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Exploring the integration of artificial intelligence (AI) and augmented reality (AR) in maritime medicine

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Abstract
This narrative literature review has analyzed the integration of artificial intelligence (AI) and augmented reality (AR) in the field of maritime medicine. A comprehensive search was conducted in academic databases using relevant search terms, resulting in the identification of 257 records. After screening for relevance and quality, a final review was conducted on 17 papers. This review highlights the potential applications and benefits of AI and AR in enhancing medical practices and safety measures for seafarers. The integration of AI and AR technologies in maritime medicine shows promise in providing real-time medical assistance, remote consultations, augmented training, and improved diagnostic capabilities. Additionally, AI-driven predictive models can aid in early detection of health issues and support proactive health management onboard ships. Challenges related to data privacy, connectivity at sea, and the need for regulatory frameworks are also discussed. The data analysis reported in this review contributes to a better understanding of the current state and future potential of AI and AR in maritime medicine and provide insights into opportunities for further research and implementation in the maritime industry.

Keywords Artificial intelligence · Virtual reality · Maritime medicine · Seafarers · Medical practice · Diagnostic capabilities · Predictive models

1 Introduction

Seafarers play a relevant role in the shipping industry by providing skilled labour that is necessary to safely transport goods and people around the world. They are responsible for maintaining ships, navigation, and other operations related to sea transportation. The captain is responsible for the health of the crew, for providing basic medical assistance and for overseeing the day-to-day hygiene and general health of the crew (Oldenburg

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et al. 2014). The Maritime Labour Convention (MLC) 2006 requires that seafarers should have equal access to the medical care and health protection that workers ashore, which includes timely access to medicines, medical equipment, facilities for diagnosis and treatment, as well as medical expertise and information [Maritime Labour Convention (MLC) 2006]. As a result, the quality of care and attention given to those in need of onboard medical assistance may vary significantly from ship to ship.

The healthcare sector has been undergoing significant transformations, driven primarily by the need for better healthcare outcomes and more effective management of resources (Quan and Taylor-Robinson 2023; Ahmadpour et al. 2020). Healthcare innovation has been transformed by the emergence of artificial intelligence (AI), and augmented reality (AR) (Acs et al. 2020; Kumar et al. 2021). AI-powered technology has been successfully applied to a range of healthcare areas, from drug discovery and medical diagnosis to advanced personalized care. In this scenario, maritime medicine holds enormous potential for AI-based technologies. Maritime medicine is a branch of medicine that deals with illnesses and injuries occurring at sea (Sidorov et al. 2007). It includes medical assistance at sea as well as the prevention of diseases and injuries that can occur on ships. This field also deals with the promotion of the health and safety of the crew and passengers onboard (Sidorov et al. 2007; Nguyen and Tran 2001). With the advent of new technologies, such as AI, AR, and machine learning (ML), various innovations are possible, including more precise remote diagnosis and treatment, predictive analytics, and real-time monitoring. These innovations may enhance the standard of care and reducing risks to human health at sea (Munim et al. 2020).

The potentialities of medical assistance at sea cannot be overstated. The ocean is a vast and unpredictable environment, and a medical emergency onboard a ship has the potential to become life-threatening (Grappasonni et al. 2012; Oldenburg et al. 2010). Moreover, the isolation of being ill at sea often means that medical assistance is not readily available, making it important for crew members to have reliable means of accessing medical care (Hadjichristodoulou et al. 2022). Since the earliest days of radio communication, medical assistance at sea has been a critical component of seafarer's safety. Despite being located in remote locations, it can provide medical treatment of reasonable quality for those aboard ships. Since international shipping demand is increasing and ships need to communicate with shores clearly and effectively, this topic is of particular relevance. The adoption of AI technologies in maritime medicine has improved healthcare practices. One of the significant areas where AI has been implemented is in diagnostic processes using ML algorithms that enhance the accuracy of diagnoses (Chintalapudi et al. 2022).

AI can also be used for remote monitoring and surveillance in the maritime setting, allowing early detection of medical issues and prompt intervention (Dubey and Tiwari 2023). Additionally, AI robots can be deployed in maritime environments that are hazardous to human health, reducing the risks of injury or exposure to toxic substances (Molina-Molina et al. 2021). The use of AI can lower costs, improve healthcare outcomes, and increase efficiency. As seafarers demand more healthcare services and ships face the challenge of providing timely and effective medical care, AI can transform maritime medicine. The integration of AI into maritime medicine requires careful consideration, appropriate regulations, and ethical considerations. The potential impact and benefits of AI technology in maritime medicine are relevant, with promising prospects for enhancing health services and safety in the marine environment (Munim et al. 2020; Chintalapudi et al. 2022; Molina-Molina et al. 2021). With the use of AI innovations, maritime medicine can improve the safety, healthcare outcomes, and well-being of seafarers.

