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A benchmark for comparison of dental radiography analysis algorithms☆

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ABSTRACT

Dental radiography plays an important role in clinical diagnosis, treatment and surgery. In recent years, efforts have been made on developing computerized dental X-ray image analysis systems for clinical usages. A novel framework for objective evaluation of automatic dental radiography analysis algorithms has been established under the auspices of the IEEE International Symposium on Biomedical Imaging 2015 Bitewing Radiography Caries Detection Challenge and Cephalometric X-ray Image Analysis Challenge. In this article, we present the datasets, methods and results of the challenge and lay down the principles for future uses of this benchmark. The main contributions of the challenge include the creation of the dental anatomy data repository of bitewing radiographs, the creation of the anatomical abnormality classification data repository of cephalometric radiographs, and the definition of objective quantitative evaluation for comparison and ranking of the algorithms. With this benchmark, seven automatic methods for analysing cephalometric X-ray image and two automatic methods for detecting bitewing radiography caries have been compared, and detailed quantitative evaluation results are presented in this paper. Based on the quantitative evaluation results, we believe automatic dental radiography analysis is still a challenging and unsolved problem. The datasets and the evaluation software will be made available to the research community, further encouraging future developments in this field. (http://www-o.ntust.edu.tw/~cweiwang/ISBI2015/)

1. Introduction

Dental radiography analysis plays an important role in clinical diagnosis, treatment and surgery as radiographs can be used to find hidden dental structures, malignant or benign masses, bone loss and cavities. During diagnosis and treatment procedures such as root canal treatment, caries diagnosis, diagnosis and treatment planning of orthodontic patients, dental radiography analysis is mandatory. Dental X-ray images can be categorized into two types, i.e. the intraoral ones and the extraoral ones (Kumar, 2011). The intraoral radiographs include the bite wing X-ray images to present the details of the upper and lower teeth in an area of the mouth, the periapical X ray images to monitor the whole tooth and the occlusal X-ray image to track the development and placement of an entire arch of teeth in either the upper or lower jaw. On the other hand, the extraoral radiographs are used to detect dental problems in the jaw and skull, such as the cephalometric projections and the panoramic X-ray images.

Cephalometric analysis describes the interpretation of patients' bony, dental and soft tissue structures and provides all images for the orthodontic analysis and treatment planning. However, in clinical practice, manual tracing of anatomical structures (as shown

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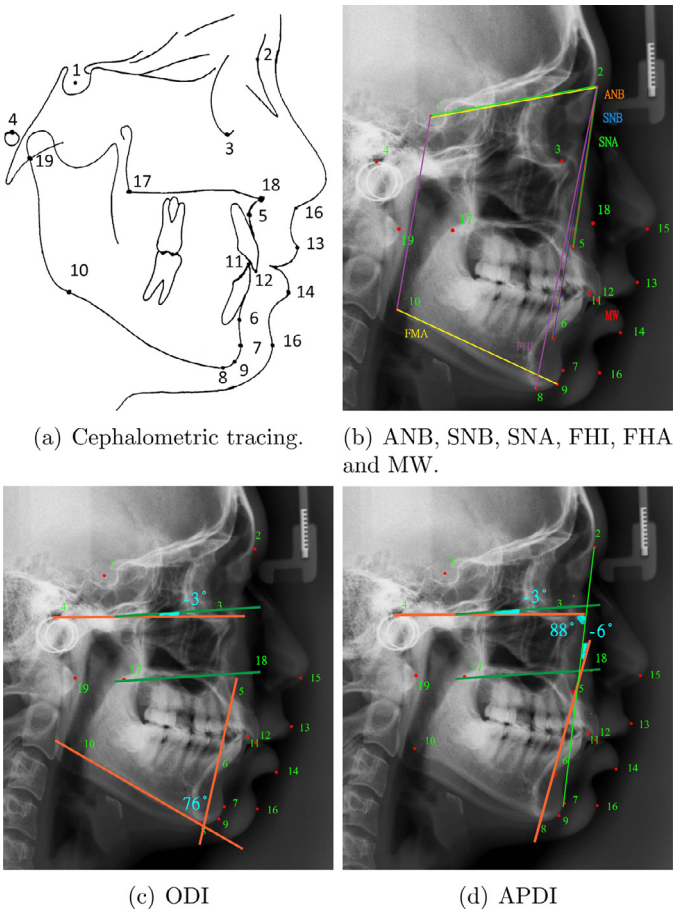

(a) Cephalometric tracing. (b) ANB, SNB, SNA, FHI, FHA and MW.

