A proof-of-concept evaluation of a cloud-based store-and-forward telemedicine app for screening for oral diseases

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Abstract
Objective: It is widely considered that telemedicine can make positive contributions to dental practice. This study aimed to evaluate a cloud-based telemedicine application for screening for oral diseases.

Methods: A telemedicine system, based on a store-and-forward method, was developed to work as a platform for data storage. An Android application was developed to facilitate entering demographic details and capturing oral photos. As a proof-of-concept, six volunteers were enrolled in a trial to obtain oral images using smartphone cameras. Following an onsite oral examination, images of participants’ teeth were obtained by a trained dental assistant. Oral images were directly uploaded from the smartphone to a cloud-based server via broadband network. The assessments of oral images by offsite dentists were compared with those carried out via face-to-face oral examinations.

Results: A complete set of 30 oral images was obtained from all six participants. Out of 192 teeth reviewed, the proportion of ungradable teeth was 8%. Sensitivity and specificity of teledental screening were 57% and 100% respectively. The inter-grader agreement estimated for two examination modalities and between two teledental graders was 70% and 62% respectively. Findings indicate that the proposed system for screening of oral diseases can be implemented to provide a valid and reliable alternative to traditional oral screening.

Conclusion: This study provided evidence that a robust system for store-and-forward screening for dental problems can be developed, and leads to the need for further testing of its robustness to confirm the accuracy and reliability of the teledentistry system.

Keywords
Telemedicine, teledentistry, smartphone, cloud, caries, dental, digital imaging, remote

Introduction
Despite significant progress in reducing oral diseases in developed countries over the past three decades, dental caries remains a significant public health problem, particularly amongst disadvantaged people and people living in remote areas.1 In most developed countries (including Australia), the majority of oral health professionals work in private practice and clustered in cities, and remote and regional areas suffer from a significant shortage of dental practitioners.2,3 Delay in seeking dental care could be considered a major contributor to poor oral health.4 This can happen not only in rural or remote areas where access is primarily limited by geography, but also in underserved urban regions where access is limited by a lack of socioeconomic resources or complexity of life.5

Due to remoteness, shortage of dentists, lack of insurance or financial burden, in Australia only half of all adults visit a dentist at least once a year.6 Thus, it is essential to seek strategies that can increase access to adequate care and avoid long waiting without compromising quality, effectiveness and safety. One of a number of growing...
solutions to address limited access to dental care is the utilization of telemedicine technologies in the screening for oral diseases, providing care, evaluation of care and referral. There are two telemedicine modalities: real-time consultation and store-and-forward. For most dental applications, the store-and-forward method provides excellent results without excessive costs for equipment or connectivity. While email remains a popular method for store-and-forward consultation with limited data security, videoconferencing is still a popular method for real-time consultation. However, video conferencing has its limitations as it needs expensive equipment and requires all parties to be online at the same time. Cloud storage represents another store-and-forward method that allows storing and retrieving data through a secured system. Despite adoption rates for email and videoconferencing within the field of dentistry increasing rapidly, adoption of cloud computing is still lagging.

With smartphone camera technology improving significantly, utilization of smartphones to obtain and transmit images for screening of dental caries has recently matured. Similar to dedicated digital oral cameras, smartphone cameras have zoom and flash features, as well as manual adjustments that allow easier capturing of intraoral or extra-oral images. The portability and accessibility features of smartphones can provide an effective means for capturing images in less time and be less intimidating for children. Recent studies reported that children were enthusiastic and cooperative during the process of capturing images using smartphones. The process of capturing images using smartphones can therefore be noninvasive and less stressful for small children than the usual oral examination. This study was designed to develop a suite of technology harnessing the advantages of ubiquitous smartphone imaging technologies and cloud-based computing and to build an easy to use, accurate tool to enhance the opportunity for dental screens for patients with otherwise limited access to dental care.

**Methods**

**System architecture**

Based on a telematic platform ‘Remote-i’, which was developed for ophthalmology and other medical applications, the Australian e-Health Research Centre (AEHRC) has built a store-and-forward based teledentistry system to carry out a screening programme for dental caries. Remote-i is a comprehensive data management server that has been widely used as a telematic platform in various screening programmes in Australia and China. The system enables uploading and storing images online either directly from a smartphone or from a computer. In addition, it is capable of image acquisition, data entry, storage and retrieval of data through a password-protected system (Figure 1).

