

Literature on real-time AI-empowered echocardiography

Miguel Xochicale

January 11, 2022

Contents

1	Introduction	1
1.1	Image Quality Assessment	1
1.2	Clustering techniques	1
1.3	Auto-encoders	2
1.4	Segmentation	2
1.5	Contrastive Learning	2
1.6	Others	2
1.7	AI-guided US imaging	2
2	Methods and materials	3

1 Introduction

In the last decades the use of echocardiography is a crucial clinical approach in Intensive Care Units (ICU) because of the advances of smaller US clinical devices, US image quality and its real-time capabilities to access cardiac anatomy [7, 20, 19, 3]. However, despite the previous advances there is still challenges on finding standard views from experienced sonographers that sometimes such quantifications are qualitative and subjective [7]. Similarly, automatic quantification of left ventricular ejection fraction (LVEF) is still challenging at the point of care due to variation of protocols, skills levels [8] and the nature of providing feedback on real-time [14].

1.1 Image Quality Assessment

[12] considers chamber clarity, depth gain, on-axis attributes, apical foreshoredness.

1.2 Clustering techniques

Zhang et al. mentioned that 23 view classes from 7168 individually labeled videos that were classified with a 13-layer CNN to then viewed with the use of t-Distributed Stochastic Neighbor Embedding [22]. Kusunose et al. mentioned that other authors have reached an accuracy of 91-94 for 15-view classification while their work mentioned a 98.1 accuracy for five-predefined views [11].

1.3 Auto-encoders

Laumer et al. proposed a novel autoencoder-based framework to learn human interpretable representation of cardiac cycles from cardiac ultrasound data [13],

Ouyang et al. presented echo-dynamic dataset as the first annotated medical video dataset with 10,036 videos. Additionally, authors reported the use of three CNN architectures varying filters in each layer to assess ejection fraction to near-expert performance. It is worthwhile to note that authors got best performance with mean absolute error of 5.44% using clip length of 16 and frame rate of 4. Such error is near-expert performance as they can get 4-5% for skilled echocardiographers in controlled settings [17].

Ghorbani et al. applied convolutional neural networks of cardiac ultrasound to identify local structures, estimate cardiac function and predict pathologies. Their deep learning model, EchoNet, can identify up to 10 cardiac biometrics which results in decreasing repetitive task in the clinical flow, provide interpretation to less experienced cardiologist, and predict phenotypes. This work can predict age, sex, weight and height from echocardiogram images. Authors mention that the increase of data does not improve model training. The homogenisation of cardiac views prior to model training improved training speed and computation time [9]

1.4 Segmentation

With the challenges of limited sampling of cardiac cycles and the considerable inter-observer variability, Ouyang et al. presented a CNN model with residual connections and spatiotemporal convolutions that surpass human performance of segmentation of left ventricle, estimation of ejection fraction and assessment of cardiomyopathy. Their model reached Dice similarity coefficient of 0.92, predicts ejection fraction with mean absolute error of 4.1% and classify heart failure based on reduced ejection fraction [18].

1.5 Contrastive Learning

Methods on Contrastive Learning apparently address the challenge of required labelled data to identify pathologies in the images of detect certain cardiac views. Recently, Chartsias et al. use contrastive learning to train imbalanced cardiac datasets and they compared a naive baseline model to achieve a F1 score of up to 26% [4] Saeed et al. recently investigated contrastive pretraining to improve the DeepLabV3 and UNET segmentation networks of cardiac structures in ultrasound imaging. Authors showed comparable results with state-of-the-art fully supervised algorithms and presents better results compared to EchoNet-Dynamic and CAMUS [15]

1.6 Others

Rank-2 non-negative matrix factorization [21] to generate End-Systole and End-Diastole for apical 4 view. Recently Robust Non-negative Matrix Factorization seems to be implement low-computation cost algorithms to automatic segment mitral valve [6].

1.7 AI-guided US imaging

Near-human quantification of LV and EF has been investigated, however Asch et al. pointed out that boundary identification is prone to errors when low quality images or artifacts

are used Asch et al. pointed out that data and materials were not publicly available and they made use of AutoEF by captionhealth co. Authors used a databases of 50000 echocardiography datasets over a period of 10 years of various clinical US systems. The training datasets included multiple views of 2 and 4-chamber views and LV EF values where clinicians use conventional methods (biplane Simpson technique) [1].

Asch et al. [2].

Hong et al. reported the evaluation of image quality assessment to demonstrate that AI can recognise nuances of varying imaging during scanning [10]

Narang et al. reported the acquisition of 10 echocardiography views of novice users using deep-learning-based software [16]. Narang et al. mentioned that CNN were used with stacks of networks and transformations. The AI-guided software consists of three estimates: (1) quality image assessment, (2) "6-dimensional geometric distance with position and orientation between the current probe location and the location anticipated to optimise the image"; and (3) corrective probe manipulation. [16] Authors mention that algorithms do not use trackers, fiducial marks or additional sensors to make guide estimations [16].

