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The accuracy of asynchronous tele-screening for detecting dental caries in patient-captured mobile photos: A pilot study

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ABSTRACT

Objectives: Unaided visual inspection is a primary dental screening technique. Given the uneven distribution of dental services and prolonged waiting periods, an alternative screening approach is required to increase access to dental care. The purpose of this study was to evaluate the accuracy and reliability of tele-screening for detecting dental caries using mobile intra-oral photos taken by participants.

Methods: Dental care seekers attending Umm Al-Qura University Teaching Dental Hospital in 2022 were invited to participate in this study. The participants were initially examined by dental interns at the hospital under the supervision of faculty dentists (reference standard) before intra-oral photos were acquired by a trained sixth-year dental student using a Samsung S10 camera. Following an introduction to the photography guide, the same participants then took intra-oral photos of their teeth at home using their mobile devices, which were all uploaded to WhatsApp for later review. Two trained dental reviewers (sixth-year dental students) independently reviewed the intra-oral photos. Sensitivity, specificity, and Kappa scores were estimated to assess the performance of the tele-screening approach relative to the reference unaided dental examination.

Results: Twenty-three participants, with a mean age of 30 ± 12 years, were enrolled. The mean decayed, missing, and filled teeth (DMFT) was 13.43 ± 5.48. Patient-delivered tele-screening demonstrated a sensitivity, specificity, and inter-rater reliability kappa of 94 %, 90 %, and 0.81, respectively, when compared to unaided dental examination. Dentist-delivered tele-screening approach demonstrated a sensitivity of 88–89 %, specificity of 88–91 %, and kappa score of 0.75–0.79 relative to unaided dental examination.

Conclusions: This study demonstrated that the tele-screening approach based on reviewing intra-oral photos taken by participants can be a valid and reliable alternative to unaided dental examination. This is important for ensuring sustainable access to dental care.

1. Introduction

Dental caries (tooth decay) continues to be one of the most common chronic diseases in the globe (Petersen, 2008). According to the 2016 Global Burden of Disease, oral diseases affect approximately four billion people worldwide, causing 15 million Years Lived with Disability (Vos et al, 2012). The caries burden in Saudi Arabia remains high as approximately 80 % of Saudi children experience dental caries (Al Agili, 2013; Alhabdan et al, 2018). A previous study revealed that the mean dmft for primary teeth among Saudis aged 3–7 years was 7.34, while the mean DMFT for permanent teeth among Saudis aged 12–19 years was 7.35 (Al-Ansari, 2014). Socioeconomic status, education level, and access to dental care is associated with an increased risk of dental caries (Al Agili & Farsi, 2020). If left untreated, dental caries can have serious health consequences that affect both physical and psychosocial well-being (Guarnizo-Herreño & Wehby, 2012; Petersen, 2008; Tran et al, 2018). Therefore, the maintenance of oral health is fundamental to overall health, well-being, and quality of life (Glick et al, 2012).

Regular dental screening is essential for identifying at-risk groups and enabling appropriate direction of resources for those who need it the

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most (Greenberg & Glick, 2012). Unaided dental examination (i.e., without radiographs) is the most common method used to assess oral health status in community settings (Day et al, 2016). However, population-wide dental screening can be challenging and costly, particularly due to factors such as travel and availability of dental services (Estai et al, 2017a). Thus, a valid and economical tool for wide-reaching dental screening and continuity of care is essential. Teledentistry provides a promising technological solution to improve accessibility and is user-friendly and economical to use at the population level (Estai et al, 2017a).

The IADR's e-Oral Health Network group defined teledentistry as "*Teledentistry represents the use of information and telecommunication technology to provide oral healthcare services between an oral healthcare provider and a patient/recipient or other health care providers, who are separated by a distance*" (Marino et al, 2023). Teledentistry services can be delivered through an asynchronous modality that involves the transmission of patient health data (e.g., intra-oral photos and dental charts) to dental care providers through secure communication systems to assess their condition or provide remote recommendations (Kopycka-Kedzierawski & Billings, 2013; Maret et al, 2021; Mariño et al, 2016; Park et al, 2019). Rapid technological advances have increased the use of teledentistry in screening, dental consultation, and education (Estai et al, 2018; Mariño & Ghanim, 2013).

