health assessment using the WHO form is considered the reference standard for campaign surveys and massive oral health assessments.[27] For this, the charting of teeth was recorded on the 2013 WHO oral health assessment form for the children, including the dmft/DMFT score, age, and the gender of each child.

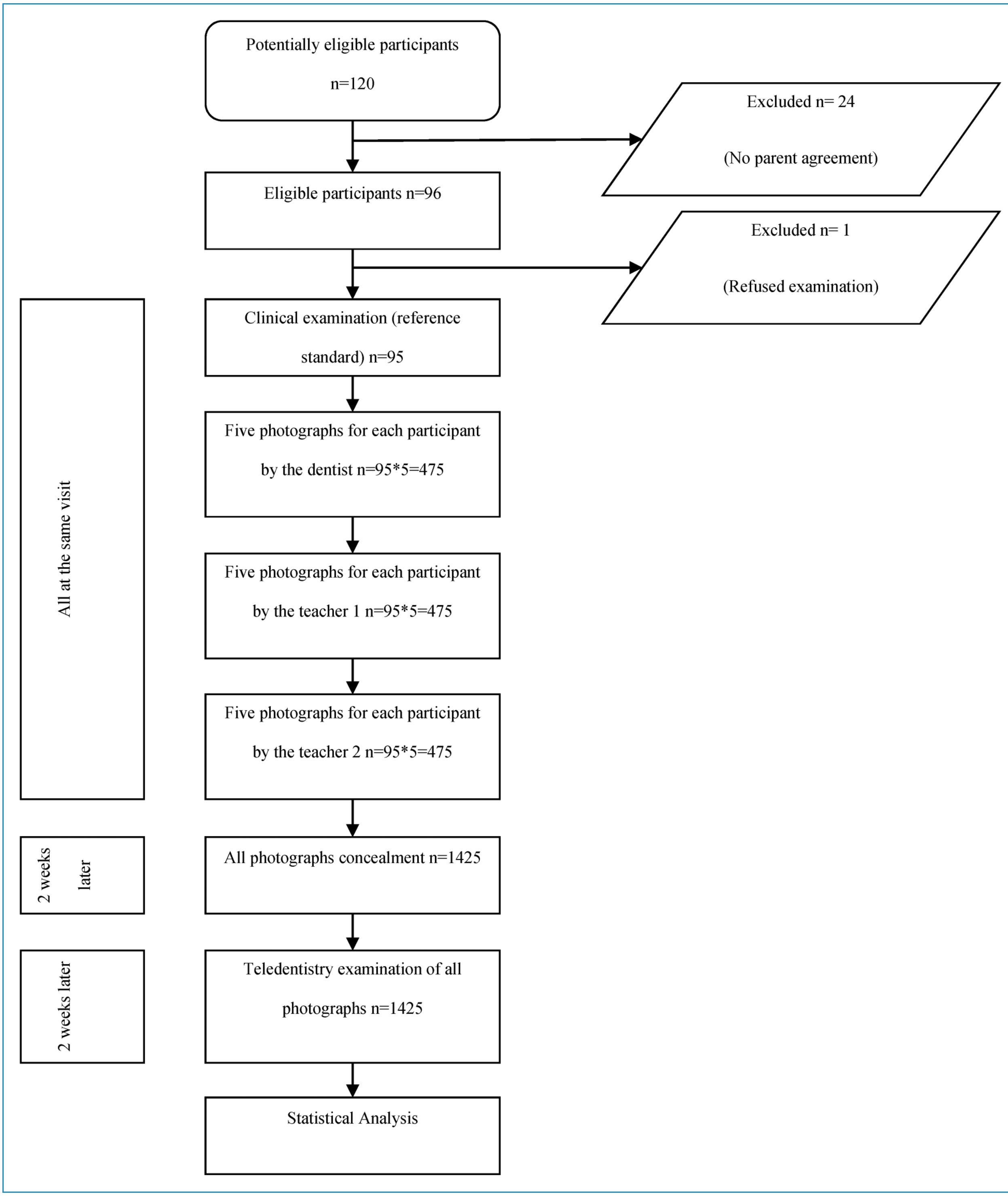

Figure 1. Study flow chart.

An experienced dentist, who was calibrated to use this form, conducted all the clinical dental examinations with the aid of disposable dental mirrors, probes, and tweezers. The children were asked to rinse their mouths with water before the clinical dental examination. Afterwards, they were asked to lie down on two regular chairs, and the dentist was seated behind the child's head. Natural light was used as the main source of lighting, as well as a phone flash held by the research assistant. Another research assistant recorded the findings dictated by the dentist.

Intraoral photographs

Two teachers were recruited to collect data in addition to the primary investigator, the dentist (the same dentist who did the clinical dental examination). The primary investigator explained the aim of the study to the teachers. He showed them an example of the photographs that should be taken and explained how many should be taken. Training was done for both teachers with the help of a child whose parents had already agreed to participate in the study. This child was not included in the study sample. The training session took two hours for each teacher.

