Oncology: the study of cancer,Integrative study of cancer pathophysiology with pharmaceutical and clinical research to develop novel therapeutics, understand disease mechanisms, and improve patient prognosis and treatment response

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***Abstract*—Modern oncology has been greatly advanced by the integrative study of cancer pathophysiology alongside pharmaceutical and clinical research. Researchers can find new therapeutic targets and create more potent treatment plans by investigating the genetic and cellular pathways behind the development of cancer. While clinical research assesses the safety, effectiveness, and patient outcomes of anticancer treatments, pharmaceutical research aids in their discovery, design, and optimization. This interdisciplinary approach promotes individualized medicine, increases diagnostic precision, and deepens understanding of disease behavior. In the end, combining these domains improves therapy response, patient prognosis, and the creation of novel treatments for a variety of cancer types. In 2025, clinical research will concentrate on cutting-edge trial designs, tailored treatments, and novel cancer therapeutics, including CAR-T, antibody-drug conjugates, and AI-guided decision systems. Through the integration of genetic insights, optimized dose, and real-world clinical data for improved therapy response, these approaches support precision oncology, improve patient outcomes, and advance drug development. WHO and global cancer research (2020–2025): WHO policies centered on equity, prevention, and better access to care propelled substantial advancements in global cancer research between 2020 and 2025. Precision oncology, immunotherapy, early detection, and understanding the molecular, genetic, and environmental elements that promote unchecked cell development are the main goals of cancer research. To find mutations, signaling pathways, and biomarkers related to tumor formation, it combines molecular biology, pathology, pharmacology, and clinical sciences. In order to enhance patient outcomes, our study supports the development of early diagnostic tools and tailored medicines. Carcinomas, sarcomas, leukemia's, lymphomas, melanomas, and brain tumors are among the most common kinds of cancer. Because each type develops differently, specific treatment strategies are needed. Immunotherapy, precision.**

I. INTRODUCTION

The primary objective of cancer research is to comprehend the molecular, genetic, and environmental factors that encourage unregulated cell proliferation. It integrates molecular biology, pathology, pharmacology, and clinical sciences to identify mutations, signaling pathways, and biomarkers associated with tumour formation. Our research encourages the creation of customized medications and early diagnostic technologies to improve patient outcomes. Among the most prevalent types of cancer are carcinomas, sarcomas, leukemia, lymphomas, melanomas, and brain tumors. Certain treatment approaches are required since each type develops uniquely. Advances in immunotherapy, precision medicine, and genetic profiling are transforming cancer care, helping researchers produce more effective therapies and reduce the global cancer incidence. Genetic alterations that impair regular cell-cycle regulation are part of its pathogenesis, which permits unchecked cell proliferation. Oncogene activation, tumour-suppressor gene inactivation, and flaws in DNA repair systems are important alterations. These changes allow cancer cells to penetrate

neighboring tissues, prevent apoptosis, and stimulate angiogenesis. Tumors may spread through lymphatic or blood channels as they develop, creating additional growths in organs that are farther away. Additionally, tumor cells alter the microenvironment by promoting immune evasion and inflammation. Cancer develops as a result of the interplay between genetic vulnerability and environmental elements such as radiation, chemicals, infections, and lifestyle. Targeted therapy and diagnosis are aided by an understanding of these pathways. In 2025, the goal of drug research will be to create more individualized, focused, and safe cancer treatments. In order to find new therapeutic targets and create precise anticancer medicines, modern research combines molecular biology, genetics, and artificial intelligence. Protein-degrading technologies such as PROTACs, immunotherapies, and targeted treatments are emerging as key strategies. Developments in AI-driven virtual screening save time and money by quickly identifying possible medication candidates. Treatment response and survival are being improved by new medications such as checkpoint inhibitors, antibody-drug conjugates, and RAS inhibitors. Repurposing current medications for oncology is becoming more and more important, which lowers the cost of treatments. Despite advancements, problems like toxicity, tumor heterogeneity, and treatment resistance still call for creative solutions. In general, the trend toward precision and mechanism-based cancer treatment will be more pronounced in 2025.The worldwide cancer burden is rising quickly, according to the WHO/IARC 2025 report. There were almost 20 million new instances of cancer and 10 million deaths worldwide in 2022, and this number is predicted to climb significantly. By 2050, there could be more than 35 million instances of cancer and more than 18 million deaths from the disease per year. According to predictions, there would be 3.2 million new cases of breast cancer and over a million fatalities annually by 2050, making it the most frequent cancer among women. Due to delayed diagnosis and restricted access to healthcare, low- and middle-income nations will be most affected. In order to lessen global disparities, WHO highlights that 30–50% of cancers can be prevented through lifestyle modifications, vaccination, tobacco control, early screening, and improved cancer care systems. The focus of current cancer clinical research is on innovative modalities, biomarker-driven therapy, and precision. Improved progression-free survival was demonstrated in 2025 by studies of targeted treatments such as camizestrant for ESR1-mutant breast cancer and zoldonrasib for KRAS-mutated solid tumors. Surgical alternatives for previously incurable malignancies, such as BRAF-mutated anaplastic thyroid carcinoma, were made possible by neoadjuvant combinations of immunotherapy and targeted medications. Liquid biopsy-guided therapy improves results by enabling early identification of resistance mutations and treatment modification. Furthermore, novel small-molecule inhibitors, antibody-drug conjugates, and T-cell receptor treatments increased the number of choices for treating uncommon lung, breast, and brain malignancies. Personalized, combination-based approaches, therapy and diagnostics, and advancing treatments to earlier stages of the disease are the main trends. These developments are intended to improve survival, lessen toxicity, and offer customized treatment for a variety of cancer types across the globe. Cancer-causing tumor suppressor genes, and DNA repair pathways, interfering with normal apoptosis and cell cycle regulation. Understanding these mechanisms has been greatly aided by Nobel Prize-winning discoveries. In order to explain how unchecked proliferation happens, Tim Hunt, Paul Nurse, and Leland Hartwell discovered cell cycle regulators and checkpoints. Immune checkpoint pathways (CTLA-4, PD-1) were discovered by James Allison and Tasuku Honjo, which revealed how cancers avoid immune surveillance and resulted in groundbreaking immunotherapies. These biological pathways are now the focus of therapeutic approaches: Immunotherapies boost T-cell activity against tumors, PROTACs and CAR-T cells directly eradicate cancer cells, and targeted medications suppress oncogenes like RAS, BRAF, or HER2. Precision medicine, which improves efficacy, lowers toxicity, and provides customized cancer therapies worldwide, is made possible by an understanding of disease mechanisms at the molecular level. A patient's anticipated course, outcome, and survival are referred to as their cancer prognosis. It relies on a number of variables, such as therapy response, patient health, and tumor features. Aggressiveness and treatment efficacy are influenced by tumor type, stage, grade, and molecular markers, including HER2, KRAS, or BRCA mutations. Compared to advanced or metastatic disease, early-

stage malignancies typically have better prognoses. Prognosis is also influenced by patient characteristics such as age, general health, and comorbidities. Surgery, chemotherapy, radiation, targeted therapy, and immunotherapy are important treatment techniques; cancers that react well to therapy have higher survival rates. 5-year survival or median survival rates are common ways to indicate prognosis. Results can be dynamically changed by ongoing monitoring, individualized treatment, and supportive care, highlighting the significance of early discovery and customized therapies for improved patient prognosis. Terms A variety of treatments are used to treat cancer, depending on the patient's health, the type of tumor, and its stage. Localized tumors are removed by surgery, which is frequently paired with radiation therapy to eradicate any cancer cells that remain. While targeted therapy blocks particular biological pathways like HER2, RAS, or BRAF mutations, chemotherapy uses cytotoxic medicines to kill rapidly dividing cells. Checkpoint inhibitors (PD-1, CTLA-4) and CAR-T cell treatment are examples of the immune system to combat cancer cells. Hormone-sensitive malignancies, such as prostate and breast cancer, are treated with hormone treatments. PROTACs and antibody–drug conjugates, which specifically target cancer proteins, are examples of recent developments. Treatment regimens are tailored to the patient's condition, tumour genetics, and molecular profiling. Cancer patients' quality of life and survival are improved, efficacy is increased, and recurrence is decreased with early detection and combination therapy.