Widespread connectivity and mobile camera evolution allow dentists to perform multiple tasks such as processing, storage, and transmission of intra-oral photos (Hardan & Moussa, 2020). A substantial body of evidence indicates that the use of asynchronous tele-screening to detect dental caries from still photos taken by a smartphone camera has an acceptable level of diagnostic accuracy (AlShaya et al, 2022; Estai et al, 2021; Kohara et al, 2018). A recent study that used teledentistry to screen for dental caries from mobile photos acquired by trained teachers reported that the tele-screening approach achieved high sensitivity and specificity (>90 %) in detecting dental caries compared with unaided dental examinations (AlShaya et al, 2022).

To date, only a few studies have evaluated teledentistry for dental screening based on intra-oral photographs taken by patients or caregivers (Azimi et al, 2023). In previous studies, data collection was mainly performed by oral health professionals or trained health personnel (Daniel et al, 2013; Mariño & Ghanim, 2013). Amid COVID-19 restrictions, this approach may be impractical and costly, as it requires patients to travel to have their teeth photographed in person. Therefore, there is a need for an alternative approach that can ensure regular dental screening, even during emergencies. Against this background, dental care seekers or caregivers (in the case of children) could help with the collection of clinical information using their smartphone devices and forward intra-oral photos online for a later review by dentists operating remotely. This approach would offer sustainable access to dental care, even in places where dental services are unavailable. The purpose of the current study was to evaluate the diagnostic performance of asynchronous tele-screening in detecting dental caries based on mobile intra-oral photos taken by participants.

2. Materials and methods

2.1. Study settings

This cross-sectional study was conducted in the dental clinics at the Umm Al-Qura University (UQU) Dental Teaching Hospital between January 2022 and March 2022. Human research ethics approval was obtained from the IRB at the UQU (ref no: HAPO-02-K-012–2021-11–853). This study followed the Standards for Reporting of Diagnostic Accuracy (STARD) statement (Bossuyt et al, 2015).

2.2. Tele-screening equipment

The participants used their smartphone devices to collect intra-oral photos. The types of smartphones used varied but included iOS-based (n = 9, 39 %), or Android-based phones (n = 14, 61 %). Intra-oral photos taken by the sixth-year dental student were acquired using the rear camera of a Samsung S10 with a light source from another device. The phone used was in a portrait setting with a 9:16 ratio, and no magnification was used during dental photography. A light source was used to simulate the real settings of patients in the clinic. To standardize the capture of photos, the same device and light source were used for all the participants. WhatsApp was used to transfer and collect participants' intra-oral photos for later review by dentists online. Once transferred to the research team, all intra-oral photos were deleted from WhatsApp. WhatsApp did not affect the quality of the photos and all photos were readable. All intra-oral photos were anonymous (showing only teeth and associated gum), and no personal information was retained. All data were stored in a password-protected cloud drive managed by the UQU. During the photo review, all intra-oral photos were displayed on a computer LCD 15-inch screen with a resolution of 1920 × 1080.

2.3. Participants and recruitment

A convenience sample of dental care seekers aged > 18 years who attended dental screening clinics was invited to participate in this study. Five participants were recruited using WhatsApp messages and follow-up phone calls. The messages included information about the research purpose, a pamphlet, an instructional video, and confirmation of participation. The research team explained the study to the participants and scheduled their first appointment at the hospital, during which written informed consent was obtained. Participants were excluded if their photos were of poor quality (i.e., more than one tooth was not clear, meaning that the desired tooth anatomy captured was obscured due to saliva, debris, shadow, or insufficient lighting), were edentulous, did not follow the study photography protocol, or were unable to provide written informed consent (Fig. 1).

