REVIEW ARTICLE

Preventive Oncology: A Public Health Priority

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ABSTRACT

Cancer remains one of the foremost causes of morbidity and mortality worldwide, with an estimated 20.6 million new cases diagnosed in 2024 and projections indicating a rise to nearly 35 million cases annually by 2050. Approximately 37% of new cancer cases globally are attributable to modifiable or preventable risk factors, underscoring the substantial potential of evidence-based prevention strategies to reduce the future cancer burden. This review synthesises current evidence on the global burden of cancer, the modifiable and non-modifiable determinants of cancer risk, and the structured framework of primary, secondary, and tertiary preventive oncology. It also examines systemic barriers to implementation and presents population-level evidence from England, Finland, Australia, and the Indian states of Sikkim and Tamil Nadu, showing that organised, evidence-based preventive interventions can measurably reduce cancer incidence and mortality. The review concludes that strengthening preventive oncology, supported by political commitment, health-system capacity, and equitable financing, is essential to complement advances in cancer diagnosis and treatment.

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1. Introduction: Understanding Cancer as a Global Health Challenge

Cancer is a broad term encompassing a large group of diseases that can affect virtually any part of the body. A defining biological feature of cancer is the uncontrolled proliferation of abnormal cells that grow beyond their usual boundaries and can invade adjoining tissues or spread to distant organs, a process known as metastasis, which remains the principal cause of cancer-related death.[1] Malignant transformation can arise in almost any cell or tissue, from the skin and blood to the lungs and bones, when the normally tightly regulated process of cell division is disrupted by changes in cellular DNA. Over time, these abnormal cells accumulate to form a tumour that can invade locally and spread distantly.

More than 100 distinct types of cancer have been described, each with characteristic clinical features, natural history, and treatment approaches. Substantial progress has been made in understanding the causes of cancer: the International Agency for Research on Cancer (IARC) has identified 135 agents that are carcinogenic to humans.[2] Age is an important determinant of cancer risk, as the body's natural mechanisms for repairing or eliminating damaged cells become progressively less efficient over time. Genetic predisposition, environmental exposures, lifestyle behaviours, and exposure to infectious agents or chemical carcinogens further modulate individual risk.

In India and globally, cancer continues to represent a major public health concern, driven by a complex interplay of genetic susceptibility, environmental exposures, and limited public awareness of modifiable risk factors. Low awareness delays both preventive action and early detection, both of which are central to improving long-term outcomes. A clearer understanding of cancer risk factors therefore enables individuals and health systems alike to

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reduce the overall burden of disease.

2. The Global Burden of Cancer

Cancer is a leading cause of death worldwide, accounting for nearly 10 million deaths in 2024.[1] The cancers most frequently diagnosed that year, by number of new cases, were cancers of the lung (2.6 million cases), breast (2.4 million cases), colon and rectum (2.0 million cases), prostate (1.5 million cases), non-melanoma skin (1.1 million cases), and stomach (1.0 million cases). The leading causes of cancer death were cancers of the lung (1.86 million deaths), colon and rectum (918,000 deaths), liver (732,000 deaths), breast (694,000 deaths), and stomach (642,000 deaths).[1]

The distribution of common cancers varies considerably between countries. Cervical cancer, for example, remains the most common cancer among women in 26 countries, predominantly located in sub-Saharan Africa and parts of South and Central America, Melanesia, and South-East Asia, reflecting persistent disparities in HPV vaccination coverage and access to screening.[1] Regional differences extend beyond individual cancer types to overall disease burden: age-standardized incidence rates for all cancers combined (world standard population, per 100,000) are highest in Oceania and Northern America, followed by Europe, Latin America and the Caribbean, Asia, and Africa, a gradient that broadly mirrors regional differences in risk-factor prevalence, screening infrastructure, and diagnostic and reporting capacity.[1] Cancer also represents a leading cause of death among children and adolescents; approximately 400,000 children and adolescents aged 0–19 years are diagnosed with cancer each year.[3]

