RESEARCH ARTICLE

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The Role of Digital Pathology in Enhancing Diagnostic Accuracy in Oncology

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Abstract

The aim of the research is to determine the role of digital pathology in enhancing diagnostic accuracy in oncology. Conventional diagnostic procedures are being reshaped by the emerging transformational force of digital pathology's incorporation into cancer. The digitalization of pathology slides, which allows for remote access, teamwork, and standardisation of interpretations, signifies this change. By utilising cutting-edge technology like artificial intelligence, integration with molecular data, and quantitative analysis, digital pathology improves the precision of cancer diagnosis and advances personalised therapy. While workflow automation expedites procedures and makes diagnosis more accurate and error-free, machine learning techniques help pathologists see patterns. The storage of digital pathology data and real-time consultations guarantee prompt and ongoing learning, promoting diagnosis accuracy advancements. In order to provide a more precise, fast, and personalised cancer diagnosis in the future, this research found the critical role that digital pathology has played in revolutionising oncological diagnostics. As digital pathology develops, continued cooperation between medical experts and tech developers will be necessary to realise its full potential and enhance patient outcomes everywhere.

Keywords: Digital Pathology (DP), Enhancing Diagnostic accurancy (EDA), Oncology (O).

Introduction

The word "Oncology" can be explained in these words: "the study of causes, symptoms, diagnosis and treatment of cancer". The treatment of cancer is dependent upon the timely diagnosis of it at an early stage. As medical science explains cancer in the body is caused by different types of mutation in particular cells because of alternation in genes and this mutation may result in uncontrolled cell division in tissue that may lead to tumor formation in the body which causes cancer. There were traditional methods for the diagnosis of cancer, but they were time-consuming, along with the risk of errors in results. In the past few decades, artificial intelligence has gained marvellous achievements in the field of medical science[1].

This digital pathology technology can be used effectively and accurately for the diagnosis of oncology. Digital pathology can be defined as " a kind of image-based environment that enables to analyze, interpret, manage and recognize pathogens by using digitized glass slide ". The important technique used in digital pathology is whole slide imaging, abbreviated as WSI, which can help understand the Morphology of tissues digitally. This whole slide imaging has got exponential reputation because of its importance and results. This technique can give high-resolution imaging in just sixty seconds.

In the preparation of these slides, a few specific staining antibodies are used to locate cellular and sub-cellular components[2]. These systems are better than traditional microscopy because, in microscopy, there is a collection of superficial information about cells. In this technique, digital images are used for the diagnosis of cancer because images can provide swift and accurate information. These digital images can be easily reviewed by physicians [3]. One of the benefits of this technology is that it can share data of digital images relevant to cancer to other physicians who can refer more than one treatment for a single person. In this technique, the tumor cells are taken from the cancerous site then these cells are placed on glass slides for reviewing under a microscope. In modern digital pathology, these glass slides are scanned, and then all of the given images are knitted in one whole image, and then this information is replicated on a glass slide. These virtual images can help physicians diagnose the type and stage of cancer by overviewing tumor cells on a glass slide[4].

Pathological examination of cells and tissues is the gold standard for diagnosing many disorders. Digital pathology techniques make it possible to scan and analyse microscope slides digitally. The diagnosis of some disease, such as breast cancer, hepatitis B, gastric cancer, and colorectal cancer, can now be aided by AI-assisted pathology techniques. AI has also been applied to prognosticate the course of diseases and forecast genetic alterations [5]. Artificial intelligence (AI) is ideally suited for low-complexity pathological examination of large-scale screening samples, such as colorectal or breast cancer screening, which relieves pathologists of some of their workload and expedites sample analysis turnaround.

A study of deep learning assistance in diagnosing metastatic breast cancer in lymph nodes revealed that the accuracy of humans working with a deep learning program was higher than that of either human working alone or the AI program working alone. Several deep learning and artificial neural network models have demonstrated accuracy comparable to human pathologists. Furthermore, it is estimated that a university center will save more than $12 million by implementing digital pathology over a five-year period, while savings directly linked to artificial intelligence have not yet been thoroughly studied. Because augmented and virtual reality may identify areas of concern on a pathology sample and display them to a pathologist in real-time for more effective assessment, they are a first step towards a wider application of AI-assisted pathology. AI has demonstrated the capacity to employ genotypic and phenotypic data to identify the tumor of origin for metastatic cancer more precisely. It also possesses the ability to recognize histological abnormalities at levels above the range of vision of the human eye. The lack of prospective, randomized, multi-

