Toward early diagnosis of arteriosclerotic diseases: collaborative detection of carotid artery calcifications by computer and dentists on dental panoramic radiographs

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ABSTRACT

Several studies have reported the presence of carotid artery calcifications (CACs) on dental panoramic radiographs (DPRs) as a possible sign of arteriosclerotic diseases. However, CACs are not easily visible at the common window level for dental examinations, and dentists, in general, are not looking for CACs. Computerized detection of CACs may help dentists in referring patients with a risk of arteriosclerotic diseases to have a detailed examination at a medical clinic. Downside of our previous method was a relatively large number of false positives (FPs). In this study, we attempted to reduce FPs by including an additional feature and selecting effective features for the classifier. A hundred DPRs including 34 cases with calcifications were included. Initial candidates were detected by thresholding the output of top-hat operation. For each candidate, 10 features and a new feature characterizing the relative position of a CAC with reference to the lower mandible edge were determined. After the rule-based FP reduction, candidates were classified into CACs and FPs by a support vector machine. Based on the leave-one-out cross-validation evaluations, an average number of FPs was 3.1 per image at 90.4% sensitivity using seven features selected. Compared to our previous method, the number of FPs was reduced by 38% at the same sensitivity level. The proposed method has a potential in identifying patients with a risk of arteriosclerosis early via general dental examinations.

Keywords: Dental panoramic radiographs, carotid artery calcifications, computer-aided diagnosis, teleradiology

1. INTRODUCTION

According to the vital statistics report by the Ministry of Health, Labour, and Welfare in 2012, heart diseases and cerebrovascular diseases were the second (15.8%) and forth (9.7%) causes, respectively, of all mortalities in Japan.[1] In the US, on the other hand, heart diseases were the leading cause of deaths based on the national vital statistics report by National Center for Health Statistics in 2010.[2] Recent studies have reported that dental panoramic radiographs (DPRs) can depict carotid artery calcifications (CACs), which are one of the signs for predicting the risk of atherosclerosis that is often asymptomatic.[3-6] However, with the common window setting for dental examinations, CACs are not easily visible and generally ignored by dentists who are focused on dental diseases.

Computerized detection of CACs may help dentists find these signs who can explain asymptomatic patients the possible atherosclerosis risk and suggest further examinations at medical centers. In this way, a new screening pathway can be established, and patients may get a chance to be treated early and unexpectedly via dental examination. Figure 1 illustrates the overview of the proposed diagnostic and secondary screening flow including computer-aided diagnosis (CAD). However, there have been a limited number of groups investigating such automated system.[7-9] Shinjo et al.[7, 8] proposed CAC detection methods based on the local information. In their method, background trend was corrected on the basis of the local gradient, clustering method was applied to detect the CAC candidates, and false positives (FPs) were removed using local features. We have also proposed an automated method for detection of CACs on DPRs by use

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of a top-hat filter and support vector machine.[9] These studies showed that CACs can be detected, however, with a relatively large number of FPs. The purpose of this study was to reduce the number of FPs and to improve system generalization. Our experience with clinical trials in which our detection system was incorporated with the cloud-based teleradiology system is also discussed.