Cheema et al. reported the use of AI-enabled guidance to sonographer which was created from the use of 500000 hand movements. Cheema et al. reported that such feature was the first cardiac authorised by Food and Drug administration in 2020. Authors presented five cases covid-19 intensive care unit (ICU) to illustrate "how decision making affect in patient care" and how the use of AI-enabled provided real-time guidance to acquire desired cardiac UL with the starting of user's transducer position and hand movement [5].

2 Methods and materials

References

- [1] F. M. Asch, N. Poilvert, T. Abraham, M. Jankowski, J. Cleve, M. Adams, N. Romano, H. Hong, V. Mor-Avi, R. P. Martin, and R. M. Lang. Automated echocardiographic quantification of left ventricular ejection fraction without volume measurements using a machine learning algorithm mimicking a human expert. *Circulation: Cardiovascular Imaging*, 12(9):e009303, 2019. doi: 10.1161/CIRCIMAGING.119.009303. URL <https://www.ahajournals.org/doi/abs/10.1161/CIRCIMAGING.119.009303>.
- [2] F. M. Asch, V. Mor-Avi, D. Rubenson, S. Goldstein, M. Saric, I. Mikati, S. Surette, A. Chaudhry, N. Poilvert, H. Hong, R. Horowitz, D. Park, J. L. Diaz-Gomez, B. Boesch, S. Nikravan, R. B. Liu, C. Philips, J. D. Thomas, R. P. Martin, and R. M. Lang. Deep learning-based automated echocardiographic quantification of left ventricular ejection fraction: A point-of-care solution. *Circulation: Cardiovascular Imaging*, 14(6):e012293, 2021. doi: 10.1161/CIRCIMAGING.120.012293. URL <https://www.ahajournals.org/doi/abs/10.1161/CIRCIMAGING.120.012293>.
- [3] S. J. Campbell, R. Bechara, and S. Islam. Point-of-care ultrasound in the intensive care unit. *Clinics in Chest Medicine*, 39(1):79–97, 2018. ISSN 0272-5231. doi: <https://doi.org/10.1016/j.ccm.2017.11.005>. URL <https://www.sciencedirect.com/science/article/pii/S0272523117301168>. Interventional Pulmonology: An Update.

- [4] A. Chartsias, S. Gao, A. Mumith, J. Oliveira, K. Bhatia, B. Kainz, and A. Begiri. Contrastive learning for view classification of echocardiograms. In J. A. Noble, S. Aylward, A. Grimwood, Z. Min, S.-L. Lee, and Y. Hu, editors, *Simplifying Medical Ultrasound*, pages 149–158, Cham, 2021. Springer International Publishing. ISBN 978-3-030-87583-1.
- [5] B. S. Cheema, J. Walter, A. Narang, and J. D. Thomas. Artificial intelligence-enabled pocus in the covid-19 icu: A new spin on cardiac ultrasound. *JACC: Case Reports*, 3(2):258–263, 2021. ISSN 2666-0849. doi: <https://doi.org/10.1016/j.jaccas.2020.12.013>. URL <https://www.sciencedirect.com/science/article/pii/S2666084920314637>.
- [6] Y. Dukler, Y. Ge, Y. Qian, S. Yamamoto, B. Yuan, L. Zhao, A. L. Bertozzi, B. Hunter, R. Llerena, and J. T. Yen. Automatic valve segmentation in cardiac ultrasound time series data. In E. D. Angelini and B. A. Landman, editors, *Medical Imaging 2018: Image Processing*, volume 10574, pages 493 – 504. International Society for Optics and Photonics, SPIE, 2018. URL <https://doi.org/10.1117/12.2293255>.
- [7] H. Feigenbaum. Evolution of echocardiography. *Circulation*, 93(7):1321–1327, 1996. doi: 10.1161/01.CIR.93.7.1321. URL <https://www.ahajournals.org/doi/abs/10.1161/01.CIR.93.7.1321>.
- [8] L. C. Field, G. J. Guldán, and A. C. Finley. Echocardiography in the intensive care unit. *Seminars in Cardiothoracic and Vascular Anesthesia*, 15(1-2):25–39, 2011. doi: 10.1177/1089253211411734. URL <https://doi.org/10.1177/1089253211411734>. PMID: 21719547.
- [9] A. Ghorbani, D. Ouyang, A. Abid, B. He, J. H. Chen, R. A. Harrington, D. H. Liang, E. A. Ashley, and J. Y. Zou. Deep learning interpretation of echocardiograms. *npj Digital Medicine*, 3(1):10, Jan 2020. ISSN 2398-6352. doi: 10.1038/s41746-019-0216-8. URL <https://doi.org/10.1038/s41746-019-0216-8>.
- [10] H. Hong, S. Surette, A. K. Chaudhry, N. Parajuli, C. Cadieu, R. Martin, and J. Thomas. Ai-guided echocardiography system matches the image quality assessment ability of cardiac sonographers. *Journal of the American College of Cardiology*, 77(18 Supplement 1):3240–3240, 2021. doi: 10.1016/S0735-1097(21)04594-0.
- [11] K. Kusunose. Steps to use artificial intelligence in echocardiography. *Journal of Echocardiography*, 19(1):21–27, Mar 2021. ISSN 1880-344X. doi: 10.1007/s12574-020-00496-4. URL <https://doi.org/10.1007/s12574-020-00496-4>.
- [12] R. B. Labs, M. Zolgharni, and J. P. Loo. Echocardiographic image quality assessment using deep neural networks. In B. W. Papież, M. Yaqub, J. Jiao, A. I. L. Namburete, and J. A. Noble, editors, *Medical Image Understanding and Analysis*, pages 488–502, Cham, 2021. Springer International Publishing. ISBN 978-3-030-80432-9.
- [13] F. Laumer, G. Fringeli, A. Dubatovka, L. Manduchi, and J. M. Buhmann. Deep-heartbeat: Latent trajectory learning of cardiac cycles using cardiac ultrasounds. In E. Alsentzer, M. B. A. McDermott, F. Falck, S. K. Sarkar, S. Roy, and S. L. Hyland, editors, *Proceedings of the Machine Learning for Health NeurIPS Workshop*, volume 136 of *Proceedings of Machine Learning Research*, pages 194–212. PMLR, 11 Dec 2020. URL <https://proceedings.mlr.press/v136/laumer20a.html>.

