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Artificial Intelligence in Ultrasound Imaging: A Novel Perspective

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1. Introduction to Artificial Intelligence in Ultrasound Imaging

Artificial intelligence (AI) has had a profound and transformative impact on the field of medicine. By revolutionizing the way healthcare professionals practice, AI has made significant advancements in the domain of medical imaging over the past decade. These innovations have resulted in an array of computer-aided diagnosis systems and AI algorithms that have gained regulatory approval, establishing themselves as reliable and effective tools. The integration of AI with deep learning (DL) algorithms has played a pivotal role in reshaping traditional imaging practices. This development has captured the attention and excitement of healthcare professionals due to its potential to enhance diagnostic accuracy and procedural efficiency to unprecedented levels. The prospect of leveraging AI and DL in medical imaging has the capacity to revolutionize patient care and greatly improve medical outcomes. Among the various imaging modalities, ultrasound has emerged as an exceptionally attractive option. Ultrasound offers not only superior safety but also unmatched patient comfort when compared to other techniques that rely on ionizing radiation. This attribute contributes significantly to its popularity and acceptance in healthcare settings. The versatility of ultrasound is another factor that makes it invaluable in clinical scenarios across a wide range of medical specialties. From a clinical perspective, the application of AI and DL algorithms in ultrasound imaging has demonstrated promising results. These technologies have the potential to assist healthcare professionals in accurately interpreting ultrasound images, resulting in more precise diagnoses and treatment plans. The integration of AI within ultrasound systems has also shown promise in improving workflow efficiency, reducing human error, and enhancing overall patient care. Moreover, the future of ultrasound imaging with AI holds immense potential for further advancements. As technology progresses and data collection and analysis continue to improve, AI algorithms can be refined and optimized to deliver even more accurate and reliable results. This ongoing evolution in the field of AI and ultrasound imaging promises to revolutionize healthcare practices and elevate the standard of patient care to unprecedented heights. In conclusion, the combination of AI and DL algorithms has ushered in a new era in the practice of medical imaging. Ultrasound, with its safety, comfort, and versatility, has become an indispensable tool in healthcare settings. The integration of AI within ultrasound systems offers the potential to significantly enhance diagnostic accuracy, efficiency, and patient care. As the field continues to evolve, the future of AI-powered ultrasound imaging holds immense promise for further advancements that could revolutionize the healthcare industry as we know it. [1][2][3][4][5]

In contrast to other imaging modalities, AI applications to ultrasound imaging are in their relative infancy, with limited powerful clinical AI applications available for routine clinical use. There are several ultrasound machine learning-based algorithms that immediately enhance current clinical practice, such as those used for the assessment of blood flow patterns in the transcranial Doppler examination, kidney transplant monitoring, ultrasound imaging methods, and urinary bladder volume calculations, to name a few. Traditionally, ultrasound examination results in a single operator acquiring and interpreting diagnostic images. The potential of AI to enhance the quality of ultrasound images and automate these processes means that ultrasound is a promising imaging modality for further AI enhancement with respect to automation of complex clinical routine image acquisition and interpretation tasks, among other things. With the rapid advancement of AI technologies, there is vast scope for expanding its applications in ultrasound imaging. AI can play a significant role in improving the accuracy and efficiency of ultrasound examinations. It can aid in analyzing intricate details of blood flow patterns, enabling a more precise assessment of various medical conditions. AI algorithms can also assist in monitoring the progress of kidney transplants and detecting any abnormalities at an early stage. The development of intelligent ultrasound methods holds great potential in revolutionizing the field of diagnostics and patient care. These advancements not only help in automating manual tasks but also offer clinicians valuable insights and decision-making support. By integrating AI into ultrasound imaging, medical professionals can expedite the diagnosis process and provide more accurate treatment plans. Moreover, AI can optimize the acquisition and interpretation of ultrasound images by minimizing human errors and standardizing the procedures. By harnessing the power of AI, ultrasound imaging can become a cornerstone of advanced healthcare, enabling improved patient outcomes and enhancing the overall efficiency of medical facilities. The future of AI in ultrasound imaging is incredibly promising, with continued research and development expected to unlock even more groundbreaking applications and advancements. By harnessing the potential of AI, the field of ultrasound imaging can leap into new dimensions, revolutionizing medical practices and patient care worldwide. [6][7][8][9][10][11]

1.1. Overview of Ultrasound Imaging

Ultrasound imaging, performed using sound waves, is a widely used technique that allows physicians to visualize internal body structures. It has a wide range of applications in clinical diagnosis, therapy guidance, and research, representing one of the four clinical imaging techniques used in contemporary medicine. Ultrasound imaging uses ultrasonic waves, typically in the frequency range from 1 MHz to 15 MHz, to probe the biological tissue. There are two main modes that can be used in ultrasound imaging: 1) pulse-echo, used in B-mode or brightness mode, which allows visualization of anatomical structures in two-dimensional images, and possibly the assessment of displacement or velocity; and 2) continuous wave mode, mainly used in Doppler-based ultrasound systems to assess blood flow velocities through the vasculature. The main advantages of ultrasound imaging are its non-invasive nature and real-time capabilities. The B-mode imaging, and more recently ultrafast imaging using plane, diverging, or diverging-beam waves, have been used for various applications and human organs: abdominal, cardiology, breast, musculoskeletal, elastography, endoscopy, etc. [12]

