International Journal of Trends on OncoScience

Artificial Intelligence for Cancer Diagnosis & Radiology

Wafaa Mohamed Baker Ali* **and Munirah Sultan Alhumaidi**

**Pharmacist, PHC, Sohag, Egypt*

Pharm D of pharmacy, pharmacy college, Taif University City, Taif, Saudi Arabia

Abstract: Recent developments in artificial intelligence (AI) technology have sped up the clinical use of AI-enabled devices in the healthcare industry. The Food and Drug Administration (FDA) in the United States has already authorized more than 60 AI-enabled medical devices, and the active use of AI technology is seen as a necessary trend for the future of medicine. Clinical applications of medical devices utilizing AI technology are currently under way in the field of cancer, primarily in radiology, and it is anticipated that AI technology will be positioned as a significant core technology. In particular, "precision medicine," a type of medical care that chooses the best course of action for every depending on patient a massive quantity of medical data, such as genomic data, has gained popularity on a global scale; In order to extract really valuable information from a big quantity of medical data and use it for diagnosis and treatment, AI technology is anticipated to be used. The history of AI technology, the present state of medical AI, particularly in the cancer industry, as well as the opportunities and difficulties of AI technology depending on patient profession will be reviewed. The review will also analyze the impact of AI technology on medical professionals, such as doctors and nurses, and how the technology can be used to better patient care. Finally, the review will look at the potential applications of AI technology in the healthcare sector and the ethical implications of its use.

Keywords: Precision medicine, radiography, pathology, Deep learning, machine learning and omics

***Corresponding Author**

Wafaa Mohamed Baker Ali , Pharmacist, PHC, Sohag, Egypt

Received On 8 November, 2022
Revised On 12 December, 2022
Accepted On 26 January, 2023
Published On 21 February, 2023

Funding This research did not receive any specific grant from any funding agencies in the public, commercial or not for profit sectors.

Citation Wafaa Mohamed Baker Ali and Munirah Sultan Alhumaidi , Artificial Intelligence for Cancer Diagnosis & Radiology.(2023).Int. J. Trends in OncoSci.1(1), 13-18

This article is under the CC BY- NC-ND Licence (https://creativecommons.org/licenses/by-nc-nd/4.0)

Copyright @ International Journal of trends in OncoScience, available at www.ijtos.com

1. INTRODUCTION

An increase of interest has been generated in the field of artificial intelligence (AI) across the globe due to the quick advancement of machine learning technologies, particularly deep learning, as well as the development of information infrastructure technologies like the graphics processing unit (GPU) and public databases. Big data, also known as large-scale data, can now be used Research [1]on AI has been going on for a while, and by the 1950s, the phrase "artificial intelligence" was already being used in academic circles [2]The road to AI research has not always been easy, and it has experienced a challenging time known as the AI winter period. In reality, the United States FDA has authorized higher than 60 AI-enhanced medical devices, and it is certain that AI technology will be aggressively incorporated into the medical industry going forward. Oncology is not an exception to this trend, and various medical devices with AI capabilities are currently being deployed in clinical settings, particularly in radiography. Machine learning is the primary technique used in modern AI. [3]Machine learning methods include ways to discover patterns in sample data, learn from those patterns, and then use those patterns to analyse and forecast new data.[4] While machine learning frequently employs statistics primarily for predictive reasons, classical statistics is frequently employed primarily for explanatory purposes. The two primary categories of machine learning approaches are supervised learning and unsupervised learning. [5] With the use of supervised learning, classification and regression issues may be solved by separating features from the information that has been provided to create predictions. [6]To forecast discrete data, including differentiating between benign and malignant tumors, the classification problem is utilized. The regression problem is employed to forecast continuous data, including the effects of contrast. Unsupervised learning is a technique for identifying similarities for a set of data on a question for which there is no known solution. [7] Due to its similarity to diagnosis, the classification issue of supervised learning is also thought to be the most well-known problem among doctors, such as radiologists. Machine learning technology, of which deep learning is a subset, currently shows a lot of potential in the medical industry. Because to their superior image analysis capabilities, deep learning algorithms are employed for medical image categorization, picture quality enhancement, and segmentation. [8] Depending on the type of data to be processed, there are several deep learning approaches. It is essential to choose the neural network topology that best fits the data. Convolutional neural networks for image classification,[10] recurrent neural networks for reporting tasks,[11] and a U-net for image segmentation [12] are examples of common deep learning techniques used in medical imaging. "Precision medicine" marketing which refers to medical care tailored every patient by extracting critical information from medical big data, particularly genetic information, has emerged as a global pattern in the area of cancer. Academic usage of the phrases "precision oncology" and "precision cancer medicine" is also rising.[13-17] Yet choosing a course of therapy founded on a targeted-gene panel (TGP) and next-generation sequencing, the central technique precise medical care, has grown to be a significant problem promoting precision medicine since there are so few individuals for whom the best course of action is recommended.[18,19] It is thought to be crucial to extract meaningful information from other medical data, including whole genome and epigenome information, in addition to restricted genetic mutation information, in order to maximize the number of patients who may benefit from precision medicine. Nevertheless, the amount of data that has to be processed has substantially risen; for instance, a complete genome study might produce up to 3 billion base pairs of data. [20] Innovative artificial intelligence (AI) and information and communications technology (ICT) technologies must be used to examine these very big data sets effectively and accurately. With an emphasis on the subject of cancer, we covered the background using AI technologies in this research and spoke about how it is now used in medicine and society. Also, even though AI technology has a lot of potential, there are still a lot of problems that need to be fixed. We review about the problems that the area of medical AI is now facing and what type of initiatives are required to continue to overcome these problems. We also discuss the potential of AI technology to revolutionize the treatment of cancer and how it can be used to improve accuracy, reduce costs and save lives.