As far as we know, no review studies had been conducted on the integration of AI, AR and other technologies in maritime medicine. Systematic reviews of seafarers have been presented in some works on telemedicine technologies (Battineni et al. 2023; Sagaro and Amenta 2020). Despite their valuable insights into the effectiveness and challenges of remote medical care, these studies did not present standardized outcomes. While these reviews are essential, it is important to be aware of potential limitations when interpreting them. Additionally, they must be considered alongside other types of evidence, such as qualitative research and real-world experiences from practitioners and seafarers (Araimi et al. 2023). This paper is a narrative review of the opportunities and innovations that AI and AR can bring to maritime medicine. We also provide a comprehensive overview of the topic that can help readers to be informed about the breadth of existing literature, including both empirical studies and theoretical perspectives. Moreover, in this work we aim to raise the key issues and challenges of AI in maritime medicine to make it more appealing to a broader audience, including policymakers, practitioners, and the general public.

To provide an overview of current research, applications, and potential benefits of AI and AR in maritime medicine, we aim to breaking down the research objectives (RO) and research questions (RQ) into a structured format can help clarify the research focus.

RO1: Provide a thorough exploration of the opportunities and innovations AI and AR bring to maritime medicine.

RO2: Offer a comprehensive overview of existing literature, encompassing empirical studies and theoretical perspectives.

RO3: Highlight significant challenges and issues in AI application within maritime medicine to engage a diverse audience, including policymakers, practitioners, and the general public.

The following research questions (RQ) were put to provide a comprehensive analysis of the issues covered in this narrative review and connected to above mentioned objectives.

RQ1: What is the current state of research on AI and AR in maritime medicine?

Address the current state of AI and AR in maritime medicine, in accordance with the aim of providing a comprehensive overview.

RQ2: How to utilize AI and AR for healthcare enhancement and training in maritime settings?

Investigate how these technologies specifically contribute to healthcare delivery and training for maritime workers, directly supporting the aim of providing comprehensive information to readers.

RQ3: What are the challenges in implementing AI and AR in the shipping environment?

Delve into potential obstacles and difficulties when integrating AI and AR technologies into the maritime setting, aligning with the goal to highlight key issues and challenges.

The paper was structured to comprehensively explore the impact of AI and AR in the delivery of medical assistance at sea. Beginning with an introduction that sets the context and objectives, Sect. 2 outlines the methodology employed for the narrative review.

Section 3 presents the findings derived from an extensive analysis of existing literature, while Sect. 4 delves into a thorough discussion of these results, offering insights and implications. Finally, Sect. 5 is a conclusive summary, highlighting key findings and suggesting directions for future research and application within maritime medicine.

2 Methods

2.1 Document search

The document search was conducted using the scientific libraries Google Scholar, Scopus, and Web of Science along with medical libraries like PubMed/MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL), and BioMed Central (BMC). The search period that is taken into account for this work is from 2000–2023. A snowballing technique was also employed to check the reference lists of relevant articles to locate additional sources that may not have been included in the initial database search. The search keywords used were 'Artificial Intelligence in Maritime Medicine', 'Augmented Reality Applications in Maritime Healthcare', 'AI and AR in Maritime Medical Training', 'Maritime Healthcare Technologies', 'AI-driven Diagnostics in Maritime Medicine', 'AR-based Medical Visualization in Maritime Settings', 'ML in Maritime Healthcare', 'AI and AR for Crew Health Management', 'Human–Machine Interaction in Maritime Medicine', 'AI-assisted Medical Decision Support at Sea', 'Augmented Reality Simulation for Maritime Medical Training' and 'AI-based Remote Health Monitoring for Seafarers'. For the research question being developed, these relevant keywords were selected and represent the primary concepts or themes of the narrative review. To combine keywords logically, Boolean operators (AND, OR, NOT) are employed. This enabled us to create comprehensive search strings that contain diverse combinations of search terms.

2.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria that were used for this analysis are presented in Table 1. This work included only papers that were peer-reviewed all over the world and published in English between 2000 and July 2023. Focusing on articles published from last two decades to the present ensures that the presented review included the most current developments and research with the studies related to AI and AR in seafarers' healthcare.

