

AI-DRIVEN ADVANCES IN CANCER DIAGNOSIS AND TREATMENT

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ABSTRACT

Cancer is one of the most significant concerns of the health system in the world and early diagnosis and personalised treatment will be significant drivers in improving the outcome of patients. Cancer prevention, screening, diagnosis, treatment and monitoring are today an exciting area of Artificial Intelligence (AI) for cancer. Using AI, machine learning, deep learning and natural language processing (NLP) have the potential to capture tremendous amounts of information from clinical and imaging data, pathology, the genomic and molecular data. AI analysis of the CT, MRI, PET and histopathological images can aid in early diagnosis and the detection and classification of tumours. Precise oncology uses AI to integrate genomic information and clinical data and make precise, personalized treatment choices, patient categorization, prognosis of how patients will respond to treatment and predict whether they will return. AI is also playing a role in anticancer drug discovery in repurposing drugs, prediction of drug-target interaction and optimization of drug candidates. However, there are issues like robustness of data, privacy, algorithmic bias, transparency, clinical validation and regulatory issues that need to be addressed. In total, the possibilities for AI to enhance the accuracy, efficiency, individualisation and patient-centredness of cancer treatment and care are huge.

KEYWORDS: AI's role in Oncology: Cancer Diagnosis, Medical Imaging, Precision Oncology, Personalized Treatment, Drug Discovery, Radiotherapy, Treatment Planning, Patient Monitoring.

1. INTRODUCTION AND FUNDAMENTALS OF CANCER

1.1 Artificial Intelligence in Oncology

Artificial intelligence is described in the source as technology that enables computers and machines to simulate human learning, comprehension, problem solving, decision making, creativity and autonomy.

AI is especially valuable in the field of modern oncology, where the handling of heterogeneous information with high volume is created during cancer treatment. Clinical data, imaging, pathological information, laboratory results and genomic data can be used in combination to aid in the prediction of risk, diagnosis, prognosis and treatment selection.^[1]

Machine learning (ML), deep learning (DL) and natural language processing (NLP) are critical AI methods mentioned in the source. In the medical imaging context, deep learning, such as CNN (Convolutional Neural Network) has been used for tumour detection and segmentation. AI is also making an impact in areas of digital pathology, mutation detection, discovery of biomarkers, drug-target prioritisation, drug repurposing, personalised therapy and clinical trial matching.^[2]

1.2 Cancer and Its Biological Basis

Cancer is an overarching term for a collection of diseases in which cancer cells grow in an uncontrolled manner, invade other healthy cells and in many cases, spread to other locations in the body. Cancers are biologically and clinically diverse, but all have the same mechanism of deranged regulation of cell growth, which results in cells growing abnormally and not undergoing normal cell death.^[3]

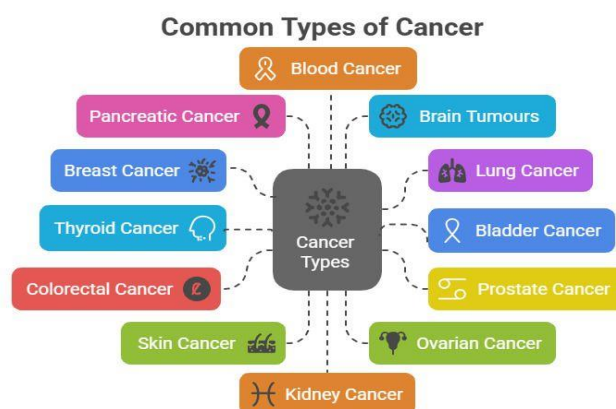


Figure 1: Common types of Cancer.^[4]

1.3 Causes and Risk Factors

- Genetic causes: If there is some defect in the genes of a person that makes it easier for them to develop cancer, they may be more prone to cancer.
- Damage to DNA may be caused by: environment (air pollution, bad chemicals, radiation, infection, smoking).
- Risk factors include lifestyle risk factors – unhealthy diet, being overweight, little exercise, smoking, drinking alcohol and excessive sun exposure.
- Biological: Cancers are more likely to occur with age and some cancers are related to the biological and sex hormones.

- Immune dysfunction and chronic inflammation can lead to a situation where cancer can develop.
- Susceptibility may be increased with previous diseases, chronic infections and inflammatory disorders.
- Selected hormone-dependent cancers can be due to hormonal influences.^[5]

1.4 Cancer Stages

- Stage 0: Carcinoma in situ; it is at the site of origin only.
- Stage I: Localized; The tumour or cancer has only spread to one specific region of the body and not yet to the local lymph nodes or other parts of the body.
- Stage II: Early locally advanced disease; Tumor is larger or nearly involved lymph nodes, but is not distinctly involved.
- Stage III: Locally advanced cancer; Cancer has grown to nearby tissues and/or nearby lymph nodes, but not to distinct parts.
- Stage IV: Metastatic disease; Cancer cells have spread from the primary site to other parts of the body, usually to several organs.^[6]