Three sets of intraoral photographs were taken for each child, one by the dentist and one by each of the teachers. The set of photographs was composed of a frontal, a right buccal, a left buccal, an upper occlusal, and a lower occlusal photograph (Figures 2 and 3). The photographs were taken while the children were in a seated position on a regular chair. Although the photographs were taken, one teacher retracted the cheeks and lips, and when it was his turn to take the photographs, the other teacher did the retraction. When it was time for the teachers to take the photographs, the dentist did not assist, correct, or comment. The confidentiality and the privacy of the participants were insured by not taking any extraoral photographs.

Participants' data concealment

The photographs of each child were saved to a PC and filed into three folders: 1) the dentist's photographs; 2) the first teacher's photographs; and 3) the second teacher's photographs. For the subsequent teledentistry examination, copies of all these photographs were merged in one folder, and each set of photographs for each child was given a computer-generated, random code. Therefore, the dentist examining the photographs did not know to which folder the photographs belonged, and the teledentistry examination was blinded.

The examination was done at the tooth and not the surface level, with a total dmft/DMFT score recorded for each child. Based on the examination, reports on the oral findings and a copy of the photographs were sent to the child's parents. The children who need dental treatment were referred for further investigation and treatment at the dental hospital of the Faculty of Dentistry at King Abdulaziz University. Intraoral photographs of 10 participants were re-examined two weeks after the initial teledentistry examination to assess the test–retest reliability. The findings were also reported using the same WHO oral health assessment 2013 form.[27] The intraclass coefficient score 97.0 (88.8–99.3 CI) and 100 with dmft and DMFT, respectively.

Smartphone specifications

The camera of an iPhone X (Apple corp.) with dual 12MP wide (f/1.8 aperture) and telephoto (f/2.4 aperture) was used. It has dual optical image stabilization as well as a 2× optical zoom and up to a 10× digital zoom. The iPhone X has true tone flash technology, which ensures the uniformity of light, resulting in more uniformly lit backgrounds and foregrounds.[28] Only one smartphone, with the above-mentioned criteria, was used for taking all the photographs, to ensure standardized specifications.

Teledentistry examination (Index test)

The same dentist assessed the three sets of photographs for each child blindly two weeks after the clinical dental examination. He recorded the findings of each set of photographs to use later for statistical analysis.

Sample size calculation

Using G power software, the sample size calculation was done based on estimating the difference in mean dmft as 0.5 between the two groups (teledentistry and clinical examination) and aiming for a power of 90% and a two-sided two-sample t-test with an alpha level of 0.05. It was found that adequate sample size should not have fewer than 75 participants; however, 120 participants were recruited to allow for those not willing to participate, exclusions for any reason, or missing data.[29,30]

Statistical analysis

A total of 1425 intraoral photographs were obtained, 15 per child (5 by the dentist, 5 by teacher 1, and 5 by teacher 2), using the same iPhone X smartphone. Since the sample size was more than 40 in each group of photographs, t-tests were used, as they are robust for non-normality when the sample size is large.[31]

The primary outcome is dmft/DMFT. The variable is used in two ways, as a binary variable: caries present and no caries (dmft/DMFT = 0 and dmft/DMFT>0). It is also used as a continuous variable. To assess the diagnostic accuracy of the teledentistry images, the diagnosis of the clinical dental examination was compared with the results of the diagnosis based on the dentist's photographs (dental teledentistry examination). To assess the diagnostic accuracy of the non-dental teledentistry (photographs taken by the teachers), the diagnosis of the clinical dental examination was compared with the diagnosis obtained based on the teachers' photographs (non-dental teledentistry examination). Using the diagnosis based on the clinical dental examination as the reference standard, the sensitivity and specificity of the photographs taken by the dentist and teachers were calculated. The unit of analysis is the children.

A paired t-test was used to compare the mean dmft/DMFT obtained from the clinical dental examination and that obtained from the dental-teledentistry examination. Then the mean dmft/DMFT of the clinical dental

Figure 2. Intraoral photographs for carious primary dentition by teacher.

examination was compared with the dmft/DMFT based on the non-dental teledentistry examination. A p value ≤ 0.05 was considered to be statistically significant. Moreover, contingency tables were used to measure the accuracy of the teledentistry examinations by calculating the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). For each participant, when caries is detected with the clinical dental examination and teledentistry examination, it is true positive (TP), while if caries is detected using teledentistry only, it is false positive (FP). Additionally, when caries is not detected with either clinical dental examination or teledentistry examination, the participant is classified as true negative (TN); however, if the clinical dental examination showed there is caries while the teledentistry examination showed there is none, the case is considered false negative (FN). Moreover, positive predictive value (PPV) means the extent to which the teledentistry examination can avoid reporting false-positive cases, while the negative predictive value (NPV) means the extent to which the teledentistry examination can avoid reporting false-negative values. Based on that, the calculations are done using these formulas: Sensitivity = TP/TP + FN; Specificity = TN/TN + FP; PPV = TP/TP + FP; NPV = TN/TN + FN; and Agreement [TP + TN/total (TP + FP + FN + TN)]. The agreement between the examinations was calculated using both percentages ([TP + TN/total (TP + FP + FN + TN)] and Cohen's Kappa, which is always in the range of 0–1. The kappa score can be interpreted as the following: (0–0.20) no agreement; (0.21–0.39) minimal; (0.40–0.59) weak; (0.60–0.79) moderate; (0.80–0.90) strong; and (0.90–1) almost perfect agreement.[32] The statistical analysis was performed using Stata version 12.1 software (StataCorp LP, College Station, TX, USA).

