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Multifactorial Approaches to Cancer Diagnosis and Prevention: Diabetes Mellitus, Resveratrol, and Artificial Intelligence in Laboratory Medicine

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ABSTRACT: The global crisis surrounding cancer still appears unresolved, considering the numbers for 2020 show how dismal the situation was with approximately 19.3 million new cases and 10 million deaths. Along with the metabolic disorders, HCC or Hepatocellular Carcinoma, usually associated with conditions as severe as type 2 diabetes (T2DM), stands at 6th rank in global cancer prevalence and 3rd in mortality rate. According to some studies, individuals with T2DM have hyperinsulinemia, persistent inflammation, and oxidative stress, which puts them at a 2-3-fold for developing liver cancer which then further emphasizes the need to study and identify these metabolic oncogenic factors. There are multiple studies corroborating that polyphenolic antioxidants such as resveratrol available in red grapes, peanuts, and berries positively influence inflammation, anti-cancer activities, and apoptosis. Despite resveratrol's low bioavailability, its attention may have been rescued by emerging systemic delivery and formulation technologies, making preclinical works appear more favorable. Even now, cancer continues to remain one of the leading health issues around the world with an estimation of 10 million deaths and 19.3 million new cases diagnosed in 2020. HCC or Hepatocellular Carcinoma ranks 6th in the global cancer prevalence list being 3rd in the death rate list mostly due to metabolic conditions like diabetes type 2. Studies in epidemiology suggest that individuals diagnosed with T2DM have almost three times greater chance of developing liver cancer compared to those without an ailment. Supporting reasons revolve around hyperinsulinemia, chronic inflammation, and oxidative stress.

Keywords: Hepatocellular Carcinoma, Type 2 Diabetes Mellitus, Artificial Intelligence, Cancer Prevention, Metabolic Disorders.

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INTRODUCTION

To this day, cancer is still considered a critical global health issue and a primary cause of mortality. Due to cancer, closely 10 million deaths happened in 2020 alongside 19.3 million original cases. The International Agency for Research on Cancer (IARC) forecasts a significant increase in the new cases, forecasting the numbers to move to approximately 28.4 million by the year 2040 [1]. This surge can be clarified by an increase in the global population age, increase in diseases associated with existence, environmental influences, and a surge in metabolic syndromes. One of the most aggressive malignancies, Hepatocellular Carcinoma Cancer (HCC), accounts for approximately 80-90% of primary liver cancers and has a post detection 5-year survival rate of under 80%. It currently holds the 6th place in global cancer cases and is the 3rd most deadly in terms of cancer mortality. Its prevalence is especially high in East Asia and

Sub-Saharan Africa, where people are widely infected with Hepatitis B and C viruses. The western world is also submitting to these illnesses as NAFLD and Type 2 diabetes become more prevalent. Diabetes, especially Type 2 Diabetes Mellitus (T2DM), is recognized to upsurge the risk of several kinds of cancer, such as liver, pancreatic, colorectal, and breast cancer. There are epidemiological educations that estimate T2DM patients are around 2 to 3 times likely to develop HCC likened to non-diabetic affected role [2]. These facts can be explained by a number of factors which are often present together, including hyperinsulinemia, inflammation, and oxidative stress – all of which increase the chances of tumor development and growth. In addition, hyperglycemic patients tend to have several other associated diseases like dyslipidemia, obesity, and NAFLD which further heightens the risk of cancer development.

In trying to unravel the complicated networks of cancer's influences with breakdown, there is increasing emphasis on natural mixtures for prevention and treatment. Resveratrol is a polyphenolic manifold originating in red grapes, blueberries, peanuts, and red wine. The best branded possessions of resveratrol are its anti-inflammatory, antioxidant, anti-proliferative and pro-apoptotic properties. These traits propose that resveratrol strength aid in cancer chemoprevention, especially amongst those affected role with T2DM. Preclinical studies by Martinez *et al*., demonstrated that resveratrol can modulate critical molecular pathways associated with tumor growth, including NF-κB, p53, and TOR signaling [3]. This does not alter the situation, however, because its clinical utility is incomplete because of bioavailability and rapid metabolism, making it essential to explore better preparations and delivery systems. While this is happening, there is an important change in cancer diagnostics universally as they integrate artificial intelligence systems. AI, and chiefly its machine learning (ML) and deep knowledge (DL) subdivisions, has demonstrable potential for the betterment of accuracy, speed, and reproducibility of the diagnostic workflow. In laboratory medicine, AI algorithms are being adopted to interpret radiological images, histopathologic slides, genomic data, and biomarker profiles with a precision that in some cases exceeds the abilities of highly trained clinicians [4]. For example, diagnostic tools using AI technology for breast and liver cancers have achieved up to 94 diagnostic accuracy increasing early detection and reducing human error. Additionally, AI aids personalized medicine by combining clinical and molecular data from multiple sources to strategize treatments according to specific patient needs. In this light, a multifactorial approach towards the diagnosis and prevention of cancer is not merely preferred; it is required. A synergistic strategy is formed by tackling the metabolic causes of cancer through T2DM management, utilizing potent natural compounds such as resveratrol, and employing AI's computational power in laboratory medicine [5]. This strategy integrates ongoing shifts towards precision oncology, which increasingly rely on personalized data for the prevention, diagnosis, and treatment of cancer. The focus of this review is to analyze the diabetic condition, resveratrol, and AI in the realm of cancer prevention and early detection, emphasizing their interplay. With the objective of constructing a coherent narrative on how these domains can provide inform cancer care, we aim to showcase emerging trends with existing evidence, overlooking knowledge gaps in the void.