2. NEED FOR EARLY DIAGNOSIS AND PERSONALIZED TREATMENT

Early diagnosis is important in helping to provide a good chance for successful treatment, quality of life and avoidance of intensive treatment. The earlier the diagnosis is made, the less health care costs will be, since advanced disease often is treated more extensively and intensively.^[7] Personalized treatment is also crucial since patients with the same type of cancer can be genetically distinct, have varying clinical histories, lifestyles, tumour features and treatment response.^[8]

2.1 Conventional Diagnostic Challenges

There are blood markers, X-ray, computed tomography (CT), magnetic resonance imaging (MRI) and mammography and tissue biopsy in conventional diagnosis of cancer. Each has limitations. Very small or deep lesions may not be detected by imaging and blood-based biomarkers may be false positive and/or false negative. While biopsy remains the most effective means of pathological diagnosis, there are areas of the tumour that biopsy may not sample. If the results are negative, it could take longer to be detected if the disease is moving on. Some cancer types, such as cancers of unknown primary, may be hard to diagnose. However, some tumours, like those of the pancreas and ovary, may have few early signs and symptoms, leading to the involvement of the organs at a late stage. These restrictions present an opportunity to computational systems that can combine multiple types of evidence, rather than using a single test.

2.2 Conventional Treatment Challenges

Treatment selection is also complicated. Surgery can be particularly helpful if the tumour is localised, but is not suitable if the disease has spread. Radiation therapy may be able to manage localized disease, and can put normal tissues around the cancer in danger. Chemotherapy works systemically, and can have negative side effects like nausea, weakness, alopecia, myelosuppression and heightened infection risk. The treatment of cancer has become more personalized with targeted therapy, precision medicine and immunotherapy, but requires consideration of tumour biology, genetic changes and the characteristics of the patient. Cost and availability is also a problem, according to the source. One of the key challenges in using AI for oncology is to integrate complex patient data with clinical expertise to determine the optimal treatment pathway and minimize unnecessary treatment.^[9]

3. AI IN CANCER DIAGNOSIS

3.1 Identification of High-Risk Individuals

AI can use various sets of demographic, medical, lifestyle, family, genetic, biomarker and imaging data to detect those who are at a higher risk. The source defines risk stratification as allocating patients to different risk categories based on that information and utilizing it to tailor patients' monitoring and preventive actions. The integration of clinical and genomic and imaging information can complement and enhance the development of risk models.

3.2 AI-Assisted Screening and Early Detection

The potential applications of AI are immense, and early detection is one of them. Computer-aided systems can analyze a great deal of medical images and identify suspicious abnormalities. It is in mammography, CT, MRI imaging and related imaging that deep learning techniques can help in the detection of lesions, to minimize variability in interpretation and to speed up the review. These systems can assist radiologists in catching nuances in the images and prioritizing patients.^[10]

3.3 Medical Imaging Modalities

- **X-ray Imaging:** X-ray imaging is a fast and non-invasive method which generates 2-D images with the help of ionizing radiation. It's primarily used to analyze bones, lungs, teeth and the chest. But it does not have a good visualisation of soft tissues.
- **Computed Tomography (CT):** It takes multiple X-ray images from various angles to create detailed cross-sectional images of the body. This is very helpful in the imaging of blood vessels, bones, organs and tumors. However, it's possible to get radiation exposure and it doesn't have the same soft-tissue contrast as an MRI.
- **Magnetic Resonance Imaging (MRI):** MRI uses magnetic fields and radiofrequency waves to produce high-resolution images without ionizing radiation. Has a unique capability to obtain images of soft tissues, brain and spinal cord, muscle and joints. Main disadvantages are it is more expensive and slower to scan.
- **Ultrasound (US):** Ultrasound imaging or ultrasonography is used to create real-time images without the use of ionizing radiation. It can be used for fetal monitoring, abdominal organ, soft tissue and blood flow evaluation.
- **Positron Emission Tomography (PET):** Positron Emission Tomography (PET) is a functional imaging technique that uses radioactive compounds to be able to image tissue metabolism and physiological activity. It can particularly assist in the diagnosis, staging and prognosis of cancer. PET can give information about cellular and metabolic function, unlike CT and MRI.^[11]
- **Mammography:** Mammography is a low dose X-ray exam that is mainly employed in the early detection of breast cancer. It is able to detect the masses and calcifications of the breasts that are related to abnormality. While screening can help to lower the risk of breast cancer death, it can also lead to false positives and overdiagnosis.^[12]
- **Histopathology:** Histopathology is put forward as the gold standard for diagnosing cancer. The tissue is either biopsied or removed by surgery and then processed, cut and stained (usually hematoxylin and eosin) prior to microscopic inspection. Digital pathology using Artificial Intelligence may assist in the diagnosis of malignant cells, tumor grading, histological classification and prognosis. One significant suggested benefit is the increased uniformity and decreased variation of observers.^[13]

4. BIOMARKERS AND MOLECULAR PROFILING

4.1 Biomarker Discovery

Biological markers that help in the early detection, diagnosis, prognosis, prediction of therapeutic response, and therapeutic decision making are called cancer biomarkers. Biomarkers are categorized into diagnostic, prognostic, predictive and therapeutic by the source. Combined with large molecular data, AI can be used to identify and understand biomarkers.