Technological advances have enabled many ultrasound-derived imaging techniques. Fertility abnormalities, ophthalmic disorders, and obstetrical complications have been detected using three-dimensional and four-dimensional enhanced ultrasound imagery with multi-planar sections and volume rendering. Contrast-enhanced ultrasonography became a safer and less costly alternative to X-ray-based angiography for patients with certain medical conditions, gestational age assessment, and rheumatological smaller joints, among other applications. In imaging, CAD and ABVS provide rapid, intuitive feedback during breast cancer screening exams, as well as quantification and risk stratification of fetal alcohol spectrum disorders. Other clinical uses include neonatal brain imaging using plane wave imaging for rapid scanning, quantitative evaluation of muscle disease progression to personalize physical therapies, and echocardiographic strain imaging to assess treatment responses for type B aortic dissection. [13]

1.2. Fundamentals of Artificial Intelligence

Artificial intelligence (AI) is a subfield of computer science aiming to invent computer systems that can imitate human intelligence in various aspects, such as reasoning, learning, adaptation, scheduling, forecasting, or problem solving. AI encompasses a variety of methods that can be used to impart intelligence to a system, including machine learning (ML), deep learning (DL), knowledge-based reasoning (KBR), human-computer interaction (HCI), and so forth. Some of these methods and their relevant applications to examination and diagnosis will be reviewed here since they are paramount for the understanding and use of AI technology in examination. [14]

At a bird's eye view, learning refers to the ability of a system to acquire knowledge or a skill that can improve its performance or generalization capacity in specific tasks over time. In the AI community, two principal approaches to learning have been developed: supervised learning (SL) and unsupervised learning (UL). SL represents the training process in which data examples come as input-output pairs. During training, a targeted set of weights (or parameters) of a learning model is optimized to minimize the discrepancy between the model output and the corresponding output measures. By contrast, UL denotes an unsupervised learning process for which the input data is not labeled, i.e., there are no specific training examples available and no associated ground-truth measures. Depending on the learning objective or the available training data, various learning algorithms have been developed, such as support vector machines, AdaBoost, neural networks (NNs), convolutional NN, Gaussian mixture model, K-means, etc. These algorithms demonstrate impressive generalization performance in specific tasks, such as image classification, segmentation, clustering, regression, etc. [15]

2. Historical Development of AI in Medical Imaging

Nowadays, information technology has made a significant leap forward due to numerous advancements. One of the most promising and groundbreaking innovations in recent times is the remarkable development of artificial intelligence (AI), especially in the vast realm of medical imaging. The evolution of AI in medical imaging has a fascinating history that can be traced back to the early 1950s when the pioneering studies were initiated. During that era, scientists began their journey by focusing their efforts on designing and creating incredibly sophisticated software that had the extraordinary ability to identify and detect polyps within the intricate colons. Such groundbreaking research marked the dawn of an era where AI became an indispensable tool in the field of medical diagnostics. [16]

Many developments have since been pursued, particularly in the integration of machine learning in medical imaging. With the ongoing progress in neural networks, a boom is expected in the next couple of years in this area. For imaging, a few useful tools are computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), and X-rays. Among these imaging techniques, CT (including cone beam CT) has the greatest imaging resolution capabilities at an average of 200 µm. Ultrasound imaging, an active research topic in imaging modalities, is becoming an increasingly frequently used imaging modality of interest for clinical applications. It has been shown that ultrasound imaging is a versatile imaging modality, with a wide range of diagnostic and therapeutic uses. Recently, AI has been integrated with ultrasound imaging. At the technological landscape level, AI-enhanced ultrasound imaging leverages the processing capabilities of high-performance computers and big data with large amounts of annotated or labeled training data. However, the major challenge in AI integration is developing a suitable algorithm to improve the diagnostic accuracy of sonographic images. Much research has been conducted in this field. [17]

2.1. Early Applications

Integrating artificial intelligence (AI) with medical imaging technology has been a long-standing goal for researchers, scientists, and developers across the globe. The primary objective is to enhance the accuracy of diagnoses, eliminating the need for clinician supervision. The computer, boasting unparalleled computational power, employs a sophisticated framework of innovative algorithms that enables it to independently identify and predict ailments and even reveal concealed indicators that would otherwise be imperceptible to the human eye. Although the initial ventures can be dated back to the 1970s, the outcomes were relatively lackluster at that time. However, this propelled further research and innovation in the field, resulting in significant advancements. [18]

However, the first clinical trials carried out with artificial intelligence and ultrasound have already provided surprising results. An application realized in 1996 reconstructed the image, with extraordinary resolution, and provided a reliable estimation of both the average blood flow and the flow velocity, starting from color signals. Similarly, a support tool with artificial intelligence proposed in 1996 reached an accuracy in the diagnosis of carotid artery occlusion close to 94%. These studies show that the revolutionary applications of AI, and more specifically, the ultrasound modality are particularly attractive in the field of diagnostics. In addition to cost savings, it would manage to speed up the diagnostic process by providing clinicians with a new reliable tool, supported by AI. The scope is to establish a foundation for enormous success in modern medical imaging. [17]