Table 1 Inclusion and exclusion criteria

Inclusion criteria	Exclusion criteria
Peer-reviewed worldwide papers	Not published in English
Published between 2000 and July 2023	Not conducted in maritime healthcare settings
Experimental or observational studies related to AI and AR in seafarers' healthcare	Not focused on clinical decision support at sea, AR, and AI simulation among seafarers
Exploration of AI and AR subjects related to maritime medicine for a holistic understanding	Studies lacking explicit links to clinical diagnosis, medical training, or improvement initiatives at sea

The importance of this relevant in rapidly evolving fields like AI. Works presented included experimental or observational studies related to AI and AR in seafarers' healthcare. All articles that explored AI and AR subjects and issues related to maritime medicine were included as well to gain a holistic understanding.

The present review excluded papers not in English, not conducted in a maritime health care setting, and not focused on clinical decision support at sea, AR, and AI simulation among seafarers. Studies that did not explicitly link clinical diagnosis, medical training, or improvement initiatives to medical practice at sea were not considered.

2.3 Screening and selection

The screening process of article selection involved various phases. At first, authors conducted search with the above-mentioned strategy, and recorded the number in spreadsheet. Each article was screened carefully by reading the title and abstracts of the retrieved articles to identify potentially relevance (Turnbull et al. Jan. 2023). In a second phase, a full-text review of the selected articles based on the inclusion and exclusion criteria was made. Subsequently, we extracted relevant information from the selected articles and organized the extracted data in a tabular or thematic format for easier synthesis. This included study design, methodology, key findings, limitations, and any other pertinent information. Ultimately, summarization of the main findings of each selected study in a coherent and narrative manner to identify common themes, patterns, and trends across the studies was made. These papers were reviewed and topics covered were extracted and presented for further analysis. The topics identified were improved diagnostic accuracy with ML, enhancing medical diagnosis, AI powered digital assistants like ChatGPT in patient monitoring and care, virtual reality and telemedicine for remote consultations, and AI based streamline work flow in maritime medicine (Sharma and Sharma 2023). Figure 1 summarizes the study selection flow chart. The search identified 257 items with given search strategy and 112 papers are excluded because of duplication. While applying inclusion and exclusion criteria 48 works left for further analysis. Ultimately, 17 papers were only included in the final review as others not fit into the given research scope.

3 Results

Technological advancements in the field of maritime medicine have led to the AI utilization to transform the approach how medical care is delivered on ships. AI and AR bring about a revolutionary change in the shipping industry by improving the accuracy and speed of medical diagnosis and treatment.

3.1 Role of AI and AR technologies in maritime medicine

With the help of AI-powered sensors and wearable devices, medical professionals can monitor the health of seafarers remotely and provide timely medical attention in case of need. AI algorithms can analyse big amounts of medical data, such as medical history, vital signs, and diagnostic test results, to identify patterns and predict potential health risks. This provides a proactive approach to medical care, allowing for early detection and treatment of illnesses before they pose a threat to the health and safety of seafarers. By considering

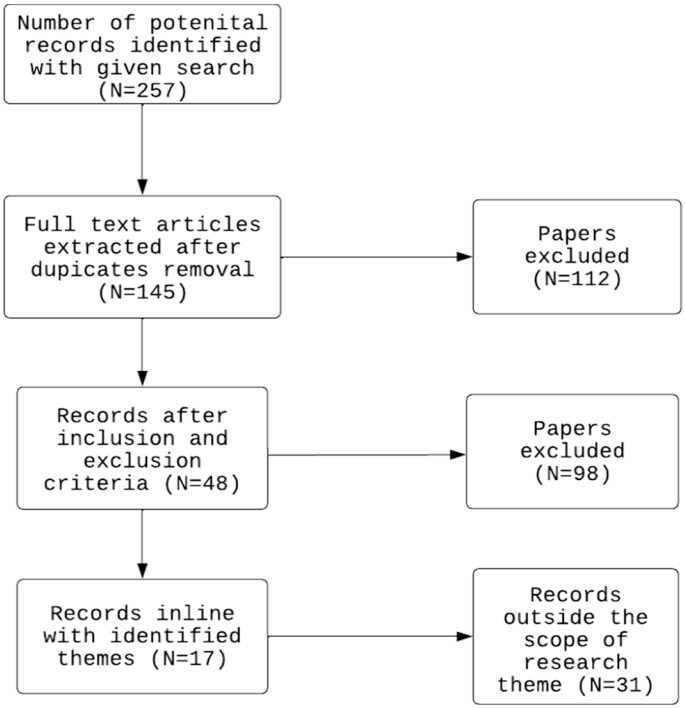

Fig. 1 Paper selection flowchart

all these factors, we have categorized selected works based on five topics discussed below and presented in Table 2.

