Journal of Interventional Cardiac Electrophysiology
https://doi.org/10.1007/s10840-024-01803-0

RESEARCH LETTER

Time to capitalise on artificial intelligence in cardiac electrophysiology

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Received: 17 March 2024 / Accepted: 28 March 2024

1 Background

The complexity and heterogeneity of data available for patients with cardiovascular disease present an ideal opportunity for artificial intelligence to enhance patient care. For patients with or under investigation for arrhythmias, data are repeatedly and frequently obtained from electrocardiograms, wearable devices, implantable cardiac devices, and during catheter-based electrophysiological procedures [1]. However, whilst artificial intelligence-enhanced electrocardiogram analysis has attracted attention [2], the application of artificial intelligence to other data sources within electrophysiology appears comparatively underdeveloped.

2 Methods and results

We sought to quantify and compare artificial intelligence research outputs between cardiac and non-cardiac healthcare specialities. We further sought to quantify research outputs using commonly available data types within electrophysiology. We performed a literature search on PubMed using medical subject headings (MeSH) for the term "artificial intelligence" followed by either the name of the healthcare speciality, the name of the cardiac sub-speciality, or the type of electrophysiology data resource (Fig. 1). We subsequently identified the numbers of published articles from inception to 17th March 2024.

The results of our searches are shown in Fig. 1. Oncology ($n = 32322$), radiology ($n = 23613$), and pathology ($n = 22299$) had the highest numbers of published articles related to artificial intelligence. Cardiology ($n = 4177$) was positioned in twelfth place. Amongst cardiac sub-specialities, cardiac electrophysiology ($n = 193$) had the lowest number of artificial intelligence-related research outputs. Within electrophysiology, the application of artificial intelligence to the electrocardiogram was most widely studied amongst the commonly available data types. The search "artificial intelligence electroanatomic" yielded only 32 results.

3 Discussion

Our findings suggest that cardiology in general, and cardiac electrophysiology in particular, is underperforming in the investigation of data driven approaches to guide therapy. Below, we discuss potential barriers to electrophysiology artificial intelligence research and propose solutions for some commonly available electrophysiology data resources.

3.1 Electroanatomic mapping data: the need to facilitate data availability

A major finding of our searches was that artificial intelligence appears to be rarely used to analyse electroanatomic mapping data. Contemporary electroanatomic mapping systems enable the acquisition of individualised cardiac anatomic and electrophysiological data. These data can provide mechanistic insights into the pathophysiology of electrophysiological disease states on a patient-specific level, opening avenues for personalised disease phenotyping. Vast volumes of data are routinely acquired during electrophysiological procedures, and artificial intelligence-enhanced analysis of these data could be used to guide intra-procedural and post-procedural care. In the intra-procedural setting, studies have recently demonstrated that the application of machine learning to electrograms can identify arrhythmogenic sites in post-ischaemic ventricular tachycardia patients [3]. Post-procedurally, the application of machine learning to intracardiac atrial signals from patients undergoing atrial fibrillation ablation procedures has been shown to improve

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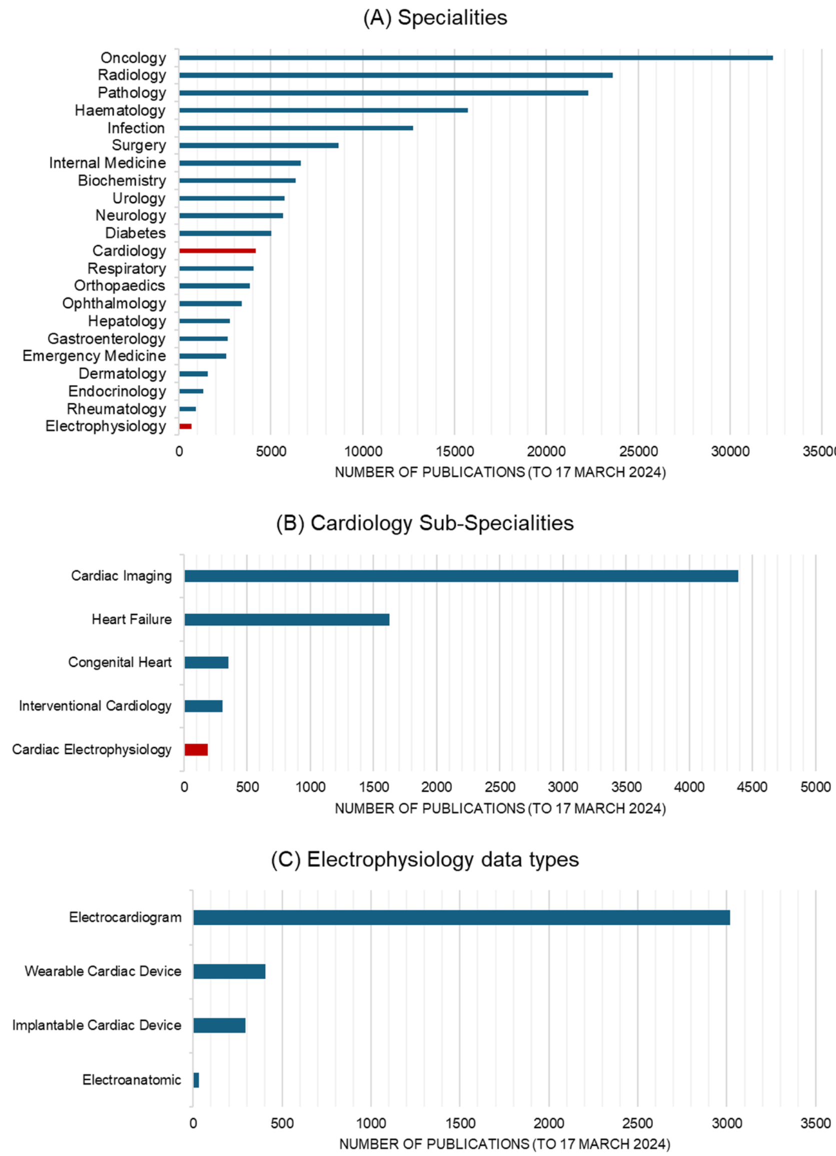

