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Emerging Trends in Non-Invasive Imaging Techniques for Cardiovascular Disease Diagnosis: A Comprehensive Review

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Abstract : Cardiovascular disease (CVD) remains a global public health crisis, claiming millions of lives annually. Early and accurate diagnosis plays a pivotal role in effective management and improved patient outcomes. Non-invasive imaging techniques have revolutionized CVD diagnosis, providing clinicians with detailed insights into cardiac structure, function, and pathology without the need for invasive procedures. This review comprehensively explores the current landscape and emerging trends in non-invasive imaging for CVD diagnosis, covering established modalities like echocardiography, cardiac magnetic resonance imaging (CMR), and computed tomography (CT) alongside novel approaches like radiofrequency (RF) imaging and artificial intelligence (AI)-powered methods. We delve into the strengths, limitations, and evolving applications of these techniques in diagnosing various CVDs, highlighting their potential to enhance diagnostic accuracy, refine risk stratification, and guide personalized therapy for CVD patients.

***Index Terms* - Cardiovascular disease, non-invasive imaging, echocardiography, cardiac magnetic resonance imaging, computed tomography, radiofrequency, artificial intelligence, diagnosis, personalized therapy, risk stratification, emerging trends.**

1. Background:

1.1 Review of Literature:

CVD covers a broad range of ailments that affect the cardiovascular system in general, including its own blood supply, like coronary artery disease, heart failure, arrhythmias, and diseases involving the valves. Although there has been massive improvement in the technological advancements in the management and prevention of CVD, it is still one of the major causes of death across the globe, with nearly 17.9 million deaths each year as per the recent data taken from the WHO (World Health Organization) [1]. Prompt and timely diagnosis is important for proper intervention and a better patient prognosis. Conventional methods like electrocardiograms (ECG) and blood investigations like analysis of biomarkers usually come up with limited information about heart structures and physiological functions. The recent non-invasive approach has emerged as a revolution in CVD diagnosis and management, which provides detailed analysis of the blood vessels and heart, not just providing information on pathological aspects but also providing guidance for better clinical decision outcomes.

1.1.1 Established Techniques:

Echocardiography: The conventional methodology consists of using the waves of sound for the imaging of the various anatomical components of the heart, such as chambers, valves, and blood flow across the valves, while at the same time understanding and reading the physiological impact created on the blood flow and heart. The advantages lie in the real-time imaging, accessibility, and range of choices in assessment of the various cardiac pathological conditions. Despite this, the main dependencies for image creation lie with the operator's hand-on operation, body habits, and orientation. Advancements like Adaptive contrast enhancement [4], Real time 3D imaging tissue Doppler imaging for myocardial strain assessment [5] and speckle-tracking[6] for early wall motion abnormalities are further refining its diagnostic capabilities.

1.1.2 Cardiac Magnetic Resonance Imaging (CMR): CMR provides dynamic and magnificent detailing of the anatomy and tissue features while at the same time offering the highest protection and exposure to the radiation to the minimal.[7] The greater advantage lies in the detailed assessment of the delineating myocardial fibrosis, the study of the perfusion abnormalities, and the study of the congenital heart defects. Not only does it make the CMR one of the best tools for detailed cardiac evaluation, but it also comes with the limitation of a higher cost and restricted availability. [8]

1.1.3 Computed Tomography (CT): A CT scan yields images of the coronary arteries with higher resolution, including the major vessels. Cardiac CT angiography (CTA) provides the imaging of the coronary visualization in a non-invasive way, aiding the diagnosis of the various CAD and guiding the revascularization procedures. For rapid scan times as well as delayed exposure to radiation, multidetector CT comes with enhanced clinical application [10]. Despite that, the risk of potential radiation and contrast-induced complications can't be ignored. [11]

Fig- 1 – Sagittal Section for Abdominal Aorta Imaging on CT Angiography

Source - Glitzy queen00 , Wikimedia (Public domain) (https://commons.wikimedia.org/wiki/File:SagitalAAA.jpg)

2. Emerging Trends:

2.1 Radiofrequency (RF) Imaging: The recent technological advancement that involves the usage of radiofrequency waves to generate detailed images of the microstructure of the cardiac tissues. In contrast to conventional ultrasound, this technique is free from acoustic impedance, providing better detailing of the subtle myocardial changes at the initial stages than most of the other modalities. The potential of the detection of preclinical CVD even before the symptoms appear is helping with further preventive measures.

2.2 Artificial Intelligence (AI)-powered Analysis: The use of the AI algorithm is enhancing the transformation of cardiovascular imaging, providing automated image interpretation [12], better workflow capabilities, and enhanced disease detection. AI tools can overcome inter-observer variability and increase diagnostic accuracy through automated quantification of the CTA [13] . In addition to this, there is the ability to analyze the existing datasets of imaging data to identify patterns and predict the future of cardiovascular events. [14] provides the way for understanding personalized risk stratification and measures for preventive aspects.