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center controlled trials in determining the true clinical utility of AI for pathologists and patients is one of the main current obstacles to the widespread implementation of AI-assisted pathology tools, highlighting a current area of need in AI and healthcare research. One difference to ordinary glass slides is that these images can easily be interpreted on the computer by using different predictive algorithms. Digital pathology is also better in that it can identify the type of tumour, whether it is malignant or benign so that this digital pathology can be effectively used for early diagnosis of cancer even when there are no considerable symptoms in the body of the patient. Not only the diagnosis of cancer can be done by digital pathology but the effectiveness of treatment given to Oncology patients can also be analyzed. Most importantly, the pathogen of Oncology can also be identified by digital pathology[6].

The whole pathological diagnosis depends upon a stain called Haematoxylin and Eosin. Some other stains are also used in some particular conditions, such as Alcian Blue, Silver stain Mucicarmine, and others. The whole slide imaging, which is used in digital pathology, is also known as virtual microscopy because of its high-resolution power[7]. These images can provide more information because, in these images, more than one images are knitted together to collect more information. The other benefit of whole slide imaging is that it can store data in electric forms using small chips, which is in contrast to traditional means of data storage. When images are taken from each type of view at very high speed [8]. Then these images are knitted with each one another. Then these slides are scanned by using different scanners, some scanners have resolution and speed to such an extent that they can scan up to thousands of slides in a single day.

The Workflow of digital pathology has also been accelerated by using whole slide imaging because pathologists can easily share these images among themselves to discuss any specific case or stage of cancer[9]. As we know, tumor cells are quite different than normal cells because of structure and function. These tumor cells are highly reactive, have prominent nuclei, abnormal in size and shape, and others thus these cells can easily be identified by using whole slide imaging the modern whole slide imaging uses artificial intelligence tools for the analysis of results at the same time. To reduce time consumption, now artificial intelligence-based robots are used for analyzing these tissues directly without using conventional glass slides. Moreover, these artificial intelligence-based robots can easily identify the type and stage of cancer in any particular tissue in the body[10].

Nowadays the total system of digital pathology is automated and computerized and there is less human labor for collecting tissue samples or for transferring these slides from ward to labs. The other benefit of whole slide imaging is that it can even identify the type of pathogen that has caused cancer in the body, whether it is an inherited genetic mutation, fungal infection, bacterial infection, or any other[11]. The other advantage of whole slide imaging is that it cannot only be used in digital pathology but it is also used in educational institutes for clarification of different scientific concepts by using a slide imaging technique. No doubt that digital pathology is effective as compared to traditional means of diagnosis because of accurate results, less time consumption, reduced human labor, and effective use in the medical field but there are some major problems associated with the use of digital pathology[12]. Workflow for digital pathology: a necessary prerequisite for implementing AI Additional Section To move towards a digital pathology workflow, WSI installation as a stand-in for glass slides is merely one of the necessary stages. As emphasized by the most recent guidelines, this really constitutes the final step of the incremental alterations that should impact the anatomic pathology laboratory, commencing from the accessioning to the reporting and archiving stages. The introduction of a fully automated and monitored laboratory workflow, made possible by the use of barcodes to individually identify each case or patient along the diagnostic process, is one of the most significant breakthroughs in this field. The use of specialized barcode readers and cameras at the grossing, embedding, and sectioning stations further improves this and considerably lowers the mistake rate resulting from missing or inadequately depicted material on the WSI. The full integration with the Laboratory Information System (LIS), a crucial interface that serves many functions in all stages of patient testing, including specimen and test order entry, specimen processing, and specimen tracking, further facilitates this. Furthermore, a LIS-centric strategy would make it simple for pathologists to include the WSI into their diagnostic procedures without interference from manufacturers of lab equipment and scanners. The first and foremost problem is the high cost of the instruments which are used for digital pathology. The other problem is that the world is getting more dependent upon computer-based systems which is decreasing the human interaction and social capital of the common man. This study has effectively explained the advantages and disadvantages of digital pathology for enhancing Diagnostics accuracy in Oncology[13].

Research Objective

The main objective of this study is to understand the importance and accuracy of digital pathology for early diagnosis in Oncology. This study has overviewed that how artificial intelligence has marked its place in each field including medical science for the improvement of the health of cancer patients.