2. THE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE AND ITS USE IN MEDICINE

2.1. From the 18th to the 19th Century: Pierre-Simon Laplace and the Bayes' Theorem

The conditional probability theorems that serve as the foundation for Bayes' Theorem were included in "An Essay towards settling a Difficulty in the Theory of Chances," which was published in 1763.[21] The Reverend Thomas Bayes' mathematical theory of probability served as the foundation for this book, which was not released until two years after Thomas Bayes' passing. His companion Richard Price made several changes and improvements. The hypothesis itself, however, was not discussed for some time after it was published.

2.2. The first AI boom, the beginning of the AI winter, and the birth of AI

A number of scientists instinctively understood that two machines that could manipulate numbers could also manipulate symbols in the mid-1950s when computers were widely available, and that the manipulation of symbols may capture the core of human mind. This evolved into a fresh perspective on "thinking machines." The study of AI as an academic discipline began in 1956 when Dr. John McCarthy suggested the term "Artificial Intelligence (AI)" at the Dartmouth Workshop. Following[22] the Dartmouth Conference, there was a period of great advancement during which computer scientists galloped across uncharted territory. Because the amount of computation they could handle was so small, even the best computers of the time, which were developed at great expense, could only solve problems in a very limited domain; nonetheless, they were still "astounding" to people at the time. Programs developed in this era relied on reasoning and exploration. They were taught how to use the computers to solve algebraic equations, validate geometric theorems, and improve their English.[23] Nonetheless, AI faced criticism and declining funding in the 1970s. One explanation for this is that the AI researchers miscalculated how complex the issue they were trying to solve was. The results did not live up to the overly optimistic and high expectations, and funding for AI research was reduced.[24]

3. INTRODUCING AI TECHNOLOGY IN ONCOLOGY

3.1. *Radiology*

One of the fields where AI technology has been utilised the most in terms of medical applications is radiography. The majority of artificial intelligence-enhanced medical devices connected to cancer that have been authorised by the FDA are in the field of radiography.[25] This is because deep learning technology is widely used in image analysis, and radiation image analysis is one of the more developed ICT areas in the past, similar to CAD (computer-assisted detection/diagnosis), which has a high affinity for AI. A typical CADx approach for finding prostate cancer is shown in Figure 1. CAD has been anticipated to increase productivity in image reading in cancer detection by increasing the diagnostic efficacy and repeatability of image reading.