Aetiology and epidemiology

These sections detail risk factors for skin cancer, classifying them as exposures and infections. Over a million cases of skin cancer are identified each year as a result of solar exposure, particularly in fair-skinned individuals at low latitudes who work outside or use tanning beds. Risk is also increased by other ionizing radiation, such as previous radiotherapy. Long-term exposure to arsenic, hydrocarbons, and soot, as well as immunosuppression from medications or illnesses like HIV and specific genetic disorders, are additional environmental dangers. Infections also play a role: Hepatitis B and C are associated with hepatocellular carcinoma, Epstein-Barr virus with certain lymphomas and nasopharyngeal carcinoma, and human papillomavirus with cervical and some skin malignancies. While Schistosoma and liver flukes are linked to bladder and biliary tract cancers, Helicobacter pylori predisposes to stomach cancer.

Genetics of The Cancer

High-throughput sequencing developments have revolutionized cancer genetics by identifying many mutations that propel the growth of tumours. Accumulated DNA mutations that interfere with normal regulation of cell proliferation, death, and differentiation are the cause of cancer. Oncogene activation (e.g., RAS, BRAF, MYC) and tumour suppressor gene loss (e.g., TP53, APC, BRCA1/2) are important genetic changes. While passenger mutations have no effect on tumour behavior, driver mutations accelerate the development of cancer. Multistep carcinogenesis demonstrates how malignancies develop through successive mutations that impact pathways like TGF-β, PI3K, and Wnt. Mismatch repair genes and BRCA1/2 are two prominent instances of inherited mutations that predispose people to cancer. Although there are still psychological and clinical issues, genetic testing aids in identifying at-risk patients, directing surveillance, and informing tailored therapy.

Surgical Oncology

A multidisciplinary team (MDT) comprising surgeons, oncologists, radiologists, pathologists, and allied health professionals supports surgical oncology, which uses surgery as a crucial part of cancer treatment. MDTs oversee clinical trial access, diagnosis, staging, treatment planning, rehabilitation, and follow-up. Prophylaxis, palliation, curative resection, identification, and treatment of metastatic disease are all important functions of surgery. Imaging, core biopsy, FNA, endoscopy, and laparoscopy for tissue collection and staging are among the diagnostic techniques. The goal of curative surgery differs depending on the biology and kind of cancer and is to remove the entire tumour with distinct margins. Palliative surgery improves quality of life by managing symptoms such as ascites, discomfort, fistulae, jaundice, bleeding, and blockage. For certain patients, surgery for restricted metastases—particularly those in the brain, lung, and liver—can extend survival. Selective surgery for metastatic cancer is beneficial for isolated metastases of the brain, liver, lung, and bone. Palliative operations,

fixation, ablation, and excision are among the options. Malignant effusions are typically treated medically. Colectomy, thyroidectomy, orchiectomy, and BRCA-related risk-reducing mastectomy or oophorectomy are examples of prophylactic surgery that prevents cancer in high-risk patients.

Principal of Radiation Oncology

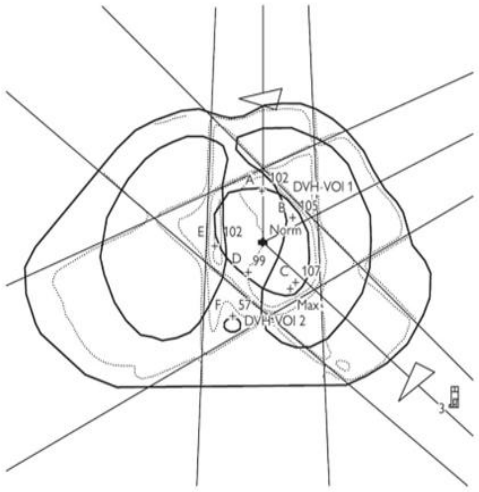
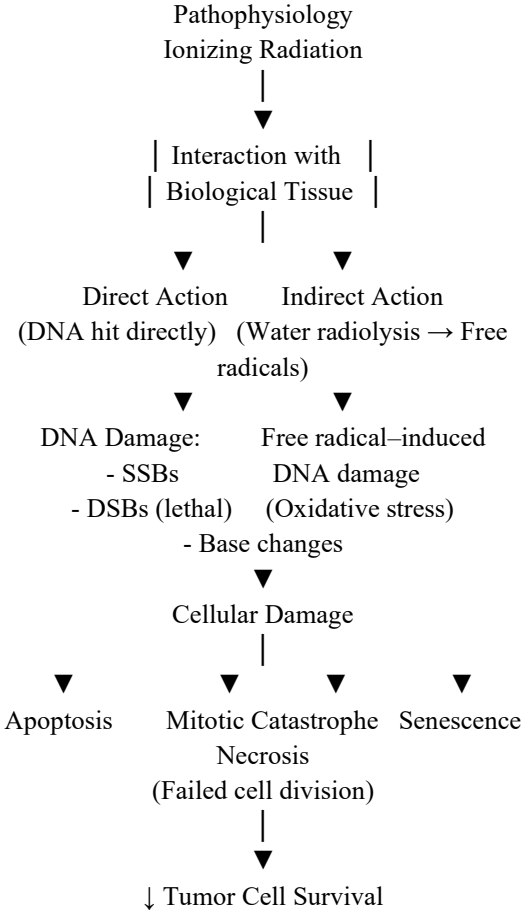


Fig. 4.2 Three radiotherapy beams converging on a CT-defined volume of lung cancer.

