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学位論文内容の要旨

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学位論文題名

Deep Learning Classification and Grad-CAM-based Visualization for Osteoporotic Lumbar Vertebral Fractures on Radiographs

（単純 X 線写真における骨粗鬆性腰椎椎体骨折の深層学習分類と Grad-CAM に基づく分類根拠に関する検討）

Introduction: Early diagnosis and initiation of treatment for fresh osteoporotic lumbar vertebral fractures (OLVF) are crucial to maintain the fresh OLVF patient's activities of daily living and quality of life. Magnetic resonance imaging (MRI) is generally performed to differentiate fresh and old OLVF. However, MRI is a high-cost exam that burdens patients with severe back pain by forcing them to maintain their body position during long examinations. Furthermore, it could be difficult to perform in an emergency. MRI should therefore be performed in appropriately selected patients with a high suspicion of fresh fractures. As radiography is the first-choice imaging examination for the diagnosis of OLVF, improving screening accuracy with radiographs will optimize the decision of whether MRI is performed. In recent years, deep learning methods such as convolutional neural network (CNN) and Gradient-weighted Class Activation Mapping (Grad-CAM) have been used to solve various problems in the field of medical imaging. One of the most important features of CNN is high image classification performance based on high feature extraction capability. Grad-CAM can visualize the basis of CNN classification, which may be able to deepen our understanding of the CNN classification process. This study aimed to evaluate a method to automatically determine the presence of OLVF and classify old and fresh OLVF using a CNN model with radiographs, and the areas of interest to our CNN model based on Grad-CAM.

Materials and Methods: 523 in Institution 1 and 140 in Institution 2 patients with suspected OLVF who underwent both lumbar vertebrae (LV) radiography and MRI were included. A total

of 3481 LV images in Institution 1 for training, validation, and testing and 662 LV images in Institution 2 for external validation images were collected. Visual evaluation with MRI images by two radiologists determined the ground truth of LV conditions such as normal, old, and fresh OLVF. Automatic object detection with you only look once at version 5 (YOLOv5) was trained to recognize each lumber vertebral body and used to create the sample images for CNN classification. Three CNNs, Resnet-50, DenseNet-161, and ResNeXt-50, were ensembled to determine the final classification result. The classification performance on the LV conditions was calculated. Grad-CAM images were quantitatively evaluated and analyzed for the areas of interest in image classification by CNN.

Results: The interobserver agreement value for visual evaluation by two radiologists was 0.801. The intraobserver agreement values for raters 1 and 2 were 0.821 and 0.861, respectively. The detection performance of YOLOv5 was mAP (0.5) of 0.995 and mAP (0.5: 0.95) of 0.993 for the validation dataset and mAP (0.5) of 0.982 and mAP (0.5: 0.95) of 0.835 for the test dataset. The accuracy, sensitivity, specificity, and area under the curve in receiver operating characteristic analysis were 0.894, 0.836, 0.920, and 0.912 in the test and 0.867, 0.674, 0.866, and 0.855 in the external validation, respectively. Grad-CAM images had higher pixel values around the center of the image. The CNN classification was correctly based on the characteristics of the vertebral body rather than on background areas. There was a definite difference in the areas of interest to our CNN model in each group, normal vertebra, old, and fresh OLVF.

Conclusions: The proposed CNN-based method demonstrated high performance in determining the presence of OLVF and classifying old or fresh OLVF on radiography without manual procedures. Utilizing objective classification results from our CNN is expected to improve the accuracy of fresh OLVF screening. This may lead to appropriate decisions on the indication for close examination with MRI. The quantitative evaluation of Grad-CAM images allowed us to identify the areas of interest for the CNN model created in this study, which were found to be mainly the anterior vertebral wall and endplates. Further detailed Grad-CAM analysis might provide new knowledge for OLVF evaluation with the human eye in clinical practice in the future.