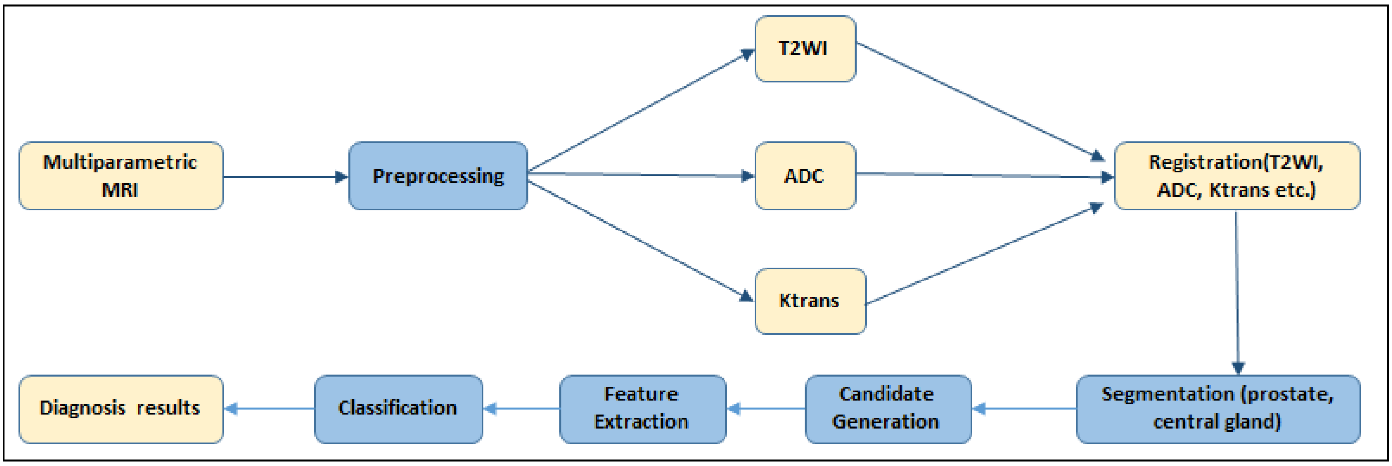

Fig 1: Common prostate CADx system's flowchart[26]

mCAD-US (AmCad BioMed Corporation) is a software tool that visualises and measures the statistical distribution of backscattered signals from ultrasound systems that are echoed by tissue compositions in the body. It was approved by the FDA in May 2017. Moreover, AmCad BioMed Company created and won FDA clearance for AmCAD-UT, which is mostly used to find thyroid cancer. The FDA originally approved Quantitative Insights' Second Reader type CADx (QuantX) in July 2017. This tool is intended to target breast magnetic resonance imaging (MRI) and help medical professionals make a breast cancer differential diagnosis. The FDA approved Arterys Oncology DL (Arterys) in January 2018 to assist doctors in quickly measuring and tracking tumours and nodules on MRI and computed tomography (CT) images. These tools are designed to provide a more accurate diagnosis and help reduce the time needed to correctly identify breast cancer. This technology is now being used in many medical facilities around the world. By providing a more accurate diagnosis, Arterys Oncology DL can help save lives by reducing the amount of time needed to accurately identify breast cancer. In June 2020, the FDA approved both QuantX and Arterys for use in detecting and diagnosing brain tumours. This approval allows for enhanced accuracy in the diagnosis and treatment of brain tumours.

3.2. *Endoscopy*

Another crucial area for AI analysis is endoscopic imaging. Endoscopic AI development is particularly active in Japan, where Japanese medical equipment makers now account for 99.1% of the worldwide endoscope market. In Japan, endoscopic AI has already been used in a clinical setting after getting regulatory authorisation from the Pharmaceuticals and Medical Devices Agency (PMDA) . AI-based endoscopy promises to provide physicians with an enhanced diagnostic capability and to reduce the amount of time and resources needed to diagnose patients. It also has the potential to reduce medical costs and to improve the accuracy of diagnoses. AI endoscopy is a promising technology that could revolutionize the medical field and have a positive impact on patient care. AI-assisted endoscopy has the potential to improve the accuracy, speed, and cost of medical diagnoses. This could lead to improved outcomes and a better quality of life for patients. By leveraging AI-assisted endoscopy, healthcare providers can deliver diagnoses more rapidly and accurately at a lower cost, ultimately resulting in better patient outcomes and improved quality of life. AI-assisted endoscopy can detect abnormalities in the digestive tract more quickly and accurately than traditional methods, meaning that diagnoses can be made more quickly and with fewer follow-up tests. This saves time and money, resulting in better patient outcomes and improved quality of life.[27]