As highlighted in the World Health Organization (WHO) Global Status Report on Cancer 2026, the global cancer burden is increasing rapidly. An estimated 20.6 million people were diagnosed with cancer worldwide in 2024, and without urgent intervention, annual new cancer cases are projected to rise to nearly 35 million by 2050.[4,5] This anticipated increase underscores the need to shift the focus of cancer control from a predominantly treatment-oriented model towards comprehensive prevention, early detection, and timely intervention. Recent estimates from WHO and IARC indicate that approximately 37% of new cancer cases globally, around 7.1 million cases in 2022, are attributable to modifiable or preventable risk factors, highlighting the substantial potential of evidence-based prevention strategies to reduce future cancer burden.[4, 5] Although no single unifying cause of cancer has been established, the scientific community has identified a well-characterized set of biological, environmental, lifestyle-related, and hereditary factors that materially influence cancer risk, discussed in the following section.

3. Risk Factors for Cancer Development

Cancer arises from the interaction of multiple, often independent, risk factors rather than from a single identifiable trigger. Understanding these determinants allows individuals and health systems to lower overall cancer risk through targeted intervention.

3.1 Biological and Environmental Risk Factors

- Tobacco Use: Tobacco exposes the body to carcinogenic chemicals through both smoking and smokeless (gum/chewing) forms. The resulting DNA damage substantially raises the risk of lung, oral, and throat cancers, making tobacco one of the leading avoidable causes of cancer.
- Radiation Exposure: Frequent ultraviolet exposure and contact with radioactive substances induce cellular mutations that increase the risk of skin and internal-organ cancers when protective measures are inadequate.
- Infections and Viruses: Persistent infections such as human papillomavirus (HPV) and hepatitis B or C viruses cause chronic inflammation and genetic damage, notably raising the risk of cervical and liver cancer, respectively.
- Hormonal Imbalances: Prolonged exposure to exogenous or endogenous hormones can alter cellular behavior, particularly in breast and uterine tissue, increasing the risk of hormone-sensitive cancers including breast, uterine, and ovarian cancer.
- Chronic Inflammation: Long-standing inflammatory states cause repeated cycles of tissue damage and repair that can promote malignant transformation, particularly within the bowel and liver.
- Pesticide and Agrochemical Exposure: Prolonged occupational and environmental exposure to organophosphate and organochlorine pesticides has been associated with an increased risk of several

malignancies, particularly among agricultural communities with intensive and poorly regulated chemical use. This risk is well illustrated in the Kashmir Valley, where orchard cultivation relies heavily on repeated application of agents such as chlorpyrifos, mancozeb, and captan; a case-control study of orchard workers, residents, and children in the region found a markedly higher risk of primary malignant brain tumours among those with long-term pesticide exposure compared with unexposed individuals.[6] This regional example underscores how localised agricultural practices and inadequate protective measures can meaningfully shape population-level cancer risk.

3.2 Lifestyle-Related Risk Factors

Certain everyday behaviours contribute substantially, and often unknowingly, to cancer risk. Modification of these behaviours represents one of the most accessible and cost-effective avenues for cancer prevention.

- Poor Diet Choices: Diets high in processed meats, refined sugars, and unhealthy fats promote obesity, chronic inflammation, and cellular damage, increasing the risk of colon and pancreatic cancers.
- Physical Inactivity: Sedentary behaviour is associated with weight gain and hormonal imbalance, both of which influence the development of breast and endometrial cancers.
- Alcohol Consumption: Excessive, long-term alcohol intake is metabolised into acetaldehyde, a toxic compound that damages DNA and impairs cellular repair, contributing strongly to liver and breast cancer risk.
- Unprotected Sun Exposure: Inadequate use of sunscreen or protective clothing allows cumulative ultraviolet damage to DNA, increasing the risk of melanoma and other skin cancers.
- Stress and Sleep Disruption: Chronic stress and irregular sleep patterns weaken immune surveillance and disrupt hormonal regulation, factors that have been indirectly linked to increased cancer vulnerability over time.