2.4. Staff calibration and training

The dental reviewers were 6th-year dental students at the UQU. Two 6th-year dental students were trained on caries detection and diagnosis using a standardized set of intra-oral photos. Training sessions were facilitated online by a specialist pediatric dentist (JP) with substantial experience in dental photography and a senior lecturer in cariology. The calibration of the two dental reviewers was deemed acceptable (inter-rater kappa score > 0.8) compared to the trainer's review.

2.5. Unaided dental examination (the reference test)

Unaided dental examinations (without radiography) were performed at dental screening clinics. Eligible participants were examined by six dental interns under the supervision of a faculty member. All dental examinations were performed with the participants lying in a dental chair and under an LED light source. Dental kits consisting of a dental mirror, blunt probes, cotton wool rolls to dry saliva, and sterile gauze were used during dental examinations. All surfaces of each tooth examined were scored as caries-free, caries-present, filled with no caries (including crowns), filled with caries, missing, or unerupted using the decayed, missing, and filled teeth (DMFT) index. The scores for each tooth were recorded on an assessment form according to the WHO oral health survey guidelines (World Health Organisation, 2013).

2.6. Dental photography procedure (the index test)

Dental photography involved two phases: patient-delivered and dentist-delivered tele-screening.

In the patient-delivered tele-screening, participants were introduced to a dental photography instructional brochure and a video guide (Fig. 2). Participants captured intra-oral photos at home with the help of

