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Review Article

Progress of computer-aided detection/diagnosis (CAD) in dentistry

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Summary The development of computer-aided detection/diagnosis (CAD) systems for dental imaging is progressing. One expected use of CAD is to detect radiological signs of medical systemic disease in the panoramic screening radiograph. The target diseases for CAD include osteoporosis, arteriosclerosis, and maxillary sinusitis.

CAD is also useful in the detection and evaluation of dental and maxillofacial lesions. Identifying alveolar bone resorption due to periodontitis and radiolucent jaw lesions (such as radicular and dentigerous cysts) are important goals for CAD. CAD can be applied not only to panoramic radiography but also to dental cone-beam computed tomography (CBCT) images. Linking of CAD and teleradiology will be an important issue.

Contents

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1. The present status of digital technology in dental radiology

The digitization of diagnostic images has led to several breakthroughs. The Japanese Ministry of Economy, Trade and Industry (METI) stated in the ''Technology Strategy Map 2010'' that the development and the promulgation of computer-assisted detection/diagnosis (CAD) [1] is an important issue. It also stated that progress in telemedicine, particularly teleradiology, is a necessary technology.

CAD and teleradiology have not made inroads into dentistry for several reasons. One is that although the medical hospital can employ radiology technicians with the skills to operate digital imaging devices and handle digital imaging data, very few radiology technicians are found in dental offices. In the majority of dental offices, one or two dentists operate every analog and digital radiological device such as intraoral and panoramic radiograph systems, dental CBCT systems, and picture archiving and communications (PACS) systems.

The second issue is that, in the medical hospital, some imaging modalities such as mammography and MRI require the skills of a radiologist to make an informed diagnosis. As the use of these complicated imaging modalities increases, the need to develop CAD systems to screen for asymptomatic disease and to provide teleradiology service to general practitioners also increases. Until the first decade of 21st century, similar requirements were not developed in dentistry because digital radiographic devices and the use of dental cone-beam computed tomography (CBCT) were not popular. There was less motivation to go to CAD and teleradiology.

However, in recent years, almost 50% of dental offices have introduced digital radiographic devices. In 2012 more than 5000 CBCTs are in use in the dental offices in Japan. The Japanese Association for Dental Science has been highlighting the relationship between health care in the maxillofacial region and medical disease such as osteoporosis and stroke. It has also noted that some systematic diseases can manifest with recognizable radiologic signs in dental images.

Panoramic radiography is the most frequently used imaging examination in dental practice. Up to 90% of the dental offices own a panoramic radiographic device. About 10 million panoramic images are acquired per year in Japan. The regions imaged include not only the teeth and jaws, but also the nasal and cervical regions. It was quite natural for panoramic radiograph to be chosen the objective modality to develop CAD system.

2. Panoramic radiograph CAD programs to screen for signs of medical disease.

Since the increase in the prevalence of osteoporosis, dental radiologists have explored the idea of detecting osteoporosis in dental radiographs. Taguchi et al. [2] proposed criteria to diagnose osteoporosis by means of the morphology of the mandibular cortical bone in the premolar region.

In the panoramic radiographs of elderly patients, calcifications are sometimes observed in the cervical soft tissues. These calcifications often are in the carotid arteries, and represent calcified plaques, one of the risk factors for arteriosclerosis, which is associated with cerebrovascular and cardiovascular disorders [3].

Although odontogenic maxillary sinusitis is familiar to dentists, inflammation in the paranasal sinuses is often due to allergic rhinitis or upper respiratory tract infections. The fundamental radiologic sign of maxillary sinusitis is soft tissue equivalent radiopacity. A radiopaque maxillary sinus can be seen not only in sinusitis, but also in cases of odontogenic tumors, carcinoma of the maxillary sinus, or maxillary mucus retention cysts. The detection of those findings in panoramic radiographs is not easy for general dentists. The diagnostic reliability of panoramic radiographs of disorders in the maxillary sinus remains controversial among radiologists because it is not easy to identify slight differences in the