Results

Out of 120 eligible participants, 95 children participated in the study, yielding a response rate of 79.2%. The sample consisted of 54 (56.8%) boys and 41 (43.2%) girls with a mean age of 7.8 ± 1.5 years. All participants had primary teeth, and 77 of them had permanent teeth as well.

Caries experience and the mean dmft/DMFT scores

Caries prevalence in children with primary teeth upon clinical dental examination was similar to both dental-teledentistry examination (examination of intraoral photographs taken by the dentist) and non-dental-teledentistry examination (average of scores recorded through examinations of intraoral photographs taken by teacher 1 and teacher 2).

The mean dmft scores, in the 95 participants who had primary teeth, were not different upon dental-teledentistry examination when compared with the clinical dental examination ($p = 0.72$). Similarly, comparing the mean dmft of the non-dental-teledentistry examination to the clinical

Figure 3. Intraoral photographs for carious mixed dentition by teacher

dental examination showed no clinically significant difference, although it was of borderline statistical significance ($p = 0.05$) (Table 1).

For the permanent teeth, caries prevalence was also similar upon visual dental examination, dental-teledentistry examination, and non-dental-teledentistry examination, respectively. Moreover, the mean DMFT scores, in the 77 participants who had permanent teeth, were similar to those in both teledentistry groups upon clinical examination (Table 2).

The percentage of mean difference in dmft/DMFT scores between the clinical examination and dental teledentistry and between the clinical examination and non-dental teledentistry of caries detection (bias), the standard deviation of differences, and limits of agreement for the approaches is presented through Bland–Altman plot. The X and Y axes represent the average and differences between the examination methods (Figures 4–7).

Upon comparing dmft/DMFT obtained by the teachers' photographs, the results were similar. Moreover, since the objective was to measure overall non-dentist (teacher) photographs, and not a specific teacher's photographs per se, the average mean dmft/DMFT for both teachers was calculated and used as one unit to ease the interpretation of the results.

Diagnostic performance

Sensitivity and specificity of the teledentistry examinations in primary teeth. In the primary teeth, the dental-teledentistry examination showed excellent accuracy, with scores above 90% for sensitivity, specificity, PPV, and NPV. The teacher-1-non-dental-teledentistry examination showed high sensitivity, specificity, PPV, and NPV, indicating high accuracy in the detection of caries. Similarly, the teacher-2-non-dental-teledentistry examination showed excellent accuracy in caries detection, with a high estimate of sensitivity, specificity, PPV, and NPV.

To overcome any potential individual differences, the average dmft for both teachers was calculated. The average results of non-dental teledentistry examination showed also high sensitivity and specificity in caries detection. Moreover, the PPV and NPV for non-dental teledentistry examination indicated that the false-positive and false-negative outcomes in examining primary teeth were minimal in our study (Table 3).

Sensitivity and specificity of the teledentistry examinations in permanent teeth. In permanent teeth, dental-teledentistry revealed good accuracy with a high score for sensitivity and specificity. It also showed high PPV and NPV,

Table 1. Caries prevalence and mean (dmft) scores in children with primary teeth according to the examination method.

	Children with caries *N* (%)	*p* Value	Dmft Mean (SD)	Median dmft	*p* Value
Clinical Dental Examination	60 (63.2)	–	3.38 (3.0)	3	–
Dental Teledentistry	59 (62.1)	0.6547[a]	3.42 (3.3)	3	0.72[b]
Non-Dental Teledentistry[c]	62 (65.3)	0.3173[d]	3.17 (3.1)	3	0.05[e,f]

[a]Comparison of dental teledentistry with clinical dental examination for caries presence (binary variable) using McNemar test.
[b]Comparison of non-dental teledentistry with clinical dental examination for caries presence (binary variable) using McNemar test.
[c]Average of teacher 1 and teacher 2.
[d]Comparison of dental teledentistry with clinical dental examination mean (dmft) score (continuous variable) using paired t-test.
[e]Comparison of non-dental teledentistry with clinical dental examination for mean (dmft) score (continuous variable) using paired t-test.
[f]Statistically significant.

Table 2. Caries prevalence and mean (DMFT) scores in children with permanent teeth according to the examination method.