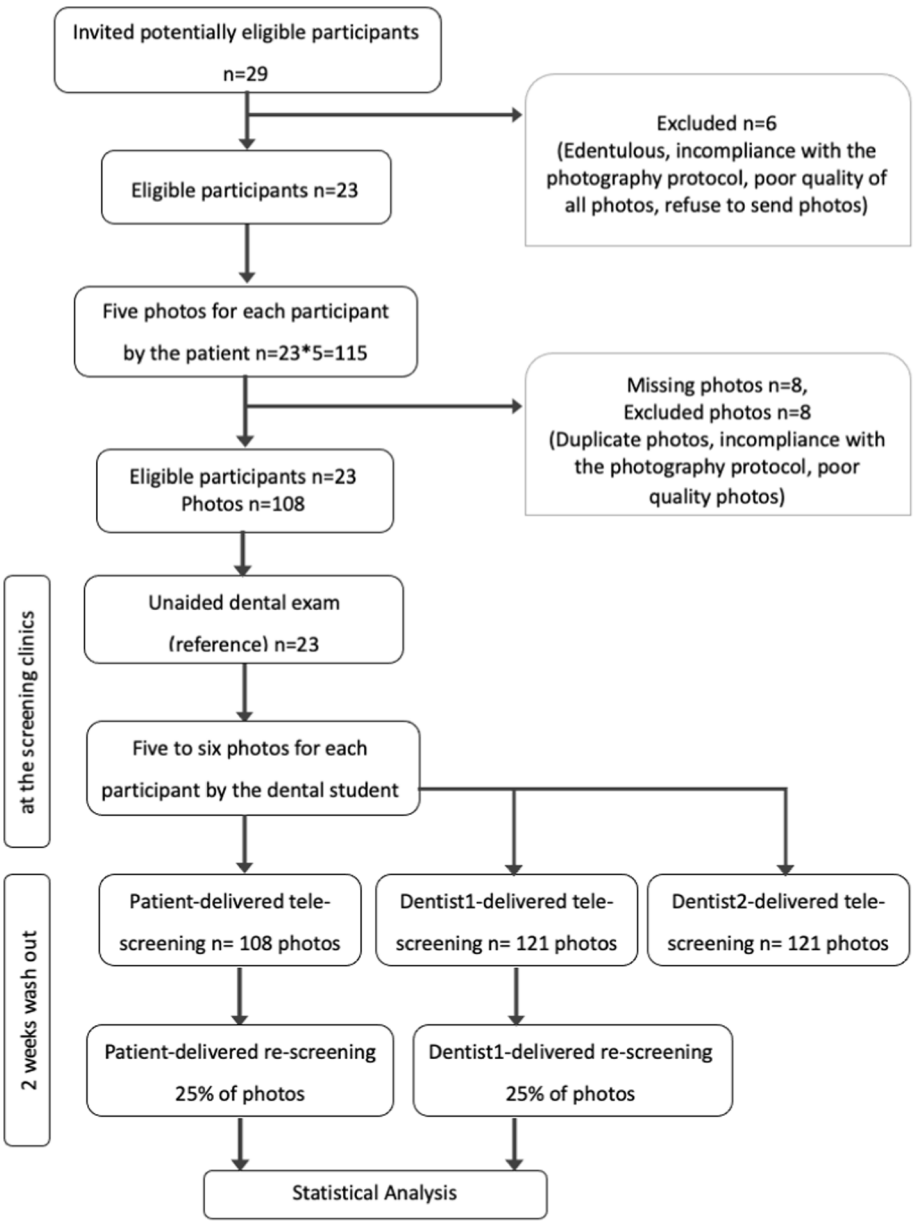

Fig. 1. Flow chart demonstrated the participants' recruitment, dental examinations, dental photography procedure.

Fig. 2. Instructional Video guide used to assist participants to take dental photos (Link of video can be found here: https://youtu.be/m9eE7GnoCbo).

a third party (e.g., a family member or friend). All intra-oral photos collected by the participants at home were sent via WhatsApp to the research team for review. Participants' demographic data were collected via a brief survey, in addition to their perspectives on the photo-taking process. Questions included age, sex, education level, phone type used in taking photos, participants' perspectives of capturing photos of their mouth and teeth (e.g., easy or difficult), and which method of instruction was helpful to them (the guide video, pamphlet, or communication with the dentist).

In the dentist-delivered tele-screening, a trained sixth-year dental student obtained intra-oral photos from the same group of participants who had unaided dental examinations at the dental screening clinic. Five photos (front, right lateral, left lateral, upper occlusal, and lower occlusal views) were obtained using a Samsung S10 camera. No cheek retractors or mirrors were used; rather, participants retracted their cheeks and lips using their fingers, as guided by dental students (Fig. 3).

All intraoral photos were screened for quality and orientation prior to the review. Two trained dental reviewers (another sixth-year dental students) independently reviewed intra-oral photos collected at the

Fig. 3. Example of intra-oral photos views captured by the study's participants.

screening clinics, referred to as dentist-delivered tele-screening. In addition, one of the dental reviewers (reviewer #1) independently assessed the intra-oral photos collected by the participants at home, referred to as patient-delivered tele-screening. The dental reviewers were blinded to each other and to the unaided dental assessments. The scores for each tooth were recorded on an online assessment form, following the WHO oral health survey guidelines (World Health Organisation, 2013).

2.7. Data analysis

The primary outcome was caries experience, measured using the DMFT index, and a binary variable was used: caries-present and caries-free (DMFT = 0 and DMFT > 0). The analysis was conducted at the tooth level (World Health Organisation, 2013). In the analysis, the teeth were coded as either caries-present or caries-free. Any visible carious lesions, including non-cavitated, active initial caries, arrested caries, or filled teeth with caries, were classified as caries (Estai et al, 2016). It is difficult to differentiate arrested caries from active caries using the human eye because oral radiography is not used during unaided dental examinations. Filled teeth with no caries or missing teeth were excluded from the analysis because they were easy to identify from the intra-oral photos. This is consistent with the protocols used in previous studies (Estai et al, 2016).

The sample power calculation was not applicable because the current pilot study aimed to assess the feasibility of teledentistry based on mobile intraoral photos collected by participants.