3.1.1 Improved diagnostic accuracy

The improvement in the diagnostic accuracy majorly concentrates on the precision and correctness of identifying illnesses or conditions. This involves utilizing AI technologies, algorithms, or methodologies to reduce misdiagnoses or errors in identifying medical conditions, thus leading to more precise treatment plans and better patient outcomes. For instance, devices based on information and communication technology (ICT) have the ability to enhance telemedicine. Software's like marine doctor uses AI algorithms in precise identification of disease among remote seafarers (Mittal et al. 2020). The use of ICT devices can improve the accuracy and efficiency of medical consultations by providing real-time monitoring of key physiological parameters such as heart rate, blood pressure, and oxygen saturation levels, etc (Mittal et al. 2020). Independent component analysis (ICA) helps to study the brain's functional connectivity in seafarers aims to uncover neural correlates of sailing-related experiences, stress responses, and their implications for seafarers' health and work performance (Shi and Zeng 2018). This knowledge can potentially drive improvements in working conditions to better support the mental health and overall well-being of those working at sea.

ML has shown great potential in improving diagnostic accuracy in various medical fields, including maritime medicine. A study incorporated two-fold SVM to provide timely

Table 2 Topic wise search distribution of selected articles

N	Topic	Technology	Outcomes	Benefits	References
1	Improved diagnostic accuracy	ICT	Symptom sequences automatically collected	Doctors make better-informed decisions with medical advice that reduces complications due to misdiagnosis	Battineni et al. (2022)
		ICT	Using AI and predictive analytics, cloud-based technology can be used to proactively manage seafarers' psychiatric concerns onshore	New ways to track and manage individual's COVID-19 responses by using seafarer's safety technology	Mittal et al. (2020)
		ICA	Examine the effect of sailing on the brain's functional connectivity. Investigated the stress response in the brain of seafarers	Health, well-being, and performance of seafarers may be improved through improved working conditions	Shi and Zeng (2018)
		Two-fold support vector machines	In comparing fMRI data between mentally healthy and mentally sub-healthy seafarers, certain brain regions and networks are differentially activated, revealing mental sub-health mechanisms	A timely intervention prevents the escalation of mental health issues and promotes well-being for seafarers	Shi et al. (2015)

Table 2 (continued)

N	Topic	Technology	Outcomes	Benefits	References
2	Enhancing medical decision making	ML classification	A model successfully identified anxiety and depression among seafarers with 82.6% accuracy and 84.1% precision	It was possible to develop a computer-based automated analysis technique with sufficient accuracy for screening	Sau and Bhakta (2019)
		Text mining	Through word clouds, symptomatic information was visualized and 96% of medical problems were correlated with diagnosis outcomes	Onshore doctors can make quick decisions by extracting clinical symptoms of seafarers and assessing patient feedback through sentiment analysis	Chintalapudi et al. (2021)
		LASSO regression ML model	A 93.8% accuracy rate was achieved when classifying seafarer's medical text documents. Each disease's symptom frequency visualized	Provides healthcare providers with valuable insights and information hidden in unstructured text. Seafarers benefit from this enhanced clinical decision-making	Chintalapudi et al. (2022)
		Bayesian network and a 'symmetric method'	Record any noticeable changes in performance of the seafarer during regular working hours, especially during critical tasks	Subjective experiences can be revealed through self-reports to ensure the safety and well-being of seafarers	Riahi et al. (2013)
		Deep learning	The feasibility of detecting mental health conditions in real-time using the deep learning method, enabling immediate intervention	It advances mental health research and intelligent detection methods for seafarers' mental health conditions	Zhen et al. (2022)

Table 2 (continued)

N	Topic	Technology	Outcomes	Benefits	References
3	Safety perception and risk assessment	ML based classification model	Proposed ML model proved to be more efficient and can achieve an average improvement of 73.72% in detained ship identification	Maintain marine safety, protect the marine environment, and provide decent working and living conditions	Yan et al. (2021)
		Data driven ML method	Analyse psychophysiological activities and predict operator qualifications	Managing seafarers' performance and eliminating subjective bias	Fan and Yang (2023)
		Automated ML (AutoML)	Automated maritime student training by using AutoML tools to select relevant features	The early identification of at-risk maritime students can greatly improve student support systems, resulting in better academic outcomes and helping maritime students succeed	Tusher et al. (2023)
		ML	A non-linear relationship between predictor variables and safety perception is captured	Predicting safety perception can help identify seafarers who may need additional training, support, or interventions to improve safety awareness and behaviour	Arslanoglu et al. (2022)
		AI modelling	This study identifies specific ship driving habits associated with safety risks. Maritime accidents can be attributed to a variety of factors	Ship operators can improve compliance with safety standards by implementing the AI model's safety recommendations	Liu et al. (2022)