(c) ODI (d) APDI

Fig. 1. (a) Cephalometric tracing (b–d) clinical measurements for classification of anatomical abnormalities: ANB = $\angle L_5L_2L_6$; SNB = $\angle L_1L_2L_6$; SNA=$\angle L_1L_2L_5$; FHI = $\overline{L_1L_{10}}/\overline{L_2L_8}$; FHA=$\angle L_1L_2L_{10}L_9$; MW=$|\overline{L_{12}L_{11}}|$ where $x(L_{12}) > x(L_{11})$, otherwise, MW=$-|\overline{L_{12}L_{11}}|$; ODI=$\angle L_5L_6L_8L_{10} + \overline{L_{17}L_{18}L_4L_3}$, in this example, the ODI is $(76^\circ + (-3^\circ) = 73^\circ)$, in the normal range with a slight tendency to be an openbite; APDI = $\overline{L_3L_4L_2L_7} + \overline{L_2L_7L_5L_6} + \overline{L_4L_3L_{17}L_{18}}$, in this example, the APDI is $(88^\circ + (-6^\circ) + (-3^\circ) = 79^\circ)$, which falls within the normal range. .

in Fig. 1) is commonly conducted during treatment planning. This procedure is time consuming and subjective. Automated landmark detection for diagnosis and orthodontic treatment of cephalometry could be the solution to facilitate these issues. However, automated landmark detection with high precision and success rate is challenging. In recent years, efforts have been made to develop computerized dental X-ray image analysis systems for clinical usages, such as in anatomical landmark identification (Nikneshan, 2015; Zhou and Abdel-Mottaleb, 2005), image segmentation (Lai and Lin, 2008; Rad, 2013), diagnosis and treatment (Lpez-Lpez, 2012; Nakamoto, 2008; Wriedt, 2012). In 2014, we held an automatic cephalometric X-ray landmark detection challenge at IEEE ISBI 2014 with 300 cephalometric X-ray images, and the best overall detection rate for 19 anatomical landmarks was 71.48% with an accuracy of within 2mm. The 2014 challenge outcomes indicate that automatic cephalometric X-ray landmark detection is still an unsolved problem. Hence, the first part of this study is to investigate suitable automated methods in cephalometric X-ray landmark detection. In this study, a larger clinical database was built using data from 400 patients.

Furthermore, apart from anatomical landmark detection in cephalometric images, a new classification task for the clinical diagnosis of anatomical abnormalities using these landmarks was added in this study. In order to be critical and descriptive in clinical practice, it is more useful to analyse angles and linear measurements rather than just point positions. Many classification methods have been proposed for cephalometric analysis, such as Ricketts analysis (Ricketts, 1982), Downs analysis (Downs, 1948), Tweed analysis (Tweed, 1954), Sassouni analysis (Sassouni, 1955) and Steiner analysis (Steiner, 1953). Therefore, the second part of this study was to automatically classify patients into different anatomical types to infer a clinical diagnosis.

Apart from the cephalometric analysis, caries detection and dental anatomy analysis are important in clinical diagnosis and treatment. Dental caries is a transmissible bacterial disease of the teeth that would destructs the structure of teeth, and the dentist has approached diagnosing and treating dental caries based mostly on radiographs. While dental caries is a disease process, the term is routinely used to describe radiographic radiolucencies.

Radiographic examination can improve the detection and diagnosis of the dental caries. In the clinical practice, caries lesions have traditionally been diagnosed by visual inspection in combination with radiography. Therefore, automated caries detection systems with high reproducibility and accuracy would be welcomed in clinicians' search for more objective caries diagnostic methods (Wenzel, 2001, 2002). Several research studies focused on pattern recognition or segmentation of dental structures, such as in caries detection (Huh, 2015; Oliveira and Proenc, 2011), root canal edge extraction (Gayathri and Menon, 2014), identity matching (Jain and Chen, 2004; Zhou and Abdel-Mottaleb, 2005) and teeth classification (Lin, 2010). Automated caries lesion detection technologies provide potential diagnostic data for dental practitioners and assist identifying signs of various diseases. However, accurate and objective methods for radiographic caries diagnosis are poorly explored. Therefore, the third part of this study was to investigate possible automated methods both for detection of caries and for dental anatomy analysis in bitewing radiographs.

This paper presents the evaluation and comparison of a representative selection of current methods presented during the Grand Challenges in Dental X-ray Image Analysis held in conjunction and with the support of the IEEE ISBI 2015. There are two main challenges, the *Automated Detection and Analysis for Diagnosis in Cephalometric X-ray Image* and the *Computer-Automated Detection of Caries in Bitewing Radiography*, and the first challenge contains two challenge tasks: (i) to identify anatomical landmarks on lateral cephalograms, and (ii) to classify anatomical types based on the anatomical landmarks. Only the first task of the first challenge of this study is similar to a related challenge held at 2014 IEEE ISBI challenge. The second challenge- *Computer-Automated Detection of Caries in Bitewing Radiography* and the second challenge task of Challenge 1 - classifying anatomical types based on the anatomical landmarks are both completely new. In addition, for the first challenge, the dataset was enlarged to now include 400 patients. In comparison to the challenge held at IEEE ISBI 2014, this study includes a new challenge, new data and a new challenge task (see Table 1). The outline of the paper is organized as follows. In Section 2, the challenge aims, participants, image datasets and evaluation approaches are described. The methodologies and detailed quantitative evaluation results of *Challenge 1* and *Challenge 2* are presented in Sections 3 **and** 4, respectively. Finally, conclusions are given in Section 5**.**

2. Grand challenges in dental X-ray image analysis

2.1. Organization

The goals of this grand challenge are to investigate automatic methods for *Challenge 1-1*: identifying anatomical landmarks on lateral cephalograms, *Challenge 1-2*: classifying anatomical types based on the anatomical landmarks, and *Challenge 2*: segmenting seven tooth structures on bitewing radiographs. The 19 anatomical