2.2. Advancements in Ultrasound Imaging

Advancements in Ultrasound Imaging

Ultrasound imaging technology has greatly evolved over the years. The gradual development of sophisticated algorithms has enabled them to be executed on slim and lightweight portable ultrasound devices. AI has made it possible to develop algorithms that enhance the quality of the signal and generate high-quality images similar to those of traditional and high-cost scanners, in a fraction of their time. Not only is the quality improved, but the rapid processing is a major advancement as it avoids any delay in further diagnosis, monitoring of intraoperative biopsy, or several musculoskeletal conditions. In particular, the performance and accuracy of AI models are advancing. AI also has the capability to make any software user-independent and automate laborious and time-consuming repetitive tasks of assessment, quantification, and associated error reduction. [19]

Several algorithms have been used to compensate for the angle of the ultrasound beam. Another fascinating feature is the augmentation in 3D visualization compared with traditional real-time 2D imaging. 3D/4D imaging has provided important clinical outcomes in the diagnosis of heart anomalies, fetal monitoring, and anatomical references in general musculoskeletal conditions.

Several companies are in the process of integrating this technology with virtual reality glasses for users to interact, hence improving the user experience remarkably and opening new dimensions in image processing and diagnosis. Furthermore, recent research in this field has indicated technological growth in portable, handheld, and smartphone-based ultrasound devices. Bioengineers have partially eliminated the transducer's role via AI algorithms, thus reducing the infrastructure hardware of the device. Recent literature also highlights the ultrasound niche in pediatric oncology, potentially minimizing the adnexal scanning protocol. This discards the use of ionizing radiation by auxiliary images before contacting technical specialists. AI has further been used to improve the imaging of blood flow analysis. For example, a B-mode and color Doppler ultrasound, if performed manually, has less than 30% to 67% intra-observer repeatability. Multiple groups have tried to solve this by using machine learning for the estimation of blood flow velocity in the vessel. Another similar innovation is the use of AI in elastography. Elastography provides essential information regarding the associated supportive tissues. AI, however, can easily identify if there is an artificially induced pattern or genuinely occurring tissues by providing 2D and 3D tissue strain and strain distribution maps. Hybrids of elastography and shear wave elastography have been developed by AI and offer exquisite lesion-stiffness detection in the diagnosis of small breast and liver lumps. Other innovations from AI and ultrasound show great advantages in cardiovascular disease, such as perfusion imaging, the role of AI during early pregnancy, cellular imaging in identifying neovascularization or peculiar cells, acoustic radiation force imaging, and imaging of perineal skeletal muscles, psoas muscles, and pelvic floor muscles. [20][21][22]

3. Current State of AI Integration in Ultrasound Imaging

While research in various guidelines has been conducted in echo imaging for both morphological, hemodynamic, and perfusion, their fast entry into clinical practice has been relatively slow compared to that in the magnetic resonance imaging and computed tomography communities, majorly due to the difficulties and challenges of controlling the real-time physics of the imaging modality to make values rather than pictures. Advances in artificial intelligence have impacted most, if not all, areas of human endeavors across the globe, poised for revolutionizing healthcare using novel, automated, and smarter means of diagnostics and treatments. Unlike the traditional practice associated with learning ultrasound imaging, which can take rounds of practice to attain reliable competency, AI-based real-time image interpretation has shown a lot of promise in year-in-year-out research-based development and, in recent times, has grown past research-level development into different companies and organizations. Regularly, the commercial-level design of AI tools to assist physicians goes apart from research papers leaps and bounds in sophistication. [23]

European and national ultrasound societies have been at the heart of the process related to the development and dissemination of guidelines concerning the application of AI in ultrasound imaging. A consortium pact between various organizations has been set in motion to make guidelines for closed-loop imaging using MRI, fMRI, ultrasound, and CT. Interest has been shown towards ultrasound imaging, but further proposed discussions are expected later. That said, AI technologies have also carried some set of challenges and limitations in the real-world clinical perspectives. These include, in the main, the long process of designing, data collection/storage, labeling, training, testing, elimination of check-mistake bias, regulatory approval for publishing, and the establishment of local computational infrastructure, before the final output can be published. [17]

3.1. Challenges and Opportunities

Ultrasound imaging is responsible for a large fraction of the imaging diagnostics conducted at present due to its safety, portability, lack of need for contrast media, and capability for real-time clinical imaging during surgery, emergency treatment, and obstetrics. Recently, integrating artificial intelligence components into the ultrasound imaging ecosystem shows great promise. The traditional machine learning and deep learning pipelines, which can reveal statistical significance among multimodal data, contribute to image reconstruction, robot-assisted imaging, motion tracking, and predictive analysis for therapy. We present an overview of the state-of-the-art ultrasound imaging technology that is integrated with artificial intelligence in terms of pipeline, system, and potential future trends. [24]