Ionizing radiation, primarily external beam radiotherapy (EBRT), is used in radiation oncology to treat cancerous conditions. Precision and safety have been enhanced throughout its development, from the discovery of X-rays to IMRT and IGRT. Ionization from radiation damages DNA, leading to apoptosis or loss of reproductive ability. Radiosensitivity, dose, and fractionation all affect normal tissue reactions. While late consequences, including fibrosis or organ malfunction, manifest months to years later, acute effects, mostly in the skin, mucosa, GI tract, and bone marrow, happen within eight weeks. The goal of radiation oncology is to minimize harm to nearby healthy tissues while administering an efficient tumour dosage. High-resolution CT, MRI, and PET for accurate 3D tumour volume delineation; image-guided radiation (IGRT) for precise positioning; and intensity-modulated radiotherapy (IMRT) that modifies beam intensity to satisfy dosage restrictions are examples of advancements in external beam radiotherapy. Precision is further enhanced by methods like 4D respiratory-gated planning, tomotherapy, and dynamic multileaf collimators. Because of its low exit dose and restricted tissue penetration, electron beam treatment is beneficial for surface tumours. In gynecological, prostate, and breast cancers in particular, brachytherapy offers quick dose fall-off and excellent local control by delivering high-dose radiation directly. The goal of radiation oncology is to minimize harm to nearby healthy tissues while administering an efficient tumour dosage. High-resolution CT, MRI, and PET for accurate 3D tumor volume delineation; image-guided radiation (IGRT) for precise positioning; and intensity-modulated radiotherapy (IMRT) that modifies beam intensity to satisfy dosage restrictions are examples of advancements in external beam radiotherapy. Precision is further enhanced by methods like 4D respiratory-gated planning, tomotherapy, and dynamic multileaf collimators. Because of its low exit dose and restricted tissue penetration, electron beam treatment is beneficial for surface tumours. In gynecological, prostate, and breast cancers in particular, brachytherapy offers quick dose fall-off and excellent local control by delivering high-dose radiation directly.

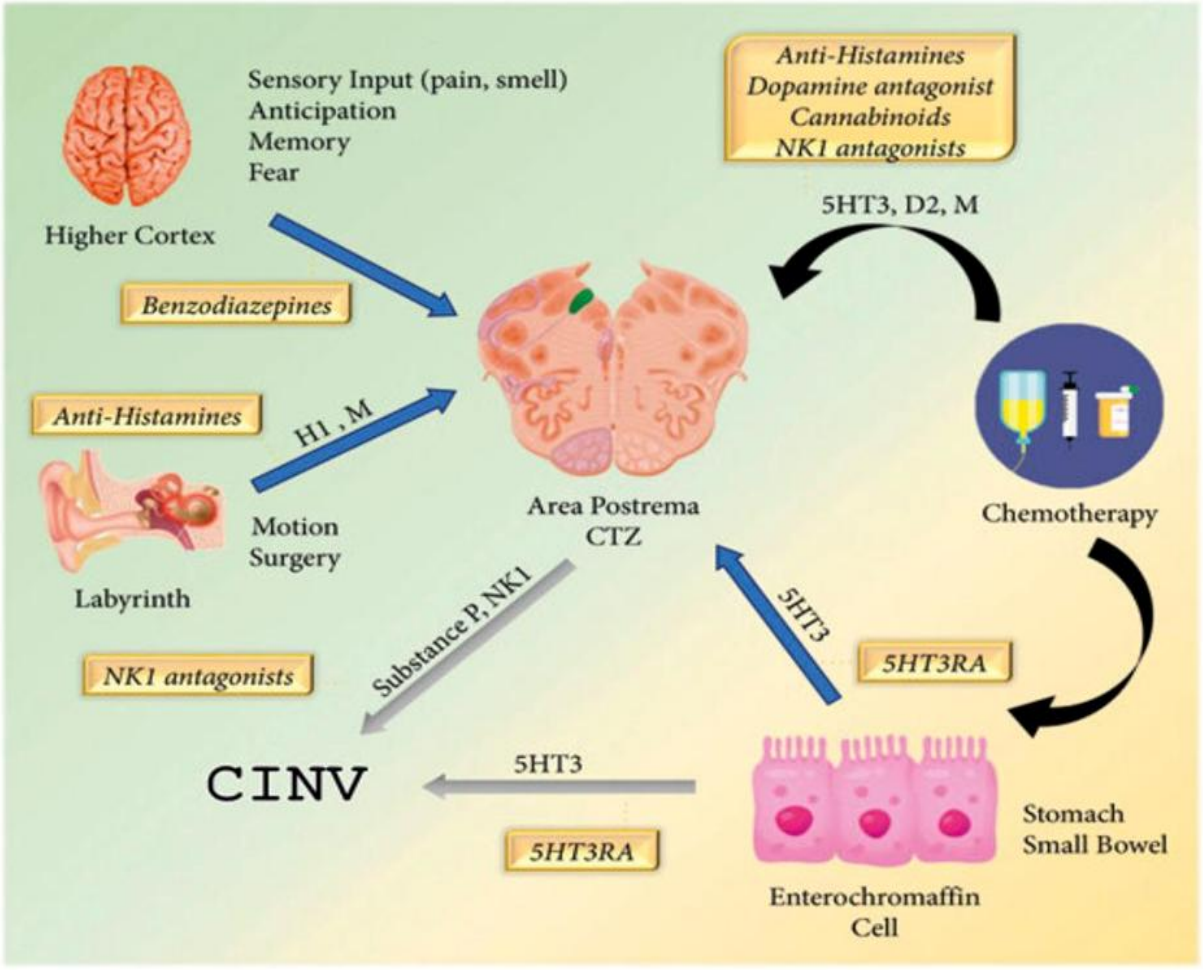


↓ Tumor Proliferation
|
▼
Tumor Control or Regression
|
▼ ▼
Normal Tissue Response | Tumor Factors (Hypoxia, cell cycle)
▼ ▼
Acute & Late Toxicities | ↓ Radiosensitivity ↓ Treatment

Chemotherapy

Radiation oncology focuses on treating cancer through targeted ionizing radiation that damages tumour DNA. Acute and late toxicities vary by organ: skin may develop atrophy, fibrosis, and telangiectasia; oral mucosa shows erythema and ulceration; the GI tract develops mucositis, diarrhoea, and long-term fibrosis. CNS effects include demyelination and radiation necrosis, while lungs may develop pneumonitis and fibrosis. Chemotherapy principles involve using cytotoxic drugs that disrupt DNA synthesis, cell division, or metabolism. Alkylating agents cross-link DNA, antimetabolites inhibit nucleotide synthesis, and anthracyclines intercalate DNA and inhibit topoisomerase II. Drug resistance arises from enhanced repair or efflux pumps. Combination regimens use drugs with different mechanisms and non-overlapping toxicities to increase cancer cell kill while minimizing side effects such as myelosuppression, mucositis, and organ-specific toxicities.

Pathophysiology chemotherapy



Pathophysiology of Chemotherapy

Chemotherapy Drug Given

⬇️

Drug enters bloodstream → reaches tumour

⬇️

Targets rapidly dividing cells

⬇️

Mechanisms of Action:

• DNA damage (alkylation / cross-linking)
• Inhibition of DNA synthesis (antimetabolites)
• Inhibition of topoisomerase (anthracyclines)
• Mitotic arrest (taxanes, vinca alkaloids)

⬇️

Cellular Effects:

• Cell-cycle arrest
• Blocked DNA replication
• Failed mitosis
• Activation of apoptosis pathways

⬇️

Tumour Cell Death → Reduced cancer growth

⬇️

Collateral Damage to Normal Rapidly Dividing Cells

• Bone marrow → myelosuppression
• GI mucosa → mucositis, diarrhoea
• Hair follicles → alopecia
• Gonads → infertility

⬇️

Possible Drug Resistance

• Increased DNA repair
• Drug efflux pumps (P-gp)
• Mutated drug targets

⬇️

Reduced Treatment Effectiveness

Clinical trials
Methodology in cancer

Introduction

Clinical trials can be classified as:

• phase I studies

• phase II studies

• phase III studies.

