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LETTER TO THE EDITOR

ν-net

Deep Learning for Generalized Biventricular Mass and Function Parameters Using Multicenter Cardiac MRI Data

Cardiac magnetic resonance imaging-derived biventricular mass and function parameters, such as end-systolic volume, end-diastolic volume, ejection fraction, stroke volume (SV), and ventricular mass, are clinically well established. Image segmentation can be challenging and time-consuming.

This study introduces ν-net (/nju:nɛt/), a deep learning approach facilitating fully automated, high-quality segmentation of the right ventricular (RV) and left ventricular (LV) endocardium and epicardium for reliable and precise estimation of cardiac mass and function parameters.

The study used datasets from Hannover Medical School (MHH), the Data Science Bowl Cardiac Challenge (DSBCC), the MICCAI 2009 LV Segmentation Challenge (LVSC), and the Right Ventricle Segmentation Challenge (RVSC). Training was accomplished on a small subset of the MHH (n = 193) and DSBCC (n = 60) datasets. Evaluation was performed on all available datasets: MHH (n = 309), DSBCC (n = 602), LVSC (n = 88), and RVSC (n = 32). Training and evaluation datasets were mutually exclusive. The network topology was based on U-Net (1). For LV ejection fraction, the single fixed rater intraclass correlation coefficient (ICC) of ν-net to ground truth was 0.98 (MHH), 0.95 (LVSC), and 0.80 (DSBCC); for RV ejection fraction, it was 0.96 (MHH) and 0.87 (RVSC); for LV mass, it was 0.95 (MHH) and 0.94 (LVSC); for RV mass, it was 0.83 (MHH and RVSC); for LV SV, it was 0.98 (MHH), 0.91 (LVSC), and 0.90 (DSBCC); and for RV SV, it was 0.92 (MHH) and 0.84 (RVSC). Caudron et al. (2) report a human-level LV ejection fraction ICC of 0.95, an RV ejection fraction of 0.80, an LV mass of 0.85, an RV mass of 0.54, an LV SV of 0.87, and an RV SV of 0.81.

ν-net achieves an LV Dice similarity coefficient (DSC) of 95 ± 2%/92 ± 4% (MHH epicardium/MHH endocardium), and 93 ± 3%/84 ± 7% (LVSC), as well as an RV DSC of 90 ± 4%/88 ± 6% (MHH) and 86 ± 6%/85 ± 7% (RVSC). To adjust for systematic errors likely due to varying segmentation styles in different cohorts, a simple linear regression correction was applied (**Figure 1**) as has been described elsewhere (3).

Regarding the MHH dataset, ν-net achieved comparable or higher agreement with the ground truth regarding ICC than 2 human experts agree on average, as determined by Caudron et al. (2). Furthermore, ν-net's accomplishments are comparable to human performance on the LVSC and RVSC datasets and outperformed a human by a wide margin, especially at the task of gauging the RV endocardial volume and ventricular mass. A slightly lower ICC score of the left endocardial volumes on the DSBCC dataset was observed, most likely due to the multicenter and multi-observer settings, resulting in inherent data heterogeneity. To improve the performance, the results would have to be evaluated for each observer independently.

A limitation of this study is the small size of openly available datasets. LVSC and RVSC contain 61 cases with freely accessible contours. Furthermore, the aforementioned datasets include the segmentation of the left or right ventricle exclusively. In addition, training and validating on a single-center dataset bear the risk of overfitting. In a multicenter, multireader arrangement, ν-net exhibited state-of-the-art performance in terms of DSC and achieved comparable or higher ICCs compared with human segmentation performance. This outcome was also true for data not included in the training set (LVSC and RVSC) and suggests a good generalization of the neural network.

The presented neural network is ready to be used on a large scale for cost- and time-efficient analysis of cardiac mass and function parameters, especially in the anatomically complex right ventricle. Additional information is available elsewhere (3,4).

