Computer Methods and Programs in Biomedicine 148 (2017) 1–11

Contents lists available at ScienceDirect

Computer Methods and Programs in Biomedicine

journal homepage: www.elsevier.com/locate/cmpb

Automatic methods for alveolar bone loss degree measurement in periodontitis periapical radiographs

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ARTICLE INFO

Article history:
Received 17 October 2016
Revised 14 May 2017
Accepted 23 June 2017

Keywords:
Periodontitis radiographs
Alveolar bone-loss measurement
CEJ localization
Enamel dentin border detection

ABSTRACT

Background and objective: Periodontitis involves progressive loss of alveolar bone around the teeth. Hence, automatic alveolar bone loss measurement in periapical radiographs can assist dentists in diagnosing such disease. In this paper, we propose an automatic length-based alveolar bone loss measurement system with emphasis on a cementoenamel junction (CEJ) localization method: CEJ_LG.

Method: The bone loss measurement system first adopts the methods TSLS and ABLifBm, which we presented previously, to extract teeth contours and bone loss areas from periodontitis radiograph images. It then applies the proposed methods to locate the positions of CEJ, alveolar crest (ALC), and apex of tooth root (APEX), respectively. Finally the system computes the ratio of the distance between the positions of CEJ and ALC to the distance between the positions of CEJ and APEX as the degree of bone loss for that tooth. The method CEJ_LG first obtains the gradient of the tooth image then detects the border between the lower enamel and dentin (EDB) from the gradient image. Finally, the method identifies a point on the tooth contour that is horizontally closest to the EDB.

Results: Experimental results on 18 tooth images segmented from 12 periodontitis periapical radiographs, including 8 views of upper-jaw teeth and 10 views of lower-jaw teeth, show that 53% of the localized CEJs are within 3 pixels deviation (~0.15 mm) from the positions marked by dentists and 90% have deviation less than 9 pixels (~0.44 mm). For degree of alveolar bone loss, more than half of the measurements using our system have deviation less than 10% from the ground truth, and all measurements using our system are within 25% deviation from the ground truth.

Conclusion: Our results suggest that the proposed automatic system can effectively estimate degree of horizontal alveolar bone loss in periodontitis radiograph images. We believe that our proposed system, if implemented in routine clinical practice, can serve as a valuable tool for early and accurate diagnosis of alveolar bone loss in periodontal diseases and also for assessing the status of alveolar bone following various types of non surgical and surgical and regenerative therapy. For overall system improvement, a more objective comparison by using transgingival bone measurement with a periodontal probe as the ground truth and enhancing the localization algorithms of these three critical points are the two major tasks.

1. Introduction

Periodontitis involves progressive loss of the alveolar bone around the teeth. Its diagnosis can be established from (a) clinical examination by probing the gingiva (gums) using a periodontal probe, or (b) radiographic examination by evaluating the patient's radiographs (X-ray films) to determine the amount of alveolar bone loss around the teeth. Determining type and degree of alveolar bone loss by examining radiographs has been a difficult task for most dentists. Recently, two reports on validation of a dental image analyzer tool to measure the degree of alveolar bone loss are available in periodontitis research literature [1,2]. In [1], the degree of bone loss is measured horizontally by using a Schei ruler [3] as shown in Fig. 1(a) to determine the ratio of the distance between the position of the alveolar crest (ALC) (also named as bone loss point BLP) and the position of the cementoenamel junction (CEJ) to the distance between the CEJ and the APEX, where ALC is the junction of the most apical extension of the intrabony defect and the tooth, and the APEX is the apical of the tooth root. Fig. 1(b) shows the measurement of length-based

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http://dx.doi.org/10.1016/j.cmpb.2017.06.012
0169-2607/

