Diagnosis of Maxillary Sinusitis on Waters' View Conventional Radiograph using Convolutional Neural Network

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Abstract

We compared the diagnostic performance of convolutional neural network (CNN) in diagnosing maxillary sinusitis on Waters' view radiograph with those of five radiologists using temporal and geographic external test sets. In the temporal external test set, area under the receiver operating characteristic curves (AUC) of CNN was 0.93, which was comparable with AUCs of radiologists which ranged 0.83–0.89. In the geographic external test set, AUC of CNN was 0.88, which was comparable with AUCs of the radiologists which ranged 0.75–0.84. The CNN can diagnose maxillary sinusitis on Waters' view radiograph as accurately as the expert radiologists.

1 Introduction

Sinusitis is one of the most commonly diagnosed diseases in the United States and appears to affect more than 1/5 of the US population annually [1]. Among them, the maxillary sinus is one of the most common sites of sinusitis. Imaging of sinusitis is indicated when clinical history and physical examination are equivocal, when conventional treatment has failed, when complication such as extrasinus extension of infection is suspected, or when a surgery is being considered. It is considered to be abnormal if the antrum of the maxillary sinus shows mucosal thickening > 4 millimeters, air-fluid level, or total opacification on the imaging studies. The presence of air-fluid level and total opacification on CT could be used as imaging criteria to triage patients who need antibiotic treatment [2].

CT is the imaging modality of choice for sinusitis, which gives the best overall anatomic detail of the paranasal sinuses. Conventional radiographs such as Waters' view are often used as the first-line investigation for sinusitis. The reported sensitivity and specificity of the conventional radiograph in diagnosis of maxillary sinusitis are 0.76 and 0.79, respectively, when the result of sinus puncture was regarded as a reference standard [3]. If the diagnostic accuracy of conventional radiograph can be improved with an assistance of deep learning, patients with suspected sinusitis may avoid unnecessary CT examination with higher radiation dose.

The purpose of this study is to compare the diagnostic performance of convolutional neural network (CNN) and that of expert radiologists in diagnosis of maxillary sinusitis on Waters' view radiograph.

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Table 1: Diagnostic performance of CNN and the radiologists (R denotes radiologist)

	CNN	R1	R2	R3	R4	R5
Temporal external set						
Sensitivity	0.77	0.75	0.82	0.71	0.79	0.81
Specificity	0.94	0.97	0.83	0.90	0.76	0.80
AUC	0.93	0.89	0.88	0.83	0.86	0.85
Geographic external set						
Sensitivity	0.56	0.55	0.60	0.52	0.67	0.62
Specificity	0.99	0.99	0.95	0.96	0.83	0.84
AUC	0.88	0.79	0.84	0.77	0.84	0.75

2 Methods

2.1 Datasets

Two radiologists labeled all the images in consensus. The radiographs used in the training (n = 8,000) and validation set (n = 1,000) were labeled based on their radiographic findings. Meanwhile, the radiographs used in temporal external test set (n = 140) and geographic external test set (n = 200) were labeled based on their concurrent CT findings. Another test set (n = 200) were made for measuring interobserver agreement between CNN and majority decision of radiologists.

2.2 Image Preprocessing

Digital Imaging and Communications in Medicine (DICOM) files of the Waters' view radiographs were loaded using the Pydicom library (Python Software Foundation; version 0.9.9). The 7 X 7 cm squared images centered on the center of the bilateral maxillary sinuses were cropped. To increase the volume of the training data and to reduce confusion, the images of left maxillary sinuses were horizontally flipped as if they were right ones. All the images were finally resized to a resolution of 224 X 224 pixels with bilinear interpolation.

2.3 Deep Learning Algorithm

We implemented a convolutional neural network with residual blocks motivated from the Residual Net, which has been showing outstanding performances particularly in image classification tasks. The network comprised a stack of ten residual blocks and one fully connected layer. Batch normalization was applied to each convolution layer. The output of the last layer was connected to a softmax function to compute the cross-entropy loss to be minimized by the RMSProp optimizer. The learning rate was set to start with the value of 0.01 and to decay in every 1,000 steps with a rate of 0.94. The mini-batch size was set to 48. We adopted the Xavier initialization to assign the initial network weights. In training procedure, for data augmentation improving performance, the input image patches (224 X 224 pixels) were randomly distorted by scaling, translation, and contrast modification at each time they were fed into the network. The output of the network is a probability distribution of maxillary sinusitis.