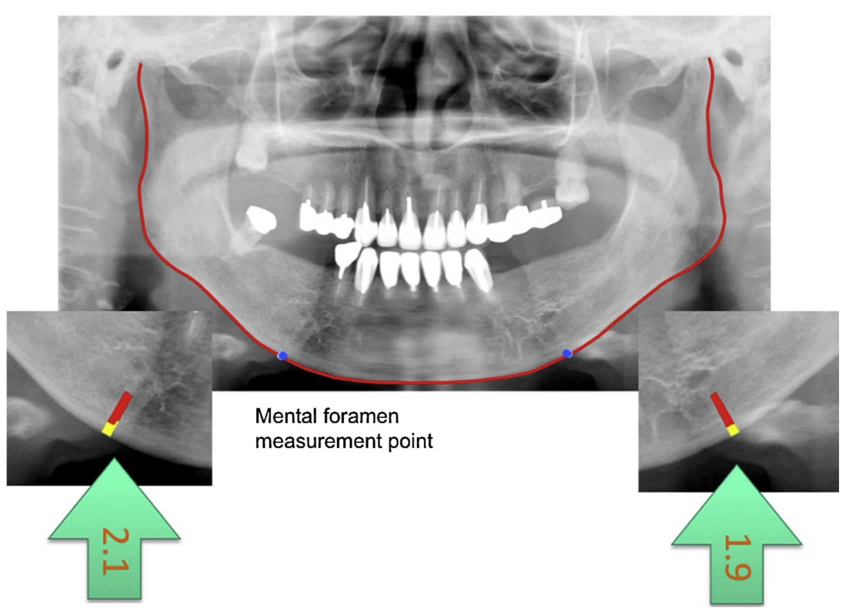


Figure 1 Using CAD to measure the thickness of the mandibular cortex. The contour line of the mandible and the measurement points are defined automatically. The thickness of the mandibular cortex is then measured.

radiopacity of the maxillary sinuses. However a CAD computer algorithm should be able to evaluate sinus density quantitatively.

2.1. CAD program to evaluate cortical bone in the mandibular molar region

The object of this CAD algorithm is to detect osteoporosis by means of evaluating the mandibular cortex [4]. The algorithm works as follows (Fig. 1):

(1) Automatic tracing the contour line of mandible.
(2) Defining the positions of the mental foramina.
(3) Drawing straight lines perpendicular to the mandibular contour.
(4) Measuring the thickness of the mandibular cortex based on the results from grayscale profile analysis.

The mandibular contour is a fundamental anatomic landmark on panoramic radiography. We designed detection filter programs and active contour methods to define the mandibular contour. It can be assumed that the mandible is in a specific location on a panoramic image. To locate the mandibular contour, the global map (atlas) that provided the candidate position of the mandible was used. Methodologies of mandibular contour detection were used in CAD programs described below. A preliminary clinical trial of several digital panoramic systems revealed that CAD, measuring the thickness of cortical bone with a 2.8-mm threshold cortical bone thickness, diagnosed osteoporosis with 90% sensitivity and a 90% specificity.

2.2. CAD program to find calcifications in the carotid arteries

The object of this CAD program is to find radiopaque calcifications in the carotid arteries [5]. This program works as follows (Fig. 2):

(1) The mandibular angles are defined based on the contour line of the mandible.
(2) Bilateral regions of interest (ROIs) are set posterior and inferior to the mandibular angles.
(3) Calcifications are detected using image filtering and a grayscale thresholding technique.
(4) A rule-based approach and an artificial intelligence algorithm to reduce the number of false positives (FP) findings are applied.

To reduce the number of FPs, we tested various parameters such as the area, location and shape of the calcifications. A hundred panoramic radiographs were used to evaluate the proposed algorithm. The sensitivity for the detection of calcifications in the carotid arteries was 90%. However appropriate specificity was not yielded at the present moment due to unremovable false positive artifacts. These results showed that CAD might be useful to detect carotid artery calcifications.

2.3. CAD program to find maxillary sinus abnormalities

To evaluate the radiopacity of the maxillary sinus quantitatively, we adopted a method using a contralateral subtraction technique [6]. The radiopacity of the maxillary sinus was evaluated as follows (Fig. 3):

(1) Image filtering for smoothing, noise reduction, and edge detection is applied.
(2) Mirror image registration is applied, using information from anatomical structures such as the hard palate and nasal cavities.
(3) Contralateral subtraction is performed and the pixel data of bilateral ROIs in the maxillary sinuses are compared.