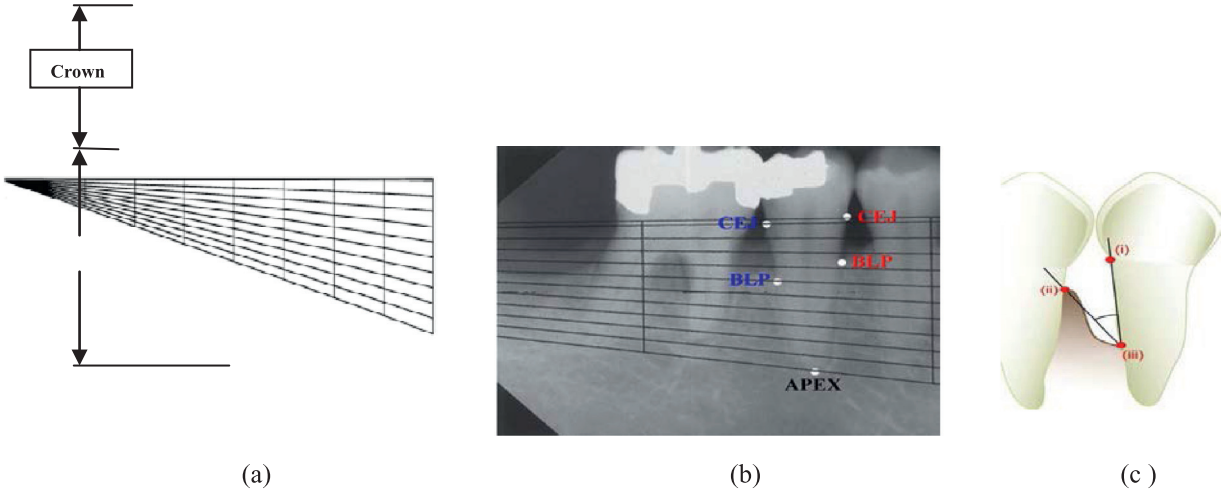

Fig. 1. Alveolar bone loss degree measurements based on length and defect angle: (a) Schei ruler (b) measured by length ratio: distal side (blue) 40 ∼ < 50%, mesial side (red) 30 ∼ < 40%, (c) measured by defect angle. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

bone loss degree of a given tooth on both distal and mesial sides, respectively. In [2], the degree of bone loss is measured vertically and is determined by a defect angle between the two lines that represent the root surface of the tooth involved and the surface of the bone defect, shown as the lines formed by points (i) (iii) and (ii) (iii) in Fig. 1(c), respectively. However, the critical points/positions for either horizontal or vertical measurement are manually marked by dentists. For automatic measurement of degree of alveolar bone loss, bone loss areas as well as the positions of CEJ, ALC, and APEX must firstly be localized automatically.

Very few studies on automatic bone-loss area localization and teeth segmentation from periodontitis radiographs have been reported in literature, although computer vision added feature or attribute extraction from radiograph images for improving diagnosis accuracy and aiding in clinical decisions are quite a few. For example, in [4], intensity histogram, continuous wavelet transform, and GLCM descriptors are combined for segmenting carotid artery ultrasound images. In [5], grayscale features, local binary patterns, and wavelet based features were combined for detecting the condition coronary artery disease. In [6], textures of periapical radiograph images were used as a tool for dental implant treatment planning.

We had presented an effective method for segmenting teeth and extracting teeth contours from periapical radiographs in [7] and a couple of methods for localizing alveolar bone loss areas in periodontitis radiographs in [8–10]. Thus, positions of ALC and APEX can be obtained from the located bone loss area and/or the tooth contour. As for CEJ localization, no automatic methods have been reported in literature up-to-date, to our best knowledge.

In this paper, we propose an automatic length-based alveolar bone loss measurement system with emphasis on a CEJ localization method. The CEJ localization method first obtains the gradient from tooth images segmented from periodontitis radiographs then detects the border between the lower enamel and dentin (EDB) from the gradient image. Finally, the method identifies a point on the tooth contour that is horizontally closest to the EDB. The bone loss measurement system first adopts the methods TSLS [7] and ABLifBm [10] to extract teeth contours and bone loss areas from periodontitis radiograph images. It then applies the proposed CEJ, ALC, APEX localization methods to obtain these three positions. Finally the system computes the ratio of the distance between the positions of CEJ and ALC to the distance between the positions of CEJ and APEX as the degree of bone loss for that tooth. For performance assessment, 18 tooth images segmented from 12 periodontitis periapical radiographs, including 8 views of upper-jaw teeth and 10 views of lower-jaw teeth will be tested. Experimental results will be presented both visually and quantitatively to demonstrate effectiveness of the system.

The remainder of this paper is organized as follows. In Section 2, the adopted teeth segmentation method TSLS and the alveolar bone loss area localization method ABLifBm are briefly introduced, followed by detail descriptions of the proposed cementoenamel localization method and the length-based alveolar bone loss measurement system. In Section 3, experimental results and performance assessment of the CEJ localization method and the bone loss measurement system are presented and discussed, respectively. Finally, conclusions are given in Section 4.

2. Materials and methods

In this section, we first briefly describe the methods and systems adopted in the proposed system. We then describe our proposed system and methods in detail.

2.1. Study samples

Twelve periodontitis periapical radiograph images of various alveolar bone loss degrees are used in this study. All images are provided by Chung Sun Medical University Hospital in Taichung, Taiwan.

2.2. Adopted methods and systems

2.2.1. Teeth segmentation using local singularity: TSLS

TSLS [7] is a threshold segmentation method that can effectively segment each tooth from a periapical radiograph. The method first applies an adaptive power law transformation to the image to reduce uneven illumination problem. It then recognizes each tooth in the radiograph by thresholding the bilateral filtered point-wise singularity image, where the singularity of each point is characterized by the Hölder exponent α at the point defined as

$$\alpha_i(x,y) = \frac{\ln(\mu_i(x,y))}{\ln(i)}, \quad i = 1,\ 2,\ 3... \tag{1}$$

where $\mu_i(x,\ y)$ is the amount of capacity measure within the observed box with size $= i$ centered at the pixel $(x,\ y)$. Some of the commonly used capacity measures are: max, min, iso, and sum of the gray-level intensity at points within the measured box. Finally,