Summer 8-16-2024

Interventional Radiology's Exploration into Artificial Intelligence

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August 2024

Abstract

Background: Artificial intelligence (AI) has become more prominent in our daily lives in recent years. This includes various aspects of healthcare. Interventional radiology (IR) is one of these specialties that has taken strides in understanding how AI can be leveraged for patient care. This literature review aims to understand what areas will be most impacted by AI in IR and how it will influence both the patient and interventional radiologist.

Methods: Twenty-six publications from 2019-2024 were selected from PubMed and Scopus. Publications were sourced through a combination of keywords, subject headings (MeSH terms), and citation searching.

Results: This literature review identified three main areas of impact within interventional radiology (IR) that artificial intelligence will significantly affect. These areas are: education, risk calculation, and patient care. AI implementation within the continuum of patient care can be organized into pre-procedural, intra-procedural, and post-procedural impacts.

Conclusion: AI has been shown to be a revolutionary tool with great potential to benefit not only the patient but the interventional radiologist. As the field continues to understand where AI can be leveraged, it is essential to maintain interprofessional collaboration, develop structured policies, and discover AI's limitations to move the field toward a future with quality-of-life-improving advancements.

Introduction

Artificial intelligence (AI) has become more and more popular, breaking out of the tech industry into other sectors, like mainstream pop culture, public health, and clinical patient care (Sezgin, 2023; (Sun et al., 2020)). According to Google Trends, global interest in artificial intelligence spiked at the beginning of 2022 and again at the beginning of 2023, resulting in all-time high searches in May of 2023 (Google Trends). Interest in the U.S. spiked in the beginning of 2023 (Google Trends).

Despite the technological strides it has achieved thus far, artificial intelligence presents numerous challenges, particularly if left unchecked or used poorly (Khan et al., 2023). Many industries still have ethical concerns about the many issues that artificial intelligence can cause (Li et al., 2022). These concerns range from ethical issues such as bias to the distribution and handling of sensitive private information, to name a few (Gichoya et al., 2023). Arguably, one of the biggest concerns with the rise of AI is the possibility for it to replace human jobs (Huang & Rust, 2018). As the implementation of AI expands, it is of great importance to continue the discussion and analysis of these concerns to work towards a future where we have answers and responses to such concerns, ultimately creating a symbiosis with AI to complement human tasks (Jarrahi, 2018)

Healthcare is one industry currently leveraging AI to improve patient care and hospital processes. The tasks benefiting from AI vary greatly (Bajawa et al., 2021). For instance, AI is being used to aid in drug discovery, streamline medical billing, and operational efficiency (Qureshi et al., 2023)). Different medical specialties have found novel and unique ways to cater AI's benefits to push advancements in their field (Luchini et al., 2021). Radiology is one of these medical specialties that have been at the forefront of utilizing AI (Pesapane et al., 2018).

Most applications of AI in radiology pertain to diagnostic radiology or medical imaging (Von Ende et al., 2023). Interventional radiology (IR) is a subspecialty of radiology that involves performing image-guided procedures such as biopsies, catheterizations, and angiograms. This branch of radiology is still in the preliminary stages of finding innovative ways to implement AI in clinical practice. Thus, it provides an opportunity in the literature to fill the gap about what the interventional radiology field is doing and how physicians can start implementing these early successes (Chapiro et al., 2022).

The current literature on AI in interventional radiology is sparse. As it stands, the current literature focuses on some preliminary successes and small-scale applications of AI in IR (Mazaheri et al., 2021). It is also composed of some foundational information/guides for those who are interested in pioneering AI in IR (Warren et al., 2024). Most literature on this topic is also theoretical/abstract and poses ideas for future endeavors to pursue (Iezzi et al., 2019). Due to the recent advancements in AI and, subsequently, its application in IR, there are few literature that provides information on which achievements are deployable to physician practice (Glielmo et al., 2024). This literature review aims to bridge this gap in the literature while providing applications that physicians can benefit from as well.