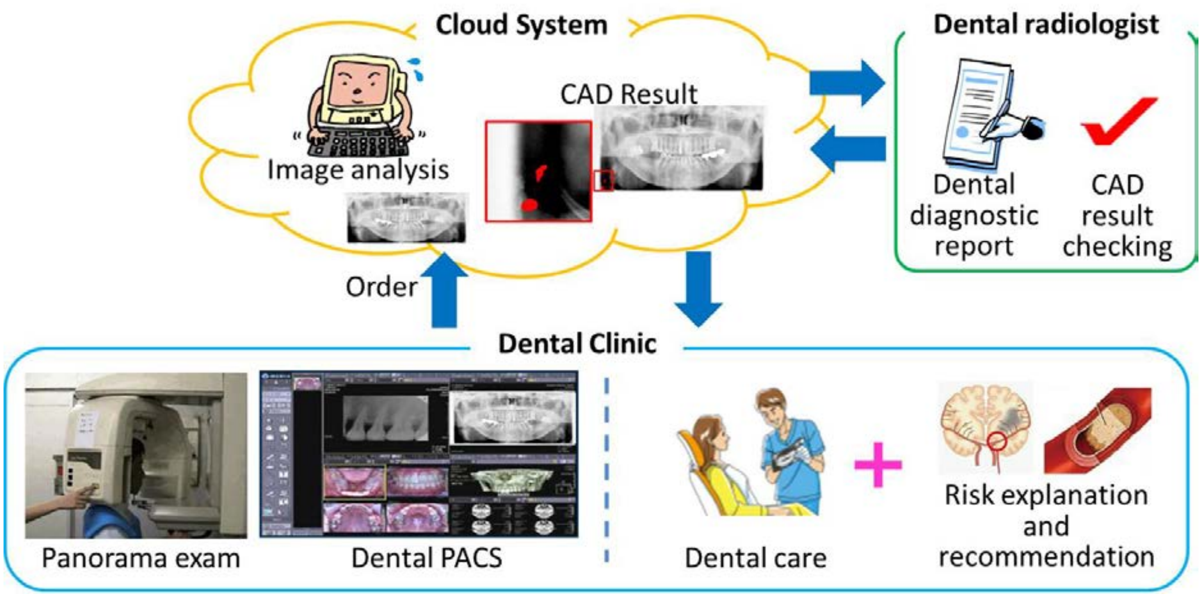

Figure 1. Overview of the proposed dental diagnostic and secondary screening flow with teleradiology and computer-aided diagnosis (CAD) system.

2. COMPUTERIZED DETECTION OF CAC

2.1 Database

The database used in this study consists of 100 DPRs, including 34 and 66 images with and without CACs, respectively. The total number of CACs is 94, and the number of CACs per image varies from 1 to 9. The calcifications were identified by a dental radiologist with reference CTs. These images were obtained at Asahi University Dental Hospital with a panoramic x-ray unit (Veraview Epocs, Morita, Japan) and a computed radiography system (CR 75.0, Agfa, Germany). The matrix size was 2920 x 1420 pixels with a spatial resolution of 0.1 mm and 12 bit grayscale. This study was approved by the Institutional Review Board of Gifu University and Asahi University.

2.2 CAC Detection Method

The CAC detection scheme proceeds as follows: (1) extraction of regions of interest (ROIs) based on the result of automatic detection of mandibular contour,[10, 11] (2) initial detection of CAC candidates using top-hat filter, and (3) FP reduction by a rule-based scheme and a support vector machine with image features. Figure 2 shows the flowchart of the overall process. Our latest improvements were mainly included in (3). The basic schemes have been described in detail elsewhere,[9] and therefore, only briefly explained here.

CACs are generally depicted below mandible and medial to cervical vertebrae. In order to exclude other areas for processing, ROIs were extracted from the lower right and left ends of images. Inferior mandibular edge was automatically detected by our previous method[10, 11] using Kirsch edge detection filter and an active contour model. The right and left mandibular angles were determined by searching the reflection points on the detected mandibular contour from the medial to lateral directions. The ROI was set below the angle and mandible and lateral to the angle with inclusion of a pre-specified margin. For initial detection of CACs, a top-hat filter was applied. The filter element was set as a circle with a diameter of 30 pixels. The candidate lesions were detected by binarizing the output with an empirical threshold.

In our previous study, 11 image features were determined for each candidate region. They include the area, average pixel value, variance of pixel values, contrast, height, width, ratio of the width and height, circularity, irregularity, and *x* and *y* locations. The definitions of these features are described elsewhere.[7] Using these features, some FPs were removed by a rule-based scheme and a support vector machine (SVM). However, many FPs still remained, especially on vertebrae and hyoid bones. Although positional information was expected to have some utility, the locations in x and y coordinates could vary between patients without an anatomical reference. In this study, therefore, a new positional feature with a reference to the mandibular contour was added. In order to take into account the individual variation in size of jaws, the distance to the mandibular contour was normalized by the width of the mandible, i.e., lateral distance between two angles. Using the 12 features, outliers were first removed by a rule-based method. The remaining candidates were classified into CACs and FPs by SVM.

For evaluation, 2-fold cross validation was performed by randomly dividing the cases with CACs and cases without CACs in half. For reducing the sampling bias, the cross validation test was repeated 10 times. Another concern in our previous study was a large number of image features for training SVM relative to a small number of positive training samples. Depending on the random sampling, the number of CACs used for training ranged from 33 to 50. In addition, the usefulness of each feature was not closely investigated in our previous study. In this study, an effective feature set was selected by a backward feature selection method. Starting with all features, a single feature was removed one by one, and the set with the highest performance in terms of the average number of FPs per image at the highest sensitivity of 92.6% was remained. This was continued until the performance was no further improved. The result was evaluated by the free-response receiver operating characteristic (FROC) analysis.