3.3. *Pathological Images*

The ultimate diagnosis of a lesion is a pathological diagnosis, which has a significant impact on the future treatment plan and the efficacy of the therapy. Nonetheless, there is now a pathologist shortage in the United States, United Kingdom, Japan, Canada, and other nations, which has made it difficult to maintain each nation's level of medical care quality. As a result, the reliance on non-invasive imaging techniques has become increasingly important to facilitate accurate diagnoses and subsequent treatments. Artificial intelligence (AI) and machine learning (ML) techniques can be used to detect and diagnose lesions with a high degree of accuracy. This can help to reduce the burden of the pathologist shortage. AI and ML can thus offer a potential solution to the growing pathologist shortage, while still providing accurate diagnoses and treatments. [28] AI and ML can reduce the time needed to diagnose and treat patients, while helping to reduce costs. This can lead to improved patient outcomes, while providing a reliable and cost-effective solution to the pathologist shortage.AI and ML techniques can process large amounts of data quickly and accurately, allowing for quicker diagnoses and treatments. This can help to reduce the burden on the pathologist, freeing them up to focus on more complex cases. AI and ML can also allow for more accurate diagnoses than manual inspection, which can lead to more successful treatments.

3.4. Skin Images

In Western nations, skin cancer is the most prevalent form of malignancy, and melanoma in particular is responsible for the majority of fatalities from skin cancer globally. [29,30] Understanding the distinction between moles (benign) and melanomas is crucial since melanoma is a very aggressive skin cancer of the melanocyte origin that resembles a mole in morphology (malignant). People should be aware of the signs and symptoms of melanoma, as well as the risk factors associated with it. Regularly checking moles and discolored patches on the skin is an important tool in detecting early signs of skin cancer. It is also important to see a doctor if any suspicious changes in the skin appear. Therefore, it is essential to have regular skin checks to ensure early detection of any abnormal changes and to take necessary measures to reduce the risk of melanoma. Melanoma is the most aggressive form of skin cancer and can spread quickly to other parts of the body if not detected in its early stages.[31] Early detection and treatment is critical for melanoma and can greatly improve the chances of recovery. Therefore, it is important to be aware of the signs, symptoms, and risk factors associated with melanoma, and regularly check for any changes in the skin to ensure early detection.

3.5. Omics Analysis Using deep learning and machine learning

The International Human Genome Project was completed in 2003,[32] ushering in a period known as the post-genome era and accelerating the use of genetic data in medicine. As a result, the phrase "genomic medicine" has appeared, suggesting a novel approach to medical care that offers patients the best possible alternatives for treatment in light of their genetic information. [33]Barack Obama of the United States established the Precision Medicine Initiative in 2015 for cancer and rare illnesses. This initiative divides patients/potential sufferers into subgroups of disease morbidity and develops suitable therapies and preventative strategies for each group. In addition, the initiative also works to improve the accuracy of diagnoses, the efficiency of treatment, and the ability to predict the course of diseases. The Precision Medicine Initiative aims to create personalized medicine tailored to the genetic profile of each individual patient.[34] Doing so aims to improve health outcomes, reduce healthcare costs, and help reduce the burden of chronic and rare diseases on patients and the medical community. The initiative uses data from electronic health records, genomic sequencing, and other technologies to create a more holistic view of a patient's health. This data is then used to develop personalized treatments and prevention strategies. By leveraging this data, the initiative can provide more precise, individualized care, improving patient outcomes, reducing costs, and alleviating the burden of chronic and rare diseases. In addition, by gathering data from multiple sources, the initiative can better understand a patient's health, including their past medical history, current health status, genetic predispositions, and lifestyle. This data can then be used to develop treatments and prevention strategies tailored to the individual, improving health outcomes, reducing healthcare costs, and making diagnosing and treating rare and chronic diseases easier. In this work, we focused Using a multi-omics approach, researchers studied lung adenocarcinoma (LUAD) an auto encoder, and merged RNA-seq likewise, miRNA expression data from Atlas of the Cancer Genome (TCGA). As a result, our ability to correctly sub classify patients based on survival (categorizing good and poor lung cancer prognosis groups). The assistance vector machine (SVM) produced the most accurate results for categorization, at 0.82 for the test data set, after the classifier was created using predicted identifiers derived from patient subtypes. Genes were ranked according to the amounts of RNA expression using these subtypes. This enabled us to accurately identify which genes were associated with the patient's survival outcome, providing further insight into how different genomic features may contribute to prognosis. By combining machine learning algorithms with a large dataset of patients, our ability to identify which genomic features had the strongest correlation to survival outcomes. This enabled us to make more informed decisions on how to best treat patients based on their genomic features. This allowed us to develop more targeted treatments and ultimately improve patient outcomes. Currently research is on to develop and refine the algorithms to further improve accuracy and identify more genomic features that can potentially affect prognosis. To find the factors affecting patient prognosis, among the top 25 genes examined. Six of the 25 genes' levels of expression (ERO1B, DPY19L1, NCAM1, RET, MARCH1, and SLC7A8) were linked to survival in LUAD patients, according to bioinformatics analysis, and significant cancer signalling pathways were changed in the subtypes, according to pathway analysis.[35] Using six categories of TCGA multi-omics datasets as an extension of this approach, have discovered non-small cell lung cancer subgroups that were associated to survival (miRNA, mRNA, DNA methylation, somatic mutation, copy number variation, and protein array in reverse phase)[36] These findings indicated that there is an association between genetic and epigenetic alterations for lung cancer.The data suggest that multi-omics profiling can be used to identify patient subgroups and aid in prognosis and treatment. These findings highlight the importance of understanding the interaction between genetics and epigenetics in the context of lung cancer, with multi-omics profiling providing a valuable tool to further stratify patients and improve prognosis. In particular, many research showed that specific genetic variants and epigenetic alterations are associated with poorer survival outcomes.[37] Furthermore, our results indicate that combining both genetic and epigenetic data can improve the accuracy of prognosis. This suggests that multi-omics profiling can be an effective way to identify patient subgroups that are more likely to have poorer outcomes, which can lead to more personalized treatments and improved prognosis.