Methods

This literature review explores the emerging role of artificial intelligence in current interventional radiology clinical practice. In addition, I investigated future areas where AI can be beneficial. This literature review analyzed sources from 2 databases: PubMed and Scopus. I used a combination of keywords, subject headings (MeSH terms), and citation searching (discussed in detail below). Results were limited to those from 2019-2024, the past half-decade to maintain relevancy in AI development as well as its emerging inclusion into healthcare.

PubMed Research Strategy

Keywords and subject headings (MeSH terms) include "interventional radiology" and "artificial intelligence."

Scopus Research Strategy

Article title, Abstract, and Keywords include "artificial AND intelligence" AND "interventional AND radiology." The exclusion filter was set to not include results that are letters, book chapters, or notes.

The initial search results for PubMed and Scopus articles contained 30 and 134 articles, respectively. After excluding irrelevant articles, articles for other specialties, or those focused on robotics and duplicates between databases, the remaining pool of articles selected for this literature review was 26 articles, 12 from Scopus and 14 from PubMed.

Results

Education

Artificial intelligence possesses room for further exploration of the benefits it can bring as an instructional instrument. ChatGPT has shown some capacity in educating patients on IR procedures, albeit at a limited and shallow capacity (Barat et al., 2023; Campbell et al., 2024). Nonetheless, offloading physician workload can improve productivity. AI has seen some early success in training future physicians as well. Combined with simulation training through Virtual or Augmented Reality, AI can help visualize and allow students to practice procedural techniques without putting patients at risk (Von Ende et al., 2023). Nuanced scenarios and various situations can be practiced in a space that encourages continual practice and involvement with AI. Thus, procedural and mechanical competence assessments for students can benefit from these high-fidelity simulations (Sariclar et al., 2023). AI can also benefit other motor-skill-based skills, such as ultrasound-guided interventions (Holden et al., 2019).

Risk Calculation

Two main risk areas need to be inspected if AI were to be embedded into clinical practice: the risk of the underlying AI and the risk of implementing this AI (Warren et al., 2024). These risks need to be inspected thoroughly in order to manage and ideally mitigate potential harm or errors. The risk of the underlying AI consists of the potential errors that may stem from "how" the model or AI was created (Warren et al., 2024). Since the training of models and synthesizing of frameworks consist of human researchers/designers, bias can be introduced into the model, whether it is intended or not (Warren et al., 2024). Consequently, ethical considerations also need to be analyzed to maintain patient privacy and safety while minimizing potential harm to the patient or even the provider (Pesapane et al., 2020; Rockwell et al., 2023; Von Ende et al., 2023).

Logistical considerations must also be considered during the implementation phase of the AI. In contrast with their diagnostic counterparts, IR has a significantly smaller dataset to pull from, complicating the training of AI models that require extensive and large amounts of data (Glielmo et al., 2024) Along with quantity, the proportion of that data that is of sufficient "quality" is thus even smaller, adding onto the factors that need to be considered (Iezzi et al., 2019). Other general logistical obstacles experienced by any new technology trying to be established in the healthcare system consist of coordinating and ensuring staff are knowledgeable on how to utilize the model (Von Ende et al., 2023). From a health economics standpoint, implementation needs to also consider long-term costs and resources that will need to be used to maintain this tool. This includes resources to keep the AI up to date and if it can reduce costs or increase productivity (Warren et al., 2024).

Areas where AI can be leveraged to …

(a) Pre-Procedural

Patient selection is a complex process in which therapies are selected based on how effective they will be for the patient (Boeken et al., 2023; Chapiro et al., 2022; Von Ende et al., 2023). This ensures objective decision-making practices are first and foremost based on clinical and genetic information (Seah et al., 2022). AI can assist in this process, such as hepatocellular carcinoma and adrenal metastases (Desai et al., 2020; Glielmo et al., 2024). This provides physicians with the ability to “predict” adverse effects and avoid them (Von Ende et al., 2023). Other pre-procedural tasks include identifying specific patterns or anatomy/biological structures to inform and assist in treatment decisions (Gurgitano et al., 2021; Mourad et al., 2022). The sum of these curated/personalized decisions could reduce not only complications but also the number of unnecessary procedures done, reducing healthcare costs (Iezzi et al., 2019).