4.2 Genomic Strategies

Genomic strategies are searching for mutations that are uncovered in the course of the tumour's growth and progression. Mutations, single nucleotide polymorphisms (SNPs), gene fusions and more can be detected using next generation sequencing (NGS) and genome wide association studies (GWAS). Complementary technologies to aid in the discovery of biomarkers and clinical decision making include AI, genomics and bioinformatics. But there are a number of problems of low genetic diversity, population variability and interpretation problems that make this a not common technology in the clinic.

4.3 Proteomics

Proteomics is the high-throughput investigation of proteins, such as their interactions, modifications and expression. Mass spectrometry and protein microarrays are methods that can be used to analyse tissue and biological fluids. The source says proteomics is helpful in the discovery of diagnosis, prognosis and predictive biomarkers and could aid in the provision of personalized therapy.

4.4 Metabolomics

Metabolomics is the study of small molecules that are generated as a result of cell metabolism. Metabolomic profiles can assist in early detection, diagnosis and monitoring of treatment for cancer as metabolic changes can occur at an early stage of cancer development. Mass spectrometry and nuclear magnetic resonance spectroscopy are examples of analytical methods. Complications such as variation in metabolite concentrations and the complexity of metabolic pathways are still a constraint.^[14]

4.5 Liquid Biopsy

Liquid biopsy involves analysing body fluids for any material that is related to the tumour, including circulating tumour DNA, circulating tumour cells and extracellular vesicles. A major strength of the source is its non-invasive, repeatable and ability to monitor tumour evolution throughout treatment. Some of the challenges that are currently being faced are low concentration of biomarkers and detection problems, in addition to the lack of complete standardization of the analytical methods.^[15]

4.6 AI-Based Genetic and Molecular Profiling

AI can be used to identify cancer-related abnormalities by analysing genomic and molecular data, to discover biomarkers, to predict the development of a cancer and to identify patients who might be candidates for new treatments that are more specific. The incorporation of genetic information with age, environmental, medical history and other clinical data can aid in prediction of recurrence, metastasis and treatment outcomes.^[16]

4.7 Cancer Biomarkers

Discovering cancer biomarkers can be separated into 4 categories:

1. Diagnostic Biomarkers

Frequently used to identify or diagnose cancer or to determine the condition of a disease.

- PSA: A test that may help be used to find prostate cancer.
- HCG: May be helpful in diagnosis and monitoring of some cancers.
- CEA: Primarily to check the treatment and recurrence of colorectal cancer.

2. Prognostic Biomarkers

Contribute to the prognosis, recurrence and survival of cancer.

- HER2: Related to the prognosis of breast cancer.
- Ki-67: High levels indicate rapid tumour growth.
- p53 is linked to an increase in tumour aggressiveness and a decrease in survival; mutations are linked to these.

3. Predictive Biomarkers

Assist in the prediction of the patient's reaction to certain treatments.

- ER: Forecasts the reaction to the hormone treatment.
- EGFR: Mutations can predict response to targeted therapy in selected cancers.
- KRAS: Mutations also predict resistance to anti-EGFR therapy in CRC.
- BRCA1/2: Predict sensitivity to PARP inhibitors.

4. Therapeutic Biomarkers done

Assist in selection of patients for targeted / immunotherapy.

- PD-L1: Aids in directing immune checkpoint inhibitor therapy.
- BRAF V600E: Identifies patients that could be treated with BRAF-targeted therapy.
- BRCA1/2: Has the potential to be associated with sensitivity to PARP inhibitors.^[17]

5. AI IN PRECISION ONCOLOGY

5.1 Personalized Treatment Planning

The goal of precision oncology is to replace the one size fits all approach with interventions to match the biology of a person's specific tumour and the person. According to the source, AI is capable of predicting a response to chemotherapy, radiotherapy, targeted therapy and immunotherapy, as it combines immunological, genomic, molecular, imaging and clinical data. The genomic sequencing and gene-expression data, tumour biomarkers and actionable molecular changes can be analyzed by AI. It can also assess some components of the tumour microenvironment such as infiltration of immune cells and stromal elements to determine the success rate of immunotherapies and to provide guidance on combination treatment strategies.^[18]

5.2 Role of Next-Generation Sequencing

NGS is able to characterize genetic changes at high throughput. Can identify mutations, gene fusions, copy-number changes and other molecular changes involved in cancer. Genomic databases like The Cancer Genome Atlas have helped the understanding of cancer biology and clinically relevant biomarkers, the source writes. NGS may also help

distinguish driver mutations from those mutations that have a less direct effect on tumour progression, known as passenger mutations.^[19]