Table 2 (continued)

N	Topic	Technology	Outcomes	Benefits	References
4	Streamlining administrative tasks	AI based genetic algorithm	A celestial navigation fix involves finding the position that best matches the observed celestial bodies	Rather than sticking to local optima, genetic algorithms can find the global optimum rather than getting stuck in local ones	Tsou (2012)
		iForest model	Identification of anomalous patterns in port state control inspections. Shared characteristics reveal different clusters of ship detentions	By updating the predictive model with new information over time, port state control inspections continue to improve	Yan et al. (2022)
5	Remote consultations	Virtual reality (VR)	Reveal specific eye tracking patterns and gaze behaviour during maritime safety training in the metaverse or VR environment	Understanding eye tracking patterns allows for the optimization of training content and presentation. By knowing where trainees focus their attention, instructional designers can highlight critical safety elements and improve information retention	Markopoulos et al. (2021)

intervention that prevents the escalation of mental health issues and enhances the well-being of seafarers (Shi et al. 2015). By analysing and learning from large sets of data, ML algorithms can accurately diagnose and predict the onset of illnesses, even before symptoms are present. In maritime medicine, this technology can be used to diagnose and predict illnesses that are common among seafarers. By using ML algorithms, medical professionals can make more accurate diagnoses and provide more effective treatments, which can improve the health outcomes of seafarers.

3.1.2 Enhancing medical decision-making through ML

Medical experts make sure that healthcare providers' decisions are aligned with the diagnosis and patient preferences, leading to optimized patient care. Three studies mentioned ML based predictive analytics to enhance medical decision-making and help medical professionals to identify patterns and trends that can be used to predict a seafarers health status (Sau and Bhakta 2019; Riahi et al. 2013; Zhen et al. 2022). These studies were used to identify seafarers who are at risk of developing mental health issues such as depression, anxiety, and loneliness. Physicians can use this information to plan targeted prevention plans to help reduce the risk of developing these diseases. Two studies supported incorporation of text mining knowledge to help doctors to identify seafarers who are most likely to expose from certain diseases along with required treatments or medications (Chintalapudi et al. 2022, 2021). These studies considered sentimental analysis allowing onshore doctors to make more informed decisions. Overall, the potential benefits of predictive analytics in enhancing medical decision-making are relevant and this technology will play a significant role in transforming maritime medicine and improving patient outcomes.

3.1.3 AI based seafarers' safety and risk assessment

AI modelling plays a significant role in safety perception and risk assessment for seafarers. Three studies presented ML based approaches in seafarers safety risks that can be identified and mitigated before they escalate into serious incidents (Yan et al. 2021; Tusher et al. 2023; Arslanoglu et al. 2022). It is mentioned that ML can be used to predict equipment failures and maintenance needs. By analysing data from ship sensors and systems, algorithms can anticipate potential breakdowns, allowing for proactive maintenance and reducing the risk of accidents caused by malfunctioning equipment. One study highlighted that data from wearable devices or sensors can be useful in assessing safety risks (Tusher et al. 2023). These models can identify patterns of behaviour that may indicate fatigue, stress, or other factors affecting performance and safety. By addressing these issues promptly, the risk of accidents due to human factors can be reduced. Historical data on maritime incidents can be used to build predictive models that assess the likelihood of specific types of accidents occurring. These models can help shipping companies and authorities identify high-risk areas and take preventive measures to avoid potential accidents (Liu et al. 2022).

3.1.4 Streamlining administrative tasks and enhancing workflow

The application of AI in streamlining administrative tasks and enhancing workflow in maritime medicine has the potential to bring significant improvements in efficiency, safety, and quality of care. Automation of administrative tasks, such as scheduling appointments, updating medical records, and filing insurance claims, can help minimize paperwork,

reduce errors, and free up valuable time for healthcare providers to focus on patient care (Tsou 2012). AI-powered electronic health records (EHRs) can improve the accuracy and completeness of patient information, facilitate information sharing among multiple healthcare providers, and enable real-time monitoring and analysis of patient data to identify potential health risks and optimize treatment plans. Moreover, AI-powered chatbots can provide quick and personalized responses to patients' queries, offer health education, and provide support to patients with chronic conditions, increasing patient engagement and satisfaction. In Yan et al. (2022), authors proposed iForest, an anomaly detection algorithm, to flag unusual or problematic inspections, which helps port state control make better decisions by highlighting ships or inspections that stray from the norm, improving inspection processes.