3.1. Challenges and Opportunities The use of AI in medical ultrasound imaging raises a number of technical, ethical, and safety challenges. Technically, as research moves from lab to clinic, there will be increasing demand for larger, high-quality annotated (and correctly aligned) datasets. Also, the 'black-box' problem in AI, meaning the great algorithmic accuracy may obscure the basis for its logic, has the potential to be a significant barrier to the widespread adoption of new AI-driven ultrasound imaging. Clinicians also need to be confident that the integration of the ultrasound device system is interoperable across institutions to allow continued access to data. Ensuring reports of safety and accuracy standardization is an important consideration for not just patients but all stakeholders interested in the medical excellence value proposition of the healthcare industry. The impacts of integrating AI into ultrasound imaging need to be proactively addressed. Finally, the credibility of AI algorithms is likely to change the way ultrasound reporting integrates into a larger, more complex image management landscape. [21]

Despite these challenges, there is significant opportunity for utilizing AI in ultrasound imaging. The advantages of ultrasound, including its lack of ionizing radiation, straightforward application, and widespread existence in many domains, mean that AI technologies will benefit many patients. Given the scope and scale of ultrasound imaging, AI will likely be utilized to improve throughput and quality of imaging, making diagnostic image acquisition more consistent and systematic compared to current practices. The data extracted from systems integrating AI and model trees are likely to be used for more in-depth diagnostic and tracking use cases where clinicians require predictions beyond the precision of current techniques. It is imperative that researchers, technologists, and clinicians begin a dialogue about the implications, challenges, and opportunities associated with integrating AI into ultrasound imaging to ensure that integration remains strategic, sustainable, and effective evidence-based practice in the future. [21]

3.2. Key Players and Initiatives

AI tools are currently being explored and developed by big players in the field of medical imaging, such as GE Healthcare, Siemens Healthineers, and Philips, outside of the public domain due to the commercial value of such systems. In addition to these major companies, there are also numerous other organizations and research initiatives in the academic space and research organizations that have dedicated significant efforts to studying and implementing AI for U.S. applications. These research groups have conducted extensive and in-depth research in order to harness the potential of AI in the medical imaging field. With their expertise and resources, they aim to develop innovative and reliable AI tools that can revolutionize the healthcare industry. These organizations are committed to advancing medical imaging technologies through the use of artificial intelligence, ultimately improving patient care, diagnosis, and treatment outcomes. Moreover, they are actively collaborating with medical professionals, universities, and other industry leaders to ensure that AI technologies are effectively integrated into the medical field. By working together, they strive to create a future where AI-powered medical imaging systems are widely accessible, providing accurate and efficient diagnoses for patients around the world. Through their dedication and commitment, these research initiatives and organizations are paving the way for a new era in medical imaging, where AI plays a central role in shaping the future of healthcare. [25]

Several initiatives regarding AI in the U.S. and related therapeutic applications are ongoing; one such initiative is a collaboration between special interest groups and working groups within relevant societies. There are yearly imaging grand challenge events, often including AI and DL-driven tasks. Recent projects have commenced, focusing on AI and beyond clinical implications when integrating AI with therapeutically focused ultrasound. Academic groups are also exploring U.S.-centric AI standardizations. Medical device manufacturers who develop acquisition equipment also have ongoing initiatives in AI research. Furthermore, academic innovation platforms are working with regulatory bodies to encourage and formalize theranostic technologies and their regulatory pathways. [26]

4. AI Techniques and Algorithms for Ultrasound Image Analysis

Artificial intelligence (AI) in medicine has attracted tremendous attention in recent years. AI techniques and algorithms have been increasingly applied in medical diagnostic imaging. AI in ultrasound has shown unique advantages and promising prospects in medical imaging, especially in prenatal care and obstetrics. This special issue will cover the application of AI techniques in ultrasound imaging. Ultrasound imaging is also a promising field for the evaluation of novel AI algorithms. This paper reviews in detail the techniques used, including algorithms and application scenarios, as well as an outlook on future research issues. [21]

We further present insights into existing algorithm training optimization techniques in machine learning and deep learning. We provide the basic data flow of a diagnostic system by using AI algorithms with big data training that includes an offline training network where diagnosis outcomes can be made online. We examine the principle of hyperparameter optimization during the offline training process. In recent years, deep learning has been increasingly involved in the exploitation of medical imaging. Deep learning involves many outstanding algorithms, and their updates are inspired by the structure of the human brain. Among these algorithms, convolutional neural networks (CNNs) are the most widely used, showing excellent diagnostic performance. An overview of AI algorithms used in medical imaging is shown, and the data analysis tools used in different algorithms are shown, focusing on deep learning techniques useful in recent years. These methods have been used for offline data feeding learning during preprocessing, where 3D medical images are transformed into 2D data for training feature networks. These methods also support certain image quality improvements by exploiting GPU and CPU. [27]