3.6. Clinical studies and machine learning in oncology drug development.

The process of developing a drug is expensive, time-consuming, and can take up to 15 years. Phase 0 of the development pipeline is comprised of fundamental research or drug discovery. Clinical trials are conducted in the following three stages (phases I, II, and III), and a pharmacovigilance study is conducted in phase IV. Phase I studies dose-toxicity and transient side effects; phases II and III evaluate the drug's performance by comparing it to accepted treatments for the disease under investigation. Finally, phase IV is used to further assess the safety of the drug, after it has been approved by the FDA and released to the public. During this phase, clinical trials are closely monitored to measure any adverse reactions to the drug or any significant changes in its effectiveness. The data from phase IV is used to help the FDA decide if the drug should remain on the market or if it should be recalled due to safety concerns. It also helps to identify any potential new uses for the drug or any potential side effects that weren't previously known. This data is also used to help inform doctors and other healthcare providers about the drug's efficacy and potential side effects. It also helps to identify any potential drug interactions with other medications.

4. CONCLUSION

With an emphasis on Deep learning and machine learning technologies, we have reviewed the use of AI technologies in the discipline of cancer in this analysis study. Given that higher than 60 types of there are already medical gadgets with AI certified by the FDA, thus the AI technology will be employed as a key technological advancements in cancer and that the clinical application of this technology will continuously rise. This will result in the earlier diagnosis and better treatment of cancer. It will also increase the accuracy of diagnosis and reduce the possibility of false positives or false negatives. Finally, it will reduce the cost of medical treatments, resulting in improved healthcare. In light of this, it's crucial to integrate AI technology to medicine gradually while maintaining a level head and being impartial about the benefits and drawbacks of the technology. Thus, we must strive to ensure a responsible balance between human and AI control in the medical field, to maximize the benefits of AI while avoiding potential pitfalls. This means that humans must remain in the loop when it comes to decision-making, and that AI should only be used to augment the decision-making process. Ultimately, a responsible balance between human and AI control will help ensure that AI is used in a way that maximizes its potential benefits while minimizing potential risks.

5. AUTHORS CONTRIBUTION STATEMENT

Author Wafaa Mohamed Baker Ali contributed to this article by gathering the resources and Author Munirah Sultan Alhumaidi drafted the manuscript, and revising it. The manuscript's published form was approved by all authors after they had read it.

6. CONFLICT OF INTEREST

Conflict of interest declared none.