In addition, some phase III studies are sometimes referred to as phase IV or Post-marketing studies.No study should be started without a protocol that describes in detail: the aim of the study the patient eligibility criteria the screening and follow-up studies the treatment the criteria to score toxicity and activity.In addition, rules for informed consent procedures should be specified. Trials of any sort should have approval by a properly constituted ethics Committee.All of these criteria have been specified in guidelines produced by the International Conference for Harmonisation for Good Clinical Practic (ICH-GCP). They are also now embedded in European Union (EU) legisla-Tion on the conduct of all trials of new therapeuPhase I studies Phase I studies are human toxicology studies. Their endpoint is safety, an They usually include 15–30 patients. They are designed to define a feasible Dose for further studies. These studies begin at a dose that is expected to Be safe in humans. Dose escalation is usually between cohorts, and infre- Quently in individual patients. It can be: according to the Fibonacci method (the dose is escalated in decreasing Percentages of the previous dose, i.e. 100%, 66%, 50%, 33%, 25%) according to pharmacokinetics (pharmacokinetically guided dose Escalation, PGDE), using a method that combines statistics wit The experience and expectations regarding side effects (continuous Reassessment method) variation on these methods. The aim of the phase I study is to describe the side effects that limit further Dose escalation (dose-limiting toxicities, DLTs) and to recommend a dose For further studies with the drug or the new administration method (maxi-Mal tolerated dose, MTD)

Phase II studies In phase II studies, the anti-tumour activity of a new drug or method is The endpoint. There are various statistical designs, including 14–60 patientsOn average. With the emergence of drugs that create tumour dormancy, Rather than cell kill, the endpoint of time to progression becomes impor-Tant. This is the time from the start of treatment, until the the first evidenceOf tumour progression. In addition, phase II studies can provide information On side effects related to cumulative drug dose Phase III studiesPhase III studies have either the time to progression or the survival time As the □° endpoint. Phase III studies always include randomization against

A standard form of therapy, or no treatment when no standard therapy Exists. 2° endpoints, such as toxicity, pharmaco-economics, and quality of Life, are often included. Phase III trials can involve between 50 and several Thousands of patients. The number of patients is dependent on the size of The difference expected/clinically important. Cancer trials have often been Criticized in the past for being too small to find realistic differences between Therapies. Breast cancer studies involving many thousands of patients have Been able to define the long-term benefits of hormone therapy and paved The way for larger-scale trials in other common tumours. In the modern Era, many large-scale cancer trials are performed, so that the true level of Benefit of a new approach can be proven and to allow for the regulatory.

Cancer Prevention

Cancer prevention focuses on reducing exposure to carcinogens, modifying lifestyle factors, and using chemopreventive agents to stop or delay cancer development. Smoking-related cancers remain the leading preventable cause of death. Tobacco smoke contains thousands of chemicals, including over 55 proven carcinogens that cause DNA mutations. Smoking accounts for about 90% of lung cancers and contributes to cancers of the larynx, mouth, oesophagus, pancreas, bladder, kidney, cervix, and stomach. Passive smoking is also recognized as harmful. Public health measures such as banning smoking in public places significantly reduce exposure.

Dietary factors may influence cancer risk, though evidence is often conflicting. Excess dietary fat is associated with cancers of the breast, colon, endometrium, and prostate. High dietary fibre may reduce colonic transit time and limit carcinogen exposure, but studies show mixed results. Fruit and vegetable intake shows inconsistent protective effects, though high consumption may lower lung cancer risk in non-smokers. Folate plays a role in DNA repair and methylation; deficiency increases intestinal carcinogenesis, while supplementation may reduce colorectal cancer risk. Carotenoids act as antioxidants, but β-carotene trials show conflicting findings.

Chemoprevention involves using natural or synthetic agents to block or suppress carcinogenesis. Agents may act during initiation (preventing DNA damage) or promotion (blocking proliferation of mutated cells). Some agents, like oltipraz, block activation of carcinogens. Others aim to reverse abnormal differentiation or inhibit pre-neoplastic lesion progression.

Clinical trials in cancer prevention differ from therapeutic trials. Phase I/II trials assess tolerability for long-term use, while Phase III trials involve large populations to determine preventive benefit. Studies involving tamoxifen and agents like retinol and acetylcysteine show mixed but evolving evidence. Emerging molecular biology and biomarkers offer promising future directions in cancer prevention.

Mechanisms of tumour suppression and examples of cancer

Mechanism	Examples
Scavenging O radicals	Polyphenols (curcumin, genistein), Selenium, tocopherol (vitamin E)
Inhibition of arachidonic acid metabolism	Acetylcysteine, NSAIDs (sulindacaspirin), polyphenols, tamoxifen
Modulation of signal transduction	NSAIDs, retinoids, tamoxifen, genistein curumin
Modulation of hormonal/growth factor activity	NSAIDs, retinoids, curcumin, tamoxifen
Inhibition of oncogene activity	Genistein, NSAIDs, monoterpenes (D-limonene, perillyl alcohol.
Inhibition of polyamine metabolism	2-difluoromethylornithine, retinoids,tamoxifen
Induction of terminal differentiation	Calcium, retinoids, vitamin D3
Induction of apoptosis	Genistein, curcumin, retinoids tamoxifen
NSAIDs, non-steroidal anti-inflammatory drug	

Role of Surgery in Cancer Prevention

Prophylactic surgery is an important strategy for cancer prevention in individuals with a significantly increased risk of developing malignancies due to genetic mutations, premalignant lesions, or chronic inflammatory conditions. The aim is to remove the organ or tissue before cancer develops, particularly when the natural history of disease progression is well understood.

In MEN type II and familial medullary thyroid carcinoma, mutations lead to a predictable progression from dysplasia to carcinoma. Therefore, prophylactic total thyroidectomy is recommended in childhood. The American Thyroid Association advises surgery before 1 year of age for MEN IIB and before 5 years for MEN IIA and familial medullary thyroid cancer. The role of additional central lymph node dissection remains debated.