Review Of Research

Researchers explain that the selection of effective treatment techniques against cancer is possible because of the advancement in the field of oncology. Cancer is one of the serious health problems characterized by the complexity of different body functions.in tissue cancer, various tissue of the patient's body gets affected.by using AI in the treatment of tissue cancer, detailed images of the tissues of cancer patients are obtained. the understating of the pathology of different cancer types through AI helps in developing an effective biomarker for its treatment[13].studies suggest that the accuracy of the cancer diagnostic process increases by using digitalized technology. The diagnosing of cancer cells using imaging-based technology is preferable to using traditional methods for cancer diagnosing. the images of the organs of cancer patients are assessed accurately through digital diagnostic techniques[14].scholars highlight that the accuracy of the diagnostic process is achieved using the digital pathology technique. AI-based computer diagnostic techniques are advanced for diagnosing cancer-related disorders[12].studies show that new technological diagnostic methods have replaced the traditional method of cancer claisifaction. AI based imaging tools capture the parts of the body that are unable to be seen by the naked eye. The detailed imaging data then helps in identifying the complex types of cancer. The process of development of translational medicine against cancer is modified using AI techniques[10]. Scholars explained that using image-based diagnosing methods helps in understating cardiology-related problems. The AI-based algorithms

employed in medical treatment procedures detect even minor details related to any disease[9].Also, the tumor-related complexities are identified using the AI-based algorithmic approach.

Precession in the oncology field is achieved by implementing AI algorithms in the working of this field. The process of decision-making for providing quality treatment to patients is assisted by AI-based clinical decision-making policies[7]. Studies predict that the problem related to prosthetics and other cancer types is solved using the approach of digital pathology. Using AI technology for research purposes on cancer holds great importance. The intelligence-driven models are used to comprehend the pathology behind breast cancer[15].Researchers claim that the internal pathology organization provides guidelines on using effective diagnosing techniques for cancer treatment. The efficiency of treatment increases by carrying out the treatment process based on the guidelines provided by international pathology organizations. The health-related diagnostic tests are used for identifying other health-related problems faced by cancer patients[4].scholar elaborates the digital microscopy is one of the modern technology technique for assessing the cells of cancer patients. Digital microscopy explains the complexity associated with breast cancer. Pathologist using the digital microcopy are well trained for carrying out the proper use of this technique. The cell cultures from patients with breast cancer are easily accessed through the digital microscopy technique[16].

Furthermore, the structure of the tissue is explained through the digital pathology approach. Prostate cancer is a disease related to tissues. the structures of prostate tissue in patients with prostate cancer are identified using digital pathology. deep learning approach is used in digital pathology for identifying the size of tumor cells in prostate cancer-affected patients[17].scholars explain that WSI is a technology used for understanding the pathology of certain cancer types. The images obtained by using WSI provide detail information related to the tissues thereby improving the quality of diagnostic process for. the workflow of medical diagnostic process is optimized using AI and deep learning models[18].the pathologist dealing with the use of digital pathology in health field are well trained. the quality of tremnet provided to the patient improves by the helsp of well-trained pathologists. Well trained pathologist knows to make the use of digital pathology effective for patient diseases classification[19] Moreover in most medical sectors the use of WSI by pathologists has increased. the increase in WSI use is because of the accuracy this technique provides in detecting cells of cancer patients. The framework of medical sectors is based on using the modern treatment approach to enhance the quality of treatment provided to patients. integrating digital pathology in clinical settings enhances the treatment quality in medical sectors[20]. The development of digital pathology is a team effort defined by a well-balanced blend of technology advancements, interdisciplinary collaborations, and patient-centred objectives.

AI-powered diagnostics, smooth EHR integration, and tailored treatment plans that transform patient care delivery are all possible in the future. It is anticipated that the possible influence on research and population health management would accelerate medical progress and address public health concerns with remarkable accuracy. The convergence of digital pathology, artificial intelligence, and the various facets of healthcare presents opportunities for improved patient care, improved diagnoses, and a society that values educated, empowered, and personalised health in the future. The shift to a digital pathology paradigm in the realm of medical innovation has a number of intricate ethical and legal ramifications that need to be carefully considered and managed in addition to the possibility for enhanced diagnostic capabilities. Discussing about patient data protection, permission, and the safe use of AI has become more crucial as a result of the ongoing technological revolution. Regulatory approvals, liability issues, and legal frameworks simultaneously impact this changing environment. This narrative review delves into the intricate facets of digital pathology, focusing on the ethical and legal factors that shape its evolution. Confidential patient data must be transferred into a digital format in order to digitise pathology slides. The previously mentioned shift raises important questions about security, privacy, and the moral need to protect patient confidentiality. Healthcare organizations are in charge of safeguarding patient data after it has been digitally converted against breaches and unwanted access. According to a 2020 American Medical Association (AMA) study, data breaches compromised almost 27 million patient records. This startling numeral emphasizes how serious the data security issues are that come along with the digitalization of medical information. The idea of informed consent is equally important. Patients must be fully informed about the consequences of utilizing their data for AI-driven diagnostics and digital pathology analysis.