(b) Intra-Procedural

AI has been providing great value in vascular procedures and techniques requiring guidance such as fluoroscopy, ultrasound, endoscopy, etc. (Glielmo et al., 2024). Image fusion has been seen as a valuable tool for interventional radiologists. AI has been able to fuse pre-procedural images with fluoroscopic images to provide real-time feedback for the practitioner, improving precision (Gurgitano et al., 2021). This allows them to preserve sterility since it would reduce the need to exit the procedural suite (Desai et al., 2022). Similarly, AI has been shown to assist in tracking other tools such as catheters, needles, probes, and similar instruments (Arapi et al., 2023; Chapiro et al., 2022; Rodriguez-Diaz et al., 2021; Zegarra Flores et al., 2021). Adjusting for radiation exposure has also been another application of AI in IR that has protected both the patient and physician. This involves considering physician attention, X-ray tube angulation, or even tissue density (Seah et al., 2022). Being able to optimize when radiation is needed based on what is happening during the procedure provides a cumulative benefit that will lead to a significant decrease over the course of a lifetime (Desai et al., 2022)

(c) Post-Procedural

AI's predictive power and potential can help provide physicians with meaningful insight. AI has assisted physicians in evaluating the efficacy or successfulness of their IR procedures (O'Brien et al., 2024). This, in turn, provides patients with a tailored and more precise follow-up and prognostication (Seah et al., 2022). Similarly, management plans and prognoses benefit from AI's predictive power, which can stem from a decision tree. This framework allows not only for a more objective assessment of outcomes, but it also allows physicians to see the logic that caused the AI to output a particular result (Von Ende et al., 2023).

Implications & Discussion

Explore Creatively

This literature review highlights critical points of leverage in patient care that artificial intelligence can augment. Pre-, intra-, and post-procedural applications such as patient selection, radiation management, and treatment prognosis are just the tip of the iceberg in terms of the capabilities of how we can improve patient care through the use of AI in IR (Von Ende et al., 2023). As we continue to trek this new era of medicine, researchers, physicians, data scientists, and innovators alike will need to think outside the box and expand how they think AI can be used in IR practice. I propose four main goals or types of research that need to be prioritized in future research. Firstly, there needs to be research that will validate and strengthen the effectiveness of these current successes. This will be a critical step in strengthening our resolve and certainty on the benefits of implementing such new and foreign advancements into everyday practice. Secondly, future research and clinical trials should expand AI implementations to other common IR procedures. This will ensure efforts will be targeted towards processes/interventions that will be of high impact due to how frequent these procedures are. Thirdly, novel and creative implementations of AI into IR practice not currently thought of in the field are paramount in pushing our understanding of AI in healthcare beyond what we currently believe is possible.

Lastly, research should not be limited to just the possible benefits of AI in IR. Experiments should strive to determine where AI fails and what its limitations are. Being cognizant of where AI falls flat and its vices will provide invaluable lessons that we can use to correct, avoid, or apply in the future. Understanding both the pros and cons of AI through research will greatly aid in predicting a model or framework's shortcomings, thus giving us the foresight to nullify future harm. Understanding where AI breaks down or will fall apart is just as valuable as knowing how to use AI to reduce physician workload or patient care costs. These types of research, in combination with ethical and efficacy review boards, bias audits, stress tests, retrospective analysis, etc. will aid in buy-in from major stakeholders and most importantly, the general population.