3.1.5 Virtual reality and telemedicine for remote consultations

One of the most promising technological advancements in the field of maritime medicine is the integration of virtual reality and telemedicine for remote consultations. These technologies have the potential to greatly improve the quality of healthcare services available to seafarers who are often isolated at sea for long times, far away from medical facilities. One study, highlighted with help of virtual reality, that medical professionals can conduct examinations and procedures on seafarers without physically being in the same location (Markopoulos et al. 2021). These virtual consultations allow patients to be treated from ships without the physical presence of a doctor on board.

A shortage of medical knowledge among ship captains, which are the persons with the duty of providing medical assistance on board ships, affects seafarers' personal health more than that of normal workers (Grappasonni et al. 2012; Hadjichristodoulou et al. 2022; Norman 2012). It has historically been difficult for remote workers to receive healthcare because of commute requirements. Advanced AR equipment enables marine industries and their workers to receive care. Depending on the clinician's schedule, a person may not even have to take leave time from work when using virtual visits (Vanagas et al. 2012; Lucas et al. 2010). It may be advantageous for some specialty practitioners to provide telemedicine to their patients because they can see them at home. As technology continues to advance, these opportunities will be even more readily available, making healthcare on the high seas a reality that is more efficient and effective than ever before.

3.2 Addressing challenges of implementing AI in maritime medicine

Despite the promising potential of AI in revolutionizing maritime medicine, significant challenges and obstacles remain in implementing AI in this field. The first challenge is the lack of availability and accessibility of reliable data sources, which are necessary to train and test AI models. Additionally, the standardization of data formats across different hospitals and nations is a crucial issue that needs to be addressed. Another significant challenge is the lack of trust in AI technology by healthcare providers, especially considering the high stakes associated with saving lives at sea. Furthermore, the high cost of implementing AI systems and acquiring the necessary hardware and software can also be a barrier to adoption. Finally, regulatory approvals and policies on the use of AI in healthcare need to be developed and implemented to ensure ethical and responsible use of the technology. Addressing these challenges is essential for the successful implementation of AI in maritime medicine and the provision of effective and efficient healthcare services for seafarers.

3.2.1 Infrastructure

It is necessary to have appropriate hardware and software components for AI and AR platforms. Health professionals and patients can use videoconferencing equipment, devices for remote monitoring, secure data storage servers, and user-friendly software interfaces (Markolf et al. 2021). Developing virtual medical platforms requires hardware and software components equipped with videoconferencing devices, remote monitoring devices, and secure data storage servers (Markolf et al. 2021; Prabhakaran et al. 2022). The development of user-friendly software interfaces can enhance the experience of healthcare professionals and seafarers. As smartphones and tablets become more prevalent, virtual medical platforms should be compatible with mobile devices to improve accessibility and convenience for seafarers. In order to protect the integrity and confidentiality of seafarers' patient data as it is transmitted over networks, strong network security measures are needed, such as firewalls, encryption protocols and intrusion detection systems.

3.2.2 Ethical and legal considerations

Ethical and legal considerations are critical to ensuring the responsible development and deployment of these new technologies (Martin et al. 2022; Flores and Young 2022). One ethical challenge is the potential for AI systems to perpetuate biases and discrimination, which can have serious implications for patient care. For example, if a system is trained on a dataset that primarily includes data from a certain demographic group, it may not be as accurate or effective for patients from other specific groups like seafarers.

Additionally, there are legal considerations related to patient privacy, data security, and liability. AI systems must comply with regulations such as the General Data Protection Regulation (GDPR) and the Health Insurance Portability and Accountability Act (HIPAA) to ensure patient data is protected. Furthermore, the liability for any harm caused by AI systems is still unclear. It is crucial that developers and stakeholders in the marine industry carefully consider these ethical and legal considerations to ensure that AI-powered maritime medicine is used to promote patient safety and well-being (Naik et al. 2022). Moreover, the implementation of AI in maritime medicine requires a high degree of coordination among stakeholders, including ship owners, medical professionals, and technology providers, to ensure its effective deployment and integration.

4 Discussion

This narrative review has highlighted the opportunities, innovations, and future perspectives of transforming maritime medicine with latest technologies like AI and AR. Based on the available literature we have identified five topics that have discussed the potential benefits of implementing AI in the maritime health sector, including improved diagnosis, prevention, and treatment of maritime-related illnesses.