By giving their informed permission, people may make decisions that suit their tastes and maintain control over their data. Studies claim that providing accurate results or data related to patient health conditions is critical.to obtain the right set of technology-based approaches in medical sectors increases the chances of accurate data accusation. The field of medical imaging has been advanced to provide accurate data through implementing a digital pathology approach in this field [21].Studies reveal that certain biomarkers are used in oncology to carry out clinical oncology practices. the imaging analysis of cancer patients provides details about the biomarkers causing cancer. Also, the histology of cancer-related tissue is easily determined using the DL approach in imaging techniques. The response of cancer patients to therapy-based treatment is assessed by DL algorithms[22] Scholars' studies show that the development of new technology has advanced the medical-based computer field. The diagnostic tools employed in the medical treatment process are based on AI. To implement AI in the pathology file, the legal medical implication rules are followed in all health sectors[23]. Researchers predict that FL is diagnosed using imaging-based techniques in clinical practices. The application of machine learning in pathological studies enhances diagnostic procedures[24].AI-based pathological diagnosing processes are specialized for obtaining accurate medical results related to cancer patients. The chances of error in the data obtained through AI-assisted techies are lower as AI is the most advanced technology for obtaining accurate forms of data. Also, the digital pathology technique is the most advanced technique used for identifying the genetic properties of patients. The mutation in genes of cancer patients is easily detectable through AI-based medical equipment[25]. Studies explain that using AI tools for prostate cancer detection provides clinical applications. The AI algorithm is specialized for grading the cancer type in order of its severity. As AI is intelligence-based software, the integration of AI in medical sectors only generates authentic data[26]. Studies suggest that WSI has been internationally approved to be used in diagnosing cancer-related disorders. The implementation of WSI in routine clinical trials of cancer is effective for analyzing different cancer variants. By identifying cancer types, the treatment process becomes easier[27]. Diagnosis of cancer accurately is of great importance because it can affect patient care directly, making correct treatment

decisions and outcomes. A specific diagnosis is required to determine the most effective treatment strategies, predict disease development, and guide patient management [28]. A wrong diagnosis can lead to inappropriate, poor, and unacceptable treatments, likely possibly compromising patient well-being and survival. That's why it is very important to ensure accurate cancer diagnoses to provide individualized and effective patient care[29, 30].

Challenges faced in traditional diagnostic methods

Healthcare advisers or doctors face many challenges and complexity in traditional pathology methods. In today's age, where everything is getting digitized, diagnostic processes can also get digital to get more accurate results. One of the significant challenges is not getting reliable information because different pathologists can give the same diagnosis but use different approaches according to their experiences, which can cause inconsistent diagnoses, particularly for complex cases. Diagnostic errors, like false-positive and false-negative results, cause risk with likely clinical effects. Examining tissue samples using the light microscope is a time-consuming and manual process, which can cause delays in diagnosis and treatment initiation. Having limited access to expert advice is also a noticeable concern, especially if you want to take advice from someone at a remote station, thus causing a lack of quality and timeliness of diagnostic services. Having great training and experience for pathologists, combined with limitations in some areas, causes additional challenges. In addition, having limited resources and costs makes traditional pathology methods restrictive for some healthcare settings, especially those with limited resources. These challenges demand innovative solutions to improve the accuracy, efficiency, and enhancement of pathology diagnosis, leading to the exploration and integration of digital technologies in the field of pathology.

