Detection of Hypertrophic Cardiomyopathy Using a Convolutional Neural Network-Enabled 12-Lead Electrocardiogram

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Abstract

Background: Hypertrophic cardiomyopathy (HCM) is one of the leading causes of sudden cardiac death in adolescents and young adults. We aimed to develop an artificial intelligence (AI) approach for the detection of HCM based on the 12-lead ECG.

Methods: We trained and validated a convolutional neural network (CNN) using digital 12-lead ECGs from 2,448 patients with verified HCM diagnosis and 51,153 non-HCM age- and sex-matched control subjects. The ability of the CNN to detect HCM was then tested on a different dataset of 612 HCM and 12,788 non-HCM subjects.

Results: In the combined datasets, mean age was 54.8 ± 15.9 years for the HCM group and 57.5 ± 15.5 years for the control group. After training and validation, the area under the curve (AUC) of the CNN in the validation dataset was **0.95** (95% CI 0.94-0.97) at the optimal probability threshold of 11% for having HCM. When applying this probability threshold in the testing dataset, the CNN's AUC was **0.96** (95% CI 0.95-0.96) with sensitivity 87% and specificity 91%. In subgroup analyses, the AUC was **0.95** (95% CI 0.94-0.97) among patients with LVH by ECG criteria and **0.95** (95% CI 0.90-1.00) among patients with a completely normal ECG. The model performed particularly well in younger patients (diagnostic OR 195.0 [CI 84.3-451.2]) in patients age <40 years).

Conclusions: ECG-based detection of HCM by an AI algorithm can be achieved with high diagnostic performance. The model may enable effective and relatively inexpensive screening for HCM using the 12-lead ECG.

Objectives

Hypertrophic cardiomyopathy (HCM) is one of the leading causes of sudden cardiac death (SCD) among adolescents and young adults and is associated with significant morbidity in all age groups. More than 90% of patients with HCM have electrocardiographic abnormalities and the 12-lead ECG may offer an attractive non-invasive, low cost, and rapid means of screening for the condition. It may be possible to refine the ECG detection of HCM by leveraging the power of state of the art computing technology,. We have used this approach successfully to identify left ventricular dysfunction with a model area under the curve (AUC) of 0.93. Accordingly, the aim of the current study was to train, validate, and test an AI-based deep learning approach for the detection of HCM based solely on the 12-lead ECG in a large cohort of HCM cases and non-HCM controls.

Figure 1: Model Performance

Results

Following training and validation, the AUC of the CNN in the validation dataset was 0.95 (95% CI 0.94-0.97) with the optimal probability threshold of 11%, which results in sensitivity and specificity of 90% and 90%, respectively, for having HCM. When applying this probability threshold in the test dataset, the CNN's AUC was 0.96 (95% CI 0.95-0.96) with sensitivity 87% and specificity 91% (Figure 2). Positive predictive value was 31% and negative predictive value was 99%.

Among the controls with false positive detections, 31% satisfied the LVH ECG criteria. In a model developed and tested based only on a single ECG lead (lead I), the AUC was 0.91 (95% CI 0.89-0.92), sensitivity was 83% and specificity was 81%.

Methods

We identified 3,060 adult patients (18 years or older) with a diagnosis of HCM and a control group of 73,543 adult patients based on standard diagnostic criteria who had at least one digital, standard, 10-second, 12-lead ECG acquired in the supine position between July 1987 and November 2017.

Each ECG was converted to a 12 x 5000 matrix (i.e., 500 Hz sampling over each of 12 separate leads; the first dimension is spatial and the second dimension is temporal). We then applied a convolutional neural network (CNN) using the Keras Framework with a Tensorflow backend and Python. The internal validation dataset was used to optimize the network architecture (identify hyperparameters, batch, and step size). We tested multiple networks and selected the simplest (i.e. the one with fewest parameters and layers) that resulted in the highest area under the curve (AUC) of the receiver operator curve (ROC).

Figure 2: Subgroup Results of Network Performance

Figure 3: Model Development

Discussion

In this study, we report the first AI-based CNN for detection of HCM based on the 12-lead ECG. The network demonstrates high discriminatory ability in distinguishing HCM cases from non-HCM controls with an AUC of 0.96. The network is associated with an extremely low false negative rate across a range of HCM probability thresholds. The model performance was superior in our youngest age cohort (<40 years) in this study which suggests that it may perform well as a screening tool in young adults. Furthermore, in the subgroup of subjects with ECG criteria of LVH, model performance is nearly identical to the overall population with AUC of 0.95 (95% CI 0.94-0.97), suggesting that the model is valuable in distinguishing HCM from other causes of LVH. Similar performance was demonstrated among subjects with ECGs that had been considered completely normal by standard interpretation.

Conclusions

A fully-automated, AI-based network to detect HCM based on the standard, 12-lead ECG is feasible and can be performed with high diagnostic performance. Our model may improve the yield of population-based ECG screening for those at risk of HCM-related adverse events. Combining the HCM network with similar networks for other SCD-predisposing conditions (LV systolic dysfunction, arrhythmogenic right ventricular cardiomyopathy, channelopathies, congenital anomalies, etc.) may further improve the effectiveness and cost-effectiveness of ECG screening approaches as a whole.