The current trends and innovations in AI technology and their potential applications in maritime medicine have been discussed. Furthermore, this study has explored the challenges that may arise with the implementation of AI and AR technologies in the maritime health sector, including ethical concerns and education of medical personnel (Das et al. 2023; Teo and Ting 2023). AI-powered medical devices designed for maritime

environments necessitate a rigorous technical analysis of their diagnostic capabilities and adaptive algorithms. The literature reviewed sheds light on the specific AI algorithms integrated into these devices, highlighting their intricate design tailored for maritime settings. This includes the detailed specifications and functionalities of these devices, emphasizing their ability to deliver accurate and rapid diagnostics, ultimately contributing to improved healthcare delivery for seafarers.

The application of ML algorithms in predictive modeling for maritime health demands a detailed examination. Extracting insights from the reviewed literature, this analysis scrutinizes the complexity of these algorithms and their application to maritime health data. The articles reviewed offer technical depth in describing the models' architecture, data sources, and methodologies utilized to forecast patterns and risks in maritime health emergencies. Such technical intricacies underscore the potential for advanced predictive tools tailored to maritime settings. The integration of AI into telemedicine for maritime healthcare requires an in-depth exploration of its technical functionalities and impact (Paolo et al. 2021; Meyers et al. 2021). The literature review exposes technical insights into AI-enhanced communication systems used to bolster telemedicine aboard vessels. These insights delve into the technical mechanisms that optimize communication between seafarers and medical professionals onshore, elucidating the impact on healthcare quality and responsiveness in remote maritime environments.

The advent of AI and AR technologies in maritime medicine presents transformative opportunities, leveraging real-time solutions and innovative healthcare delivery systems (Dutta et al. 2020; Singh et al. 2022). These technological advancements have significantly elevated healthcare outcomes by integrating AI-powered medical devices and virtual teleconferencing software. Such integration has not only optimized healthcare provision but also reduced operational costs for shipping companies. Despite concerns regarding AI displacing human healthcare workers, it is crucial to recognize AI's role as a complementary tool rather than a replacement. Continued innovation and development in AI within maritime medicine promise substantial contributions to enhancing healthcare delivery at sea and ensuring safer global logistics. For stakeholders in the maritime industry, ongoing incorporation of AI in healthcare systems remains imperative to elevate overall industry performance.

AI's potential in preventive healthcare interventions within maritime medicine is notably substantial. Leveraging predictive analytics, AI harnesses data from diverse sources—such as sensors, wearables, medical records, and environmental data—to forecast potential health risks proactively (Singh et al. 2022; Sun et al. 2022; Kumar et al. 2023). This facilitates timely preventive measures, including crew schedule adjustments, targeted interventions, and safety protocol implementations to avert foreseeable health crises. Moreover, AI-powered virtual assistants and chatbots play a pivotal role in granting crew members access to medical information and self-diagnosis capabilities (Vouitsis 2023; Batat 2021). Empowering crew members to manage minor health concerns independently reduces the workload on maritime medical providers while encouraging proactive measures for health maintenance. As AI technology evolves, its potential to furnish maritime medicine with data-driven insights and proactive interventions remains boundless.

Medical data analytics and predictive models within telemedical maritime services are crucial decision-making tools for healthcare practitioners. These data-driven approaches enable informed treatment decisions by leveraging AI-powered diagnostic algorithms. These algorithms accurately discern medical conditions and recommend treatment strategies, substantially reducing the margin of human error and augmenting patient outcomes (Floridi 2019; Pecqueux et al. 2022). Moreover, AI technologies can revolutionize health and safety

management within maritime organizations, fostering a safer and more efficient shipping sector. The evolving technological landscape forecasts boundless applications of AI in maritime medicine, poised to catalyse a transformative shift in the industry's landscape.

Another substantial domain for AI's application in maritime medicine lies in the anticipation and prevention of disease outbreaks. The confined populations inherent to maritime settings create an environment ripe for infectious disease propagation (Neubauer 2021; Dwivedi et al. 2023). Although existing monitoring systems aid in outbreak detection, AI offers a proactive approach to pre-empting and averting outbreaks. By analysing extensive datasets encompassing electronic health records, shipping itineraries, meteorological data, and social media feeds, AI demonstrates the potential to forecast outbreak probabilities and identify vulnerable groups. This predictive capacity equips decision-makers with crucial insights for deploying pre-emptive interventions like screening, quarantines, and vaccinations to prevent or contain outbreaks. Effective outbreak prediction and prevention strategies not only safeguard lives and public health but also curtail disruptions to maritime operations. However, the efficacy of AI in disease prediction hinges on data quality, accessibility, and the development of robust algorithms. Thus, stakeholders must ensure the ethical and responsible utilization of AI, upholding individual rights and privacy while harnessing its predictive potential for the greater benefit of maritime healthcare.