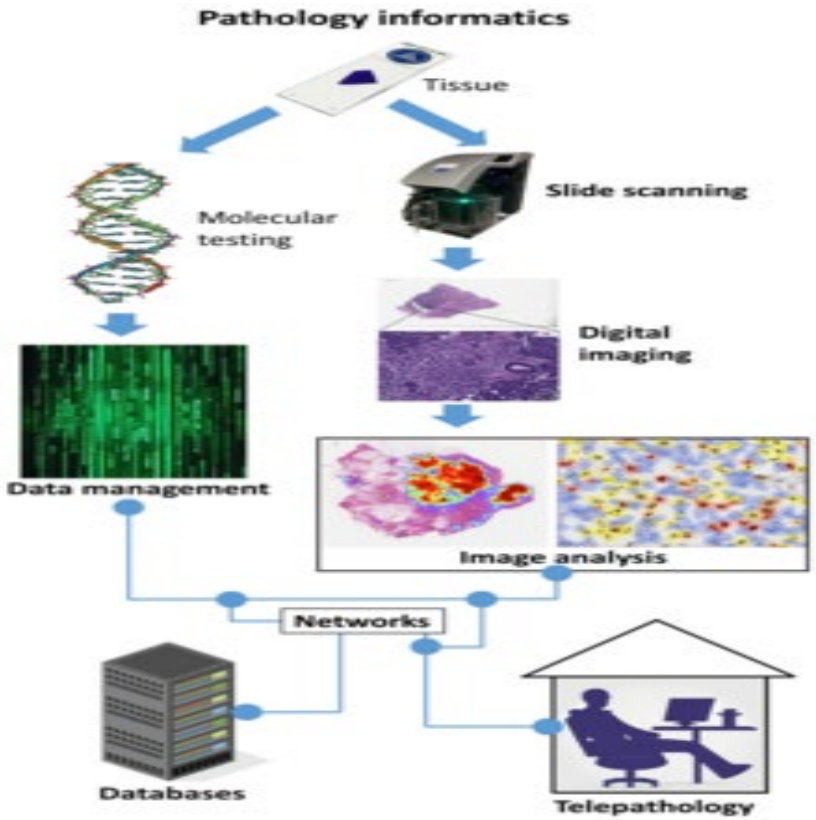

Figure 1: Digital pathology

The emergence of digital pathology

Digital pathology, which is also known as whole-side imaging (WSI), is a quickly emerging technology that has the potential to change the history of pathology being practised. This method involves the digitization of glass slides, which allows pathologists to view and analyze high-resolution digital images of tissue samples on a computer screen. This technology helps track workflow, increases efficiency, and provides accurate diagnosis. Digital pathology technology enables the creation of large-scale digital-slide libraries, making storage and analysis of pathology images easy. By using digital pathology, pathologists can access broad and high-resolution images, which help them maintain workflow more accurately and develop advanced computational analysis using the application of AI (Artificial Intelligence) and ML (Machine learning) algorithms. Digital pathology is a positive method of significantly impacting the delivery of healthcare services and improving patient care in the field of oncology.

Working in digital pathology

Digital pathology transforms traditional tissue analysis into digital images by digitizing glass slides that contain tissue samples. This can be done by scanning the slides using a digital scanner, which captures the entire slide into a high-resolution image. That image is then stored in a digital pathology system so that pathologists can view that image and analyze the image on the computer screen. As it is on the computer, it can be magnified, annotated, and manipulated to enhance its quality and analysis. This technology can eliminate the need to use physical glass slides, reducing the risk of loss and damage.

It can also help access images remotely, leading to collaboration and consultation among pathologists. Thus, digital pathology offers a more accurate and efficient approach to tissue analysis. This technology can improve diagnostic accuracy, enable more precise information, and predict danger, thus ultimately contributing to improving patient care in the field of oncology.

Advantages of using digital pathology

Using digital pathology in the field of oncology can be very beneficial, and it can provide many advantages, especially in the diagnosis and management of cancer. Digital pathology helps pathologists access high-quality images of tissue samples, which help in more accurate and precise diagnoses. Computational approaches, including Artificial intelligence and machine learning algorithms, can be applied to digital images to get valuable information that cannot be visible with the naked eye, helping increase the accuracy of diagnosis. Digital pathology reduced the need for physical slides, thus reducing the risk of damage and loss and providing remote access to images. This technology smoot the pathology workflow and makes it easy for pathologists to analyze images more efficiently and effectively.

Using digital pathology allows pathologists to easily access and share images and collaborate with colleagues, regardless of which state they are in. This technology enables knowledge-sharing and enables pathologists to access a range of expertise, ultimately moving to improved patient care. Digital pathology has the power to improve patient care in oncology by enhancing workflow, diagnostic accuracy, workflow efficiency, and collaboration and making it possible to give more precise predictive assessments.