5.3 Patient Stratification

Patient stratification involves grouping patients according to clinical, pathological and molecular characteristics. Patients affected by the same type of cancer can have different genes, the extent of the tumour, how the cancer genes are expressed, and various health factors. The differences may affect how a person responds to treatment. Stratification thus aids in identifying patient sub-sets, which could be more likely to respond to specific treatments and/or which could be more susceptible to side effects.^[20]

5.4 Predicting Treatment Response and Recurrence

Machine learning may be able to integrate clinical, imaging, pathological and genomic characteristics to predict treatment response, recurrence and survival. These predictions can help plan individual follow-up schedules for patients, and allow for reassessment of treatment plans if a patient does not look like they will benefit from a treatment. The source calls this predictive capability an "important" aspect of precision oncology.^[21]

6. AI IN ANTICANCER DRUG DISCOVERY AND DEVELOPMENT

6.1 Conventional Drug Development

The process of drug discovery is referred to as lengthy, expensive and high-risk process in the search for anti-cancer drugs. Mechanism, efficacy, toxicity, pharmacokinetics, pharmacodynamics, and dosing and safety of candidate compounds need to be evaluated prior to clinical use. Treatment is unsuccessful in many instances, and some patients do not respond to treatment, and even when treatment is effective, there is considerable variation in the toxicity of therapeutic agents.

6.2 AI as a Complement to Computer-Aided Drug Design

AI adds to the capabilities of traditional CAD with the ability to analyze vast amounts of biological and chemical data. It can facilitate the identification of molecular targets, prediction of molecular interactions, virtual screening, design of new chemical entities and prediction of pharmacological properties prior to experimental testing.^[22]

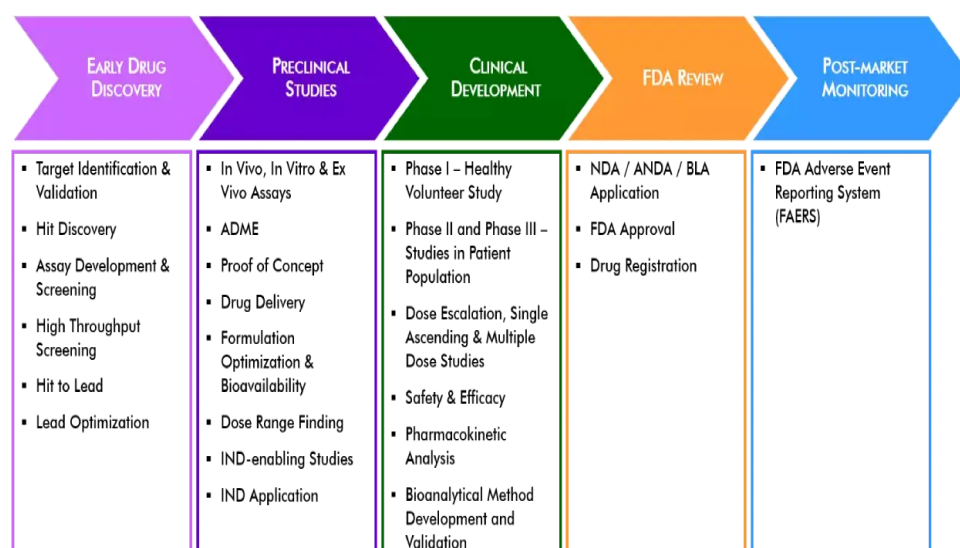


Figure 2: Drug Discovery and Development Process.^[23]

6.3 Major Challenges in Anticancer Drug Discovery

- Variability between patients and within patient tumours.
- Intrinsic and Acquired Drug Resistant.
- Toxicity such as myelosuppression, cardiotoxicity, gastrointestinal toxicity and neurotoxicity.
- Drug delivery/tumour penetration.
- Lack of ability in determining therapeutic targets.
- Complex tumour microenvironment.
- Few predictive preclinical models.
- Slow development process and expensive.
- Regulatory and ethical needs.
- Relapse of cancer.^[24]

7. DRUG REPURPOSING AND DRUG–TARGET INTERACTION PREDICTION

7.1 Drug Repurposing

Drug repurposing, or repositioning, is the process of looking at an existing drug or one that has already been developed to seek out a new indication for cancer. A repurpose could potentially accelerate development since much of the information on pharmacological properties, safety and manufacturing already exists, thereby reducing development costs and some development risks. The source involves this as especially applicable in cases where patients require treatments quickly or if there are few effective treatments available.