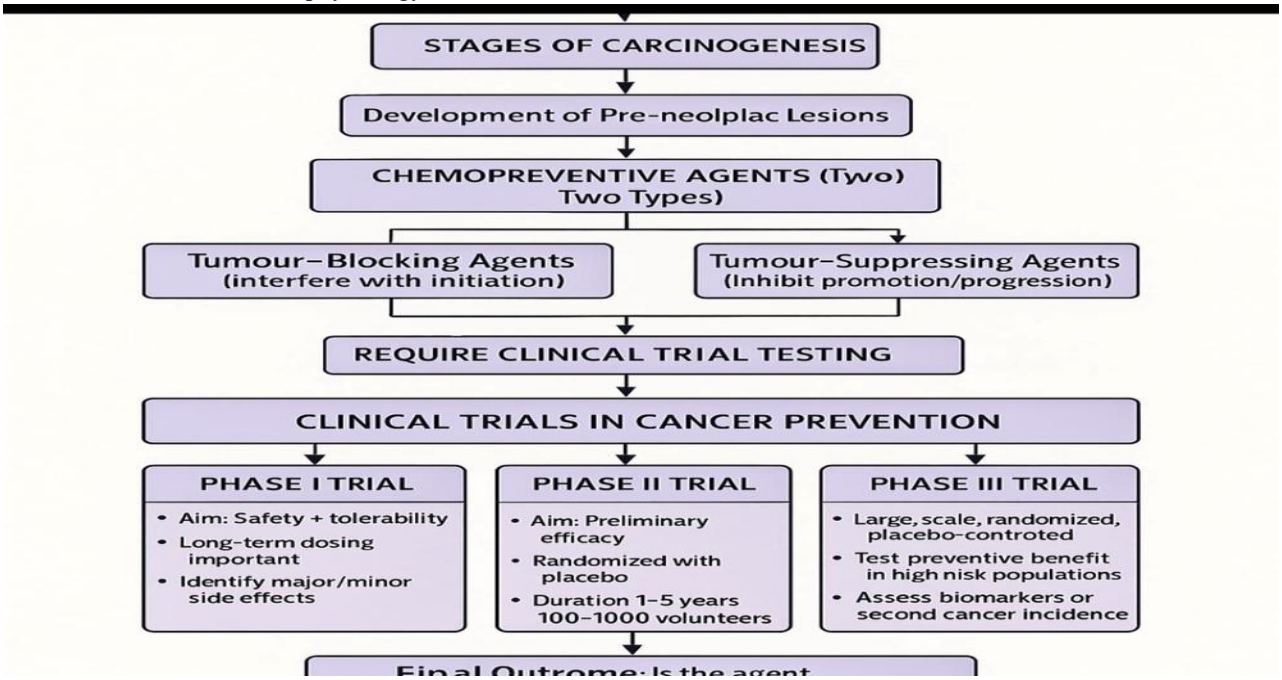
For Barrett's oesophagus, patients with high-grade dysplasia have a 30–40% chance of concurrent invasive adenocarcinoma. Thus, prophylactic oesophagectomy is indicated. Newer endoscopic therapies such as radiofrequency ablation (RFA) may be considered in selected, especially elderly, patients to avoid surgical morbidity.

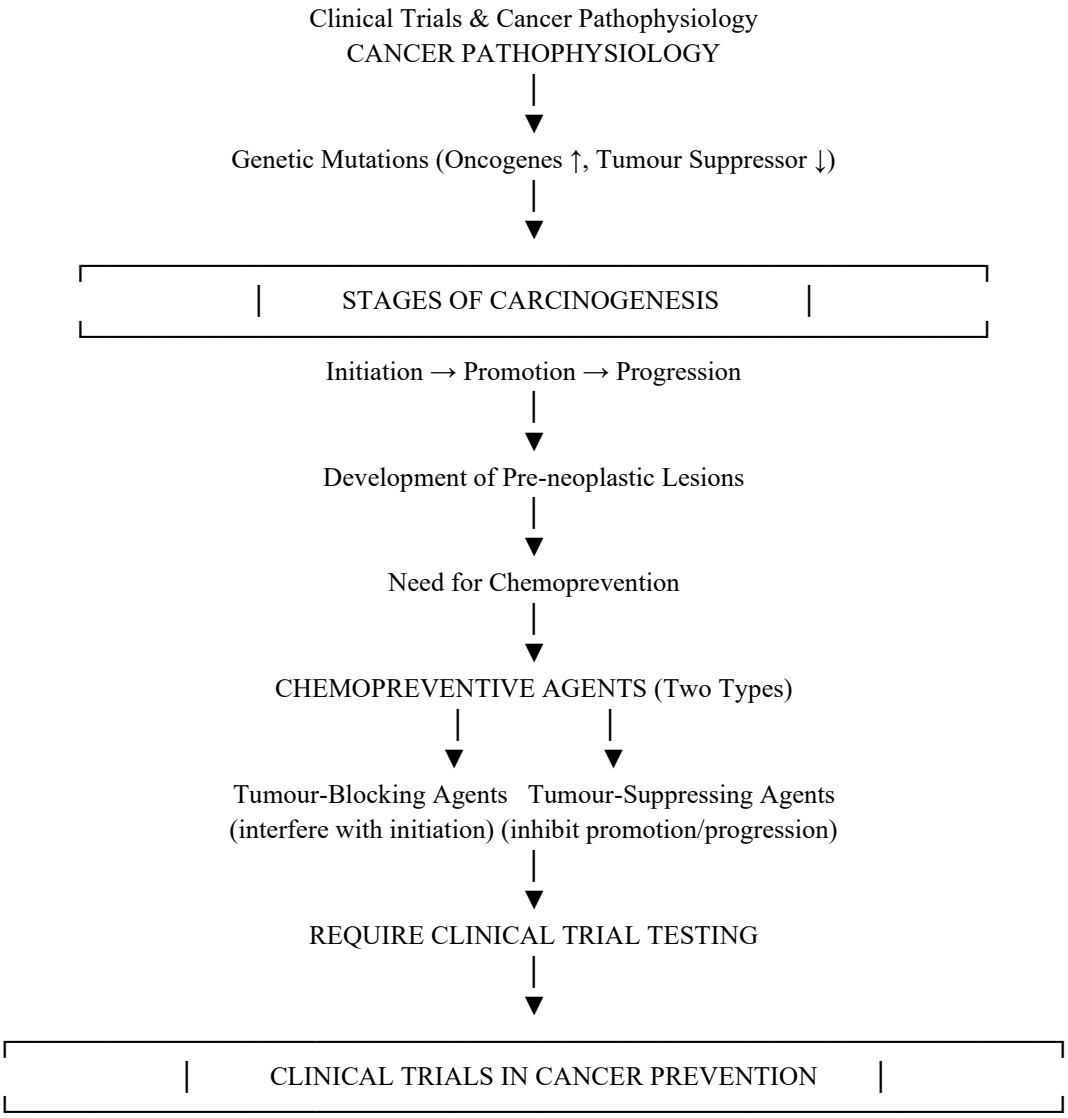
In hereditary diffuse gastric cancer (HDGC) caused by CDH1 gene mutations, individuals carry a high lifetime risk and are advised to undergo prophylactic total gastrectomy.

Patients with long-standing ulcerative colitis (>10 years) and high-grade dysplasia are candidates for proctocolectomy, with or without ileoanal pouch formation. Those with low-grade dysplasia require close colonoscopic surveillance. In familial colorectal cancer syndromes, surgery plays a major preventive role. In FAP (familial adenomatous polyposis), where patients develop hundreds of adenomas, recommended options include proctocolectomy with ileoanal pouch or subtotal colectomy with ileorectal anastomosis, followed by rectal surveillance. For HNPCC (Lynch syndrome), most centres prefer regular colonoscopic surveillance, reserving colectomy for high-grade dysplasia, villous lesions, or unresectable polyps.

In hereditary breast cancer, BRCA1/2 mutation carriers face an 80–90% lifetime risk of breast cancer. Bilateral prophylactic mastectomy, with or without reconstruction, reduces risk by approximately 95%. Conditions like Cowden syndrome also increase risk of breast, endometrial, and thyroid cancers, making prophylactic surgery an option based on risk assessment.Overall, prophylactic surgery provides substantial cancer-risk reduction in well-defined high-risk populations.