The abnormal regions and the normal cases were verified by a board-certified radiologist using CT images. A preliminary

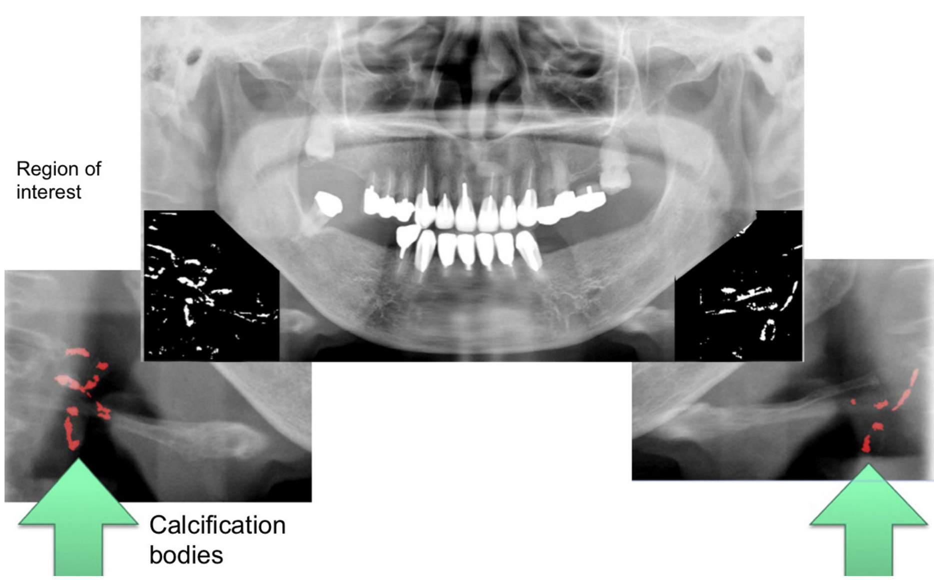


Figure 2 CAD assessment of calcifications in the carotid arteries. CAD searches for calcifications in the tissues posterior and inferior to the mandibular angle.

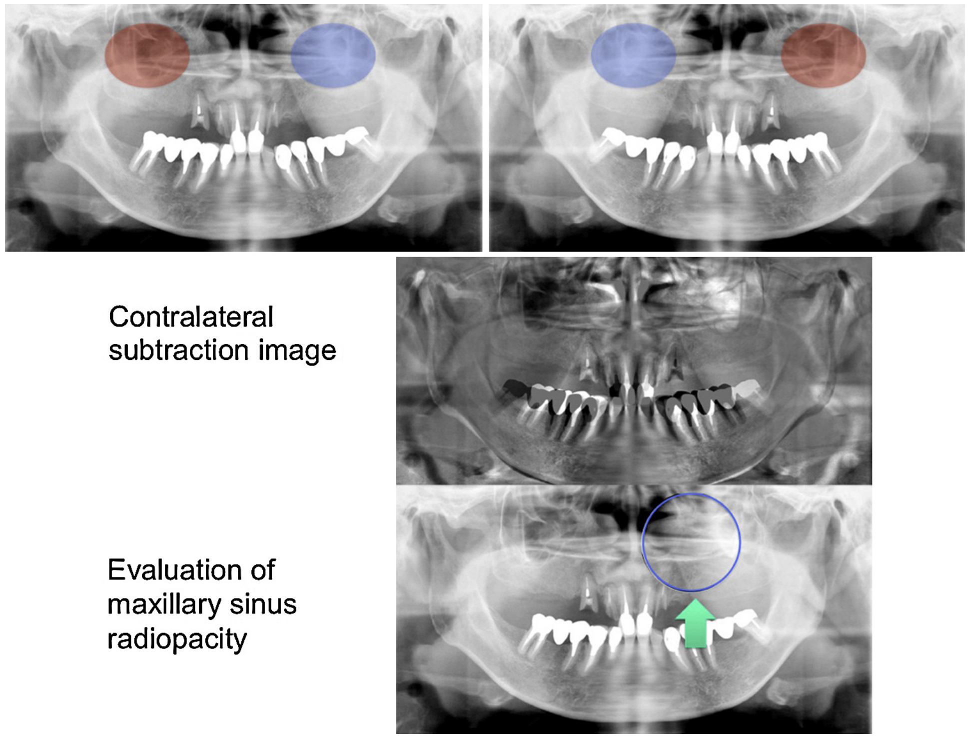


Figure 3 CAD screening for maxillary sinus abnormalities. The contralateral subtraction technique is used to detect a radiopaque maxillary sinus.

trial for the detection of radiopaque single maxillary sinuses revealed an approximately 80% sensitivity and 70% specificity. Although the contralateral subtraction images of panoramic radiographs may improve the detection rate of abnormalities of the maxillary sinuses, there are some issues that we should improve in the CAD program, including better definition of the maxillary sinus position and refining or replacing the contralateral subtraction technique to detect bilateral maxillary sinusitis.