7.2 Three Broad Phases of Repurposing

- Target identification: Determine molecular targets for the disease and predict drug action on pathways involved in the pathogenesis of cancer.
- Characterization of candidates: AI, Molecular Docking, Network Pharmacology, Pathway Analysis, Bioinformatics, Experimental Validation.
- Clinical evaluation: Bring forward candidates that have sufficient preclinical data for clinical evaluation; current safety data may allow for accelerated development in specific cases.^[25]

Table 1: Examples of Drug Classes Repurposed for Cancer Therapy.^[26]

Drug Class	Representative drugs	Basic Anticancer Mechanism
Antiplatelet agents	Aspirin	Prevents tumour growth mediated by platelets and decreases inflammation
Anti-inflammatory drugs (NSAIDS)	Diclofenac, Celecoxib	Suppress COX-2 signalling, inhibit angiogenesis, induce apoptosis
Antidiabetic agents	Metformin, Pioglitazone, Rosiglitazone	Activate AMPK pathway and inhibit cancer cell proliferation.
Anthelmintic agents	Albendazole, Flubendazole	Disrupt microtubules, inhibit angiogenesis and metastasis
Antipsychotic agents	Aripiprazole, Valproic acid	Prevent tumour growth, promote cell death, control epigenetic pathways
Antiviral agents	Zidovudine, Ritonavir, Brivudine	Inhibit tumour cell growth and increased sensitivity to chemotherapy
Antifungal agents	Itraconazole, Ketoconazole	Inhibit AKT/mTOR and Hedgehog signalling and decrease angiogenesis
Antibacterial agents	Doxycycline	Prevents cancer cell growth and mitochondrial (energy producing) cell growth

7.3 Prediction of Drug–Target Interactions

The purpose of drug–target interaction prediction is to find out how a drug interacts with proteins, enzymes, genes and/or receptors that are associated with cancer. Experimental discovery is costly and time consuming! Chemical, genetic, proteomic and pharmacological data can be used to predict new interactions using AI, ML and DL. It notes some developments that can bolster this field, including network biology, graph neural networks, and transformer architectures and multi-omics integration.^[27]

8. AI IN CANCER TREATMENT SELECTION

8.1 Chemotherapy Optimization

Chemotherapy also affects rapidly growing tissues but these tissues are normal, such as the lining of the gut, bone marrow and hair follicles. Mucositis, myelosuppression, nausea and alopecia are reported as important toxicities in the source. The aim of the ongoing chemotherapy is to obtain an anti-tumorous effect at a minimum toxicity, and adapt the chemotherapy dose, timing and support to the individual. Combination chemotherapy is often employed since drugs with different mechanisms will kill more tumour cells and may help to decrease resistance. Chemotherapy can be used as a neoadjuvant (before), definitive (main) or palliative (after) therapy or in combination with other therapies (targeted therapy, immunotherapy and/or radiotherapy) depending on clinical situation.^[28]

8.2 Immunotherapy

One method of treating cancer is by means of the body's immune system. According to the source, immune checkpoint strategies such as PD-1, PD-L1 and CTLA-4 may aid in reactivating the activity of T-cells. Immunotherapy can yield long-term results in certain individuals, but not in all individuals or all tumors. Patterns that can be identified by integrating tumour, immune, genomic and clinical features can be used to make use of AI.^[29]

8.3 Targeted Therapy

The aim of targeted therapy is to work on the molecular abnormalities that help the tumour to grow and spread. The molecular profiling can detect actionable mutations by pathways including HER2, EGFR, VEGF, ALK, BRAF and PARP. The source notes that targeted therapy is more precise than conventional chemotherapy, but may also be responsible for side effects and resistance.^[30]

8.4 Hormonal Therapy

Hormonal therapy is indicated for hormone-dependent cancers, like breast cancer and prostate cancer. It could possibly interfere with the action of the hormones and/or with the production of hormones at tumour cells. Depending on the purpose and stage, may be used as neoadjuvant, adjuvant, metastatic or palliative treatment. AI can be helpful in incorporating receptor status and clinical data into personalised therapy decisions.^[31]

8.5 Stem Cell Transplantation

Hematopoietic stem cell transplantation can be used to restore function of the blood and immune system following intensive chemotherapy or radiotherapy. The source refers to key areas of haematological malignancies and selected solid tumours. The opportunities listed for AI involve risk assessment, treatment monitoring and integration of lab and clinical information, although the information provided is mostly about treatment and not an actual AI transplant algorithm.^[32]

9. AI IN RADIATION THERAPY

9.1 Fundamentals and Types of Radiation Therapy

Radiotherapy involves the way in which cancer cells are damaged and prevented from growing by using ionizing radiation. May be used in conjunction with surgery, chemotherapy, targeted therapy and immunotherapy or for symptom relief. The source elaborates on external beam radiation therapy, brachytherapy and systemic radiation therapy, and fractionation, and advanced techniques like 3D-CRT, IMRT and IGRT.