3.3 Genetic and Hereditary Risk Factors

- Family History of Cancer: Multiple affected relatives with the same cancer type suggest an inherited mutation, such as BRCA1 or BRCA2, raising the likelihood of breast, ovarian, or colorectal cancer. A family history of colorectal cancer is itself among the most consistently recognized risk factors for the disease, and its occurrence across multiple generations, or at an early age, warrants clinical evaluation for hereditary syndromes such as Lynch syndrome.
- Inherited Gene Mutations: Genetic alterations passed across generations can affect cell growth and division, facilitating malignant transformation even in the absence of external triggers.
- Hereditary Cancer Syndromes: Rare inherited syndromes such as Lynch syndrome and Li-Fraumeni syndrome markedly increase cancer risk owing to impaired DNA repair or dysregulated cell-cycle control.
- Early-Onset Cancer in Relatives: A cancer diagnosis before age 50 in a family member is a red flag for potential inherited risk, often warranting earlier and more frequent screening.
- Ethnic and Racial Genetic Risk Factors: Certain cancers cluster within specific populations; for example, Ashkenazi Jewish individuals have higher rates of BRCA mutations, while some Asian populations face elevated risk of gastric cancer.[7]

4. Why Preventive Oncology Is an Urgent Priority

4.1 Rising Early-Onset Cancers

The increasing incidence of several cancers among younger adults is an emerging public health concern. Early-onset colorectal cancer, in particular, has shown a marked birth-cohort effect: compared with individuals born around 1950, those born around 1990 face approximately twice the risk of colon cancer and four times the risk of rectal cancer. This changing epidemiological pattern highlights the need to strengthen prevention, risk-factor reduction, and early-detection strategies across younger populations.

4.2 Growing Economic and Financial Burden

Cancer imposes substantial economic and financial consequences on individuals, families, and health systems. The WHO Global Status Report on Cancer 2026 highlights the considerable financial hardship associated with a cancer

diagnosis, while broader economic analyses estimate that the global economic cost of cancer between 2020 and 2050 could reach US$25.2 trillion, equivalent to an average annual burden of approximately 0.55% of global GDP. (8) These costs reflect not only direct healthcare expenditure but also lost productivity and premature mortality.

4.3 Persistent Challenges in Timely Diagnosis

Delayed diagnosis remains a major challenge, particularly in low- and middle-income countries (LMICs), where access to screening, diagnostic services, specialised care, and timely treatment is often limited. Late presentation is associated with poorer treatment outcomes, higher treatment costs, and increased pressure on health systems. The WHO Global Status Report on Cancer 2026 highlights persistent inequities in access to cancer prevention, early diagnosis, and treatment, underscoring the need to strengthen health systems across the entire cancer-care continuum.[9]

4.4 Impact on the Oncology Workforce

The rising cancer burden also places substantial demands on the healthcare professionals responsible for cancer care. Studies among oncology residents have documented high rates of burnout, anxiety, and depression; in one Indian tertiary cancer centre, personal and work-related burnout were reported by 71.1% and 67.6% of respondents, respectively, rising to 95% and 85% among medical oncology residents specifically.[10] These findings underscore the importance of workforce well-being as an integral component of sustainable cancer control.

4.5 The Case for Prevention

A substantial proportion of cancers are attributable to modifiable risk factors, making prevention a central pillar of cancer control. Preventive strategies, including tobacco control, vaccination against oncogenic infections, promotion of healthy lifestyles, reduction of harmful environmental exposures, and evidence-based screening, hold considerable potential to reduce both cancer incidence and associated mortality. As the global cancer burden continues to rise, strengthening preventive oncology is essential to complement ongoing advances in diagnosis and treatment.[8–11] Taken together, these challenges demonstrate that a predominantly treatment-oriented approach is insufficient to address the future cancer burden. Strengthening preventive oncology instead offers an opportunity to reduce avoidable risk, detect disease at earlier and more treatable stages, relieve pressure on health systems, and lessen the long-term social and economic consequences of cancer.