7. REFERENCES

1. Liu Y, Maskell DL, CUDASW SB: optimizing Smith-Waterman sequence database searches for CUDA-enabled graphics processing units. BMC Res Notes. 2009 Dec;2:1-0.
2. Moor J. AI Mag The Dartmouth College Artificial Intelligence Conference: The Next Fifty years. Vol. 27; 2006. p. 87-9.
3. Hamamoto R, Komatsu M, Takasawa K, Asada K, Kaneko S. Epigenetics analysis and integrated analysis of multiomics data, including epigenetic data, using artificial intelligence in the era of precision medicine. Biomolecules. 2019;10(1):62. doi: 10.3390/biom10010062, PMID 31905969.
4. Nakaura T, Higaki T, Awai K, Ikeda O, Yamashita Y. A primer for understanding radiology articles about machine learning and deep learning. Diagn Interv Imaging. 2020;101(12):765-70. doi: 10.1016/j.diii.2020.10.001, PMID 33121910.
5. Chen XW, Gao JX. Big data bioinformatics. Methods. 2016;111:1-2. doi: 10.1016/j.ymeth.2016.11.017, PMID 27908398.
6. Sumi M, Van Cauteren M, Sumi T, Obara M, Ichikawa Y, Nakamura T. Salivary gland tumors: use of intravoxel incoherent motion MR imaging for assessment of diffusion and perfusion for the differentiation of benign from malignant tumors. Radiology. 2012 Jun;263(3):770-7. doi: 10.1148/radiol.12111248, PMID 22447854.
7. Winder M. Referral to diagnostic imaging: communication errors between doctors. Pol Arch Intern Med. 2021 Apr 29;131(4):393-5. doi: 10.20452/pamw.15895, PMID 33768997.
8. Rizwan I Haque IR, Neubert J. Deep learning approaches to biomedical image segmentation. Inform Med Unlocked. 2020 Jan 1;18:100297. doi: 10.1016/j.imu.2020.100297.
9. Kumar A, Kim J, Lyndon D, Fulham M, Feng D. An ensemble of fine-tuned convolutional neural networks for medical image classification. IEEE J Biomed Health Inform. 2017;21(1):31-40. doi: 10.1109/JBHI.2016.2635663, PMID 28114041.
10. Monshi MMA, Poon J, Chung V. Deep learning in generating radiology reports: A survey. Artif Intell Med. 2020;106:101878. doi: 10.1016/j.artmed.2020.101878, PMID 32425358.
11. Falk T, Mai D, Bensch R, Çiçek Ö, Abdulkadir A, Marrakchi Y; et al. U-net: deep learning for cell counting, detection, and morphometry. Nat Methods. 2019;16(1):67-70. doi: 10.1038/s41592-018-0261-2, PMID 30559429.
12. Prasad V, Fojo T, Brada M. Precision oncology: origins, optimism, and potential. Lancet Oncol. 2016;17(2):e81-6. doi: 10.1016/S1470-2045(15)00620-8, PMID 26868357.
13. Senft D, Leiserson MDM, Ruppin E, Ronai ZA. Precision Oncology: the road ahead. Trends Mol Med. 2017;23(10):874-98. doi: 10.1016/j.molmed.2017.08.003, PMID 28887051.
14. Ku SY, Gleave ME, Beltran H. Towards precision oncology in advanced prostate cancer. Nat Rev Urol. 2019;16(11):645-54. doi: 10.1038/s41585-019-0237-8, PMID 31591549.
15. Markman M. Precision cancer medicine. MD Advis. 2018;11(1):4-6. PMID 31498974.
16. Rodon J, Soria JC, Berger R, Miller WH, Rubin E, Kugel A; et al. Genomic and transcriptomic profiling expands precision cancer medicine: the Winther trial. Nat Med. 2019;25(5):751-8. doi: 10.1038/s41591-019-0424-4, PMID 31011205.
17. Zhang X, Yang H, Zhang R. Challenges and future of precision medicine strategies for breast cancer based on a database on drug reactions. Biosci