Hinrich B. Winther, MD*
Christian Hundt, PhD
Bertil Schmidt, PhD
Christoph Czerner, MD
Johann Bauersachs, MD
Frank Wacker, MD
Jens Vogel-Claussen, MD

*Institute for Diagnostic and Interventional Radiology
Hannover Medical School
Carl-Neuberg Strasse 1
30625 Hannover
Germany
E-mail: hbwinther@metalabs.de

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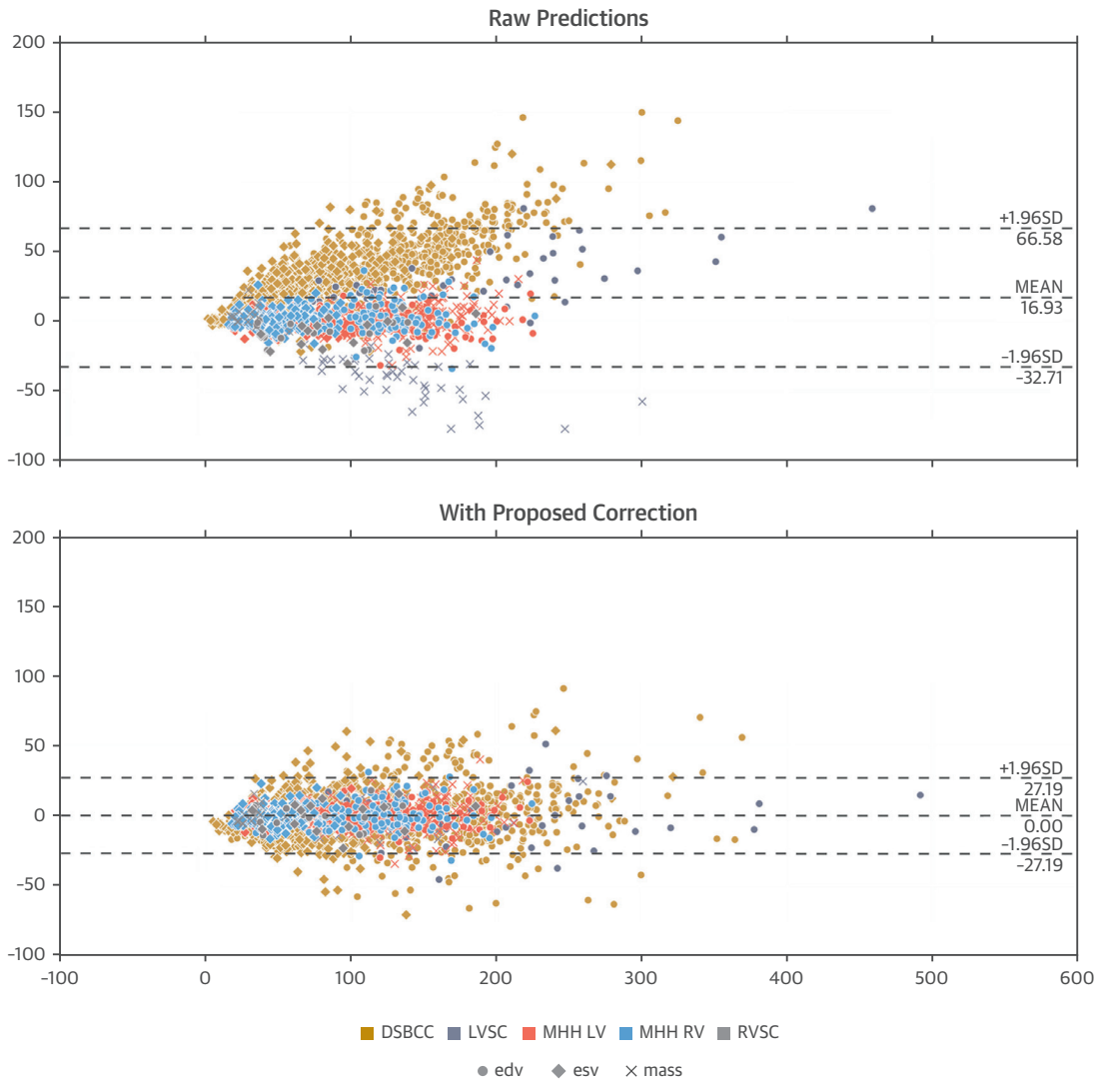
FIGURE 1 **Bland-Altman Plot of the Predicted Clinical Parameters and the Ground Truth**



The **upper plot** depicts the raw predictions of the clinical parameters of v-net against the ground truth derived from manual segmentations. Please note that the systematic divergence of the point clouds inherent to each dataset is likely due to different segmentation styles. The **lower plot** illustrates the proposed linear regression correction (as described elsewhere [3]), resulting in notably improved agreement between v-net and ground truth. DSBCC = Data Science Bowl Cardiac Challenge; edv = end-diastolic volume; esv = end-systolic volume; LV = left ventricular; LVSC = MICCAI 2009 LV Segmentation Challenge; MHH = Hannover Medical School; RV = right ventricular; RVSC = Right Ventricle Segmentation Challenge.

disclose. Drs. Winther and Hundt contributed equally to this work and are joint first authors.

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