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ARTIFICIAL INTELLIGENCE IN PATHOLOGY: PRESENT AND FUTURE

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ABSTRACT

Artificial intelligence is the future and its use in pathology can create a tremendous impact on health care in different aspects.Its use is being initiated in the field of pathology and is on the rise with a increasing acceptance.Pathology services will undergo a paradigm shift due to the implementation of computational pathology and the use of tools based on AI, which would increase the effectiveness and would be able to satisfy the demands of the precision medicine age. Moving AI models from research to clinical applications has been sluggish, notstanding their success. There may be too much distance and neglect between the clinical setting and self-contained research. The merge of AI technologies into pathology has significantly impacted diagnostic precision and speed. Digital pathology platforms equipped with machine learning algorithms enable pathologists to analyze large volumes of histological images with enhanced accuracy. These systems have demonstrated remarkable capabilities in identifying subtle morphological features indicative of various diseases such as cancerous lesions or infectious conditions. Moreover, AI-driven image analysis tools can assist pathologists in differentiating between benign and malignant tumors by quantifying cellular characteristics beyond human visual perception.

Furthermore, AI-powered predictive models have the potential to refine prognostic assessments based on pathological findings. By leveraging vast datasets encompassing clinical outcomes and molecular profiles associated with specific diseases or tissue alterations, these algorithms can generate more tailored predictions regarding disease progression or treatment responsiveness. Through this approach,pathologists can offer more precise guidance on patient management while harnessing valuable insights from diverse sources for optimizing therapeutic intervention.The convergence of advanced image recognition techniques,virtual microscopy,and genomics data analysis could enable comprehensive profiling of individual disease phenotypes at an unprecedented level.In conclusion,AI technologies have already begun reshaping the landscapeof modern pathologypracticesthrough improved diagnostic capabilities,enriched prognostic insights,and envisaged pathways towards personalized healthcare delivery.The seamless integrationofAI-driven solutionsinto daily laboratory workflowswill undeniably propelpathologyintoa new era marked by heightened efficiencyand unparalleled precisionin diagnosticsand therapeuticsupport.

KEYWORDS: AI in pathology, digital pathology, machine learning algorithms, diagnostic accuracy, prognostic prediction.

INTRODUCTION

Traditionally pathology laboratories have been using automated analyzers and tissue processors, manual and automated staining techniques and manual to automated reporting methods (1). But with the advent of technology involving digitalized whole slide image (WSI), quite interest for pathologists has been generated worldwide (2).However still some robust workflow-related algorithms including automated information triage, AI assisted WSI annotations and readings along with quality assurance and control are being continuously studied and integrated into the system (3). Another advancement in AI is using image based diagnosis and its integration with predictive outcome, prognosis and treatment has generated interest in application of AI in daily practice (1-2).Convulational neural networks are the most commonly used image-based algorithms in AI (5). With the help of digitalized pathology WSI as input, a correlation can be done between the diagnosis, prognosis and treatment outcomes in patients (6). These algorithms establish connections between certain parameters and labels of interest, such patient survival or responsiveness to adjuvant/neoadjuvant therapy, as well as pathologist diagnoses and underlying molecular characteristics (7). AI has also been shown to improve accordance between practicing pathologists in a number of points, such as the assessment anisokaryosis,degree of atypia, mitosis, and proliferation index (8). In the interim, these algorithms may be able to provide not only the visual evaluation of the important histology markers, but also detect subtle patterns that are missed by human eye, such as the cancer microenvironment (9). By integrating information from many different features, AI is able to make broad diagnoses. In order to provide potentially helpful insights about the progress of the disease, the prognosis of patients, or the possibility that a patient might respond to treatment, it may then link these qualities with additional patient-related data (10). As a result, AI technology can be used to improve the quality and quantity of reporting system overall, reducing turn around time for reporting, and objectively assess morphological elements. AI-assisted reporting of certain traits or lesions would also enable pathologists to focus on challenging cases, which will help them manage the increasing demands of their work (11). Currently many AI techniques are being in Pathology which are summarized in Table1.

Current AI Techniqes	Applications in Pathology
1. Convolutional Neural Networks (CNNs)	CNNs are in depth learning algorithm that are frequently applied to image analysis in pathology. They are ideal for tasks like tissue segmentation and cell classification because of their ability to recognize patterns and characteristics within images.
2. Generative Adversarial Networks (GANs):	Generator and discriminator neural networks, which make up GANs, collaborate to create new synthetic data by using training samples. GANs can be used in pathology to enhance pre-existing datasets or produce realistic tissue samples.
3. Reinforcement Learning:	Using this method, an AI agent is trained via trial and error to maximize rewards in a specific environment. Reinforcement learning could be used in pathology to improve treatment suggestions based on patient results and histology data.
4. Transfer Learning:	Utilizing expertise from one job or area to enhance performance on a similar task or domain with sparser data is known as transfer learning. By applying knowledge from comparable datasets, transfer learning can enhance the precision of illness classification models in the context of pathology.
5. Natural Language Processing (NLP):	In pathology, NLP approaches are utilized to process clinical notes, reports, and other textual data in order to extract pertinent facts regarding patient outcomes and illness diagnosis.