Collaboration with AI and other sectors

Now is not the time to be siloed in our specialties or respective industries. Continued interprofessional collaboration with other fields, such as the biomedical, technology, private, and public sectors, will ensure a more holistic approach to creating and implementing AI in IR, improving patient care and, consequently, patient outcomes. Interventional radiologists need to be deeply involved in every step of the development process, critically appraising how the end product will affect the patient. Collaboration with other delivery mediums, such as augmented reality, virtual reality, and robotics, can innovate the training and education of upcoming physicians so that they are accustomed and normalized to the physician-artificial intelligence collaborative dynamic. These mediums will also play a factor in improving physician diagnosis, planning, and treatment (Iezzi et al., 2019).

Recognizing Artificial Intelligence's Limitations

When inspired by new technological advancements and promising results, clinicians, innovators, and public health practitioners can easily overestimate its present applications and challenges. The current landscape of the applications of AI in IR contains plentiful hurdles and shortcomings (Gaddum & Chapiro, 2024; Rockwell et al., 2023). One notable limitation of AI relates to the constant need for a voluminous amount of data for the AI to be adequately trained (Seah et al., 2022; Waller et al., 2022). Although some AI applications provide a certain level of autonomy, significant physician oversight is still a large factor. Moreover, understanding the biases that are embedded into an AI's code, whether intentional or not, is foundational in preventing AI from exploiting shortcuts to produce optimal solutions at the cost of the patient or physician (Waller et al., 2022; Warren et al., 2024). Ethical and logistical obstacles are both valid factors that must be weighed when determining real-world applications. These limitations are especially important when considering how and where AI will be manifested in real-world clinical settings (Pesapane et al., 2020). Acknowledging and understanding these limitations will clarify what space AI can fit into and where it is not appropriate when augmenting patient care.

Policy

Currently, the regulations for AI applications in healthcare are far and few between, with one noticeable guideline developed by efforts from Health Canada, the United States Food and Drug Administration (FDA), and the United Kingdom Medicines & Healthcare products Regulatory Agency (Warren et al., 2024). AI needs to be evaluated in its many forms, as either an AI augmented medical device or an AI software as a medical device (SaMD) (Warren et al., 2024). As the continual development of AI tools in IR becomes ever closer to real-life implementation, now is the time to set up parameters and synthesize an environment where the risks of AI are minimized while benefits to both patients and physicians are maximized. For instance, a policy emphasizing a standardized reporting system for AI applications in IR can alleviate concerns and is a preventative approach that may catch errors or complications before they occur. Building infrastructure for universal labeled datasets and communications hubs alike will further facilitate collaboration between the various sectors. We need to lay the ground now so that AI may grow, live, and thrive in a set area that can be kept in check.

Limitations

One of the limitations of this literature review relates to sample size. While this paper included articles from only PubMed and Scopus, my review consisted of only 26 articles, which limited the scope of the review. Additionally, the search string and search methodology employed may not display all of the relevant articles pertaining to the goal of this literature review. Manual review/selection for the literature in this review can inadvertently lead to the possible exclusion of relevant articles or vice versa, inclusion of weakly or non-relevant articles. Furthermore, due to only selecting articles from the past five years, this review may overlook preliminary discoveries of AI in IR that may be relevant to this review.

Conclusion

Artificial intelligence is here to stay. AI has great potential to become a revolutionizing point in the history of medicine. The flexibility of being able to apply AI assistance at every point on the continuum of patient care provides the field with a wealth of possibilities that are waiting to be discovered and implemented. Despite this, it is crucial to recognize limitations in the AI model itself as well as both the logistical and ethical challenges inherent in developing an AI model that is holistic and will "do no harm." AI will not replace interventional radiologists but rather become another tool that they can use to enhance clinical practice. Thus, current and future interventional radiologists should prioritize and gain an understanding of AI just as they would for any other clinical tool. This ever-growing and inevitable prominence of AI in healthcare justly warrants structured policies and infrastructure to create boundaries and parameters that will safely allow AI to operate in. Only through embracing AI with ethical integrity and scientific creativity will we be able to shape the future of interventional radiology into one that is safe, unbiased, precise, and profoundly transformative.

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