Fig. 1 Results of searches on PubMed using the term “Artificial Intelligence” followed by **A** specialities within healthcare, **B** cardiology sub-specialities, and **C** electrophysiology data resources. The specific search strategy was: (“artificial intelligence”[MeSH Terms] OR (“artificial”[All Fields] AND “intelligence”[All Fields]) OR “artificial intelligence”[All Fields]) AND (“name of healthcare speciality/name of cardiac sub-speciality/type of electrophysiology data resource” [All Fields] OR [MeSH Terms])

prediction of patient outcomes compared with existing clinical risk prediction scores [4].

Despite the promise of artificial intelligence-enhanced analysis of electroanatomic mapping data, research outputs in this area are failing to keep pace with artificial intelligence-based research advances in other areas. To try to address this need, our group has developed OpenEP, an open-source platform which provides a standardised, vendor-agnostic approach to electroanatomic mapping data collection and analysis [5]. The use of such a tool could enable the democratisation of electroanatomic mapping data and accelerate the development of artificial intelligence-enhanced algorithms using electroanatomic mapping data. Indeed, studies are already accumulating to demonstrate how the platform can be leveraged to interpret and assess complex intracardiac electrograms and conduction patterns [6, 7], offering true potential to advance understanding of arrhythmia mechanisms and develop personalised treatments for patients.

3.2 Cardiac devices: the need for standardised data exchange

Despite the widespread use of wearable and implantable cardiac devices in healthcare, the application of artificial intelligence to data acquired from these resources appears underdeveloped. Enormous volumes of data are continuously acquired from cardiac devices and artificial intelligence presents a practical means of utilising these data to derive clinical benefit. Such devices can facilitate disease screening and prediction and aid in the management of patients with pre-existing disease [1]. Despite the promise of such developments, and in similarity to electroanatomic mapping systems, data acquired from these tools are typically vendor-specific limiting their accessibility to researchers.

It is notable that the two specialities with the most data driven publications (oncology and radiology) are highly dependent on medical imaging. In imaging, the Digital Imaging and Communications in Medicine (DICOM) standard exists as an international protocol for medical imaging data [8]. Data stored in the standardised DICOM format within Picture Archiving and Communication System (PACS) provides centralised repositories of medical imaging data from multiple modalities. Unfortunately, a standardised approach to data collection, storage, and transfer does not exist for device-derived data. Indeed, the requirement to promote data interoperability has been recognised by the Heart Rhythm Society who have been leading efforts to unlock data from vendor-specific implantable devices by attempting to develop a lexicon of implantable device terminology and a vendor-agnostic platform capable of communicating device-derived data across electronic systems [9]. Such developments could lead to the creation of vast data repositories capable of significantly enhancing artificial intelligence research.

3.3 Accelerating artificial intelligence-related research in electrophysiology

Given the multitude of electrophysiology companies and the projected growth of the electrophysiology market from $4350.7 billion in 2024 to $9078.4 billion by 2034 [10], it will be necessary to collaborate with industrial partners to augment artificial intelligence-related outputs. Indeed, it is feasible that some artificial intelligence technologies may currently be proprietary and therefore not captured in our searches, which may have accounted for the results obtained. Nevertheless, this emphasises the requirement to overcome issues pertaining to data accessibility and transfer. Collaborative efforts will be essential for breaking down barriers to data sharing. Implementing strategies such as data-sharing agreements, fostering a culture of openness and transparency, could help overcome these barriers. Additionally, the creation of platforms such as OpenEP, and enabling researchers to securely share and access data whilst adhering to privacy and confidentiality standards, could facilitate broader data sharing across institutions.

4 Conclusions

Artificial intelligence is promising to transform medical practice through its ability to rapidly analyse vast volumes of data and to unravel patterns of clinical significance. Unfortunately, its integration into electrophysiology research appears to be falling behind other specialities. The development of standardised approaches to data collection, storage, and transfer would facilitate research data exchange. The development of electrophysiology data exchange infrastructures is urgently needed to promote artificial intelligence research in electrophysiology, offering in turn, enormous potential to revolutionise the care pathways for patients with arrhythmias.

Acknowledgements This research is part of the British Heart Foundation Centre for Research Excellence at The University of Edinburgh (RE/18/5/34216).

Funding SEW is supported by the British Heart Foundation (FS/20/26/34952). The authors acknowledge the support of the British Heart Foundation (RG/20/4/34803).

Declarations

Ethics approval Not applicable.

Conflict of interest The authors declare no competing interests.

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