4.1. Machine Learning Algorithms

Researchers have sought new machine learning algorithms, such as convolutional neural networks and recurrent neural networks, to enhance the ultrasound diagnosis process. Machine learning algorithms, statistical learning algorithms, and pattern-matching algorithms from machine learning are widely used in ultrasound diagnosis. In general, machine learning investigates and learns from the various reported cases, diagnoses, and treatment programs of ultrasound, which aids physicians in disease diagnoses or therapeutic options. In clinical scenarios, the machine learning algorithms are typically used for segmentation, vector flow, speckle tracking, and deep learning algorithms. Generally, machine learning algorithms are utilized as diagnostic support. In this category, the algorithms are incorporated with multiple modalities, such as combining echocardiography and speckle tracking ultrasound for left ventricular wall motion estimation. In addition, most of the learning features in more generalized approaches refer to the use of convolutional neural networks fed with raw data, metadata, or handcrafted features. For automated diagnosing, feature learning algorithms are developed from raw and/or intraoperative data; this is called cascaded feature learning. Although machine learning algorithms are widely applied to ultrasound imaging, there remain some weaknesses, such as generalization challenges, data scarcity, and various settings and resolutions between different ultrasound images and scanner companies. The applications and pitfalls of different machine learning approaches in ultrasound imaging are still important to address. Studies involving supervised learning, convolutional neural network-based learning, cascaded learning, and unsupervised learning are of particular importance, and it is beneficial to move forward in these directions to further enhance diagnostic accuracy. These four machine learning techniques are advanced technologies because they allow automated data processing. Typically, they start with segmentation in order to understand the region of interest. Current trends in ultrasound imaging focus on the automatic and semi-automatic analysis of ultrasound data. Accurate ultrasound image analysis is usually based on a machine learning approach for the automatic quantification of different parameters of interest. This beginning of image analysis opens the door to further developing and refining this type of learning. [28][29][30][31]

4.2. Deep Learning Techniques

Deep learning coincides with a new wave of artificial intelligence (AI), while being a subset of machine learning (ML) methodology where a large volume of input image data can be processed. An artificial neural network (ANN) serves as the basic architecture of deep learning; it is a composition of several interconnected processing elements. Most neural networks are feedforward networks, where the ANN has standard sequential input patterns which are the middle layer in a deep neural network (DNN) with an input layer, inner layer (hidden layer), output layer, and feedback loops. The functioning of a DNN lies in initially setting a large number of input-output tuples. The network on its own decides the feasible feature classes to classify the input patterns. Additionally, each hidden neuron processes the weighted sum of input pixel values and creates output (feature) to contribute to the next layer. Each neuron installs a pivot position value as per the tapping weights. The selected pivot classifies the most critical neurons in which each neuron's weights and signed input values give the output. This upgrade in the ANN is employed for image pattern recognition, especially in medical imaging to decrease the burden on the sonologist. [32][33][34]

Several convolutional neural network (CNN) architectures decrease the training difficulties arising in constructing the CNN by increasing the capacity and depth of the network to recognize the low-level features of the image. CNN is designed based on the partial differences derived from the neurons' receptive spacing in a field unit. Due to this utility, CNN has found application in the deep learning approach for ultrasound images in various medical applications, including breast lesion detection, liver image analysis, handmade fetus specification scoring, prostate cancer identification, ocular tissues, arterial wall stiffness levels, transfusion-free drilling detection in robots, and cardiac uses in echocardiography, among many others. Deep learning comprises a progression from classic ML techniques to boost the skill of machines to exhibit human-like comprehension for each sensory facet. Automated ultrasound image analysis is exclusively established as a data processing task, and it is this precise treatment of data in ultrasound that is hard to be processed by human professionals. Scalars suffer extensively from reverberation, and each constituent wants to undergo different preprocessing patterns for data reliability computation until the computer can acknowledge the component union. This is where deep learning strategies kick in and present a strong and trainable image feature adaptation for reasoning and intelligibility, and consequently, it is a prime faction of AI for processing and analyzing ultrasound images for medical examination. [35][36]

5. Applications of AI in Ultrasound Imaging

Artificial intelligence (AI) has the potential to change the way healthcare professionals approach disease detection and diagnosis. One area where AI can potentially be highly impactful is in disease detection using imaging as the primary mode of detection. A promising technique for initial imaging is ultrasound imaging. This versatile modality offers detailed images of superficial organs and is non-ionizing, making it extremely safe for use. Furthermore, this small, narrow, minimally invasive probe is highly effective for imaging the developing fetus and cardiac imaging, which traditional computed tomography and magnetic resonance imaging lack. However, the interpretation of these images to identify the presence of various conditions is still highly subjective and highly dependent on the skills and expertise of the professionals. [21]

To increase the accuracy of these interpretations and reduce analysis times, AI can be extremely useful in automating the tedious process of segmentation and extracting the specific features representative of the condition. AI in general and deep learning, in particular, has the capacity to transform the clinical workflow and management of patients. For instance, AI can be instrumental in developing an inexpensively modifiable technique that can be used for initial screening and monitoring therapy response and prognostication in a variety of clinical settings. In this manuscript, we discuss various applications of AI in ultrasound imaging and its potential use in various common conditions. We also succinctly discuss the process of image formation and the possible use of visual question answering to have a more robust framework to which it can apply. Various techniques used by AI for automatic description of clinical ultrasound are illustrated. [37][38]

5.1. Disease Detection and Diagnosis

A plethora of research algorithms have been proposed to analyze ultrasound images for disease detection and diagnosis. A multi-modal strategy for this consists of texture features, wavelet entropy, and fractal dimension to improve the diagnosis of breast cancer using an artificial neural network supported by a hybrid feature selection approach. This helps in distinguishing cancer from benign tumors efficiently to validate the system's outcomes. With the help of the algorithm, radiologists can diagnose and distinguish between invasive lobular carcinomas and other histological entities. Other multi-modality analyzers can accurately diagnose fibrostinal changes, identifying elastography-based indices to detect prostate cancer and classify tissue and benign cancer accurately. The dual model uses a 3D U-Net model and an efficient detector that can rapidly innovate pancreatic tumors. Using other details from the resolution modeling of the clinical protocol, it increases the detection performance of the mixed AI-Clinician model. It has shown that a unique CADx approach of artificial intelligence is feasible for use in ontogeny. With well-defined ultrasound populations, our findings propose the potential of AI use in routine clinics. [39]

