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Further opportunities for digital imaging in dental epidemiology

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ABSTRACT

Dental epidemiological research permits accurate tracking of the prevalence and distribution of oral disease across population groups, enabling planning and evaluation of public health interventions and healthcare service provision.

This first section of this paper aimed to review traditional assessment methods in dental epidemiology and to consider the methodological and logistical benefits provided by digital imaging, both generally and specifically in relation to an established dual-camera system.

The remainder of this paper describes the results of a semi-structured examination of an image archive from previous research utilising a dual-camera system, exploring whether the diagnostic yield of the images might be increased. Common oral conditions are presented alongside suggestions of the diagnostically useful data displayed in example images. Possible scoring mechanisms are discussed with consideration of the limitations that might be encountered for each condition. The retrospective examination suggests further data is obtainable from images acquired using the dual-camera system, however, consideration should be given to how best to validate this clinically. Additionally, other imaging modalities are discussed whilst taking into account the potential limitations of the dual-camera system.

1. Introduction

Significant improvements in oral health have been observed over the past 30 years, particularly in industrialised countries [1–3]. Despite these improvements, oral diseases remain highly prevalent across global populations and burden many with pain, infection and an overall reduced quality of life [3,4]. When the preventable and, in many cases, reversible nature of commonly occurring oral diseases are considered, there is a clear need for continued efforts to address the enduring effects that these conditions have on the majority of the world's population. Of particular relevance to both clinicians and public health bodies, these efforts should target those of lower socio-economic status who are burdened most by poorer oral health [4,5].

In order to remain informed of shifting population needs and to foster advancements in scientific knowledge, the World Health Organisation stipulates the importance of established "oral health information systems" [1]. A major component of these systems is epidemiological surveillance, capable of tracking the prevalence of oral diseases and their distribution across population groups. This essential data provides a contemporary understanding of oral health, enabling healthcare policy makers to both plan and assess the effectiveness of public health interventions and healthcare service provision [1,6].

1.1. Limitations of traditional epidemiology studies

Traditionally, oral epidemiological studies are designed around visual or visuo-tactile methods of assessment, whereby clinical examiners directly assess large numbers of the target population using relevant indices in relation to the condition(s) of interest [6,7]. Whilst the use of direct clinical assessment is well tested and 'simple' by design, the subjectivity of this method may lead to potential forms of bias [7].

Of particular note, the inability to blind examiners to factors such as the socio-economic status or residential location of the participant may lead to observer bias [6–8]. This issue is of particular relevance in epidemiological studies measuring fluorosis prevalence and severity, a legislative requirement in England for areas with artificial water fluoridation [9]. The York Review, a systematic review investigating the safety and efficacy of water fluoridation, highlighted the heterogeneity of both study design and analysis plans in epidemiological fluorosis research. In particular, the lack of examiner blinding to the fluoride exposure status of the participant was criticised due to the subsequent introduction of subjectivity and bias into the assessment method [10].

Attempts to address this issue have included transportation of study participants to a central location, as well as removal or masking of

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identifiers on participant clothing [11]. These strategies present their own logistical issues, particularly in relation to consent and safety. They would be instantly undermined should a participant disclose any information to the examiner, either explicitly through a statement that directly discloses their school or residential location, or, indirectly through the examiner's conscious or unconscious evaluation of a subject's accent, vocabulary, dress, or mannerism.

Further limitations of direct clinical assessment include the risk of examiner fatigue, particularly with high numbers of subjects and/or if multiple conditions are being measured. Additionally, onerous assessment procedures may impact on participant co-operation, particularly in children and adolescents. Lastly, direct assessment of large samples requires the physical presence of multiple examiners with associated support staff in each study site, a potentially limiting factor in relation to the financial burden and time consumption imposed by these requirements [8].

1.2. Digital imaging in oral epidemiology

Digital imaging has been utilised in oral epidemiology in an effort to overcome some of the limitations of direct clinical assessment. Recent studies have demonstrated successful mitigation of observer bias through the use of digital imaging, with the option to remotely score anonymised images facilitating effective examiner blinding [6,9,11,12]. Beyond reduction of bias in the assessment, remote scoring enables simultaneous assessment by multiple examiners across multiple locations, reduces the time between training/calibration of examiners and image assessment, and permits standardisation of examination conditions, further reducing environmental confounders [7,8].

The ability to archive the images presents obvious benefits in relation to data storage and research governance. Furthermore, this archiving permits re-assessment of conditions using different indices, if desired, as well as robust follow-up assessment in longitudinal studies [7–9,13]. Acquired image sets can be used for training and calibration purposes, with favourable evidence supporting the inter- and intra-examiner reliability achievable through this endeavour [14].