	Children with Caries *N* (%)	*p* Value	DMFT Mean (SD)	Median Dmft	*p* Value
Clinical Dental Examination	26 (33.8)	–	0.75 (1.2)	0	–
Dental Teledentistry	24 (31.2)	0.4795[a]	0.69 (1.1)	0	0.3726[b]
Non-Dental Teledentistry[c]	25 (32.5)	0.6547[d]	0.65 (1.0)	0	0.1065[e]

aComparison of dental teledentistry with clinical dental examination for caries presence (binary variable) using McNemar test.
bComparison of non-dental teledentistry with clinical dental examination for caries presence (binary variable) using McNemar test.
[c]Average of teacher 1 and teacher 2.
[d]Comparison of dental teledentistry with clinical dental examination mean (DMFT) score (continuous variable) using paired t-test.
[e]Comparison of non-dental teledentistry with clinical dental examination for mean (DMFT) score (continuous variable) using paired t-test.

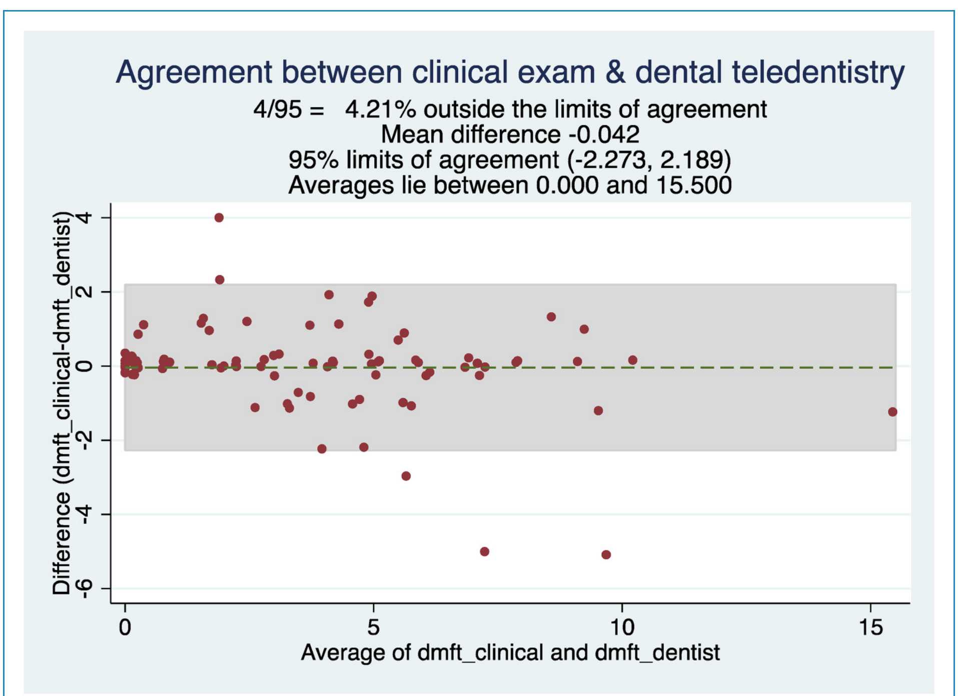

Figure 4. Bald-Altman plot for dmft assessment by clinical examination and dental teledentistry
dmft_clinincal: the dmft of primary teeth obtained by clinical examination
dmft_dentist: the dmft of primary teeth obtained by examination of the dentist's photographs.