Data were entered into an Excel spreadsheet (Microsoft 2022, Redmond, WA, USA), where they were cleaned, re-coded, and collated. The data were subsequently entered into the SPSS statistical software program (IBM SPSS Statistics, version 28) for the purpose of analysis. Using unaided dental examination as the reference standard, we calculated the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) with 95 % confidence intervals (95 % CI) for each reviewer by employing a 2 × 2 contingency table. In addition, kappa scores were used to test the inter-rater reliability of the tele-screening method versus the reference unaided dental examination. Finally, 25 % of the dataset (intra-oral photographs) were selected randomly and re-assessed by the same dental reviewers after two weeks of washout to test for consistency. As per the Landis and Koch measurement of observer agreement for categorical data, the interpretation of kappa scores was as follows: 0.01–0.20 as none to slight, 0.21–0.40 as fair, 0.41–0.60 as moderate, 0.61–0.80 as substantial, and 0.81–1.00 as almost perfect agreement.

3. Results

A total of 29 participants were enrolled in this study. Data from six participants were excluded from the analysis due to edentulism, non-compliance with the photography protocol, or poor quality of all dental photos. Data from 23 participants were included in the final analysis, of which 644 teeth were examined. A total of 108 intra-oral photos were captured by participants. The mean age of the participants was 30 ± 12 years, and 52 % of them were female. The caries experience (DMFT > 0) was 100 % and the mean DMFT was 13.43 ± 5.48. The demographic information of the participants is presented in Table 1.

For the patient-delivered tele-screening approach, 39 % of the

Table 1
Demographic characteristics of the participants (N = 23).

Characteristics	n (%)
Age	
18–35 years	17 (74 %)
≥ 35 years	6 (26 %)
Gender	
Female	12 (52 %)
Male	11 (48 %)
Education Level	
Primary or intermediate school	10 (44 %)
High school or bachelor	13 (57 %)

participants used an iPhone, 39 % used Samsung devices, and the rest used other phone types for dental photography. Regardless of the type of phone, all intra-oral photos were gradable by the team, except for photos of participants who did not follow the photography protocol. Most participants (87 %) perceived taking intra-oral photos at home as easy to use. More than half of the participants felt that instructional videos helped them acquire intra-oral photos and that communication with dentists was helpful (78 %). The rest of the participants found the educational pamphlets helpful (22 %).

Dentist1-delivered tele-screening compared to the reference unaided dental examination had a sensitivity and specificity of 88.43 % and 90.58 %, respectively. Dentist2-delivered tele-screening showed a sensitivity of 88.50 % and specificity of 87.76 % compared to an unaided dental examination.

Patient-delivered tele-screening versus unaided dental examination demonstrated a sensitivity of 93.90 % and a specificity of 89.73 %. Patient-delivered tele-screening versus dentist1-delivered tele-screening achieved a sensitivity and specificity of 97.02 % and 93.27 %, respectively. A summary of the diagnostic accuracy of tele-screening is presented in Tables 2 and 3.

The inter-rater agreement for tele-screening versus unaided dental examination was substantial to almost perfect, with kappa coefficients ranging from 0.75 to 0.88. The intra-rater agreement for dental reviewers who participated in tele-screening was almost perfect, with a kappa coefficient > 0.95.

4. Discussion

The present study aimed to compare the diagnostic accuracy of tele-screening for dental caries with that of unaided dental examinations. The findings from this study suggest that tele-screening offers an accurate and reliable means for the virtual screening of dental caries based on mobile intra-oral photos obtained by participants at home.

The prevalence of caries was very high in our sample, with DMFT being 13.43 ± 5.48. This is consistent with a previous systematic review, which found that DMFT ranged from 13.81 to 20 among Saudi adults (Alshammari et al, 2021). We acknowledge that the unaided dental examination used in this study was not a comprehensive oral examination; thus, the absence of oral radiography may underestimate detection and prevalence of dental caries.