9.2 Advanced Radiotherapy Approaches

- External Beam Radiation Therapy (EBRT): radiation therapy is given by a machine outside of the body.
- Brachytherapy: radioactive material is put into or close to the tumour.
- Systemic radiation therapy: radioactive drugs which circulate about the body to treat disseminated disease.
- 3D-Conformal Radiation Therapy (3D-CRT): Three dimensional picture of the tumour and the surrounding organs is used to create radiation therapy treatment beams in a 3D shape.
- Intensity-Modulated Radiation Therapy (IMRT): beams are beamlets with independently-controlled intensities that are able to be made more conformable.
- Image-Guided Radiation Therapy (IGRT): Imaging during therapy to improve tumour localization and correct for the motion of the therapy
- Intraoperative Radiation Therapy (IORT): the radiation is given in the operating room, during surgery, directly to the tumour bed.
- Stereotactic Radiation Therapy: very precise radiation to small targets with an aim of trying to spare normal tissues.
- Selected advanced technologies: proton and particle therapies may be incorporated to reduce the radiation dose to neighbouring organs and tissues or are also available for certain radioresistant tumours. ^[33]

10. AI IN RADIOTHERAPY PLANNING AND SURGICAL ONCOLOGY

10.1 Image Contouring

Deep learning (DL) segmentation with AI is revolutionizing radiotherapy contouring by automatically segmenting GTV, CTV, PTV and OARs. When a treatment plan fails to meet its original goals, AI can help quickly identify the cause for the change and achieve the desired changes. AI can save time, workload, inter-observer variability, and human error; it aids in the reproducibility and efficiency of treatment planning when compared to manual contouring. Recent CNN, U-Net and attention networks can perform on par with expert clinicians. These have been shown to be effective in head and neck, prostate, lung, breast, liver and oesophageal cancers. ^[34]

10.2 Dose Optimization

AI can play a role in optimizing cancer treatment doses, by determining the optimal dose for the greatest efficacy and lowest toxicity. AI-based optimization methods do not rely on the Maximum Tolerated Dose (MTD) as traditional methods do, but focus on clinical, molecular, pharmacokinetic, pharmacodynamic, and imaging data to optimize the dose for each individual patient. Machine learning can help strike the balance between the effectiveness and safety of the treatment, and thus aid in transitioning towards optimized dosing highlighted by efforts like FDA Project Optimus. ^[35]

10.3 Organ-at-Risk Protection

With the aid of AI, healthy organs, also known as organ at risk or OAR, can be automatically identified and contoured from the CT and/or MRI scan to accurately define the treatment area for radiation therapy. Very useful when optimizing treatment plans to ensure that the dose is given to the tumour and that healthy tissues surrounding the tumour are not given as much radiation as needed. This can lead to a reduction in toxicity, maintain organ function, minimize contouring time and variability, and increase the safety, accuracy and quality of radiation treatment.^[36]

10.4 AI-Assisted Robotic Surgery

Robot-assisted surgery is a combination of AI and robot technology and real-time imaging to enhance the precision of cancer surgery. It can also be used to view in 3D, motion scale, reduce tremor, magnify and control the instruments, helping surgeons to remove tumours and carry out complex procedures with less damage to healthy tissues. Image-based, sensor-based and navigation systems – powered by Artificial Intelligence – also help to identify the tumour and make real-time decisions on the surgical procedures to be used. Overall, the surgery performed with the robot will have a positive effect on the reduction of bleeding, complications, hospital stay and recovery time.^[37]

11. AI IN PATIENT MONITORING AND DATA SOURCES

11.1 Continuous Health Monitoring

While real-time physiological data is being collected, via wearables or Electronic Health Records and medical sensors, AI can analyse the data as it comes in and offer real-time analysis. This will allow early recognition of clinical deterioration and individual care.

11.2 Wearable Devices and Remote Monitoring

Biosensors, smart patches and smartwatches collect the data, such as activity, quality of sleep, heart rate, temperature, oxygen saturation, etc. continuously. These data can be analysed using AI and alerts issued. Using remote monitoring, follow-up outside the hospital is possible, and can aid in the detection of complications earlier.

11.3 Treatment Response and Recurrence

AI can analyze medical images, lab data, biomarkers, patient-reported outcomes to assess treatment efficacy. The clinical, imaging, pathological and genomic information can also be used to estimate the recurrence risk in models. The more intense surveillance or early intervention may then be given to high-risk patients.

11.4 Early Detection of Treatment Complications

Possible detection of infection and organ toxicity and adverse drug reaction by means of AI. Early warning can help the health system to act before complications get out of hand.^[38]

Table 2: Major Data Sources of AI.^[39]