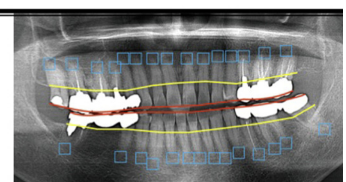
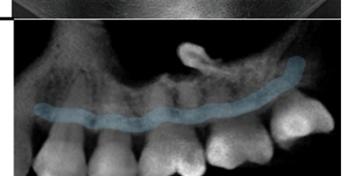
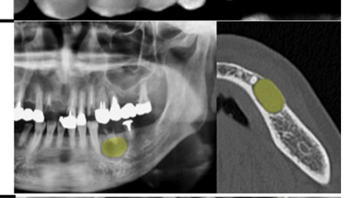
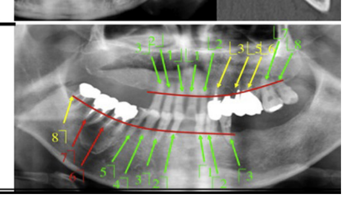
CAD subject	Imaging modality	Schema
Preliminary alveolar bone level of entire dental arch	Panoramic radiograph	
Precise alveolar bone resorption of a tooth	Dental CBCT	
Radiolucent lesion in the jaws	Panoramic radiograph and/or dental CBCT	
Automated dental charting systems	Panoramic radiograph	

Figure 4 Other possible targets for CAD screening and recording in a digital dental record.

It has been reported that panoramic radiograph is a useful modality to find maxillary sinus abnormalities [7]. However, it has been also noted that diagnostic reliability of panoramic radiograph was lower than CT [8].

3. Future CAD programs in the field of dentistry

There are several other possible targets for dental radiological CAD (Fig. 4). In addition to the panoramic radiograph, CBCT and other imaging modalities are CAD candidates.

One promising CAD program is to evaluate the degree of alveolar ridge bone resorption (absorption) due to periodontitis. This task may be divided into two algorithms. One is to evaluate the progress of alveolar bone resorption within the general dental arch. A radiographic image to assess the entire dental arch could be acquired using the both intraoral and panoramic radiographs, though the panoramic radiograph is a better modality for a CAD algorithm. Another algorithm would be to measure precise bone resorption in each individual tooth. A CAD algorithm based on dental CBCT may be better for this purpose, given the ability of CBCT to generate three-dimensional images.

Another major aim of dental CAD is to detect solitary radiolucent lesions in the jaws. These include common odontogenic pathologies such as radicular cysts and dentigerous cysts. This subject may be appropriate to both panoramic radiography and dental CBCT. A key issue to detect radiolucent lesions may be in the accuracy of pixel density value in the panoramic radiograph. Similarly, in dental CBCT images, a stable CT value is important for a CAD algorithm to distinguish between lesions and surrounding osseous tissue, because radiolucent jaw lesions measure from 20 to 60 Hounsfield Unit (HU) and the surrounding cancellous bone measures over 200 HU. However as we mention later, it is difficult for dental CBCT to employ HU as a reliable unit of density.

The principles of panoramic radiograph are also to hamper density measurements. The pixel value of panoramic radiograph is unstable. The rotational panoramic radiograph scans around the face using narrow X-ray beam. On the way to rotation, various anatomical structures such as the cervical vertebrae and the mandibular angle of opposite side are overlapping to objective imaging layer.

It would be very convenient if a complete electronic dental chart was created automatically based on data from panoramic radiographs, which, unlike visual inspection, can detect dental implants, endodontic treatment, and impacted wisdom teeth. Similarly, it is vital in the examination of a child with mixed dentition to check the completeness of permanent teeth. Although the technological level required for this CAD algorithm is high, automated dental charting systems are under consideration.

4. Dental CBCT and CAD programs

Dental CBCT lends itself well to CAD algorithms; many current CAD programs were developed for whole-body CT image data. However it has been reported that it is difficult for dental CBCT to measure density reproducibly [9]. This is especially problematic in small fields of view (40—60 mm). We attribute the cause of this phenomenon to projection data discontinuity caused by maxillofacial hard tissue structures outside the reconstructed volume affecting the density value of the structures within the volume of interest.