- [14] X. Liu, Y. Fan, S. Li, M. Chen, M. Li, W. K. Hau, H. Zhang, L. Xu, and A. P.-W. Lee. Deep learning-based automated left ventricular ejection fraction assessment using 2-d echocardiography. *American Journal of Physiology-Heart and Circulatory Physiology*, 321(2):H390–H399, 2021. doi: 10.1152/ajpheart.00416.2020. URL <https://doi.org/10.1152/ajpheart.00416.2020>. PMID: 34170197.
- [15] S. Mohamed, R. Muhtaseb, and Y. Mohammad. Is contrastive learning suitable for left ventricular segmentation in echocardiographic images?, 2021.
- [16] A. Narang, R. Bae, H. Hong, Y. Thomas, S. Surette, C. Cadieu, A. Chaudhry, R. P. Martin, P. M. McCarthy, D. S. Rubenson, S. Goldstein, S. H. Little, R. M. Lang, N. J. Weissman, and J. D. Thomas. Utility of a Deep-Learning Algorithm to Guide Novices to Acquire Echocardiograms for Limited Diagnostic Use. *JAMA Cardiology*, 6(6):624–632, 06 2021. ISSN 2380-6583. doi: 10.1001/jamacardio.2021.0185. URL <https://doi.org/10.1001/jamacardio.2021.0185>.
- [17] D. Ouyang, B. He, A. Ghorbani, L. P. Matt, A. E. A., L. D. H., and Z. J. Y. Echonet-dynamic: a large new cardiac motion video data resource for medical machine learning, 2019.
- [18] D. Ouyang, B. He, A. Ghorbani, N. Yuan, J. Ebinger, C. P. Langlotz, P. A. Heidenreich, R. A. Harrington, D. H. Liang, E. A. Ashley, and J. Y. Zou. Video-based ai for beat-to-beat assessment of cardiac function. *Nature*, 580(7802): 252–256, Apr 2020. ISSN 1476-4687. doi: 10.1038/s41586-020-2145-8. URL <https://doi.org/10.1038/s41586-020-2145-8>.
- [19] S. Singh and A. Goyal. The origin of echocardiography: a tribute to inge edler. *Texas Heart Institute journal*, 34(4):431–438, 2007. ISSN 0730-2347. URL <https://pubmed.ncbi.nlm.nih.gov/18172524>.
- [20] A. Vieillard-Baron, M. Slama, B. Cholley, G. Janvier, and P. Vignon. Echocardiography in the intensive care unit: from evolution to revolution? *Intensive Care Medicine*, 34(2):243–249, Feb 2008. ISSN 1432-1238. doi: 10.1007/s00134-007-0923-5. URL <https://doi.org/10.1007/s00134-007-0923-5>.
- [21] B. Yuan, S. R. Chitturi, G. Iyer, N. Li, X. Xu, R. Zhan, R. Llerena, J. T. Yen, and A. L. Bertozzi. Machine learning for cardiac ultrasound time series data. In A. Krol and B. Gimi, editors, *Medical Imaging 2017: Biomedical Applications in Molecular, Structural, and Functional Imaging*, volume 10137, pages 617 – 624. International Society for Optics and Photonics, SPIE, 2017. URL <https://doi.org/10.1117/12.2254704>.
- [22] J. Zhang, S. Gajjala, P. Agrawal, G. H. Tison, L. A. Hallock, L. Beussink-Nelson, M. H. Lassen, E. Fan, M. A. Aras, C. Jordan, K. E. Fleischmann, M. Melisko, A. Qasim, S. J. Shah, R. Bajcsy, and R. C. Deo. Fully automated echocardiogram interpretation in clinical practice. *Circulation*, 138(16):1623–1635, 2018. doi: 10.1161/CIRCULATIONAHA.118.034338. URL <https://www.ahajournals.org/doi/abs/10.1161/CIRCULATIONAHA.118.034338>.