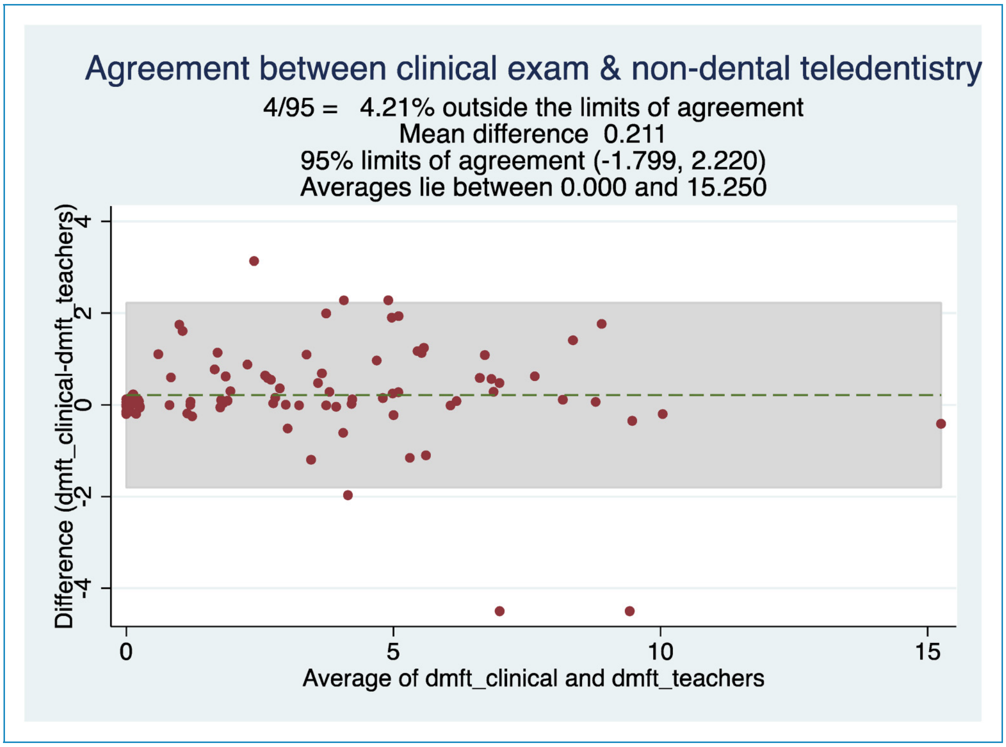

Figure 5. Bald-Altman plot for dmft assessment by clinical examination and non-dental teledentistry
dmft_clinincal: the dmft of primary teeth obtained by clinical examination
dmft_teachers: the average dmft of primary teeth obtained by examination of teachers' photographs.

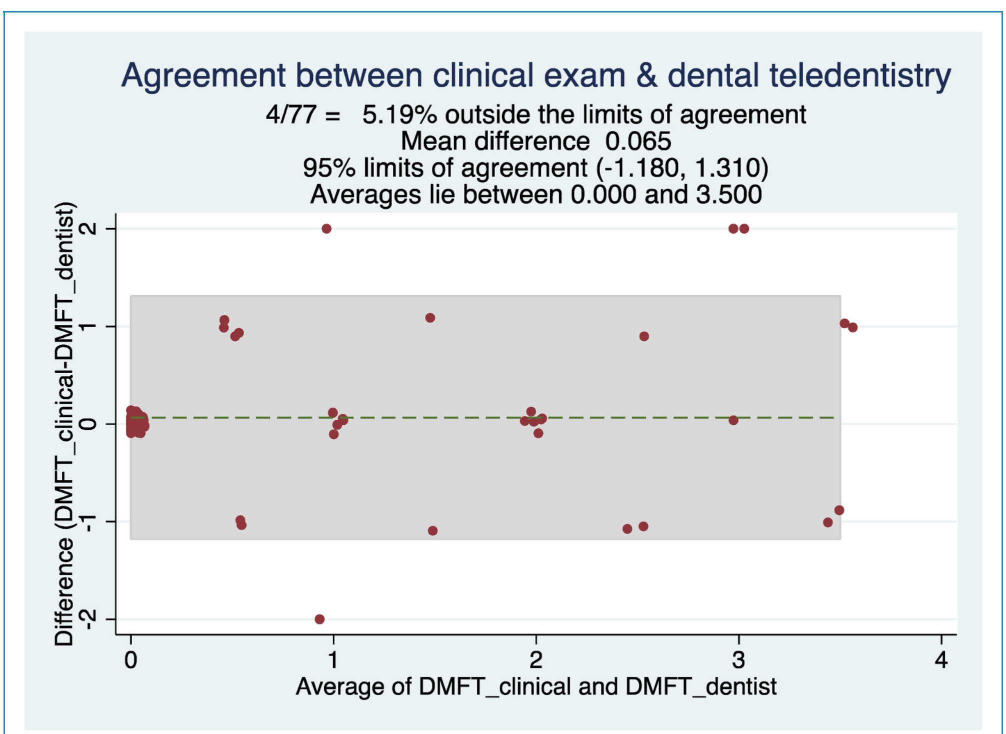

Figure 6. Bald-Altman plot for DMFT assessment by clinical examination and dental teledentistry
DMFT_clinincal: the DMFT of permanent teeth obtained by clinical examination
DMFT_dentist: the DMFT of permanent teeth obtained by examination of the dentist's photographs.