Ways of digital pathology

By utilizing technology to enhance pathology practice, digital pathology plays a vital role in improving diagnosis accuracy in cancer. Examining tissue samples under a microscope is a tedious and subjective process in traditional pathology. This procedure is transformed by digital pathology, which uses computer technology to digitize and analyses pathology slides. The following are some of the ways that digital pathology helps oncologists diagnose patients more accurately:

1. Cooperation and Remote Access:

Pathologists working remotely may view and collaborate on cases due to digital pathology. This is especially helpful when knowledge from experts across different regions is required. It speeds up consultation times and promotes interdisciplinary dialogue, which results in more precise diagnoses.

2. Standardisation of Interpretation:

The interpretation of pathology slides is made easier by using digital pathology. Pathologists may see high-resolution photographs utilizing digital platforms, guaranteeing standardized and uniform assessments. This improves overall accuracy and lowers variability in diagnostic interpretations.

3. Quantitative processing:

Using digital pathology, one may quantitatively evaluate various characteristics, including biomarker expression, nuclear features, and cell shape, using sophisticated image processing techniques. The diagnostic accuracy can be improved by using this quantitative data to offer new insights that might take time to be obvious using standard procedures.

4. Integration with Molecular Data:

A more thorough knowledge of the disease is made possible by combining digital pathology with molecular data, such as proteomic and genomic data. This integrated approach may describe tumours more precisely, allowing for more individualised and focused treatment plans.

5. Artificial Intelligence and Machine Learning:

Pathologists can use artificial intelligence (AI) and machine learning algorithms in digital pathology to help them recognise patterns and make decisions. These tools improve diagnosis accuracy by analysing vast datasets, spotting subtle trends, and predicting disease outcomes.

6. Effective Workflow and Automation:

By automating repetitive operations like slide scanning and image processing, digital pathology optimises workflow procedures. This efficiency lowers the possibility of mistakes and increases overall accuracy by allowing pathologists to concentrate on more intricate areas of diagnosis.

7. Archiving and Retrieval:

Digital pathology makes archiving and retrieving pathology slides easier, making past cases available for review or reassessment. This capacity supports quality enhancement, retroactive analysis, and ongoing learning.

8. Real-time discussions:

Pathologists can seek quick input on difficult situations by holding real-time discussions with specialists or colleagues. The accuracy of the diagnosis can be significantly impacted by this real-time collaboration, particularly in circumstances where speed is of importance.

Conclusion And Discussion

To sum up, using digital pathology for cancer significantly advances patient care and diagnostic precision. Through the utilization of cutting-edge technologies, digital pathology resolves many issues related to conventional pathology techniques. Remote access to, analysis of, and collaboration on pathology slides promotes a more integrated and effective healthcare system. A more thorough knowledge of cancer is made possible by standardising interpretation, quantitative analysis, and integrating molecular data. This enables more accurate and individualized treatment plans. Machine learning and artificial intelligence are applied to help pathologists see patterns and make decisions. This increases computational capacity and improves diagnostic skills. In addition to speeding up the diagnosis process, the efficiency obtained by workflow automation and real-time consultations supports ongoing learning and quality improvement. Digital pathology data storage and retrieval ensure that past cases are available for review and further study.

Understanding the role of digital pathology in oncology is important because it gives a transformative approach to cancer diagnosis, treatment, and research. Digital pathology has several advantages over traditional microscopy-based methods. The role of digital pathology in oncology is crucial for healthcare professionals and researchers to support the full potential of this innovative field and

improve cancer care. With continued advancements, digital pathology has the potential to completely transform oncology practices and provide the groundwork for more precise, rapid, and individualized cancer diagnoses. To benefit patients everywhere, the continued cooperation of researchers, technology developers, and healthcare practitioners will be essential to realizing the full potential of digital pathology. Through the meticulous examination of tissue samples and cytological specimens, pathology, a core component of medical practice, has continuously provided essential insights into the diagnosis and prognosis of diseases. However, there are several drawbacks to the traditional pathology framework, which includes glass slides, physical storage, and the requirement for in-person expert consultations.