**Smartphone application (Android)**

An image acquisition Android application was developed and installed on the Motorola® Moto smartphone (USA) to facilitate entering patient personal details and capturing dental photos, and then uploading data corresponding to each patient to cloud storage, using Wi-Fi hotspots or the cellular data networks (Figure 2). At this stage, the app only supports Android devices, but an app that can support other operating systems such as iOS and Windows is under consideration. The patients’ data stored on the database system are accessible via a specially designed web interface. The web interface also allows users to plug in any USB dental camera, capture images and add them to the current patient’s record without the need to import them from the mobile device. The research team can also access the server and follow up with the remote screening site for further action (Figure 1).

**Technical details of the telemedicine system**

The Remote-i server uses Microsoft ASP.NET server technology under the Windows 2008 server and is built using the ASP.NET MVC framework. Dental screening data is stored on the server using the Microsoft SQL Database engine. The website is built using modern web standards (HTML5, JavaScript and CSS technologies), and can be rendered in any mobile/desktop web browsers with proper size proportions. Users can log in to Remote-i using any web browser, including Chrome, Mozilla Firefox and Safari, from any location. The database is highly portable across various platforms, including Microsoft Windows, Mac OS X, and Linux. Only authorized users (investigators and teledental examiners) are allowed to access the database using individual user IDs and passwords. For security purposes, all data transmissions go over encrypted internet connections such as Secure Socket Layer (SSL) and hypertext transfer protocol over SSL. The speed of data transmission depends on the network bandwidth available at the facility, but at a maximum it may take 2–3 minutes (using the 3G network in rural areas) to transmit data from the smartphone to the server.

The phone app is developed using Java on the Android platform. The Android app uses an SSL to transfer information to and from the cloud server. The cloud server and Android app communicate using the JSON (JavaScript object notation) messaging standard to promote open interoperability within different kinds of systems. The teledental Android app is designed to invoke existing Android camera applications installed in the user smartphone to capture images, which provides the user with the flexibility to choose suitable camera apps for dental imaging or use the default one. The teledental Android app can seamlessly take control after image capture and manage the captured images using adding, deleting, clipping and reviewing functions (Figure 2).
Proof-of-concept trial protocol

All data collection was completed under ethics approval from The University of Western Australia. Six adult volunteer patients enrolled in the proof-of-concept trial. Each participant received an in-person oral examination by a registered dental practitioner (without radiographs) to record caries and existing restorations; this was used as the gold standard. The onsite dentist spent an average 10 minutes per patient for oral screening. The dentist recorded data on an oral assessment sheet aligned with World Health Organization (WHO) protocol\textsuperscript{14} and provided treatment recommendations or referral (Figure 3). In a separate visit, a trained teledental assistant took photographs of each participant’s oral cavity using a smartphone application. Techniques for obtaining each oral view were demonstrated during training, and each teledental assistant is provided with image photography protocol. Cheek retractors and intraoral mirrors were not used in the screening so as to simulate the final expected working conditions. An average of five oral images were taken per patient including: one anterior view; one upper occlusal view; one lower occlusal view and two lateral view images. Additional views of the teeth, intraoral soft tissue or extra-oral structures were taken in some cases. The photographs were then directly transmitted from the smartphone to a secure online server (Remote-i) for evaluation by an offsite grader (Figure 3). Although the patient’s data transmitted to the server is de-identified or anonymous, it was not de-identified to the main investigator or clinicians as we used patients ID numbers in the database as a key. Techniques for obtaining each oral view were demonstrated during training, and each teledental assistant was provided with image photography protocol.

Role of the teledental assistant

Dental screening can be performed by teledental assistants (who were, in the proof-of-concept environment, dental students or assistants). The teledental assistants were oriented to basic oral visualization and provided hands-on training on how to capture good quality images using a smartphone app and the camera. Each assistant had the opportunity to practice using the smartphone’s camera on adult volunteers for as long as it took for them to feel competent. The formal training was kept to a bare minimum to simulate the situation expected in the working situation.