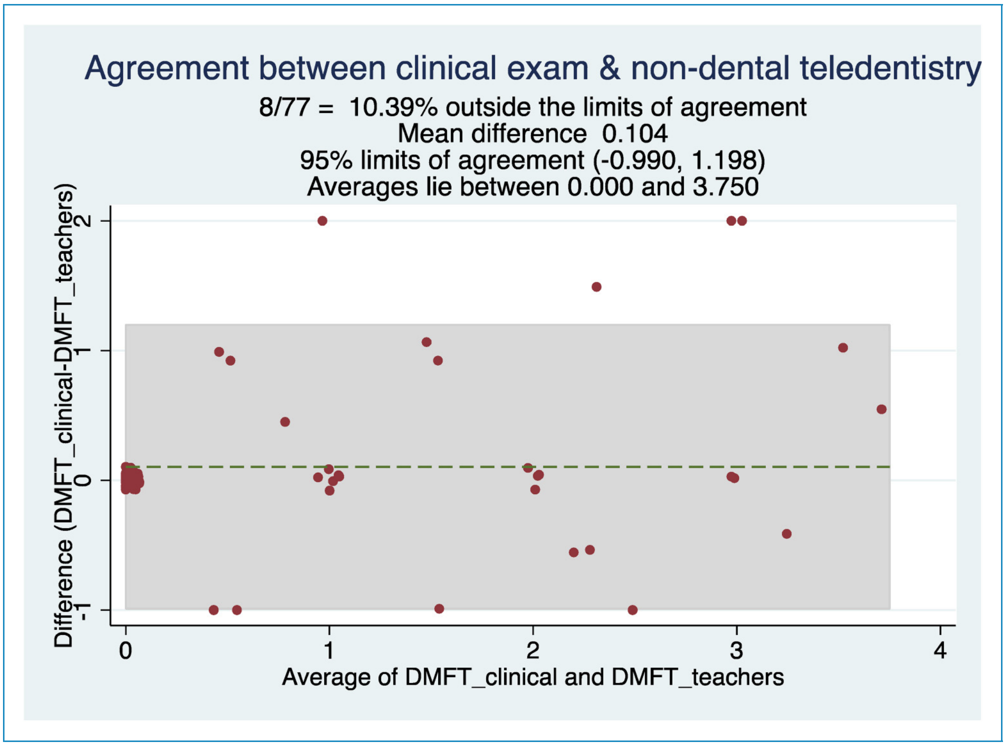

Figure 7. Bald-Altman plot for DMFT assessment by clinical examination and teacher (average 1 and 2) teledentistry.
DMFT_clinincal: the DMFT of permanent teeth obtained by clinical examination
DMFT_teachers: the average DMFT of permanent teeth obtained by examination of teacher's photographs.

Table 3. Accuracy of photographic assessment of carious lesions in primary teeth.

Comparison of oral health assessments	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Clinical exam vs Dentist	95 (86.1–99)	94.3 (80.8–99.3)	96.6 (88.3–99.6)	91.7 (77.5–98.2)
Clinical exam vs teacher 1	96.7 (88.5–99.6)	91.4 (76.9–98.2)	95.1 (86.3–99)	94.1 (80.3–99.3)
Clinical exam vs teacher 2	93.3 (83.8–98.2)	97.1 (85.1–99.9)	98.2 (90.6–100)	89.5 (75.2–97.1)
Clinical exam vs teacher 1 and teacher 2	98.3 (91.1–100)	98.3 (91.1–100)	95.2 (86.5–99.0)	97 (84.2–99.9)

indicating the ability to avoid false results. Teledentistry examinations of teacher 1's photographs likewise showed high accuracy for primary teeth. The sensitivity score was above 80%, and the specificity score was above 90%, with PPV and NPV scores above 90%. Moreover, teacher 2's photographs showed high sensitivity and specificity in caries detection, with high PPV and NPV as well.

Similarly, the average DMFT for both teachers was calculated to overcome any potential individual differences. Therefore, the average results of non-dental teledentistry examination were calculated, which showed high sensitivity and specificity. Positive predictive values (PPV) and negative predictive values (NPV) were noted to be high, indicating that the false-positive and false-negative outcomes in permanent teeth were minimal in our study (Table 4).

Agreement and reliability of teledentistry examinations

The dental and non-dental teledentistry examinations showed a high percentage of agreement for the primary and permanent teeth. Based on Cohen's kappa scores classification,[32] both dental and non-dental teledentistry examinations showed, respectively, strong and almost perfect reliability in caries detection in the primary teeth, while in the permanent teeth, the reliability was moderate in the

Table 4. Accuracy of photographic assessment of carious lesions in permanent teeth.

Comparison of oral health assessments	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Clinical exam vs Dentist	80.8 (60.6–93.4)	94.1 (83.8–98.8)	87.5 (67.6–97.3)	90.6 (79.3–96.9)
Clinical exam vs teacher 1	84.6 (65.1–95.6)	96.1 (86.5–99.5)	91.7 (73–99)	92.5 (81.8–97.9)
Clinical exam vs teacher 2	84.6 (65.1–95.6)	98 (89.6–100)	95.7 (78.1–99.9)	92.6 (82.1–97.9)
Clinical exam vs teacher 1 and teacher 2	88.5 (69.8–97.6)	96.1 (86.5–99.5)	92.0 (74.0–99.0)	94.2 (84.1–98.8)

Table 5. Comparison of reliability (kappa score) between clinical, dental-teledentistry, and non-dental teledentistry examinations in primary and permanent teeth.

	% Agreement[a]	Kappa (CI)
Primary teeth		
Dental teledentistry vs. clinical examination	94.7	0.89 (0.79–0.98)
Non-dental teledentistry vs. clinical examination	95.8	0.91 (0.82–1.0)
Permanent teeth		
Dental teledentistry vs. clinical examination	89.6	0.76 (0.61–0.92)
Non-dental teledentistry vs. clinical examination	93.5	0.85 (0.73–0.98)

[a]% agreement calculated by dividing total number of agreement/total [TP + TN/total (TP + FP + FN + TN)].
TP: true positive; TN: true negative; FP: false positive; FN: false negative.

dental-teledentistry examination and strong in the non-dental-teledentistry examination (Table 5).