As mentioned above, the limitations substantially influence productivity, teamwork, and ease of use, which propels the shift to digital pathology. Digital pathology's intrinsic significance stems from its capacity to surmount the constraints linked to traditional methods. Pathology has advanced significantly with this paradigm change. It transforms the small dimension into a digital format, embracing the digital era and moving beyond actual glass slides. Whole slide imaging is the foundational idea of digital pathology (WSI). Glass slides may be converted into high-resolution digital pictures with WSI, making storing and sharing data and doing sophisticated analysis easy. As such, it offers fresh possibilities for a thorough understanding and interpretation of disease beyond physical restrictions. This narrative review's major goal is to thoroughly investigate digital pathology and how it can affect the larger field of medical diagnosis.

Combining technology improvements with medical experience, this study explores the intricate link between remote consultations and artificial intelligence (AI)-assisted analysis in digital pathology. In conclusion, digital pathology uses technology to increase diagnosis accuracy, which has revolutionary implications for the area of cancer. The amalgamation of remote access, automation, machine learning, quantitative analysis, and molecular data improves the accuracy and productivity of cancer diagnosis. It helps to provide more effective and individualized patient treatment. Through a combination of in-depth analysis, real-world applications, and new developments, this research provides a thorough overview of the significant influence digital pathology has had on medical diagnosis.

Advancement in the future

The field of digital pathology is evolving rapidly, with many prospects and advancements to come. The future of digital pathology promises advancements, including combining 3D tissue representation with more extensive sampling to improve diagnostics and predictive decision-making in oncology. Combining AI and machine learning algorithms into a digital pathology system can improve diagnostic accuracy and efficiency. These technologies can analyze large amounts of data and identify patterns that may be difficult for human pathologists to detect.

Telepathology is a technique that involves the use of digital pathology systems to diagnose and get consultations on cases remotely. VR (virtual reality) and AR (augmented reality) are two technologies that can enhance the visualization and analysis of digital pathology images, allowing pathologists to view images in three dimensions. Integrating digital pathology systems with EHRs (Electronic health control) can improve data management and facilitate the sharing of patient information among healthcare providers.

Reference

[1] B. Acs, M. Rantalainen, and J. Hartman, "Artificial intelligence as the next step towards precision pathology," *Journal of internal medicine,* vol. 288, no. 1, pp. 62-81, 2020.

[2] D. R. Snead *et al.*, "Validation of digital pathology imaging for primary histopathological diagnosis," *Histopathology,* vol. 68, no. 7, pp. 1063-1072, 2016.

[3] F. Akman, "How to Utilize LJS Allen's" An Introduction to Mathematical Biology" in a Biomathematics Course," *Letters in Biomathematics,* vol. 1, no. 2, pp. 127-137, 2014, doi: https://doi.org/10.30707/LiB1.2Akman.

[4] S. W. Jahn, M. Plass, and F. Moinfar, "Digital pathology: advantages, limitations and emerging perspectives," *Journal of clinical medicine,* vol. 9, no. 11, p. 3697, 2020.

[5] J. Zhou, "Safety management of karst construction in railway tunnels and tunnel farming as compared to traditional farming," *Journal of Commercial Biotechnology,* vol. 27, no. 2, 2022, doi: https://doi.org/10.5912/jcb1042.

[6] G. Litjens *et al.*, "Deep learning as a tool for increased accuracy and efficiency of histopathological diagnosis," *Scientific reports,* vol. 6, no. 1, p. 26286, 2016.

[7] Y. Jiang, M. Yang, S. Wang, X. Li, and Y. Sun, "Emerging role of deep learning-based artificial intelligence in tumor pathology," *Cancer communications,* vol. 40, no. 4, pp. 154-166, 2020.

[8] M. I. Youssef and B. Webster, "A multi-criteria decision making approach to the new product development process in industry," *Reports in Mechanical Engineering,* vol. 3, no. 1, pp. 83-93, 2022.

[9] M. K. K. Niazi, A. V. Parwani, and M. N. Gurcan, "Digital pathology and artificial intelligence," *The lancet oncology,* vol. 20, no. 5, pp. e253-e261, 2019.

[10] V. Baxi, R. Edwards, M. Montalto, and S. Saha, "Digital pathology and artificial intelligence in translational medicine and clinical practice," *Modern Pathology,* vol. 35, no. 1, pp. 23-32, 2022.

[11] T. Onega *et al.*, "Accuracy of digital pathologic analysis vs traditional microscopy in the interpretation of melanocytic lesions," *JAMA dermatology,* vol. 154, no. 10, pp. 1159-1166, 2018.

[12] A. S. Azam *et al.*, "Diagnostic concordance and discordance in digital pathology: a systematic review and meta-analysis," *Journal of Clinical Pathology,* 2020.