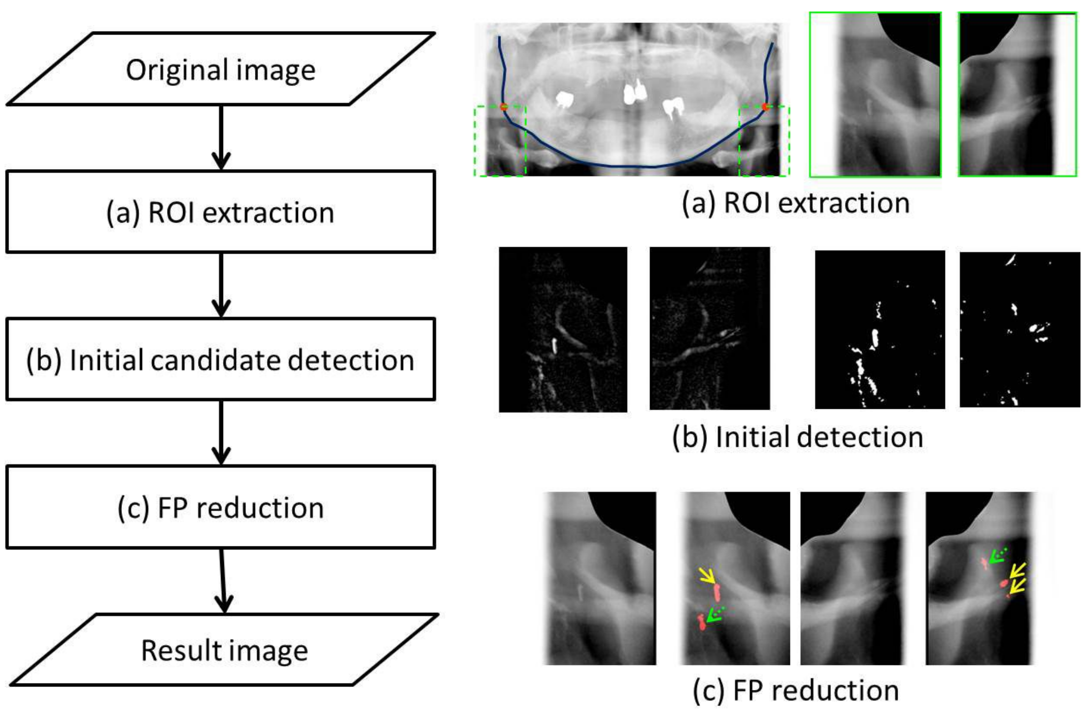

Figure 2. A flowchart of CAC detection method. (a) ROI extraction based on mandibular contour, (b) initial candidate detection by top-hat filter, and (c) FP reduction by a rule-based scheme and a SVM. Solid arrows (yellow) indicate true positive detections and dotted arrows (green) indicate FP detections.

3. RESULT

By the backward feature selection, 7 features were selected. The features include the area, height, average pixel value, contrast, circularity, x location, and the relative distance from the mandible, which is the new feature included in this study. This result suggests that the size, shape, pixel value and location features are all important features for differentiating CACs from FPs; however, some correlated features might be redundant. Figure 3 shows the change in the number of FPs during the feature selection. With the set of 7 features, the numbers of FPs per image at the sensitivities of 92.6% and 90.4% were 4.5 and 3.1, respectively. In our preliminary study with 11 features, the average numbers of FPs were 6.7 and 5.0 per image, respectively. By inclusion of the new feature, the number of FPs at 90.4% sensitivity was reduced to 4.0 per image. With the feature selection, the average number of FPs was further reduced. Figure 4 shows the FROC curves by the previous method and the proposed method. With the smaller set of features, variation in the results of 10 random trials was also reduced, indicating the improved generalizability of the proposed method.

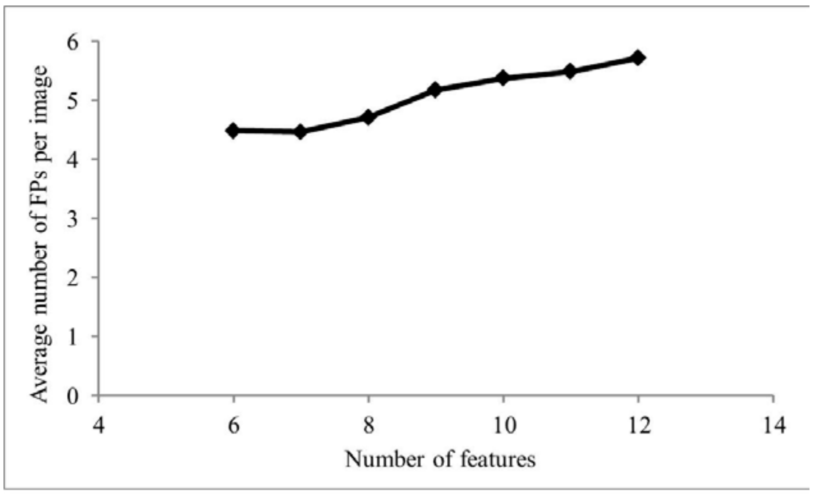

Figure 3. Change in the average number of FPs per image at the sensitivity of 92.6% as the number of features was decreased during the backward feature selection.