Discussion

This study aimed to assess the accuracy of caries detection through the examination of intraoral photographs taken by teachers (non-dental personnel) compared with reference standard clinical dental examination. Lacking cost-effective and regular standardized oral health surveys mandated to search for an innovative way to address this issue. This study revealed that the caries prevalence in our sample was high in both primary and permanent teeth. Additionally, the findings of this study suggest that non-dental teledentistry has reliable accuracy, with moderate to strong sensitivity and specificity in detecting caries in primary and permanent teeth. Furthermore, there was no significant difference between the mean dmft/DMFT of the dental-teledentistry examination and that of the reference standard clinical dental examination. The difference between the mean dmft/DMFT of the non-dental-teledentistry examination and that of the reference standard clinical dental examination was not as clinically significant as it was statistically. The clinical importance of these findings should not be confused with the statistical importance, since the latter means that the results may be due to chance by less than 5%. However, the interpretation of any clinical findings should not be isolated from the clinical implication of these findings.[33] Consequently, from the clinical perspective, there is no proportional dmft/DMFT score, since it is always an absolute number. This means that the dmft score of 3.17 is not different clinically from 3.38, which makes it possible to consider the accuracy of dental and non-dental teledentistry examinations as the same.

The sensitivity of a teledentistry examination to detect true-positive findings is the extent to which teledentistry examinations can correctly identify participants who have dental caries. On the other hand, the specificity of the teledentistry examination is the extent to which the teledentistry examination can correctly identify participants who do not have dental caries. However, potential confounders might exist and affect the sensitivity and specificity scores.[34] These factors are, for example, the prevalence of the intended condition and how rigorous the index test is. This makes it important to interpret the sensitivity and specificity in connection with their corresponding positive predictive value (PPV) and negative predictive values (NPV), while taking the prevalence of the target condition to be diagnosed into consideration, which is dental caries in our case. The PPV reflects the ability of teledentistry examinations not to only identify true positive cases, but also to avoid reporting false-positive cases. On the other hand, the NPV is the ability of the teledentistry examination to avoid reporting false-negative values. In our study, all the PPVs and NPV ranged from 87.5 to 98.2, which justifies our interpretation of the accuracy of the sensitivity and specificity scores in the current study.

In primary teeth, our study showed that the sensitivity and specificity of both teachers' teledentistry examinations were similar to the sensitivity and specificity of the dental teledentistry examination. However, when the average for both teachers was taken for the dmft, the sensitivity and specificity rose significantly. This could suggest that regardless of the teachers' experience with digital photography, they produced diagnostic photographs and could serve as a reliable resource in teledentistry examinations to detect caries.

Due to the young age of the participants, the permanent teeth have had less time to develop caries than the primary teeth, and therefore, there was less prevalence of dental caries in the permanent teeth. Nevertheless, the dental and non-dental teledentistry examinations showed acceptable sensitivity and specificity when compared with the clinical visual dental examination.

In the current study, there was a higher sensitivity for both dental teledentistry (95) and non-dental teledentistry examinations (98.3) in the primary teeth than that reported by studies that investigated the accuracy of intraoral camera photographs taken by dentists to detect dental caries in children either in dental practice or in schools, such as the results of Elfrink et al. (85.5), Boye et al. (88), AlShaya et al. (75), and Estai et al. (82).[35–38] Regarding specificity, the current study showed a specificity of 94.3 for the dental teledentistry examination and 91.4 for the non-dental teledentistry, which is similar to findings by Boye et al. (82).[36] This similarity between the current results and those in previous studies indicates that our model, utilizing non-dentist personnel and smartphone photography, is reliable and in line with the previous studies in detecting dental caries. Moreover, it is exigent to note that the technological advancement in smartphones cameras enhanced the quality of the photographs, which was reflected positively in the current results.

With regard to permanent teeth, the current study showed a sensitivity of 80.8 for the dental teledentistry and 88.5 for the non-dental teledentistry, both of which are higher than that of studies that used intraoral camera photographs taken by dental personnel (dentists or dental assistants) either in dental practices or public settings, such as Boye et al. (72) and Morosini et al. (73).[36,39] In terms of specificity, the current study showed a specificity of 94.1 and 96.1 for the dental teledentistry and non-dental teledentistry examinations, respectively, which are higher than the findings of Boye et al. (78) and Estai et al. (78).[36,38] However, our specificity scores were similar to those reported by Morosini et al. (98).[39] This relative drop in the sensitivity of teledentistry examination of permanent teeth could be attributed to the low prevalence of dental caries in these teeth, which were few in number and recent in eruption, since the sensitivity of such an examination depends on the prevalence of the targeted disease. Nevertheless, the interpretation can be considered accurate, with acceptable sensitivity and specificity. Moreover, there is an ascending trend in sensitivity and specificity over time, which can be explained by the continuing technological advancement in photography, and in smartphone cameras in particular.