Clinical Trials Cancer Pathophysiology





PHASE I TRIAL
- Aim: Safety + tolerability
- Long-term dosing important
- Identify major/minor side effects

PHASE II TRIAL
- Aim: Preliminary efficacy
- Randomized with placebo
- Duration 1–5 years
- 100–1000 volunteers

PHASE III TRIAL
- Large-scale, randomized, placebo-controlled
- Test preventive benefit in high-risk populations
- Assess biomarkers or second cancer incidence

Final Outcome:
Is the agent SAFE + EFFECTIVE for CANCER PREVENTION?

WHO Research Trials

Tab 1: Overview of the childhood cancer drugs

Out of the 440 drugs identified: Drugs were divided into 9 general drug categories. The three most common drug categories were molecular targeted therapies (135; 31%), followed by immunotherapy (108; 25%) and then cytotoxic chemotherapy (93;

21%). Together, the top two categories, molecular targeted and immunotherapy made up 56% of the drugs currently in use (chart A.1).

Drugs were divided into more specific drug types, based upon physical characteristics and/or mechanism of action. Of those, the three most common were small molecule (139; 32%) followed by monoclonal antibody (55; 13%), and then vaccine (49; 11%) (chart A.2).

132 specific drug targets of molecular targeted or immunotherapy were identified. By clicking on a specific target (chart A.3), the drugs with that specific target will be listed in chart E and characteristics of those specific drugs in the remainder of the visualization charts. Certain drugs may have more than one target

Approximately two thirds of all drugs are in phase I (98; 22%) or in phase II (176; 40%) of development.

The most common routes of administration are intravenous (196; 45%), and oral (170; 39%) (chart B.3).

Only 33% of the oral drugs studied were available in paediatric friendly formulations (57 out of 170 drugs) (chart B.3). Criteria for paediatric-friendly included at least one of the following: commercial oral liquid, data available regarding compounding into liquid, available crushable formulation.

18% (78) of the drugs require refrigeration and 25% (112) require light protection. This information was not available for approximately 50% of all the drugs (charts C).

Gliomas, neuroblastoma, and osteosarcoma were the top three malignancies with the highest number of drugs in clinical trials. Note that one drug can be studied for multiple malignancies (charts D).

Overview of the clinical trials on childhood cancer drugs

A total of 2,159 childhood cancer clinical trials have been registered in the ICTRP database between 2007-2022 of which:

47% (1,006 trials) are conducted in the region of the Americas, followed by the Western Pacific region (843; 39%) and the European Region (588; 27%) (chart E.1).

74% (1,601 trials) are located in high income countries (chart E.2).

Select the grouped phases (top left tick boxes) to see the drugs and trials characteristics by these groups.

Select a specific malignancy type (chart D.2) or any other specific element or combination of elements to display the corresponding data in the other charts. For example, by selecting Gliomas in chart D.2, we can see that 156 drugs are studied for this malignancy type, of which 62 (40%) are at phase II (chart B.1). 70 are available in oral formulation (chart B.2) of which 24 are paediatric friendly (chart B.3).

Hold the 'Ctrl' key on your keyboard to select more than one option. For example, in addition to the selection above, by selecting phase II in chart B.1, we can see that 10% of the 62 corresponding drugs are known to require light protection (chart C.2).

Hover the cursor on a bar or a cell in a table to see more information in a pop-up window. For example, hover over the malignancy type in chart E to see the list of corresponding clinical trials (the list of clinical trials is only available for drugs in phase I and phase II)

Undo a selection by clicking 'undo' or 'reset' near the bottom of the page or by clicking the same element again.

Scope, analysis and limitations of the data

Scope

This current landscape and pipeline analysis focuses on drugs in use in paediatric cancer clinical trials registered over the past 15 years (2007-July 2022) with information on the specific drugs included in each of the trials (categories, targets, types, phases, storage needs, etc.).

Trials were restricted to cancer treatment studies (registries, biology studies, supportive care studies, psychosocial studies, etc. were excluded). Minimum age of study participants had to be less than 16 years old.

Data regarding Chimeric antigen receptor (CAR) T-cell therapy were also collected, analysed separately and displayed on a different dashboard.

Analysis

Data collection involved the following sources:

Drug lists:

Drugs were extracted by reviewing the full entries of all relevant trials for childhood cancers registered in the International Clinical Trials Registry Platform (ICTRP)

Drug details information were collected from the following sources:

International Clinical Trials Registry Platform (ICTRP) trial entry

Clinical information platform and literature
Drug information embedded in individual protocols
Direct communication by email or phone with principal investigator or drug company, where applicable.
Trial detailed information was collected from:
International Clinical Trials Registry Platform (ICTRP)
Drug category consists of a general grouping by drug mechanism of action.
Drug type is a more specific clinically relevant characterization of the agent based upon physical characteristics and/or mechanism of action.
A target was listed if the drug, primarily molecularly targeted agents and immunotherapies, had a specific target.

Limitations of the data
This analysis relies on data available in the public domain or from contacted trial leads or pharmaceutical companies.
Up-to-date data on some drugs was not available (e.g., for the storage temperature or the light protection status), particulary for those drugs earlier in the development
Paediatric formulation analysis covers only oral drugs.
This analysis does not cover primarily adult cancers that are occasionally seen in children.
Specific malignancies included for a drug were based upon study inclusion criteria which were sometimes general (e.g. solid tumours) or included a long list of malignancies that qualified and may not reflect actual trial enrollment.

WHO sets new global standard for child-friendly cancer drugs, paving way for industry innovation
Geneva, October 2025 — World Health Organization (WHO) has released six new target product profiles for child-friendly formulations of essential cancer medicines. This publication provides pharmaceutical manufacturers with a clear, technical roadmap to develop much-needed, optimized versions of the medicines specifically designed for use in children worldwide.

Each year, an estimated 400,000 children and adolescents develop cancer, yet survival rates remain below 30% in most low- and middle-income countries (LMICs) compared with over 80% in high-income settings. A significant barrier is the lack of age-appropriate medicines. Children with cancer often rely on adult formulations that are difficult or impractical to administer, leading to inaccurate dosing and unnecessary treatment risks.
The "Accelerating the development of priority formulations in childhood cancer" publication defines targets product profiles (TPPs) with optimal and minimum standards for new, child-friendly formulations of six medicines: cyclophosphamide, etoposide, mercaptopurine, methotrexate, procarbazine, and temozolomide.
The TPPs were developed through a standard WHO procedure including an expert consultation held virtually in December 2024, leveraging expertise of partners and global experts in the WHO's Global Accelerator for Paediatric Formulations Network (GAP-f).
Since announcing its first-ever list of priority paediatric cancer formulations in January 2024, WHO has been leading the work on the development of TPPs in childhood cancer, working closely with GAP-f partners including St. Jude Children's Research Hospital, the European Paediatric Formulation Initiative (EuPFI) and the International Society of Paediatric Oncology (SIOP).
A public consultation in spring 2025 gathered additional feedback from industry experts, product developers, the scientific community including paediatric oncologists, pharmacists and formulations experts, implementers, clinicians, and health programme personnel currently involved in the management of childhood cancer.
These efforts led to the successful launch of the six TPPs providing a blueprint outlining the desired characteristics of optimized child-friendly formulations. This work directly supports the goals of the Global Initiative for Childhood Cancer and complements the efforts of the Global Platform for Access to Childhood Cancer Medicines by promoting equitable access to safe, effective, and easy-to-administer cancer medicines for children worldwide.
"Every child with cancer deserves medicines that are safe, effective, and suitable for their age," says Martina Penazzato, GAP-f lead in WHO's Science for Health, Science Division, "The work of WHO and its GAP-f partners on these TPPs serves as a reminder of the urgent need for investment and innovation in

paediatric oncology drug development — a field that still trails adult oncology by nearly a decade."