Role of the teledental grader (offsite practitioner)

The reviewing of the dental images was carried out by an offsite dental practitioner using a separate web-based data and image-viewing app built upon the Remote-i system.
In the proof-of-concept, two independent teledental graders were provided with written and oral instructions about how to log in to the Remote-i server to review the intraoral images, how to insert comments or findings on the predefined oral assessment form and how to submit their findings into the Remote-i server. Offsite practitioners can access the database using individual user IDs and passwords. After selecting a record, a predefined dental chart appears for the reviewers to insert their comments. The chart includes an oral health assessment form based on the data from the WHO protocol (Figure 3). The assessment form is designed to facilitate the processing of results and minimize errors. Each grader reviewed the oral images and commented on the dentition status for each tooth (dental caries or existing restoration) on a predefined assessment form. A final question required to be answered is an assessment of interventional urgency, and the need for patient referral to a dental practice to receive further treatment. After completing the review, the grader could submit the report (and recommendation) into the Remote-i server for storage in the cloud based server.

**Findings from the proof-of-concept trial**

A complete set of 30 oral images was obtained from all six participants using the smartphone’s camera and uploaded to the Remote-i server (Figure 3). All uploaded files were stored in a database in an uncompressed JPEG format; the average file size was 900 KB. Participants’ characteristics collected during the trial are summarized in Table 1. It took approximately one minute to register a patient (entering personal details) and five minutes to take pictures. The quality of images obtained by the teledental assistants was assessed by an independent practitioner to ensure that they were complete, colour-balanced, focused and clear. Oral images of poor diagnostic quality were re-captured when necessary.

The proportion of the captured digital images that were gradable was 100%. Out of 192 teeth reviewed, the proportion of ungradable teeth was 8%. Statistical testing of the reliability of the two sets of oral examinations (clinical and teledental) and two graders (grader 1 and grader 2) was completed using kappa statistics. The calculation of sensitivity and specificity of teledental screening was based on the presence or absence of untreated caries; the sensitivity of the teledentistry examination was 57% and specificity was 100% versus in-person oral examination (Table 2). The inter-grader agreement between traditional oral examinations and teledentistry examinations was 70%, while inter-grader agreement between teledental grader 1 and teledental grader 2 was 62% (Table 2).

**Discussion**

Our findings suggested that the combination of a smartphone camera and store-and-forward technology for oral health screening can be adequate for screening purposes and offers a reliable alternative to traditional oral examinations. The trial showed at the level of proof-of-concept that there was a good concordance between teledental and face-to-face oral assessments. This reflects previous research which shows no statistical difference between teledentistry and clinical screening for caries, with Kappa statistics for inter-grader reliability between clinical and teledentistry screenings ranging from moderate to very good agreement. Telemedicine has become a viable option to address limited access to specialist care, particularly in locations far from specialist centres. Specialists do not need to be physically present with the patient, as they can provide consultation and guidance for local practitioners at a distance. Teledentistry would expedite early diagnosis and facilitate timely treatment of oral diseases by reducing the isolation of practitioners and increasing access to specialist care. In addition, it has the potential to improve the quality of care for the underserved by facilitating the provision of timely information to dentists for better decision making and effectively triaging patients who require specialist consultation, thus reducing waiting lists and supporting locally based oral treatment. Telemedicine applications within dentistry are highly diverse, including preventive dentistry, oral medicine, oral and maxillofacial surgery, orthodontics, periodontics and education, with...
preliminary evidence suggesting positive outcomes in comparison to clinical settings.\(^{20}\)

The quality of images and the capability to grade images accurately are very important factors when evaluating the feasibility of telediagnosis of diseases.\(^{21}\) During testing we found that many of the oral images were blurred or over saturated when the default camera application was used. This is because the flash of the camera is too bright, and when we move the camera close to the mouth it will overexpose the area and the resulting image will be bleached out. However, a third party camera app has a feature called ‘the torch mode’ (e.g. Camera360 Ultimate, China), which can keep the flashlight turned on during the initial focus and will not change until the capturing is finished. Using this mode, we were able to obtain high quality photos with proper focus and illumination. This is likely due to the ability of the mobile phone computer to analyse the over-exposed areas and adjust its exposure values appropriately.