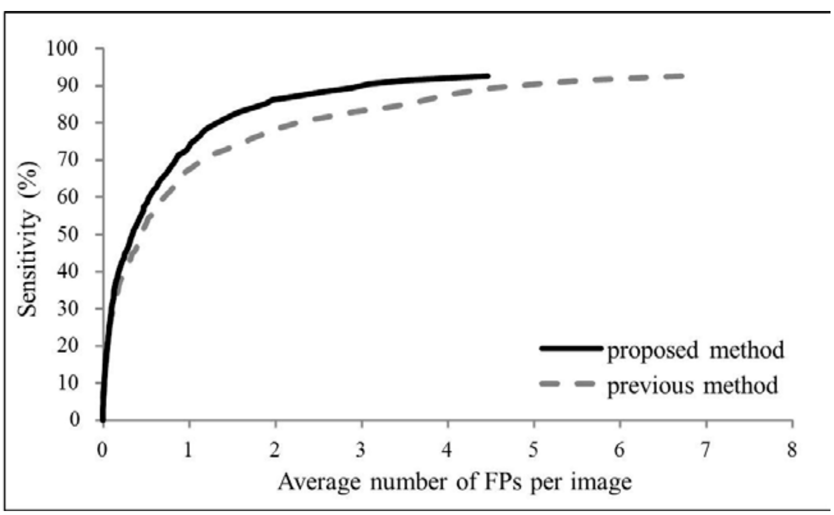

Figure 4. FROC curves for detection of CACs by the previous method and the proposed method.

4. COOPERATION WITH CLOUD-BASED DIAGNOSTIC SUPPORT

Our CAC detection system together with other two dental CAD systems[10-13] was incorporated into the cloud-based teleradiology system provided by Support Association for Diagnostic Imaging in Dentistry of Japan (SADID Japan). Other CAD systems include the measurement of mandibular cortical width for detection of osteoporosis[10, 11] and detection of elevated gray values in paranasal sinuses for diagnosis of maxillary sinusitis.[12] The SADID service aims to assist dentists at dental clinics in the image diagnosis by providing the second opinion by dental radiologists. For the first clinical trial, 7 dental clinics have participated. Once the dentists at the participating clinics upload a DPR, the image is automatically processed by 3 CAD systems. The teleradiology order is sent to a contracted dental radiologist with the results of CAD outputs. The dental radiologists review the DPRs and send the dental opinion reports. In addition, they check the CAD results, and provide remarks regarding possible systemic diseases.

In this trial, 459 cases were processed and 8 cases were found to contain suspected CACs by the dental radiologists. Our system detected CACs on 7 out of 8 cases (87.5%) with 2.2 FPs per case. The one case missed by our system contained a large CAC, which could have been detected if the top-hat filter size was larger. Although the specificity by the system was low about 36%, most of the FPs were detected on vertebrae and hyoid bones and easily dismissed by the dental radiologists.

5. DISCUSSION AND CONCLUSION

An automated method for detection of CACs on DPRs was investigated for a possible secondary screening of atherosclerosis. In this study, we attempted to improve our system by reducing the number of FPs and possibly improving generalizability to unknown cases. By including the new feature and selecting the effective feature set, the number of FPs was successfully reduced by 38% at the same sensitivity level compared to the previous method, while the variation in the results by 10 randomized trials was also reduced. For the purpose of screening to recommend further examination at hospitals, it might be sufficient if one of the CACs is detected when multiple calcifications present. For detecting at least one CAC per case, the number of FPs can be held down to 1.1 per image with 91.2% case sensitivity.

Our system was tested by cooperation with teleradiology system in SADID project. Although the number of positive cases was small in this initial clinical trial, the result seems promising. Because of the variety in image contrast and size of DPRs obtained by different panoramic units at different dental clinics, the standardization of image quality and some techniques to normalize image contrast are desired in the future. Many FPs could be easily dismissed by dental radiologists; however, further improvement in specificity is preferable.

In general, dentists do not pay attention to regions under lower mandible, and some of the CACs are almost invisible at the general window level for dental examination. The proposed method can be useful in identifying the patients with arteriosclerotic risk early via collaboration of a computer and dentists.

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