However, a decrease in accuracy on a larger data subset is a possible concern for algorithms based on ultrasound only. With a diversity of imaging technology types and more comprehensive data sets, learning can be advanced. It will also be beneficial to use the expert channel to develop hybrid models of radiology and AI, so decisions by radiologists and clinicians can be made based on integrated perceptions. However, the extreme difficulty of mimicking radiologists or clinicians accurately has been shown, and it is still unresolved how to manage this complex development process in clinical settings. The development and use of techniques using high-quality ultrasound images are underdeveloped and should be further investigated. This can help in reducing the number of procedures. In the future, this will be a key consideration given the importance of patient care and ethical considerations. For the particular clinical setting, the diversity of examined images should be better considered. Researchers have revealed non-normal results for the usual clinical test loads. Critical discussion of the new AI-driven approach against the traditional models will boost international recognition and trust in computer-aided diagnosis and treatment. [40][41]

5.2. Image Segmentation and Feature Extraction

2. RESULTS 83 5.2 Image Segmentation and Feature Extraction Segmentation is an important research field in medical ultrasound image analysis aimed at accurately identifying and classifying different anatomical and pathological structures from given ultrasound data. Due to the complex nature and multiple variations in ultrasound, segmentation remains a hot research field in medical imaging over the last couple of years. AI-based techniques, network architectures, and methods are designed and employed for automated or semi-automated segmentation. After accurate segmentation masks are obtained, the next step is feature extraction for subsequent analysis. Deep learning techniques are employed in the complex field of ultrasound image analysis for highly accurate and potentially efficient segmentation, which is a challenging problem due to image quality degradations and the availability of limited datasets. Segmenting anatomical structures is an important part of daily clinical practice for various applications, including treatment planning, intervention, disease staging, or progression monitoring. The heavy workload on experienced radiologists, the availability of limited experts, and inter- and intra-observer annotation discrepancies are major difficulties in this field for accurate image segmentation and subsequent feature extraction. Lesion detection, biomarker extraction and analysis, urine flow, and urinary system segmentation are some of the areas that use AI tools to address these issues. CT datasets, X-ray, MRI, fundus, PET-CT, video, and 3D and 4D ultrasounds are some examples of datasets used for feature extraction. Splitting the image into smaller distinct patterns, matrix representation, multi-channel feature extraction, and landmark-based ultrasound analysis are the feature extraction methodologies. Thus, the presented review emphasizes the popularity of AI techniques for image segmentation and feature extraction, and future directions include the methodology of fusing global

and local features extracted for image classification. [42][43]

6. Ethical and Legal Implications of AI in Ultrasound Imaging

While there are concerns about the clinical, technical, administrative, and societal implications and adoption of AI in various areas of diagnosis and healthcare, we have mainly focused on the ethical and legal aspects related to the deployment of AI algorithms in enhancing ultrasound imaging. In order to adopt AI algorithms in ultrasound examinations, many issues have to be addressed, such as: How can we guarantee that the data generated by the scanner remains secure and cannot be manipulated? Who is responsible for the decisions made by the AI? How can we verify the efficacy of an AI algorithm and ensure its proposed enhancements are genuinely those obtained from the original data? This is particularly problematic in machine learning approaches, as the decision pipeline is essentially a "black box" mechanism. Impact on Patient Health Once the "best" proposed artifact-free or enhanced data is obtained, this new data can be readily used to make a more accurate diagnosis and better monitor patients' responses to treatments, by using techniques and programs made available or developed by manufacturers. The AI-generated data can be kept confidential or only shared among stakeholders, thus potentially discriminating against other patients who may not have access to better treatments. [17][6]

Regulations and Ethical Issues In this rapidly growing field, several challenges have emerged that are being increasingly addressed by competent national and international agencies and organizations. A calibration of AI deployment to the accepted legal and ethical rules is required to enable safe and efficient use for the benefit of society. Ethical issues such as transparency, consent, bias regulation, accountability, and others can affect the acceptability and successful implementation of artificial enhancement of ultrasound. New guidelines and regulations for the introduction of AI in ultrasound should provide clear warnings to developers of AI tools, which are better informed about the considerations to be addressed for integration and implementation in clinical practice. These include the necessity for larger and more comprehensive validation beyond the already existing guidelines. The ethical considerations regarding patient approval for consent, reticence in clinical medicine for AI to make decisions for a patient, and the demands for responsibility from manufacturers and operators of AI, starting from the training data to the decision algorithm itself, are raised to guarantee good clinical practice. [44][45]