[13] K. Bera, K. A. Schalper, D. L. Rimm, V. Velcheti, and A. Madabhushi, "Artificial intelligence in digital pathology—new tools for diagnosis and precision oncology," *Nature reviews Clinical oncology,* vol. 16, no. 11, pp. 703-715, 2019.

[14] A. M. Mills *et al.*, "Diagnostic Efficiency in Digital Pathology," *The American journal of surgical pathology,* vol. 42, no. 1, pp. 53-59, 2018.

[15] P. J. Schüffler *et al.*, "Integrated digital pathology at scale: A solution for clinical diagnostics and cancer research at a large academic medical center," *Journal of the American Medical Informatics Association,* vol. 28, no. 9, pp. 1874-1884, 2021.

[16] B. J. Williams, A. Hanby, R. Millican-Slater, A. Nijhawan, E. Verghese, and D. Treanor, "Digital pathology for the primary diagnosis of breast histopathological specimens: an innovative validation and concordance study on digital pathology validation and training," *Histopathology,* vol. 72, no. 4, pp. 662-671, 2018.

[17] Y. Tolkach, T. Dohmgörgen, M. Toma, and G. Kristiansen, "High-accuracy prostate cancer pathology using deep learning," *Nature Machine Intelligence,* vol. 2, no. 7, pp. 411-418, 2020.

[18] A. V. Parwani, "Next generation diagnostic pathology: use of digital pathology and artificial intelligence tools to augment a pathological diagnosis," vol. 14, ed: Springer, 2019, pp. 1-3.

[19] L. Browning, R. Colling, J. Rittscher, L. Winter, N. McEntyre, and C. Verrill, "Implementation of digital pathology into diagnostic practice: perceptions and opinions of

histopathology trainees and implications for training," *Journal of Clinical Pathology,* pp. jclinpath-2019-206137, 2019.
[20] M. G. Hanna *et al.*, "Integrating digital pathology into clinical practice," *Modern Pathology,* vol. 35, no. 2, pp. 152-164, 2022.
[21] R. Aggarwal *et al.*, "Diagnostic accuracy of deep learning in medical imaging: a systematic review and meta-analysis," *NPJ digital medicine,* vol. 4, no. 1, p. 65, 2021.
[22] A. Echle, N. T. Rindtorff, T. J. Brinker, T. Luedde, A. T. Pearson, and J. N. Kather, "Deep learning in cancer pathology: a new generation of clinical biomarkers," *British journal of cancer,* vol. 124, no. 4, pp. 686-696, 2021.
[23] S. Sarwar *et al.*, "Physician perspectives on integration of artificial intelligence into diagnostic pathology," *NPJ digital medicine,* vol. 2, no. 1, p. 28, 2019.
[24] C. Syrykh *et al.*, "Accurate diagnosis of lymphoma on whole-slide histopathology images using deep learning," *NPJ digital medicine,* vol. 3, no. 1, p. 63, 2020.
[25] S. Försch, F. Klauschen, P. Hufnagl, and W. Roth, "Artificial intelligence in pathology," *Deutsches Ärzteblatt International,* vol. 118, no. 12, p. 199, 2021.
[26] L. Pantanowitz *et al.*, "An artificial intelligence algorithm for prostate cancer diagnosis in whole slide images of core needle biopsies: a blinded clinical validation and deployment study," *The Lancet Digital Health,* vol. 2, no. 8, pp. e407-e416, 2020.
[27] N. Kumar, R. Gupta, and S. Gupta, "Whole slide imaging (WSI) in pathology: current perspectives and future directions," *Journal of digital imaging,* vol. 33, no. 4, pp. 1034-1040, 2020.
[28] J. Zhou, J. Jung, C. Kueh, and Y. Lin, "Personalized mobile health and fitness apps guidance model for students," *Journal of Commercial Biotechnology,* vol. 27, no. 5, pp. 201-214, 2022.
[29] O. Akman, D. Cairns, T. D. Comar, and D. Hrozencik, "Integrated pest management with a mixed birth rate for prey species," *Letters in Biomathematics,* vol. 1, no. 1, pp. 87-95, 2014, doi: https://doi.org/10.30707/LiB1.1Akman.
[30] F. Wu, Z. Wang, D. Song, and H. Lian, "Lightweight design of control arm combining load path analysis and biological characteristics," *Reports in Mechanical Engineering,* vol. 3, no. 1, pp. 71-82, 2022.