The dentist-delivered tele-screening approach demonstrated relatively high specificity (88–93 %,) which reflects the dental reviewers' ability to avoid rating a tooth as dental caries when it is, in fact, sound (i.e., fewer false positive errors). Similarly, the sensitivity was high, ranging from 88 to 97 %. Notably, the patient-delivered tele-screening approach demonstrated high specificity (>90 %) and sensitivity (>94 %) compared with dentist-delivered tele-screening and unaided dental examinations. These findings suggest that the proposed tele-screening has improved diagnostic performance compared to previous research evaluating caries detection from mobile dental photos (AlShaya et al, 2020; Azimi et al, 2023; Estai et al, 2017b; Estai et al, 2021). For instance, our findings were comparable to those of a previous study that indicated that teledentistry (based on photos collected by teachers) had a sensitivity of 89–98 % in detecting dental caries in children (AlShaya et al, 2022). Our study also demonstrated a higher level of accuracy than a recent tele-screening study that involved primary caregivers in collecting dental photos from preschool children with a sensitivity ranging from 44 % to 88.4 % (Azimi et al, 2023). The improved results in the present study could be attributed to the sufficient training provided to dental reviewers, the quality of photos, and the equipment used in dental photography. This may be further emphasized by the WHO oral health guidelines, which focus on analysis at the tooth level.

The tele-screening approach demonstrated substantial to almost perfect concordance with unaided dental examinations. Additionally, the intra-examiner reliability was high, suggesting that the dental reviewers were consistent in their scoring and identification of carious lesions from the intra-oral photos. These findings are consistent with previous studies (AlShaya et al, 2022; AlShaya et al, 2020; Estai et al, 2017b; Estai et al, 2021).

The quality of photos and the ability to accurately review photos are critical when evaluating the feasibility of the tele-screening approach (Park et al, 2009). Five records were excluded from the analysis because of the poor quality of the photos, indicating that they could not be graded by dentists. The inherent limitations of the photographic method mainly stem from camera autofocus delay, improper illumination, and the two-dimensional view of photos, which permits the visualization of all tooth surfaces. Although an instructional photography manual (including a video guide) was provided to the participants to obtain high-quality photos, adherence to the protocol may still present some challenges. Further research is needed to explore the use of artificial intelligence to perform quality checks in dental photography. Despite these challenges, most participants found dental photography to be easy to use. Perceived usefulness and ease of use are crucial for the adoption

Table 2
The diagnostic accuracy and reliability of tele-screening approach.

	Unaided dental examination* vs. Dentist1-delivered tele-screening#	Unaided dental examination vs. Dentist2 -delivered tele-screening#
Sensitivity	88.43 % (83.39–92.37 %)	88.50 % (83.25–92.57 %)
Specificity	90.58 % (86.89–93.51 %)	87.76 % (83.81–91.03 %)
Accuracy	89.72 % (86.86–92.14 %)	88.03 % (85–90.64 %)
PPV	86.04 % (81.45–89.63 %)	80.82 % (75.97–84.89 %)
NPV	92.26 % (89.17–94.52 %)	92.90 % (89.89–95.06 %)
Kappa	0.79 (0.73–0.84)	0.75 (0.69–0.81)

Values in the brackets are 95% CI.
PPV = positive predictive value.
NPV = negative predictive value.
* Unaided dental examination refers to the reference unaided dental examination.
# Dentist-delivered tele-screening refers to dental photos collected by 6th-year dental student at dental clinics which were independently reviewed by dentist1 and dentist2.

Table 3
The diagnostic accuracy and reliability of the patient-delivered tele-screening.