Table 1: Current AI Techniques and applications in Pathology

Following are the potential uses of AI in pathology along with future challenges in its implementation and uses:

1. **Algorithms for independent reporting:**

Potential use: These comprise AI systems that are capable of diagnosing patients without the need for pathologists' involvement. Examples include automated screening algorithms that are able to recognize normal tissue and generate automated reports on cases that meet the given criterias (e.g., biopsy from gallbladder, appendix, colon , gastric and other organs with normal morphology) (13).

Challenges: Though this seems like the simplest work, there are certain things to keep in mind, like further checks in circumstances where there are discrepancies. When creating these algorithms, the developers ought to take into account the diverse ranges of normal tissue to prevent overlooking some microcarcinoma or carcinomas in situ that can be overlooked in the screening process (14-15).

2. Tools for assisting in diagnosis:

Potential use: These comprise algorithms that evaluate one or more characteristics of the slides, such as the type, extent, and grade of the tumour (2,16)

Challenges: To make a diagnosis, pathologists usually evaluate several features and aggregate them all. The way that these single-feature diagnostic algorithms are integrated into the diagnostic process and how easily pathologists may use them should be of great concern to those who develop them. These AI algorithms' additional value will depend on several factors, such as the features to be evaluated, how quickly the findings will be available, and how easily the integrated algorithms may be used (15,17).

3. Automated measurement of particular characteristics:

Potential use: The automated evaluation of immunohistochemistry (IHC) staining of receptors along with their percentage of staining, intensity and other parameters for scoring in breast carcinoma has attracted a lot of interest. Attempts have also been made to simultaneously predict biomarkers involved in carcinoma breast directly from H&E slides recently (18). These algorithms also need to consider the cost-savings aspect and the extent to which the objectivity and accuracy of AI-assisted assessment adds value for clinical application. AI systems that are able to predict the expression of IHC markers from H&E results are very promising (19).

Challenges: In some circumstances, pathologists use auxiliary tests—IHC, most commonly—to aid in the patient's diagnosis. Selecting which IHC markers to employ is a decision that is made in part by the pathologist. The diagnosis on H and E , the morphology of tumour is correlated with the IHC expression of positive and negative expression of receptors, their pattern of involvement and intensity and percentage before a final diagnosis is rendered. An AI algorithm based only on H&E is unlikely to diagnose such diagnostically challenging cases (18,20). Additionally, sufficient evidence of the effectiveness of the specific targeted therapy that the AI techniques are meant to address must be present before these tools may be implemented in clinical practice.

4. Applications for prognosis and prediction

Potential uses: One of the most important useful and promosing applications of AI in pathology is the predicting the prognosis and outcome of patient along with response of treatment based on morphological features (21). Although the morphology, architecture, pattern, stromal features, atypical mitosis, necrosis and presence of lymphovascular /neurovascular invasion of tumor cells are associated with numerous variables, image-based artificial intelligence (AI) techniques can provide a completely novel categorization system based on treatment result and response. Additionally, they have the ability to connect a subset of characteristics from a wide range of characteristics pertaining to the pattern, architecture, stromal features, and presence of lymphovascular/neurovascular invasion of tumor cells (22). Additionally, they are able to associate each of these characteristics with specific clinically outcome goals, like the probability of metastasis, recurrence and response to treatment.

Challenges: There is a paucicity of research which establish a direct correlation between pathology images and its corresponding genetic profiles, tumour microenvironment and related prognosis along with treatment response to chemo and radiotherapy, despite some well studies pathological features including tumour grade, stage and subtypes. Also its quite diffucult to integrate various morphological parameters and microenvironment patterns into a single prediction score or index (15, 22- 23).

5. Combining genetic and genomic characteristics of patients

Potential use: AI technologies are being studied to correlate patient tumor genetic and genomic profiles with their morphological characteristics which would be helpful for understanding the underlying pathophysiology of the development of cancer along with choosing a targeted therapy (24-25).