5. Key Strategies of Preventive Oncology

Preventive oncology is a subspecialty of oncology focused on measures that either prevent the development of cancer or delay progression of the malignant process. These measures are conventionally organised into three structured lines of defence: primary, secondary, and tertiary prevention.[12,13]

5.1 Primary Prevention: Eliminating Causes Before

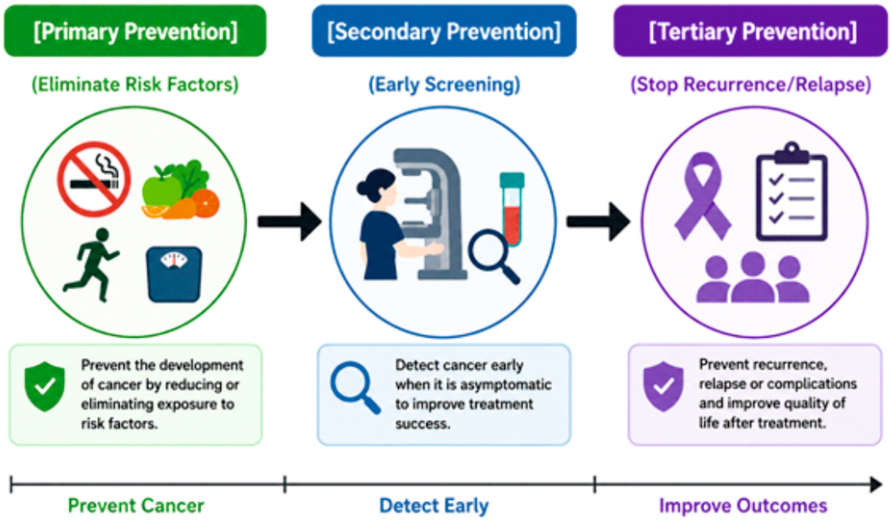


Fig. 1. The three levels of preventive oncology — primary prevention (eliminating risk factors), secondary prevention (early screening and detection), and tertiary prevention (preventing recurrence and improving quality of life after treatment).

Disease Onset

Primary prevention focuses on lifestyle modification, policy change, and medical intervention to prevent cellular damage before it occurs.

- Tobacco Cessation: Tobacco remains the leading preventable cause of cancer, driving more than 20% of global cancer deaths.
- Immunization: Widespread administration of the HPV vaccine blocks cervical, throat, and anal cancers, while the hepatitis B vaccine prevents chronic liver infection that can progress to hepatocellular carcinoma.[14]
- Diet and Lifestyle: Limiting alcohol intake (a Group 1 carcinogen), maintaining an optimal body mass index, avoiding reheated or burnt cooking oils, and remaining physically active substantially reduce metabolic cancer pathways.

5.2 Secondary Prevention: Detecting Pre-Cancer or Early Sub-Clinical Change

Identifying abnormalities before symptoms manifest markedly improves five-year survival rates.

- Routine Screening: Regular Pap smears, mammograms, low-dose CT scans, and colonoscopies enable detection of disease at an earlier, more treatable stage.
- Genetic Surveillance: Individuals with a strong family history may undergo genomic testing to screen for mutations such as BRCA1/2.
- Prophylactic Surgery: High-risk genetic carriers may opt for pre-emptive organ removal, such as risk-reducing bilateral mastectomy or oophorectomy.

5.3 Tertiary Prevention: Preventing Recurrence and Complications

Tertiary prevention applies to patients who have already undergone active cancer treatment. Chemoprevention in this setting involves managing high-risk individuals or post-treatment patients with low-dose medications; for example, long-term low-dose aspirin reduces colorectal adenoma recurrence, while selective oestrogen receptor modulators (SERMs) such as tamoxifen lower the risk of invasive breast cancer recurrence.