These six TPPs provide clear guidance to manufacturers to address these issues by prioritizing:

Flexible, child-friendly dosage forms such as dispersible or orodispersible tablets, minitablets, or multiparticulates;

Stable formulations suitable for hot and humid climates, with shelf-lives over 24 months;

Palatable and acceptable taste profiles, tested through validated assessments;

Clear caregiver instructions for safe handling, including in low-literacy settings; and

Affordable, sustainable production to ensure accessibility in LMICs.

The new TPPs will set the basis for potential future inclusion of these formulations in WHO's Prequalification Expression of Interest list and, eventually, in the Model List of Essential Medicines for Children once new formulations are available.

Next Step:

Join the 2025 GAP-f private sector entities dialogue

Build on this momentum, GAP-f invites private-sector innovators and manufacturers to join the 2025 private sector entities dialogue on 11 November 2025, a virtual event hosted in collaboration with the Access to Medicine Foundation.

This dialogue will explore technical solutions, shared challenges, and partnership opportunities to accelerate paediatric formulations development and access. Agenda highlights include discussions on how to strengthen partnership among stakeholders active on paediatric medicines development and the pharmaceutical sector, in alignment with GAP-f 2025-2030 Strategy, as well as a dedicated thematic session on childhood cancer to enhance mutual understanding of remaining challenges and shared solutions,

Be part of this collaborative dialogue and help shape the next phase of GAP-f's work to ensure better medicines for children everywhere

Childhood cancer

Key facts

Each year, an estimated 400 000 children and adolescents of 0–19 years old develop cancer (1).

The most common types of childhood cancer include leukemias, brain tumours, lymphomas, and solid tumours such as neuroblastoma and Wilms tumour.

In high-income countries, where comprehensive services are generally accessible, more than 80% of children with cancer are cured. In low- and middle-income countries (LMICs), less than 30% are cured (2).

Avoidable deaths from childhood cancers in LMICs result from lack of diagnosis, misdiagnosis or delayed diagnosis, obstacles to accessing care, abandonment of treatment, death from toxicity and relapse (2).

Only 29% of low-income countries report that cancer medicines are generally available to their populations compared to 96% of high-income countries.

Overview

Cancer is a leading cause of death for children and adolescents. The likelihood of surviving a diagnosis of childhood cancer depends on the country in which the child lives; in high-income countries, more than 80% of children with cancer are cured, but in many LMICs less than 30% are cured (2).

Although childhood cancer cannot generally be prevented or identified through screening, most types of childhood cancer can be cured with generic medicines and other forms of treatment, including surgery and radiotherapy.

The reasons for lower survival rates in LMICs include delay in diagnosis, an inability to obtain an accurate diagnosis, inaccessible therapy, abandonment of treatment, death from toxicity (side effects) and avoidable relapse. Improving access to childhood cancer care, including to essential medicines and technologies, is highly cost-effective, feasible and can improve survival in all income settings.

Childhood cancer data systems are needed to drive continuous improvements in the quality of care, and to inform policy decisions.

Causes

Cancer occurs in people of all ages and can affect any part of the body. It begins with genetic change in single cells, that can then grow into a mass (or tumour), invade other parts of the body and cause harm and death if left untreated. Unlike cancer in adults,

most childhood cancers do not have a known cause. Many studies have sought to identify the causes of childhood cancer, but very few cancers in children are caused by environmental or lifestyle factors. Cancer prevention efforts in children should focus on behaviours that will prevent the child from developing preventable cancer as an adult.

Some chronic infections, such as HIV, Epstein-Barr virus and malaria, are risk factors for childhood cancer. They are particularly relevant in LMICs. Other infections can increase a child's risk of developing cancer as an adult, so it is important to be vaccinated (against hepatitis B to help prevent liver cancer and against human papillomavirus to help prevent cervical cancer) and to other pursue other methods such as early detection and treatment of chronic infections that can lead to cancer.

Current data suggest that approximately 10% of all children with cancer have a predisposition because of genetic factors (3). Further research is needed to identify factors impacting cancer development in children.

Improving outcomes of childhood cancer

Because it is generally not possible to prevent cancer in children, the most effective strategy to reduce the burden of cancer in children and improve outcomes is to focus on a prompt, correct diagnosis followed by effective, evidence-based therapy with tailored supportive care.

Early diagnosis

When identified early, cancer is more likely to respond to effective treatment and result in a greater probability of survival, less suffering, and often less expensive and less intensive treatment. Significant improvements can be made in the lives of children with cancer by detecting cancer early and avoiding delays in care. A correct diagnosis is essential to treat children with cancer because each cancer requires a specific treatment regimen that may include surgery, radiotherapy, and chemotherapy.

Early diagnosis consists of 3 components:

Awareness of symptoms by families and primary care providers;

Accurate and timely clinical evaluation, diagnosis, and staging (determining the extent to which a cancer has spread); and

Access to prompt treatment.

Early diagnosis is relevant in all settings and improves survival for many cancers. Programmes to promote early and correct diagnosis have been successfully implemented in countries of all income levels, often through the collaborative efforts of governments, civil society and nongovernmental organizations, with vital roles played by parent groups. Childhood cancer is associated with a range of warning symptoms, such as fever, severe and persistent headaches, bone pain and weight loss, that can be detected by families and by trained primary health-care providers.

Screening is generally not helpful for childhood cancers. In some select cases, it can be considered in high-risk populations. For example, some eye cancers in children can be caused by a mutation that is inherited, so if that mutation or disease is identified in the family of a child with retinoblastoma, genetic counselling can be offered and siblings monitored with regular eye examinations early in life. Genetic causes of childhood cancers are relevant in only a small proportion children with cancer. There is no high-quality evidence to support population-based screening programmes in children.

Treatment

A correct diagnosis is essential to prescribe appropriate therapy for the type and extent of the disease. Standard therapies include chemotherapy, surgery and/or radiotherapy. Children also need special attention to their continued physical and cognitive growth and nutritional status, which requires a dedicated, multi-disciplinary team. Access to effective diagnosis, essential medicines, pathology, blood products, radiation therapy, technology and psychosocial and supportive care are variable and inequitable around the world.

However, cure is possible for more than 80% of children with cancer when childhood cancer services are accessible. Pharmacological treatment, for example, includes inexpensive generic medications included on the WHO List of essential medicines for children. Children who complete treatment require

ongoing care to monitor for cancer recurrence and to manage any possible long-term impact of treatment.

Palliative care

Palliative care relieves symptoms caused by cancer and improves the quality of life of patients and their families. Not all children with cancer can be cured, but relief of suffering is possible for everyone. Paediatric palliative care is considered a core component of comprehensive care, starting when the disease is diagnosed and continuing throughout treatment and care, regardless of whether a child receives treatment with curative intent.