The use of digital imaging enables inclusion of other members of the dental team into the data collection process; nurses and hygienists could be trained to capture images, reducing the logistical complexities and cost of labour and consumables associated with mobile examination units manned by examiners across multiple sites [15,16].

A number of processing techniques exist which are capable of improving the diagnostic performance and variable quality of digital images, i.e. contrast optimisation, colour standardisation, noise reduction and artefact reduction [17]. Additionally, digital imaging modalities result in the ability to resize images. When these image enhancement options are coupled with the increased viewing time permitted by image assessment, it has been shown that conditions may be more readily apparent, resulting in higher prevalence rates than those found with clinical assessment [7].

As with all methods of assessment, there are limitations on the use of digital imaging in dental epidemiology. The loss of tactile feedback and an inability to assess oral structures from different positions using different lighting conditions results in a loss of holistic clinical judgement [18]. Additionally, some surfaces may not be recorded adequately enough to enable remote assessment, even if multiple images are captured from differing angles [8]. Depending on the imaging modality, the cost of developing or purchasing suitable equipment as well as provision of satisfactory training in its use can be a barrier to implementation [7]. The use of imaging increases the objectivity of assessment through reduction of bias, however, remote scoring is still subjective in nature due to the use of clinical indices. Whilst outside the scope of this paper, automatic detection by digital software should continue to be considered for digital imaging modalities to further improve the objectivity of the assessment [7].

Whilst image enhancement offers advantages for assessment, inappropriate use of this feature could result in falsification of the presence or absence and severity of conditions. Additionally, the ability to view the images for potentially unrestricted time periods can lead to inefficiency, examiner fatigue and 'second-guessing' of initial diagnosis [18].

1.3. Dual-camera system in oral epidemiology

Returning to fluorosis epidemiology specifically, in an effort to address the limitations of conventional clinical assessment, a dual-camera system was developed and successfully employed in large-scale fluorosis studies; a full description of the technical components of this system is available elsewhere [7,9]. This system simultaneously captures polarised white light (PWL) images as well as quantitative light-induced fluorescence (QLF) images of anterior teeth, permitting remote visual scoring of fluorosis and computer analysis of the change in fluorescence respectively. The use of a geometry-stabiliser improves image quality and intra- and inter-subject reproducibility.

The use of this technology was validated in a sample of 190 children in Chang Mai, Thailand [7], subsequently, this imaging system was used to assess almost two thousand children across four cities in England, UK [9]. Following successful validation of this technology, the system has been employed in national epidemiology programmes to monitor fluorosis prevalence; most notably, it forms part of the oral health component of the National Health and Nutrition Examination Survey (NHANES) conducted by National Centre for Health Statistics, USA [19].

As discussed, one of the benefits of digital imaging is the ability to archive images for future use and as would be expected from the subject numbers involved, the resulting image archive from the aforementioned studies is substantial. Feedback from those capturing the images as well as the examiners involved in remote scoring suggests that the images might carry diagnostically useful information for conditions other than fluorosis. As a result of this feedback and the availability of archived images, a semi-structured examination of previously acquired images was conducted to explore the potential of increasing the diagnostic yield of this imaging system.

2. Exploration of images

An informal review of images previously acquired using the dual-camera system offers potential insight into other oral conditions; however, the diagnostic value of this insight remains unknown. This section aims to introduce the oral conditions visible in the images, discuss possible scoring mechanisms for each condition and consider potential limitations of the system on a condition specific basis. As the dual-camera system captures anterior teeth only, this can be considered a universal limitation of the system; whilst this has been shown not to significantly impact on prevalence estimates of fluorosis [7], the same cannot be assumed of other conditions. Each section, therefore, will consider the impact of the loss of posterior data on accurate assessment of the condition.

2.1. Plaque accumulation

Plaque levels are of continuous interest in research, particularly to those investigating caries, periodontal health, compliance with oral hygiene interventions or new oral care products [20]. From an epidemiological perspective, the measurement of plaque can provide a deeper understanding of whole mouth health when combined with measurement of other conditions, as well as the typical characteristics of different population groups in relation to oral hygiene habits [21].

Various plaque indices have been utilised in research, notably, those developed by Silness and Loe, Greene and Vermillion and Quigley and Hein (later modified by Turesky et. al)[22–26]. With regards to remote scoring of plaque deposits, selection of an appropriate index would be