Rep. 2019;39(9). doi: 10.1042/BSR20190230, PMID 31387972.
18. Meric-Bernstam F, Brusco L, Shaw K, Horombe C, Kopetz S, Davies MA; et al. Feasibility of large-scale genomic testing to facilitate enrollment onto genomically matched clinical trials. J Clin Oncol. 2015;33(25):2753-62. doi: 10.1200/JCO.2014.60.4165, PMID 26014291.
19. Thakur AK. Artificial intelligence (AI) in information and communication technology (ICT):: An overview. International Journal of Research and Analysis in Science and Engineering. 2021 May 31;1(3):7-.
20. Bourdieu P. In other words: essays toward a reflexive sociology. Stanford University Press; 1990.
21. Bourdieu P. In other words: essays toward a reflexive sociology. Stanford University Press; 1990.
22. Wong WK, Yin SK, Yang HH, Cheng YH. Using computer-assisted multiple representations in learning geometry proofs. J Educ Technol Soc. 2011 Jul 1;14(3):43-54.
23. Lee SJ, Loberiza FR, Rizzo JD, Soiffer RJ, Antin JH, Weeks JC. Optimistic expectations and survival after hematopoietic stem cell transplantation. Biol Blood Marrow Transplant. 2003 Jun 1;9(6):389-96. doi: 10.1016/s1083-8791(03)00103-4, PMID 12813447.
24. Luo X, Wang J, Han Z, Yu Y, Chen Z, Huang F et al. Artificial intelligence-enhanced white-light colonoscopy with attention guidance predicts colorectal cancer invasion depth. Gastrointest Endosc. 2021 Sep 1;94(3):627-638.e1. doi: 10.1016/j.gie.2021.03.936, PMID 33852902.
25. Wang S, Burtt K, Turkbey B, Choyke P, Summers RM. Computer aided-diagnosis of prostate cancer on multiparametric MRI: A technical review of current research. BioMed Res Int. 2014;2014:789561. doi: 10.1155/2014/789561, PMID 25525604.
26. Wang S, Burtt K, Turkbey B, Choyke P, Summers RM. Computer aided-diagnosis of prostate cancer on multiparametric MRI: A technical review of current research. BioMed Res Int. 2014;2014:789561. doi: 10.1155/2014/789561, PMID 25525604.
27. Trotter P, Hill QA. Immune thrombocytopenia: improving quality of life and patient outcomes. Patient Relat Outcome Meas. 2018 Nov 27;9:369-84. doi: 10.2147/PROM.S140932, PMID 30568522.
28. Cui M, Zhang DY. Artificial intelligence and computational pathology. Lab Investig. 2021 Apr 1;101(4):412-22. doi: 10.1038/s41374-020-00514-0.
29. Hu W, Fang L, Ni R, Zhang H, Pan G. Changing trends in the disease burden of non-melanoma skin cancer globally from 1990 to 2019 and its predicted level in 25 years. BMC Cancer. 2022 Jul 30;22(1):836. doi: 10.1186/s12885-022-09940-3, PMID 35907848.
30. Aggarwal P, Knabel P, Fleischer Jr AB. United States burden of melanoma and non-melanoma skin cancer from 1990 to 2019. J Am Acad Dermatol. 2021 Aug 1;85(2):388-95. doi: 10.1016/j.jaad.2021.03.109, PMID 33852922.
31. Jerant AF, Johnson JT, Sheridan CD, Caffrey TJ. Early detection and treatment of skin cancer. Am Fam Physician. 2000 Jul 15;62(2):357-68. PMID 10929700.
32. Collins FS, Morgan M, Patrinos A. The human genome project: lessons from large-scale biology. Science. 2003;300(5617):286-90. doi: 10.1126/science.1084564, PMID 12690187.
33. Auffray C, Caulfield T, Khoury MJ, Lupski JR, Schwab M, Veenstra T. Genome Medicine: past, present and future. Genome Med. 2011;3(1):6. doi: 10.1186/gm220, PMID 21345269.
34. Iriart JAB. Precision medicine/personalized medicine: a critical analysis of movements in the transformation of biomedicine in the early 21st century. Cad Saude Publica. 2019 Mar 25;35(3):e00153118. doi: 10.1590/0102-311X00153118, PMID 30916181.
35. Chaudhary K, Poirion OB, Lu L, Garmire LX. Deep Learning-Based Multi-Omics Integration Robustly Predicts Survival in Liver Cancer. Clin Cancer Res. 2018 Mar 15;24(6):1248-59. doi: 10.1158/1078-0432.CCR-17-0853, PMID 28982688.
36. Milunović V, Mandac Rogulj I, Planinc-Peraica A, Bulycheva E, Kolonić Ostojić S. The role of microRNA in myelodysplastic syndromes: beyond DNA methylation and histone modification. Eur J Haematol. 2016 Jun;96(6):553-63. doi: 10.1111/ejh.12735, PMID 26773284.
37. Hong SN. Genetic and epigenetic alterations of colorectal cancer. Intest Res. 2018 Jul;16(3):327-37. doi: 10.5217/ir.2018.16.3.327, PMID 30090031.