Palliative care programmes can be delivered through community and home-based care, providing pain relief and psychosocial support to patients and their families. Adequate access to oral morphine and other pain medicines should be provided for the treatment of moderate to severe cancer pain, which affects more than 80% of cancer patients in the terminal phase.

WHO response

In 2018, WHO launched, with the support of St. Jude Children's Research Hospital, the Global Initiative for Childhood Cancer (Global Initiative), to provide leadership and technical assistance to governments to support them in building and sustaining high-quality childhood cancer programmes. The goal is to achieve at least 60% survival for all children with cancer by 2030. This represents an approximate doubling of the current cure rate and will save an additional 1 million lives over the next decade.

The CureAll framework and its accompanying technical package have been developed to support implementation of the Initiative. The package helps governments and other stakeholders assess current capacity, set priorities, generate investment cases, develop evidence-based standards of care and monitor progress. An information-sharing portal has been created to facilitate sharing of expertise between countries and partners.

The Global Initiative is part of the response to the World Health Assembly resolution Cancer Prevention and Control through an Integrated Approach (WHA70.12), focused on the reduction of premature mortality from NCDs and the achievement of universal health coverage.

In December 2021, WHO and St Jude Children's Research Hospital launched the Global Platform for Access to Childhood Cancer Medicines (Global Platform), the first of its kind, to provide an uninterrupted supply of quality-assured childhood cancer medicines with end-to-end support from selecting to dispensing medicines according to best possible care standards. The Global Platform synergizes with the Global Initiative, with activities implemented through this new effort expected to contribute substantially to the achievement of the initiative's goals.

WHO and the International Agency for Research on Cancer (IARC) collaborate with the International Atomic Energy Agency (IAEA) and other UN organizations and partners, to:

Increase political commitment for childhood cancer control;

Support governments to develop high-quality cancer centres and regional satellites to ensure early and accurate diagnosis and effective treatment;

Develop standards and tools to guide the planning and implementation of interventions for early diagnosis, treatment and palliative and survivorship care,

Improve access to essential medicines and technologies; and

Support governments to safeguard families of children with cancer from financial harm and social isolation as a result of cancer care.

Controlling Cancer

Address this growing burden and achieve targets for premature mortality reduction from noncommunicable diseases (NCDs) set out in the WHO Global action plan for the prevention and control of NCDs 2013–2020 and achieve target 3.4 of the 2030 United Nations Sustainable Development Goals effective programmes in comprehensive cancer control are needed.

The key mission of WHO's work in cancer control is to promote national cancer control policies, plans and programmes that are harmonized with strategies for NCDs and other related health concerns. Our core functions are to set norms and standards for cancer control including the development of evidence-based

prevention, early diagnosis, screening, treatment, and palliative and survivorship care programmes, as well as, to promote monitoring and evaluation through cancer registries and research that are tailored to the local disease burden and available resources.

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II. CONCLUSION

The integrative study of cancer pathophysiology, combined with pharmaceutical and clinical research, represents a transformative approach in modern oncology. Understanding cancer at its molecular, genetic, and cellular levels provides the foundation for identifying key pathways responsible for uncontrolled cell proliferation, invasion, metastasis, and resistance to therapy. This deep knowledge guides the discovery and development of innovative therapeutics, including targeted agents, immunotherapies, hormone therapies, and personalized treatment strategies. Pharmaceutical research contributes by designing and optimizing drugs that precisely interact with dysregulated cancer pathways, while preclinical studies evaluate their biological effects and safety.

Clinical research plays an equally crucial role by determining the real-world effectiveness of these therapies. Through well-structured clinical trials, researchers can assess drug responses, monitor side effects, establish dosing standards, and identify patient-specific variations that influence outcomes. The integration of clinical evidence with laboratory discoveries enhances the reliability and applicability of new treatments in diverse patient populations.

This multidisciplinary approach improves early diagnosis, refines prognostic tools, and supports the development of individualized treatment plans that maximize therapeutic benefit while minimizing toxicity. It also fosters continuous improvement in patient care by addressing emerging challenges such as drug resistance, tumor heterogeneity, and treatment-related complications.

Overall, integrative oncology strengthens the connection between scientific understanding and clinical practice, ultimately improving patient survival, quality of life, and long-term wellness. As research continues to advance, this combined approach promises more innovative, effective, and compassionate cancer care for future generations.

III. DISCUSSION

The integrative study of cancer pathophysiology, pharmaceutical sciences, and clinical research has become essential for advancing modern oncology. This multidisciplinary approach bridges the gap between laboratory discoveries and patient-centered clinical outcomes. By understanding the molecular drivers of cancer—such as genetic mutations, epigenetic alterations, and disrupted signaling pathways—researchers can develop therapies that target precise mechanisms rather than relying on broadly toxic treatments. This shift has contributed to the emergence of personalized medicine, where individual tumor profiles guide therapy selection to improve effectiveness.

Pharmaceutical research contributes significantly by identifying drug targets, designing therapeutic molecules, and refining formulations to enhance safety and delivery. Preclinical models allow scientists to evaluate drug behavior before entering human trials, ensuring that only the most promising strategies progress. Clinical trials, on the other hand, validate these treatments in real-world scenarios, providing crucial data on efficacy, side effects, and patient heterogeneity.

Despite progress, several challenges persist. Tumor heterogeneity and the ability of cancer cells to develop resistance continue to limit long-term treatment success. Moreover, disparities in access to advanced diagnostics and therapies affect global cancer outcomes. Collaborative research, better biomarker discovery, and integration of artificial intelligence may help address these limitations by improving prediction of treatment response and enabling more precise therapeutic approaches.

Overall, the discussion highlights that the future of oncology relies on seamless collaboration between basic sciences, pharmaceuticals, and clinical practice. Only through such integration can we achieve safer, more effective, and patient-tailored cancer therapies capable of significantly improving survival and quality.

IV. RESULT

The integrative analysis of cancer pathophysiology, pharmaceutical development, and clinical research revealed several significant findings. First, the study highlighted that understanding molecular mechanisms—such as oncogene activation, tumor suppressor gene inactivation, angiogenesis, and metastatic signaling—directly contributes to the creation of more precise and effective therapeutic strategies. This molecular insight supports the development of targeted therapies and immunotherapies, which demonstrated improved specificity and reduced toxicity compared to traditional chemotherapy.

The review of pharmaceutical research indicated that advancements in drug design, nanocarrier formulations, and biomarker-driven drug development have enhanced treatment precision and therapeutic index. These innovations showed promising results in preclinical and early clinical trial stages, particularly in cancers with identifiable molecular signatures.

Clinical trial data emphasized the importance of personalized treatment approaches. Patients receiving therapies tailored to their tumor biology exhibited better treatment response, longer progression-free survival, and improved quality of life. Additionally, the integration of genomic profiling and advanced diagnostics significantly improved early detection and prognostic accuracy.

However, results also indicated challenges, including treatment resistance, tumor heterogeneity, and variations in patient response across different populations. These findings highlight the need for continuous research, better biomarker discovery, and wider access to advanced therapies.

Overall, the results suggest that integrating cancer biology with pharmaceutical and clinical research leads to more effective therapeutic strategies, improved patient outcomes, and stronger foundations for future innovations in oncology.

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