The technical challenges entwined with AI integration in maritime medicine, as elucidated in the review, delve into intricate aspects such as data interoperability, algorithmic biases, and cybersecurity. The exploration of these technical challenges aligns with the literature's discussion on addressing ethical concerns in AI applications within maritime healthcare. By highlighting technical nuances in proposing solutions to these challenges, the paper emphasizes the critical importance of resolving technical issues to ensure the ethical and efficient deployment of AI in maritime medicine.

Narrative reviews, while valuable in offering a comprehensive and insightful overview of a topic, are inherently susceptible to limitations. Unlike systematic reviews that rigorously follow predefined search and selection protocols, this study lacks a systematic search methodology. Consequently, the absence of a systematic process might result in overlooking pertinent studies, thereby introducing a selection bias. Reliance on the author's judgment and personal biases is another notable limitation in narrative reviews. The subjective nature of such reviews may influence the comprehensiveness of the review, potentially omitting crucial perspectives or studies that could alter the overall findings. Moreover, the absence of a predefined protocol and transparent methods complicates the replication and verification of findings by others, hindering the validation and reliability of the review's conclusions.

Despite these limitations, this narrative review contributes to the literature analysis by providing a comprehensive and accessible synthesis of research on AI and AR in maritime medicine. While acknowledging these inherent limitations, the study could serve as a valuable resource, offering a detailed summary and analysis of the existing body of knowledge. It is important for future studies to consider employing systematic approaches to enhance objectivity, minimize biases, and ensure the reproducibility and robustness of findings within the realm of AI and AR in maritime medicine.

5 Conclusions

The integration of AI in maritime medicine heralds a paradigm shift, offering numerous opportunities and innovations. Evidence supports the positive impact of AI systems on enhancing diagnostic accuracy and treatment efficacy for ship crew members. Innovations like chatbots, wearables, and diagnosis platforms play pivotal roles in augmenting healthcare provision for seafarers. Additionally, AI tools, employing predictive analytics and risk assessment algorithms, optimize medical services in remote areas. The amalgamation of AI and AR technologies holds significant promise in revolutionizing medical training and education for maritime healthcare professionals. These advancements bear potential to elevate healthcare quality for seafarers, curtail costs, and ultimately bolster the safety and well-being of crew members at sea. However, realizing the full benefits of AI in maritime medical assistance mandates further exploration while addressing ethical implications associated with these digital tools.

The development of AI-based applications in maritime medicine introduces a new era of possibilities to increase seafarer safety. While essential to enhance technology training for seafarers, it's crucial not to overlook the user-centric design of equipment (Allen 2010). The robust data analytics capabilities of AI systems enable informed decision-making, error reduction, and early warning systems to prevent or mitigate accidents. Furthermore, AI facilitates treatment optimization, enhances medical diagnoses, and extends telemedicine services to seafarers. Notwithstanding its potential, AI adoption in maritime medicine is not without challenges. Ethical considerations and the imperative for comprehensive training and regulation pose critical hurdles (Casero-Ripolles and M.-F. de-Lima-Santos, and W. Ceron 2022; Thomas et al. 2021). Therefore, concerted efforts among academic entities, maritime stakeholders, developers, and policymakers are imperative to advance AI's role in maritime medicine, ensuring responsible implementation while mitigating potential misuse. Overall, the incorporation of AI holds immense promise for the future of maritime medicine, with ongoing research expected to further elucidate its transformative potential.

The rapid adoption of AI in maritime medicine holds the promise of significant transformations, including enhanced efficiency, cost-effectiveness, and precision in healthcare delivery in this area. This becomes particularly pertinent within the maritime industry, characterized by limited and challenging healthcare accessibility. AI's prowess in enabling accurate diagnoses and tailored treatment plans tailored to individual patients' needs addresses these challenges. AI also facilitates remote consultations, enabling real-time medical care for seafarers, irrespective of their location. The rising adoption of AI in maritime medicine stands as a beacon of hope for advancing healthcare provision and bolstering seafarers' well-being worldwide.

The future of maritime medicine reflects substantial changes driven by the integration of AI and other emerging technologies, marking a transformative phase in practice. The implications of these transformations encompass enhanced healthcare access, improved patient outcomes, cost reduction, and heightened efficiency in medical decision-making. These innovations effectively tackle the unique healthcare challenges encountered in maritime environments, such as resource limitations, remote locales, and extreme weather conditions. Overall, the future trajectory of maritime medicine is enthralling, with the integration of AI and AR technologies projected to substantially influence the sector's growth and evolution.

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Declarations

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