The smartphone camera used in this study produces images of 10 megapixels, and is considered adequate for producing good-quality images. However, in some cases there was concern about the loss of detailed diagnostic information due to the poor quality of the images. Because graders sometimes found difficulty identifying caries spots and differentiating them from darkened defects or artefacts, some teeth were graded as unrated or not shown by teledental graders. Depending on the

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### Table 1. Participants’ characteristics.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Age (in years)</th>
<th>Sex</th>
<th>Indigenous status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33</td>
<td>Male</td>
<td>None</td>
</tr>
<tr>
<td>2</td>
<td>61</td>
<td>Male</td>
<td>None</td>
</tr>
<tr>
<td>3</td>
<td>53</td>
<td>Male</td>
<td>None</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>Male</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>47</td>
<td>Female</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>22</td>
<td>Male</td>
<td>None</td>
</tr>
</tbody>
</table>

### Table 2. Accuracy and reliability of teledental screening.

<table>
<thead>
<tr>
<th>Comparison of oral health assessments</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Kappa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold standard vs teledental</td>
<td>57%</td>
<td>100%</td>
<td>0.70</td>
</tr>
<tr>
<td>1st grader vs 2nd grader</td>
<td>60%</td>
<td>99%</td>
<td>0.62</td>
</tr>
</tbody>
</table>

Calculation of sensitivity and specificity of teledental screening was based on the presence or absence of untreated caries. Kappa value refers to the level of inter-grader agreement between the first and second teledental graders of photographic assessment and between two modalities of oral assessment (gold standard versus teledentistry).
lighting, identifying amalgams or composites was also a challenge. Although training teledental assistants to obtain good quality oral images did not take much time, adherence to the given photography protocol was a challenge especially in the situation where patients are uncooperative or stressed, such as preschool children. In this trial, the sensitivity of the teledentistry examination was 57%, and specificity was 100%. The sensitivity value of 57% was because missing and filled teeth were not included in the analysis, as they can be easily recognized on digital images. In addition, sub-optimal sensitivity and specificity ratings are often associated with poor quality images which are likely attributed to the method, limitations of digital image acquisition (e.g. lighting, autofocus) or non-optimal image review modalities (e.g. monitors).\textsuperscript{21}

The shortcomings of current policy that govern telemedicine services have been a matter of concern for many practitioners.\textsuperscript{22} Lack of remuneration, licensure and taxation guidelines as well as medico-legal and copyright issues have created a barrier to the adoption of teledentistry in practice.\textsuperscript{23} Well-defined and efficient policies and laws are essential to regulate teledentistry practice and expand the use of technology in clinical practice. Despite teledentistry being applicable in both public and private dental settings, barriers impeding the integration of telemedicine technology into dental practice exist. The increasing costs of setting up telemedicine equipment were regarded by many advocates of telemedicine as a major obstacle.\textsuperscript{20} However, almost all dental practices possess intraoral cameras, digital radiographs, computers and internet access, which provide the core infrastructure for teledentistry practice.\textsuperscript{23} The use of available infrastructure can reduce overall practice expenses and consultation fees. Integration of teledentistry into practice has the potential to address certain aspects of routine dental practice such as reducing consultation times and practice expenses, as well as improving practice management, referrals and patient satisfaction.\textsuperscript{24} Further well-designed efficacy and cost-effectiveness trials in rural or remote communities are needed to determine whether specific populations may benefit from the use of teledentistry.

**Conclusion**

In order to improve oral health for the underserved or people living in rural and remote areas we need robust and readily deployable screening tools. Simple telemedicine applications hold considerable promise in bridging the gap in oral healthcare for the remote or rural communities. This trial shows that teledental screening has the potential to be utilized as a valid and reliable screening tool to identify high-risk individuals with decay and can allow onsite practitioners to triage referrals in a timely manner and treat more patients. However, this study was only a proof-of-concept trial and a full study is needed to confirm the accuracy and reliability of the teledentistry system.

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**Declaration of Conflicting Interests**

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