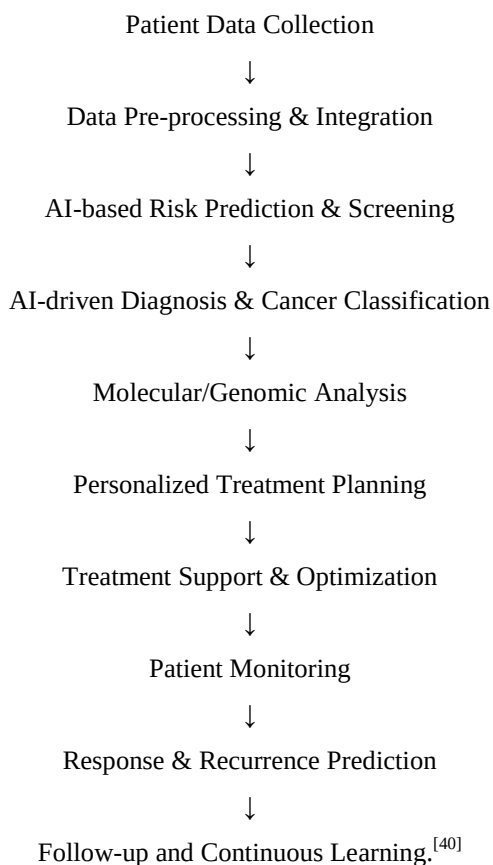
Data source	Examples and role
Electronic Health Records	Demographic, diagnosis, visits, lab data, treatments and follow up.
Medical imaging	X-ray, Mammography, CT scanning, MRI scanning, PET, Ultrasound (ultrasound) for detection, classification and monitoring.
Genomic and multi-omics	Genomics, transcriptomics, proteomics, metabolomics and epigenomics.
Histopathology	The diagnosis, grading, typing and prognosis of malignant cells (histopathology) is possible by digital biopsy/surgical slides.
Laboratory Reports	Blood counts, Biochemical tests, Tumour marker and Molecular report.
Clinical trial data	Patient characteristics, treatments, efficacy, adverse effects and survival.

Wearables	Heart rate, activity, temperature, sleep, oxygen saturation and other physiological data.
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12. AI WORKFLOW AND ADVANTAGES IN ONCOLOGY

12.1 AI Workflow in Cancer Care

The application of AI in cancer care follows a systematic approach and is a process that translates the clinical and biological data into knowledge to inform cancer diagnosis, treatment planning and patient management. All of these take steps to improve the accuracy of diagnosis, to help optimize patient treatment and future monitoring of patient outcomes.



12.2 Major Advantages

- Early and potentially more reliable diagnosis via pattern analysis.
- Enhanced decision making in treatment choice based on clinical, imaging, pathological and genetic data.
- Tailored treatment based on individual patient's and the tumour's biology.
- Medical images and pathology interpreted in a faster manner.
- Minimization of diagnostic variability with the use of AI and clinician skills.
- A prediction of response, progression, recurrence and survival to treatment.
- More effective patient surveillance and timely detection of complications.
- Savings in healthcare resources due to efficiency and avoiding further tests/late-stage treatment.^[41]

13. CHALLENGES AND LIMITATIONS OF AI IN ONCOLOGY

13.1 Limited Availability of High-Quality Datasets

Large and diverse datasets that are properly labeled are needed for AI systems. The data from oncology studies can be incomplete, institutionally siloed, and/or may have a small sample size or be gathered inconsistently. Such constraints may impact generalizability and lead to performance disparities in how a model performs on a population or institution not included in training.^[42]

13.2 Data Security and Integrity

Oncology data is sensitive data with electronic health records, imaging, pathology and genetic data being of particular importance. The source emphasizes on secure storage, encryption, anonymization, and compliance with healthcare regulations. Another key consideration is data quality, as poor data quality can lead to unreliable results from the model.

13.3 Algorithmic Bias

By learning from its training data, AI adapts to its surroundings. However, in case some demographic or clinical subgroups are not represented, the performance of the model may be weaker in those subgroups. The source suggests using representative datasets, collected across multiple centres, to minimize bias, and ongoing testing to ensure equity in clinical decision making across populations.^[43]

13.4 Explainability and the Black-Box Problem

Many of these sophisticated deep-learning systems are hard to interpret. In the field of oncology where decisions can mean the difference between life and death, physicians might not want to base treatment on predictions that are not thoroughly understood. The concepts of Explainable AI methods like SHAP and LIME are called to explain the factors behind the predictions and to enhance trust and responsible use.^[44]

13.5 Integration into Healthcare Systems

Needs to integrate with hospital-hospital information system / EHR and imaging software. Other challenges include infrastructure, process redesign, training the workforce and ongoing maintenance. AI should not be a process unto itself but should be added to the clinical process.^[45]

14. ETHICAL AND REGULATORY CONSIDERATIONS

14.1 Patient Privacy and Informed Consent

One of the essential components of AI is data from patients. Institutions should have the data stored securely, anonymized and meet privacy requirements, the source says. Patients should also be educated about data analysis using AI and how the information should be consented.

14.2 Transparency and Explainability

An important aspect of using AI to assist in diagnosis or treatment is transparency. Explainable AI is a means to develop AI that is understandable and trustworthy to the clinicians. Providing better explanation and identification of areas that the model is not reliable can be helped by clinical validation.

14.3 Fairness and Bias Mitigation

For fairness, there should be various training sets and performance measures for various patient groups. It is important to assess it on a regular basis as it may work well in one place but not in another.