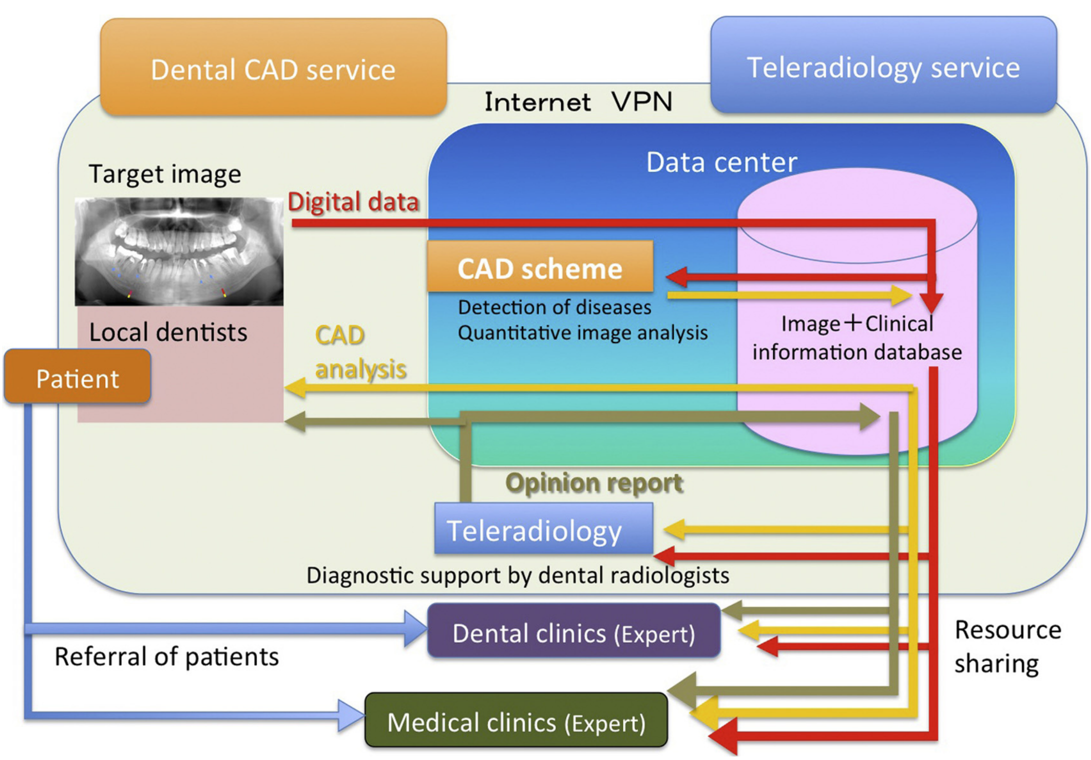


Figure 5 The coordination of CAD and teleradiology. CAD screens the panoramic radiographs before teleradiology, and transmits them to a centralized group of radiologists for final interpretation.

Generally, a CAD algorithm discriminates between different anatomical structures based on the morphological character and the density value (CT number). Without stable CT number values, it is difficult for CAD to determine the density of a tissue or organ in CT images.

5. Cooperation between CAD and teleradiology

Teleradiology is becoming widespread in medical hospitals. Typically, radiologists in a central location distant from the patient receive and interpret diagnostic images and make a report. Because of the need for privacy and security, teleradiology uses secure network transmission technologies such as virtual private network system. In Japan, the Support Association for Diagnostic Imaging in Dentistry of Japan (SADID Japan) was established in 2011 and is providing a remote interpretation service of dental diagnostic images (such as panoramic radiographs and CBCT).

When a panoramic radiograph with a sign of medical disease (such as osteoporosis or arteriosclerosis) is interpreted at SADID Japan, the radiologist in charge provides the general dentist the interpretation report plus suggestions regarding the work-up of the medical aspects of the case. However, as it was previously mentioned, it is not easy for general dental practitioners to check every diagnostic image in detail, then to choose suspect panoramic images for transmission to SADID Japan.

Therefore we designed a systematic approach to screening large numbers of panoramic radiographs by means of a combination of CAD and teleradiology (Fig. 5). In this approach, a dental practitioner sends every panoramic image to a CAD system on a secure web browser. CAD assesses the images automatically, and routes those cases with possible medical disease to SADID Japan. We have tested this procedure with the cooperation of more than 10 dentists. Over 800 panoramic images were studied so far and several suspect cases of medical disease have been found. We think that the combination of CAD and teleradiology is useful to improve patient care by early detection of medical disease. It is also useful for risk stratification for patients sent for dental procedures.

Conflict of interest statement

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