2.4 Observer Study by Expert Radiologists

Five invited radiologists with 3–19 years of experience in neuroradiology were also requested to rate diagnostic confidence level of sinusitis based on the 5-point ordinal scale: 1, definitely not sinusitis; 2, probably not sinusitis; 3, indeterminate; 4, probably sinusitis; 5, definitely sinusitis.

3 Results

The area under the receiver operating characteristics curves (AUC) of the deep learning algorithm were 0.93 for the temporal external test set and 0.88 for the geographic external test set. The AUCs of invited radiologists ranged 0.83–0.89 for the temporal external test set and 0.75–0.84 for the geographic external test sets (Figure 1, Table 1).

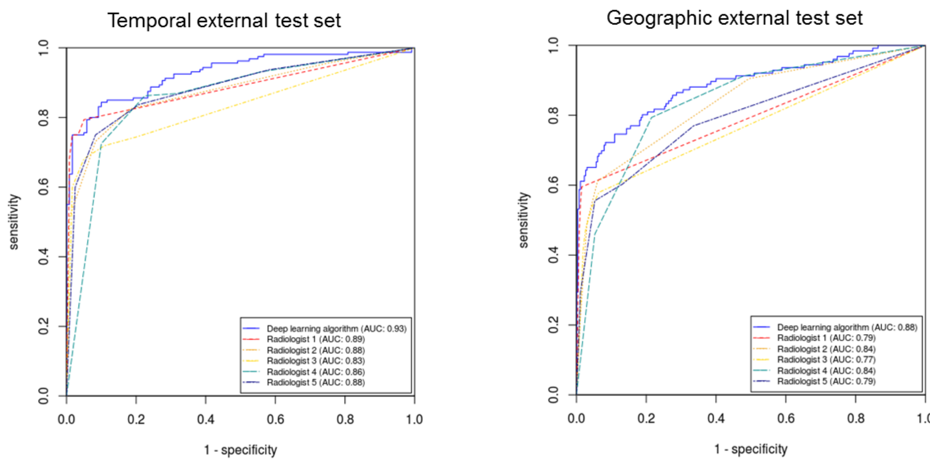

Figure 1: AUC of CNN and the radiologists

There was strong interobserver agreement between the algorithm and the majority decision by the radiologists with Cohen's kappa coefficient of 0.82.

The correlation coefficient between the predicted probability of the algorithm and the confidence level of invited radiologists was 0.89 and 0.84 with the two test sets, respectively.

Sample images from the test set with class activation mapping are shown in Figure 2. The most sensitive regions in cases with sinusitis were mucus or mucosal thickening in the maxillary sinus. The most sensitive regions in non-sinusitis cases were located along the bony wall of the maxillary sinus.

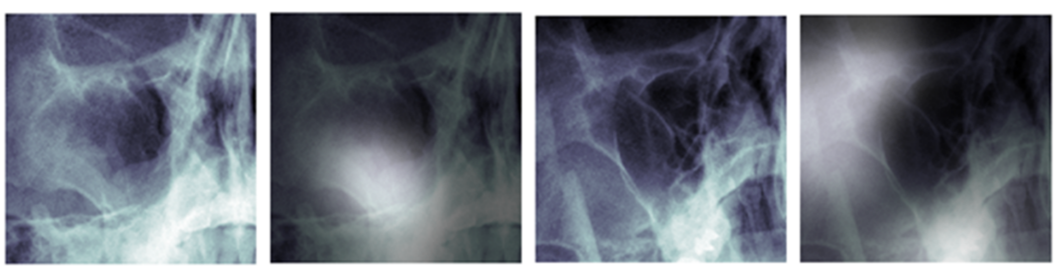

Figure 2: Class activation mapping for sinusitis (left two images) and normal (right two images)

4 Conclusion

The convolutional neural network could diagnose maxillary sinusitis on conventional Waters' view radiograph as accurately as the expert radiologists.

References

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