6.1. Patient Privacy and Data Security

Given the highly sensitive nature of the information contained in ultrasound images, it is paramount that they are handled securely and with adequate professional care to preserve patient trust and protect them from exploitation. Artificial intelligence (AI) systems require vast amounts of correctly annotated clinical imaging data to train, which opens up numerous possibilities for exploiting patients' personal information. AI systems must therefore be designed to respect privacy and incorporate principles of data protection by design. Data must be handled in such a way that the risk of breaching a patient's privacy is extremely low. Additionally, as the systems could be incorporated into clinical pathways, security must be a priority, as adversaries gaining access to the system could have a significant impact on impacted patients' clinical outcomes. [33]

Patient privacy and the security of medical data are currently enshrined by legal frameworks such as the General Data Protection Regulation in the European Union and the Health Insurance Portability and Accountability Act in the US. According to GDPR, data security should be made up of organizational and technical measures, including encryption of personal patient data, regular vulnerability and penetration testing, and staff training. In order to begin to secure ultrasound imaging data sufficiently, access to raw imaging data must be heavily restricted. This could involve extreme access control, so that imaging data can be viewed, annotated, or used for training purposes only in specific environments such as hospital servers. Another option might be secure enclaving, where raw imaging data can be accessed only in trusted hardware environments. Finally, the possibility of reversible obfuscation of imaging data might be considered. For example, federated remote learning involves training models on devices and only sharing updates. Ethically, it requires that patients are fully aware of how their information is taken and where it is sent and used. Frameworks that enable patients' rights to data ownership and consent for data use must also be developed as a priority to establish these systems, potentially by reimbursing patients in the event that data are used commercially. A strong link between developers and the medical world is also required to ensure this is upheld in clinical practice, in work practices, pressures at work, and consistently upheld in high-risk areas. [46][47]

It is vital to ensure patient trust in AI systems, and robust security practices will aid in this. In order to promote transparency, enable auditability, and allow independent verification of security, systems are encouraged to engage in security testing. The qualitative independent reporting is beneficial in building public and professional trust. It may be preferable to have a standard assessment system for algorithms as they are implemented clinically. Data protection and confidentiality guidance are crucial in any clinical AI study that plans to use sensitive personal information. The recording of any unexpected adverse effects on processing and security is a regulatory requirement as well as an ethical requirement. Meeting regulatory requirements (secure system infrastructure, integrity and insurance, including for international data processing, data protection by design and by default) will be necessary to get a CE mark and conduct large-scale multicenter research. [48]

6.2. Regulatory Frameworks

AI-based medical devices have recently attracted attention from national, regional, and international authorities, which are not only required for safety and health protection but also for legal compliance. The conducted regulatory assessment of medical software and AI has the potential for guidelines or regulations that are worldwide accepted and applicable, with influences on companies, clinical trials, development processes, and safety and effectiveness for AI-based algorithms for their intended use. The regulation presents another threat to innovation: without the requisite data resources, firms cannot innovate in a way that secures regulatory approval. Hence, the firms do not innovate. [49]

According to the FDA framework, the regulatory approval process follows a software review mandate that is equivalent to that for obtaining approval for every iteration using a large re-learning data model. Hence, the time invested in the FDA approval algorithm depends on data size and model complexity. As for the European Commission, a proposal for a regulation on AI has to be considered as it concerns the AI used in diagnostics and could be classified as part of in vitro diagnostic medical devices. Hence, AI algorithms deployed in ultrasound imaging must meet all regulatory approvals prior to their enabled use. In this context, it is essential to think about regulations early in the development of the AI algorithm. There is support for an early involvement of legislators in the discussions on desirable standards for AI in medical diagnosis. Advice from stakeholders' industries and advice for a comprehensive and balanced regulatory policy is urged. The directive or legislation has to be updated to consistently reflect demonstrated technologies and to ensure that all new developments are compatible with regulations in force. Although AI/robotics offers great potential for society, it is essential that the technology is regulated and developed. The gradual adaptation and updating of these standards are highly recommended. Regulatory laws for therapeutic AI diagnosis must be flexible enough to adapt innovative methods. [37]

7. Future Directions and Emerging Trends in AI and Ultrasound Imaging

Automated Object Segmentation and Clinical Outcome Prediction with Founder Breast Ultrasound Images Based on Deep Learning