	Unaided dental examination vs. Patient-delivered tele-screening*	Dentist1-delivered tele-screening vs. Patient-delivered tele-screening*
Sensitivity	93.90 % (89.07–97.04 %)	97.02 % (93.19–99.03 %)
Specificity	89.73 % (85.94–92.78 %)	93.27 % (89.99–95.74 %)
Accuracy	91.11 % (88.25–93.47 %)	94.55 % (92.16–96.38 %)
PPV	81.91 % (76.67–86.19 %)	88.11 % (83.18 %-91.74 %)
NPV	96.74 % (94.21–98.19 %)	98.39 % (96.26 %-99.31 %)
Kappa	0.81 (0.75–0.86)	0.88 (0.84–0.93)

Values in the brackets are 95% CI.
PPV = positive predictive value.
NPV = negative predictive value.
* Patient-delivered tele-screening refers to dental photos obtained by patients at home that were reviewed by dentist1 only.

and acceptance of any technology (Venkatesh et al, 2012). Thus, gathering feedback from users regarding tele-screening is useful for informing the design and implementation of future teledentistry programs.

In 2020–2021, all elective surgeries and non-essential medical and surgical procedures (including dental care) were delayed during the onset of the COVID-19 outbreak as part of government efforts to control the spread of infection. The use of teledentistry in virtual dental screening can help avoid congestion in oral health facilities and ensure sustainable access to dental care, which would directly contribute to reducing the risk of COVID-19. To facilitate dental screening, training non-oral health professionals (e.g., school staff or primary caregivers) regarding the use of teledentistry can be valuable for collecting clinical data from children for later evaluation by dentists (Maret et al, 2021). In addition, engaging trained non-health personnel in epidemiological surveillance can be beneficial, particularly in places where access to dental care is limited (AlShaya et al, 2022; Azimi et al, 2023; Sankaranarayanan et al, 2005). Within the framework of its limitations, teledentistry could still offer a low-cost and reliable means of virtual dental screening, even during pandemics or extended lockdowns.

The scope of this study adheres to Saudi Vision 2030, particularly the National Transformation Program, which seeks to transform the healthcare system to improve quality and access to healthcare (Saudi Vision 2030, 2023). This is also aligned with the national initiative to prevent dental caries in Saudi Arabia (Ministry of Health, 2019). More recently, the Saudi Telehealth Network was established to support the digital transformation of healthcare in Saudi Arabia (Saudi Health Council, 2020). The findings of this study will help inform health policymakers about the capabilities of digital health in dental care and facilitate the rolling out of teledentistry in the mainstream health system.

The current study has some limitations. Due to time constraints, only one reviewer assessed intra-oral photos collected by the participants. The use of different smartphone devices and camera specifications by the participants may also have contributed to the variation in the quality of the photos. The current pilot study used a small sample size, which may have affected the generalizability of the findings. However, this would provide a platform for further research using a larger sample size. Most participants enrolled in this study were adults; therefore, further research among children is warranted, as dental caries remain a common health problem among Saudi children. In addition, data analysis in the present study was carried out at the tooth level following the WHO oral health survey protocol. Additional investigations are required to explore the performance of the tele-screening approach at the tooth surface level and lesions of varying severity using the International Caries Detection and Assessment System (ICDAS).

5. Conclusions

The asynchronous tele-screening approach demonstrated excellent diagnostic accuracy in detecting dental caries based on mobile dental photos obtained by participants. These findings suggest that digital photography and mobile technology can be combined to create an inexpensive, practical, and reliable screening tool for dental screening. In the long run, parents or school staff could help collect clinical data from children for later review by a dental expert. This would enhance the efficiency of healthcare systems; instead of sending health staff to collect patient records, they would focus on the treatment and referral of urgent cases. This is important to ensure sustainable access to preventive dental care, particularly during times of lockdown or in rural regions, where access to dental services is limited.

6. Credit authorship contribution statement

A.H.Q., I.K.B., J.P., and M.E. conceived of the research and study design.

A.H.Q., I.K.B., M.H., A.A., A.A., and M.A. contributed to the data collection and review.

A.H.Q. and M.E. led the data analysis and interpretation.

J.P. led the training and calibration.

A.H.Q. and M.E. led the writing and drafting of the manuscript.

Ethical statement

Human research ethics approval for this study was obtained from the IRB office at the Umm Al-Qura University (ref no: HAPO-02-K-012–2021-11–853).

All participants provided written informed consent prior to their participation in the study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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