2.3 Fusion Imaging: Instead of relying solely on the specific investigation, a combination of diagnostic modality like CMR and PET provides even better insights about cardiovascular pathology [15] . This multidimensional and multiple parametric method comes with a better diagnostic modality, particularly in complex cases. Considering the combination of CMR and PET perfusion imaging, it can actually help in the differentiation of the scar tissue in patients with heart failure by guiding targeted theraphy decisions. [16],[17]

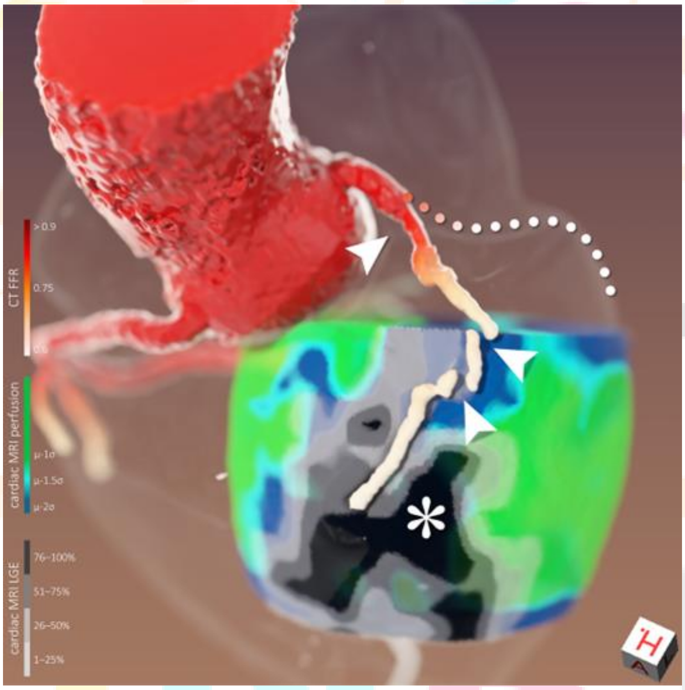

Fig- 2 – The visuals depict a 56-year-old male identified as patient 10. The images include both three-dimensional image fusion (referred to as 'a') and standard two-dimensional images (noted as 'b' for curved multiplanar CT coronary angiography reformation of the left anterior descending artery [LAD] and 'c' for cardiac MRI late gadolinium enhancement [LGE]). The images reveal several significant findings: there is a near-complete blockage in the proximal LAD, indicated by arrowheads in both 'a' and 'b', leading to decreased blood flow in the surrounding area. However, the viability of the myocardium remains relatively intact in the nearby region (with scar transmurality less than or equal to 50%). Conversely, a complete blockage in the distal LAD has resulted in a large area of extensive scar tissue formation in the distal region, denoted by '*' in 'a' and 'c'. Additionally, due to a narrowing in the proximal left circumflex artery (LCx), the segmentation algorithm failed to accurately map its path, as shown by the dotted line in 'a'. Nonetheless, it is evident that the reduced blood flow in the LCx is leading to decreased perfusion in the lateral wall of the heart, although widespread scarring has not yet occurred. The text also mentions the CT-derived fractional flow reserve (CT FFR).

Source - https://doi.org/10.1148/ryct.2020190116

3 Limitations and Challenges:

While non-invasive imaging comes with lots of advantages, it does have certain limitations, such as echocardiography being operator-dependent and body habits affecting the image quality. CMR and CT have a higher cost of operation, witha higher risk associated with radiation exposure. Emerging techniques include RF imaging and AI, which are still under development and require further clinical review. Apart from that, providing equitable access to technologies is still a challenge, especially in resource-limited settings.

4 Conclusion:

Non-invasive imaging modalities are the frontier pioneers in revolutionizing CVD diagnosis. Conventional modalities like echocardiography, CMR, and CT play a pivotal role in the diagnosis. With these upcoming trends, the chances of precision are even higher, which can help in making a diagnosis early.

References

1. https://www.who.int/health-topics/cardiovascular-diseases#tab=tab_1

2. Jakubiak AA, Konopka M, Bursa D, Król W, Anioł-Strzyżewska K, Burkhard-Jagodzińska K, Sitkowski D, Kuch M, Braksator W. Benefits and limitations of electrocardiographic and echocardiographic screening in top level endurance athletes. Biol Sport. 2021 Mar;38(1):71-79. doi: 10.5114/biolsport.2020.97670. Epub 2021 Aug 21. PMID: 33795916; PMCID: PMC7996387.

3. Omran F, Kyrou I, Osman F, Lim VG, Randeva HS, Chatha K. Cardiovascular Biomarkers: Lessons of the Past and Prospects for the Future. Int J Mol Sci. 2022 May 19;23(10):5680. doi: 10.3390/ijms23105680. PMID: 35628490; PMCID: PMC9143441.