Voice recognition and natural language processing technologies have the potential to provide a viable solution for substantially reducing the need for traditional image-based manual analysis. At its current stage, AI's proficiency in natural language processing is in its early development, and the integration of voice-assist radiology reporting and compatibility with PACS (Picture Archiving and Communication Systems) systems presents a challenge in fully harnessing this capability in everyday clinical settings. However, it is conceivable that in the near future, AI-powered virtual assistants built upon dependable and accurate natural language processing algorithms will be able to effectively support radiologists in their work. Such advancements would greatly enhance the efficiency and effectiveness of radiology practices, allowing for more streamlined workflows and improved patient care. With the continuous progress in voice recognition and natural language processing, the utilization of these technologies holds immense potential for revolutionizing the field of medical imaging analysis. By leveraging the power of AI, radiologists can benefit from enhanced diagnostic capabilities and reduced reliance on time-consuming image interpretation tasks. The integration of voice-assist radiology reporting and seamless compatibility with PACS systems is a crucial step towards unlocking the full potential of these technologies in everyday clinical practice. Imagine a future where an AI-powered virtual assistant, equipped with advanced NLP algorithms, seamlessly integrates into the radiologist's workflow. This virtual assistant would be capable of accurately analyzing radiology reports, extracting critical information, and providing valuable insights. With its ability to comprehend natural language, the AI assistant would effectively bridge the gap between medical imaging data and actionable clinical knowledge. The impact of such advancements on radiology practices would be significant. The efficiency gained through automated analysis and interpretation of radiology reports would allow radiologists to focus more on complex cases and dedicate their expertise to critical patient care decisions. The accelerated workflow provided by AI-powered virtual assistants would minimize turnaround times, facilitating prompt diagnosis and timely interventions. Not only would this technology enhance the productivity and effectiveness of radiology practices, but it would also have a profound impact on patient care. With reduced manual analysis, the chances of human error would decrease, leading to higher accuracy in diagnoses. Timely access to vital information through voice-assist reporting would enable faster treatment decisions, ultimately improving patient outcomes and satisfaction. As AI continues to advance and NLP algorithms become more sophisticated, the integration of voice recognition and natural language processing in radiology will become increasingly seamless. The potential for AI-powered virtual assistants to become valuable collaborators for radiologists is within reach. By harnessing the power of voice recognition and NLP, the future of radiology holds immense promise, revolutionizing the field and paving the way for improved healthcare delivery. [50][51][52]

Based on the AI trends and research discussed above, there are several anticipated advancements in the near future with AI-assisted ultrasound imaging. Primarily, AI-assisted ultrasound or Smart ultrasound would promote clinical accessibility of ultrasound to non-radiology specialties at POCE. Secondly, AI-assisted ultrasound is anticipated to promote “personalized medicine,” wherein AI algorithms will tailor image acquisition, interpretation, and therapy for individual patients based on imaging, genetic, and patient-specific parameters. The ultimate objective of AI research in ultrasound is to ensure the full and unwavering support for improving the overall value of health care in our population through advancing the performance of ultrasound in early detection, diagnostic work-up, disease quantification, risk stratification, therapy response, treatment planning, surveillance, and predicting time to clinical outcome or death. Given this ongoing research, one can anticipate that in the next 20 years, AI will redefine practically every aspect of the performance, interpretation, and reporting of ultrasound. [53][54]

7.1. Integration of AI with Point-of-Care Ultrasound

One-of-a-kind applications may be to implement AI into miniaturized point-of-care ultrasound systems for timely decision-making in home care conditions and remote diagnostic processing. By definition, point-of-care ultrasound systems are image acquisition and diagnostic tools that are intended for use with minimal training. The use of AI for enhanced diagnostics, which incorporates user information into the diagnostic to make the final disease prediction, will make ultrasound more accessible. Embedded AI systems reduce the time to diagnostics, allowing healthcare providers to make timely decisions. In emergency medical conditions, drug selection based on biochemical diagnosis and starting procedures based on visual inspection with the ultrasound may happen simultaneously without the need to wait for a report. In primary care settings, a definitive assessment prevents the need for hospital referrals and other specialized diagnostic methods, ultimately decreasing healthcare costs. Smart USG integrated AI systems endorse the incorporation of trained AI models into user-friendly systems. The data to information transfer of the embedded AI to healthcare professionals may take a set of appearances, and reports may be given via secure means and incorporated in digital records. The clinician training would be to accept the AI-based systems' decision rather than updating the AI model, thus decreasing the training time. Real-time processing AI algorithms for smart USG may require some alterations in the logging processes for protective measures and accelerated processing of large data collected where the ethical approval adheres to the updated protocols. [55][56][57]

7.2. AI-Driven Personalized Medicine

Pulling down the homogenization process has allowed for great quality healthcare, where a treatment is selected based on the average responses of similar patients, such as in evidence-based medicine, and returning the approach to the patient has emerged with strength in the past few years. In such an era, predictive medicine can anticipate the outcome of a specific therapy for a patient, even when this edge cannot be inferred by a definite model, making a step further from precision medicine, where the drug dose can be adjusted based on patient response and characteristics. Machine learning and AI can provide the healthcare sector with new tools to process large amounts of data generated in many bioscience studies to tailor the best treatment or diagnostic option for a single person or a family, thus contributing to drive healthcare services to the next level in treatment efficacy, patient satisfaction, and substantial savings of resources. In the field of ultrasound imaging, AI seems to be the key to customized analysis of the data and the clinical problems around the drifting liver or the natural course of vascular damage or lung involvement. [37][58]

The achievement of AI-driven personalized medicine can be the result of many players or come from within unique enterprises and different processes starting from diagnostics and R&D up to the drug. Thus, an outcome as we describe it here is near the commonly described model that explains the inherent complexity of such an approach in a very concise and self-explanatory way. Several voices underline that the data to deliver such insights must come from multi-omics, including the clinical data that link genetic information to the allergens provoking the clinical problem when considering a personalized approach to allergic diseases. As a matter of fact, the analysis of genetic, proteomic, and lipidomic data could deliver potential druggable targets after pathway investigation in model systems, but other patient-specific information such as the clinical phenotype must be integrated. Many challenges will illustrate the journey to pull down the homogenization. Is the home language of … [59][60][61]

• A high-quality AI-based virtual twin of all the patients to be once and for all.

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