6. Chemoprevention and Targeted Preventive Strategies in Selected Cancers

6.1 Breast Cancer

Chemoprevention has been most extensively studied in breast cancer and has provided an important model for cancer risk-reduction strategies more broadly. Selective oestrogen receptor modulators, particularly tamoxifen and raloxifene, reduce the risk of invasive breast cancer in appropriately selected women at increased risk. These agents act by modulating oestrogen receptor signalling and are particularly effective in reducing the incidence of oestrogen receptor-positive breast cancer. Clinical trials have demonstrated substantial risk reduction, although potential benefits must be weighed against adverse effects and individual patient characteristics; consequently, the decision to use chemoprevention should be based on an individualised assessment of breast cancer risk and treatment-related harms.[15] Chemoprevention is also under investigation in other malignancies, including cancers of the colorectum, skin, lung, and head and neck region, though widespread clinical use will require evidence from adequately powered trials demonstrating a favourable balance between risk reduction and toxicity.

6.2 Cervical Cancer

Cervical cancer is largely preventable through a combination of primary and secondary prevention strategies. Persistent infection with high-risk human papillomavirus (HPV) is the principal cause of cervical cancer, and important risk factors influencing HPV acquisition, persistence, and progression include tobacco use, immunosuppression, and specific sexual and reproductive factors.[16] High-quality cervical cancer screening can detect precancerous lesions before progression to invasive disease; when combined with appropriate diagnosis and treatment of detected lesions, organised screening programmes can substantially reduce cervical cancer incidence and mortality. HPV vaccination provides a further, highly effective primary-prevention strategy by preventing infection with the high-risk HPV types responsible for the majority of cervical cancers.

7. Systemic Barriers to Implementation

Despite clear and well-documented benefits, several systemic barriers continue to slow the widespread adoption of preventive oncology.

- **Financial Disparity:** Public healthcare funding disproportionately favours reactive treatment over

early-screening infrastructure. Five-year breast cancer survival, for instance, exceeds 85% in high-income countries but may fall to as low as 42% in low-income settings.[9]

- **Clinical Time Constraints:** High patient volumes leave oncologists with limited time to counsel patients and families on lifestyle modification, and opportunities to recommend vaccination or weight-management interventions to relatives are frequently missed.
- **Biomarker Limitations:** A shortage of validated surrogate biomarkers hampers clinical monitoring, making it difficult for clinicians to track the real-time efficacy of pharmacological chemoprevention.

8. Global Implementation Progress: Achievements and Persistent Gaps

Significant and measurable progress has been made in cancer prevention and control globally, particularly through the increasing adoption of national cancer policies and evidence-based interventions. Nonetheless, a substantial gap persists between the development of policy and its effective implementation at the population level.[4]

Moderate progress has been achieved in tobacco control: implementation of measures under the WHO Framework Convention on Tobacco Control (WHO FCTC) has contributed to a 27% reduction in tobacco-use prevalence since 2010. However, incomplete adoption of the recommended MPOWER measures continues to limit progress, particularly in LMICs, where tobacco use remains an important and preventable cause of cancer.

Progress has also been observed in cervical cancer prevention. The introduction of simplified HPV vaccination schedules, including single-dose regimens, has created new opportunities to accelerate progress towards cervical cancer elimination. Although approximately 85% of countries have introduced HPV vaccination into their national immunization programmes, population-level coverage remains inadequate: first-dose HPV vaccination coverage among girls is estimated at 31%, an improvement from approximately 17% in 2019 but still far below the WHO target of 90% coverage by 2030. This gap illustrates an important distinction between policy adoption and effective vaccine delivery.

Breast cancer control presents a further implementation challenge. Although breast cancer is a priority within global noncommunicable-disease control efforts, outcomes vary substantially across countries, consistent with the survival disparities noted above. (9) Early detection and timely diagnosis, which have contributed substantially to improved outcomes in high-income settings, remain inadequately implemented at scale in many LMICs because of limited infrastructure, shortages of trained personnel, weak referral pathways, and inadequate long-term financing.

Access to cancer care also remains highly unequal. Only 28% of countries include a minimum package of cancer-management services within their universal health coverage benefit packages, leaving a large proportion of the global population without reliable access to essential cancer services. Even where treatment is available, high out-of-pocket expenditure can result in catastrophic financial hardship and may prevent patients from initiating or completing recommended treatment.[4] Overall, progress in preventive oncology depends not only on the existence of policy, but on equitable implementation, strong health systems, adequate financing, and sustained political commitment to translate prevention goals into a reduced burden of cancer and cancer-related inequity.