Challenges: A considerable knowledge on the utility of the Next Generation Sequencing must be acquired before the algorithms can be applied for diagnosis. Also it is quite difficult to integrate such massive-scale genomic and genetic data such as next-generation sequencing (NGS) data with the imaging data and thus to establish any relation between them whatsoever. Even if such intergration of genomics with imaging is done , further developing and refining of such data for each lesion and individual tumour would pose a considerable challenge (20, 26).

6. Efficiency of the pathology workflow

Potential Uses: Use if AI can decrease largely preanalytics, analytic and post analytic errors increasing the overall turn around time . Also it can enhance the existing quality assurance and quality control programmes (27). This can be done by integrating the pathology workflow of a lab with the laboratory information management systems (LIMS) and Digital pathology image management system .Artificial intelligence algorithms are capable of detecting a wide range of defects on scanned slides including any processing fault, under and overstaining, staining quality , fixations artefacts and those tissue representation on the slide which add to the quality control. AI can triage cases on the basis of urgency and prioritise examination of such critical cases on priority, thus helping in the workflow management.Also it can eliminate the requirement for duplicate reporting of patients with subjective diagnoses (25-28).

7. AI in pathology training and education

Artificial Intelligence (AI) tools have the potential to enhance the education of the trainees , post graduates and also practicing pathologists. This can be done by labelling, automatic annotations and other interactive options that would provide a more practical and faster method of learning . Also this can be used as a addition to the primary reporting of post graduates and making differential diagnosis of similar lesions. Also the undergraduates can be taught in a similar way. Since the scanned images can be uploaded to the software and can be assessed from anywhere remotely, this would further enhance the learning experience as it could be accessed from anywhere and anytime, even on mobile phones and help in dynamic learning (29).

Challenges: A multidisciplinary approach must be taken to build clinically practical and useful AI applications, with input from other stakeholders like surgeons and oncologists in addition to AI researchers and pathologists(28-29). It is important to take into account the detrimental effects of unreasonably high expectations for technology on its clinical application and utilization, as well as the trade-off between technology's performance and its practical benefits (2,5).

Future of AI and Word of Caution:

When sponsoring AI-based projects, healthcare institutions ought to take into account the technologies' clinical usefulness in addition to their analytical capabilities. The whole benefits of the algorithms, including their costs, hazards, and additional value when compared to current practice, are measured by the clinical utility (3,7). The evaluation of an algorithm involves comparing its predictions on a held-out set to a reference standard. As a result, a comprehensive strategy that takes into account all relevant factors is needed, including the algorithms' intended use case, algorithm performance evaluation, platforms that will be used in the future and present, the possible environment in which AI tools will be processed ,integrated and used, and any potential therapeutic benefits. The most reliable way to get this degree of confidence is usually through randomized control studies, which are difficult to conduct in the field of diagnostic pathology. To get accurate results, retrospective cohorts with superior data collection could be employed cautiously (11,23,29).

The usefulness and additional value of the suggested AI technologies, as well as any potential interruption to the current workflow, are other factors that must be taken into account. Regarding added value specifically, it is noteworthy that in addition to these algorithms' ability to integrate complex image-based data with genomic, radiological, and other clinical data, it is crucial to promote the use of these algorithms in routine clinical practice by measuring the number of diagnostic components they contain. (13,15,19). Artificial intelligence (AI) technologies can only be useful in clinical practice if they are built to function in areas where the highest need exists, such screening typical cases, detecting situations that require two reports, or elements where several components need to be evaluated simultaneously. The best and most beneficial use of this technology will be facilitated by these kinds of applications. Long-term storage is costly for most hospitals because WSIs demand hundreds of terabytes of space. Because of current guidelines requiring the storage time of glass slides for a longer time , expenses of storing diagnostic materials is increased (18, 23-24). Furthermore, AI systems will need access to radiography, WSI, genomic, and in situ hybridization images in order to support the multimodal use case. This will complicate the integration of these disparate data sources (5,7).

CONCLUSION

The implementation of AI technologies connected to pathology and computational pathology can be viewed as a gigantic shift that will alter the management of diagnostic services and enable them to fulfil the demands of the precision medicine era while also increasing their efficiency. The creation of pathology-based AI tools necessitates input from various allied branches of medicinal and surgery with majorly involvement of pathologists in order to improve the sustainability and implementation of these technologically advanced applications. Artificial intelligence (AI) can further optimize process streamlining. Enhancing the pathology service workflow's efficiency, having trainee and junior pathologists report, having pathologists report on time, using cost-effective diagnostic and prognostic/predictive algorithms, producing multidimensional pathology report outputs, and merging with genomic/genetic data. The future of precision oncology will benefit from this combination, which may lead to more individualized treatment regimens.

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