14.4 Clinical Validation and Regulatory Approval

AI tools must be internally and externally validated, and be subjected to study projections if applicable, before they can be routinely used in clinical practice. The source indicates that the product is subject to regulatory review by agencies like the U.S. Food and Drug Administration (FDA), the European Medicines Agency (EMA) and national approval agencies. The goal is to make sure that medical technologies powered by AI are safe, effective and clinically reliable.

14.5 Human Oversight

AI is clearly not a clinical diagnostic tool, but rather a clinical decision support system, according to the source. Recommendations should be used, in addition to clinical judgement, patient preference and ethical considerations. In oncology, in particular, human involvement is essential for crucial decisions.^[46]

15. CASE STUDIES

15.1 Case Study: AI-Assisted Breast Cancer Detection Using Mammography

Breast Cancer Screening via Mammography is among one of the initial clinical applications where AI has shown huge advantages. In the first international study of its kind, McKinney et al. (2020) developed a deep learning model, an artificial intelligence system that has been trained with thousands of mammographic images from the UK and the USA. The AI system was able to accurately detect the presence of malignant lesions even when using mammograms alone and to decrease false positive and false negative results. The model also achieved a reduction of 5.7% in the number of false positive cases in the US, and 1.2% in the UK, compared to an expert radiologist, and 9.4% in the number of false negatives cases in the US, and 2.7% in the UK, compared to an expert radiologist. The findings of this research were quite evident that AI could enhance diagnostic accuracy, help radiologists make early cancer diagnoses and save unnecessary biopsies and follow-ups.^[47]

15.2 Case Study: Lung Cancer Detection from CT scan

The most important thing to remember about lung cancer is that at the time of diagnosis, the cancer is at a late stage and therefore it is a deadly disease. Ardila et al. (2019) created a three-dimensional deep learning model that can analyse and identify lung cancer in low dose computed tomography (CT). The AI system evaluated the CT images without relying on the manual diagnosis, and estimated the likelihood of malignancy in the pulmonary nodules. The model proved to be more accurate than experienced radiologists in identifying malignant lesions in those patients who had previously been scanned with CT. The system was found to be more useful for detecting small lung nodules that may not be detected by the human doctor, allowing for early clinical treatment, with high success rates.^[48]

15.3 Case Study: Skin Cancer Diagnosis Using Dermoscopic Images

Diagnosis of skin cancers used to be made by a dermatologist's knowledge and physical examination and dermoscopy. This is done via training a convolutional neural network (CNN) on more than 129,000 clinical pictures of skin diseases created by Esteva et al. (2017) that encompasses over 2,000 skin diseases. The AI model was able to accurately detect malignant melanoma and other skin cancers from benign skin lesions and performed as well as board-certified

dermatologists. AI's ability to accurately interpret dermoscopic images and offer a valuable diagnosis, especially in areas lacking in specialist skills, has been shown by the study.^[49]

16. FUTURE PERSPECTIVES

- AI-powered precision oncology, involving the integration of genomic, clinical, pathological, radiological and lifestyle data.
- Create Digital Twins of patient specific clinical, imaging, genetic and physiological data to simulate disease and treatment outcomes.
- Wide range of all-in-one multi-omics analysis (genomics, transcriptomics, proteomics, metabolomics and epigenomics).
- Generative AI to quickly design and optimize potential drug molecules.
- Federated learning for multiple institutions to train models without sharing of sensitive patient data.
- Smart oncology clinics enabled by AI and connected to EHR, imaging, lab and wearables.^[50]

17. CONCLUSION

AI is proving to be a significant technology in cancer diagnosis and treatment, and in long-term management of the disease. The source of the review is shown to be applicable in applications such as: high risk identification, screening, medical imaging, histopathology, biomarker discovery, genomic and molecular profiling, precision oncology, drug discovery, drug repurposing, drug–target interaction prediction, chemotherapy and immunotherapy support, radiotherapy planning, robotic surgery and patient monitoring. AI can assist physicians in analysing huge and complex datasets, pinpointing subtle abnormalities, foreseeing treatment outcomes and recurrence, tailoring treatment plans, and tracking patient progress over time. Automated contouring, dose optimization and organ-at-risk protection are possible points of efficiency and uniformity in radiotherapy. It is critical to measure, monitor and decrease algorithmic bias and provide explanations for clinical trust. AI tools must be internally and externally validated, be evaluated in the future (if possible), be regulated and be incorporated into healthcare systems. Above all, AI should enhance, not supplant, trained medical practitioners. Professional judgement and patient preferences and ethics should be included in clinical decisions. The integrated precision oncology, digital twins, multi-omics AI, and the use of generative AI for drug discovery are all envisioned in the future to link the diagnosis, treatment, and monitoring into a continuous personalized-care pathway, thus further demonstrating the potential for AI to become even more integral to the future of health care. By leveraging AI alongside clinical knowledge, there is a potential to enhance the precision, productivity and patient-centricity of cancer care.

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