4. Wang CL, Hung KC. Recent Advances in Echocardiography. J Med Ultrasound. 2017 Apr-Jun;25(2):65-67. doi: 10.1016/j.jmu.2017.03.010. Epub 2017 May 9. PMID: 30065461; PMCID: PMC6029319. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6029319/#ref6),

5. Monaghan MJ. Role of real time 3D echocardiography in evaluating the left ventricle. Heart. 2006 Jan;92(1):131-6. doi: 10.1136/hrt.2004.058388. PMID: 16365369; PMCID: PMC1861009. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1861009/)

6. Yadav K, Prajapati J, Singh G, Patel I, Karre A, Bansal PK, Garhwal V. The correlation between speckle-tracking echocardiography and coronary angiography in suspected coronary artery disease with normal left ventricular function. J Cardiovasc Thorac Res. 2022;14(4):234-239. doi: 10.34172/jcvtr.2022.30520. Epub 2022 Dec 17. PMID: 36699556; PMCID: PMC9871166.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9871166/

7. Tseng WY, Su MY, Tseng YH. Introduction to Cardiovascular Magnetic Resonance: Technical Principles and Clinical Applications. Acta Cardiol Sin. 2016 Mar;32(2):129-44. doi: 10.6515/acs20150616a. PMID: 27122944; PMCID: PMC4816912. (https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4816912/)

8. Saeed M, Van TA, Krug R, Hetts SW, Wilson MW. Cardiac MR imaging: current status and future direction. Cardiovasc Diagn Ther. 2015 Aug;5(4):290-310. doi: 10.3978/j.issn.2223-3652.2015.06.07. PMID: 26331113; PMCID: PMC4536478. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4536478/#:~:text=The%20main%20disadvantages%20of%20the,reaction%20and%20relatively%20high%20cost.

9. Ramjattan NA, Lala V, Kousa O, et al. Coronary CT Angiography. [Updated 2023 Jan 19]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2024 Jan-. Available from: https://www.ncbi.nlm.nih.gov/books/NBK470279/

10. Burrill J, Dabbagh Z, Gollub F, Hamady M. Multidetector computed tomographic angiography of the cardiovascular system. Postgrad Med J. 2007 Nov;83(985):698-704. doi: 10.1136/pgmj.2007.061804. PMID: 17989269; PMCID: PMC2659964.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2659964/#:~:text=Multidetector%20CT%20scanners%20have%20an,using%20invasive%20conventional%20angiographic%20techniques

11. Grandhi R, Weiner GM, Agarwal N, Panczykowski DM, Ares WJ, Rodriguez JS, Gelfond JA, Myers JG, Alarcon LH, Okonkwo DO, Jankowitz BT. Limitations of multidetector computed tomography angiography for the diagnosis of blunt cerebrovascular injury. J Neurosurg. 2018 Jun;128(6):1642-1647. doi: 10.3171/2017.2.JNS163264. Epub 2017 Aug 11. PMID: 28799874
   a. https://pubmed.ncbi.nlm.nih.gov/28799874/

12. Lin A, Pieszko K, Park C, Ignor K, Williams MC, Slomka P, Dey D. Artificial intelligence in cardiovascular imaging: enhancing image analysis and risk stratification. BJR Open. 2023 May 17;5(1):20220021. doi: 10.1259/bjro.20220021. PMID: 37396483; PMCID: PMC10311632.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10311632/

13. Patel B, Makaryus AN. Artificial Intelligence Advances in the World of Cardiovascular Imaging. Healthcare (Basel). 2022 Jan 14;10(1):154. doi: 10.3390/healthcare10010154. PMID: 35052317; PMCID: PMC8776229.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8776229/

14. Lim LJ, Tison GH, Delling FN. Artificial Intelligence in Cardiovascular Imaging. Methodist Debakey Cardiovasc J. 2020 Apr-Jun;16(2):138-145. doi: 10.14797/mdcj-16-2-138. PMID: 32670474; PMCID: PMC7350824.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7350824/

15. Nobre C, Oliveira-Santos M, Paiva L, Costa M, Gonçalves L. Fusion imaging in interventional cardiology. Rev Port Cardiol (Engl Ed). 2020 Aug;39(8):463-473. English, Portuguese. doi: 10.1016/j.repc.2020.03.014. Epub 2020 Jul 28. PMID: 32736908.https://pubmed.ncbi.nlm.nih.gov/32736908/

16. Zendjebil S, Garot P. Apport de la fusion d'images de scanner en salle de cathétérisme [Contribution of CT-scan fusion imaging for interventional cardiology]. Ann Cardiol Angeiol (Paris). 2022 Dec;71(6):417-423. French. doi: 10.1016/j.ancard.2022.09.004. Epub 2022 Oct 21. PMID: 36280514.https://pubmed.ncbi.nlm.nih.gov/36280514/

17. Pan JA, Salerno M. Clinical Utility and Future Applications of PET/CT and PET/CMR in Cardiology. Diagnostics (Basel). 2016 Sep 2;6(3):32. doi: 10.3390/diagnostics6030032. PMID: 27598207; PMCID: PMC5039566.https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5039566/