As part of their extensive research, Estai et al. conducted a teledentistry study in which the examinations of one hundred patients, children and adults, were carried out by dental assistants who took photographs and also carried out teledentistry examinations (interpretation of the photographs), which were then compared with the visual oral examination done by a dentist. Their intraoral photographs showed sensitivity and specificity of 60 and 97, respectively, compared to the clinical visual examination.[40] In comparison, the current study asked teachers (non-dental personnel) to take the photographs, but the examination was carried out by a dentist, yielding sensitivity scores of 98.3 in primary and 88.5 in permanent teeth for the non-dental teledentistry examination, and specificity of 91.4 for primary teeth and 96.1 for permanent teeth. This big difference in sensitivity between both studies could be a result of the failure of the dental assistants to accurately detect dental caries in the photographs.

Based on the International Caries Detection and Assessment System (ICDAS), Kohara et al. found that the teledentistry examination of cavitated carious lesions photographed by dentists with a smartphone camera showed a sensitivity and specificity of 95, which is comparable to the current results. In terms of the non-cavitated lesions, the sensitivity fell to 53.[41] The drop could be attributed to the relative inherent difficulty of achieving a reliable application of the ICDAS system with non-cavitated caries lesions,[42] in contrast to the WHO criteria for oral health surveys, which were used in the current study with a high level of applicability and reliability.[27]

As can be observed, various teledentistry studies have been proposed to detect caries. Many of them needed an intraoral scanner and a dental professional to carry out the index test, and/or the study must be carried out in a dental clinic. To the best of our knowledge, this is the first study that used non-dental professionals – teachers – as data collectors and a smartphone camera as a tool for data collection and was carried out in a community setting (the school), yet yielded promising results. The results of the study would positively impact dental public health through the utilization of non-dental personnel with no previous dental experience, which is less costly, to use a widely available device (smartphone) to produce accurate enough diagnostic photographs. This is in line with the objective of the Saudi National Initiative to 'Prevent Dental Caries' by including the educational workforce in the process of caries prevention.[25]

The methodology of this study was based on the WHO model for epidemiologic oral health surveys. Moreover, it used the best evidence to emphasize the value of teledentistry applications in caries detection. There is no better time than the current day to establish efficient, contemporary, and standardized dental caries survey methods among school children using widely available smartphones and by training teachers in taking dental photographs.

The training and cooperation of teachers in such a study may be a challenge if we want to scale the surveys up to include more schools or cities, or to implement them nationwide. However, the inclusion of teachers strengthens the model, as it can meet the intended level of accuracy and the cost-effectiveness needed in such services. Moreover, the methodology is clear and easy to replicate, and smartphones are widely available nowadays, which means the implementation of this study on a larger scale is achievable.

On the downside, some parents had concerns regarding the privacy and confidentiality of their children's data. However, a comprehensive discussion between the parents and the study team regarding privacy issues should minimize such concerns. It is expected that an official adoption by the Ministry of Health of teledentistry projects in caries screening studies would encourage teachers to cooperate, make the effective training of those teachers easier, and be reassuring to parents.

Teledentistry can help extend dental and oral health surveys to isolated or remote populations, such as people in rural areas and high-risk populations with limited access to dental care. Teledentistry can also facilitate conducting large-scale surveys in a practical and relatively cost-effective way. Moreover, in difficult times, such as during the COVID-19 pandemic, the incorporation of telehealth in healthcare became the new norm globally. Telehealth in all its branches is in line with the current Saudi Health Transformation Program that is being carried out at the time of writing this thesis and is based on the utilization of digital technology to serve all populations, including those living in rural areas.[43]

Conclusion

This study has shown acceptable accuracy for caries detection can be achieved with photographs taken by a smartphone camera, compared to traditional clinical dental examinations. The use of non-dentist personnel in teledentistry applications is believed to be a reliable and cost-effective approach that can help to overcome the difficulty of arranging the physical presence of the dentist in schools, due to any lack of time or scheduling issues. Smartphones are readily available and relatively inexpensive, which can make them helpful tools in caries detection surveys. The study provides strong evidence to support adopting an alternative tool for dental caries screening in schools that is reliable, accessible, less invasive, less dangerous, less expensive, less time-consuming, and less physically and psychologically uncomfortable for schoolchildren. Teledentistry enables regular mass screenings to equally detect caries in schoolchildren in rural and urban areas. It is believed to alleviate some burdens of the healthcare system and improve the oral health of children. Further research, including studies of multiple schools and teachers, is required to train more teachers in the taking of dental photographs and to address any potential difficulties that may arise before implementing the teledentistry approach nationwide.

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ORCID iDs: Mohammad AlShaya https://orcid.org/0000-0003-1891-1227
Deema Farsi https://orcid.org/0000-0003-1371-913X

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