9. Impact of Preventive Oncology: Evidence from Countries and Indian States

9.1 England: HPV Vaccination

England offers one of the most compelling real-world demonstrations of the potential of primary cancer prevention. Following introduction of the national HPV vaccination programme in 2008, cervical cancer incidence among women routinely offered vaccination at 12–13 years of age was approximately 87% lower than in an unvaccinated reference cohort. By June 2019, the programme was estimated to have prevented 448 cases of cervical cancer and 17,235 cases of cervical intraepithelial neoplasia grade 3 (CIN3); with extended follow-up to 2020, the estimated number of prevented cervical cancers rose to 687. These findings demonstrate the substantial, sustained, population-level impact of adolescent HPV vaccination and highlight its role as a cornerstone of primary cancer prevention. [17]

9.2 Finland: Organized Cervical Cancer Screening

Finland illustrates the long-term benefits of sustained, organized secondary prevention. Its national cervical cancer screening programme, implemented over several decades, has been associated with an estimated 70–80% reduction in age-adjusted cervical cancer incidence, accompanied by a substantial decline in mortality. The Finnish experience demonstrates that well-organized, population-based screening programmes, supported by systematic invitation, follow-up, and treatment, can achieve considerable reductions in cancer burden and may also be cost-effective.[18]

9.3 Australia: Organized Cervical Cancer Screening

Australia provides a further important example of the effectiveness of organized, population-based cervical cancer prevention. Following the introduction of a national cervical screening programme in 1991, substantial reductions in cervical cancer incidence and mortality were observed. The Australian experience emphasizes that the effectiveness of screening depends not merely on the availability of screening tests, but on a comprehensive system ensuring systematic invitation of eligible individuals, timely screening, appropriate follow-up, and treatment of detected precancerous lesions.[19]

9.4 Sikkim, India: Statewide HPV Vaccination

Sikkim represents an important Indian example of successful state-level implementation of preventive oncology. During 2018–19, the state introduced a statewide HPV vaccination programme targeting girls aged 9–13 years, delivered primarily through schools. The programme achieved more than 95% coverage for both doses among the target population, with no severe adverse events reported. The Sikkim experience demonstrates that high HPV vaccination coverage is achievable in the Indian setting when supported by strong political commitment, effective collaboration between health and education sectors, school-based delivery strategies, and sustained community mobilisation.[20]

9.5 Tamil Nadu, India: Cervical Cancer Screening

Tamil Nadu provides important evidence for the feasibility of cervical cancer screening in resource-constrained settings. A landmark cluster-randomised trial conducted in Dindigul district evaluated visual inspection with acetic acid (VIA) performed by trained nurses. The study demonstrated that a relatively simple screening strategy could be successfully implemented through a primary healthcare-based approach in rural India, providing evidence supporting its role in reducing cervical cancer mortality. These findings are particularly relevant for LMICs, where conventional cytology-based screening programmes may be constrained by inadequate infrastructure, workforce shortages, and limited financing.[21,22]

10. Conclusion: Translating Evidence into Action

The country- and state-level experiences reviewed above show that preventive oncology can produce measurable, population-level reductions in cancer incidence and mortality. The greatest impact is observed when prevention is integrated into the broader health system through coordinated tobacco control, vaccination, organized screening, early treatment of precancerous lesions, healthy-lifestyle interventions, and reliable follow-up, consistent with the WHO estimate that roughly 37% of new cancers, about 7.1 million cases in 2022, are attributable to preventable causes.

For India specifically, the Sikkim and Tamil Nadu experiences demonstrate that state-level, population-based preventive oncology is feasible, but successful implementation requires political commitment, a trained workforce, community mobilisation, reliable referral systems, and sustained financing. More broadly, these examples confirm that when evidence-based preventive interventions are systematically implemented and adequately resourced, preventive oncology can translate into substantial and durable reductions in the global burden of cancer.

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