Diabetes Mellitus and Cancer Risk

Epidemiological Evidence

The association of type two diabetes mellitus (T2DM) with an increased risk of developing cancer has been shown in numerous epidemiological studies. Diabetic individuals are suggested to have a comparatively 23–38% heightened risk of getting cancer as shown in (Table 1).

Table 1: Epidemiological Evidence Linking T2DM to Hepatocellular Carcinoma (HCC)

Parameter	Findings
Cancer Risk	23–38% increased risk across multiple cancer types [6].
HCC Risk	2.01–2.43× higher risk; persists after adjusting for alcohol, hepatitis, and obesity.
Large Pooled Analysis	Diabetes nearly doubles HCC risk in >20 million participants.
Prospective Cohort	16.7% of HCC cases had pre-existing diabetes.
Comorbid Factors	Risk amplified by coexisting NAFLD or hepatitis infections.

Regional Trends	In Western populations, >30% of HCC linked to T2DM/NAFLD [7].
Public Health Implication	T2DM is a modifiable risk factor; early management can reduce HCC incidence.

This increased risk encompasses developing cancer of organs such as liver, pancreas, colon, breast, and endometrium. While the reasons are multi-faceted, diabetes's chronic and metabolic inflammation certainly impacts the risk [6]. When it comes to hepatocellular carcinoma (HCC), the risk becomes even more marked. Meta-analyses of cohort and case-control studies portray that T2DM patients are 2.01 to 2.43 more likely to suffer from HCC than non-diabetes patients. This risk remains high even when several other factors like alcohol, obesity, and hepatitis infections are considered. According to a large, pooled analysis, which includes data taken from more than twenty million participants, diabetes almost doubles the risk of HCC.

A prospective cohort study with more than 200,000 participants reported that around 16.7% of all HCC cases were diagnosed with diabetes, marking diabetes as a major contributor to HCC burden. In addition, it has been noted that the prevalence of HCC among diabetics is even greater in the presence of additional risk factors, such as viral hepatitis, or non-alcoholic fatty liver disease (NAFLD), which often coexist with T2DM. Diabetics are particularly affected in Western countries, where there is a notable increase in the west-style lifestyle-related metabolic diseases [8]. Metabolic syndrome and diabetes is on the rise and is a concern along with chronic hepatitis B and C which tend to overshadow all other risks. The shift in landscape also emphasizes the worrying proliferation of metabolic related HCC. In Europe and the United States, some studies indicate a troubling correlation with T2DM and NAFLD, with more than 30% of the population suffering from these diseases [7]. Such data heightens the notion that diabetes should be perceived as more than just a metabolic disease. This attitude change is necessary in regard to prevention strategies and the approach concerning the determination and classification of cancer risk should also be changed. Therefore, the early detection and proper treatment of T2DM may be critical in lowering HCC rate and improving outcomes for patients.

metabolic activity is the destruction of cellular components such as DNA. 8-oxo-2'-deoxyguanosine, also referred to as 8-oxo-dG, is quite well establishing as an

Mechanistic Links

Diabetes T2DM and the increases in the risk of developing various types of cancer are inter-related due to chronic and well-known biological underpinnings. The most important of these factors is hyperinsulinemia or the excessive secretion of insulin, which is the case with the majority of insulin-resistant diabetic patients. Insulin occupies its receptors and exerts its effects at an almost normal level and even above normal level. Dynamically high insulin level stimulates activation of the insulin-like growth factor-1 (IGF-1) receptor signaling pathway which is central to cellular growth and to the survival of a cell. Such signaling increases the cell's reproduction by facilitating mutagenic mechanisms further such as the PI3K as well as MAPK/ERK and at the same time inhibits programmed cell death apoptosis [9]. Cancerous cell growth without limits or Uncontrolled cell growth in the body unregulated cell growth or in this case over imbalance is termed to be Tumor growth by suppressing cell division signals. Moreover, in addition to hyperinsulinemia, T2DM is also associated with a state of chronic inflammation with low metabolic control due to insulin resistance and dysregulation of metabolism. Such an inflammatory state results in increased levels of circulation of pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF-α) and interleukin-6 (IL-6). These cytokines are capable of activating transcriptional factors such as nuclear factor kappa B (NF-κB). These are known to control genes associated with cell survival, proliferation, angiogenesis, and metastasis. The continuous presence of such mediators of inflammation aggravates the microenvironment, which is conducive for tumor development, thereby aiding in the onset as well as the advancement of cancer.

Oxidative stress, which is already heightened in diabetics, is another critical mechanism decisively discerned alongside hyperglycemic states. The metabolism of glucose beyond the cellular requirements leads to the production of a variety of damaging metabolites including free radicals, sometimes referred to as reactive oxygen species (ROS). A consequence of such
indicator of oxidative damage inflicted on DNA. Its increase is infamous for mutagenic activity and genomic imbalance. If left uncorrected, these DNA defects are more

likely to trigger mutation enabling tumor development and thus accelerate the process of carcinogenesis [10]. In tandem, these mechanisms combine hyperinsulinemia-induced growth signaling, persistent inflammation, and oxidative damage to DNA to form a biological context that supports cancer progression, especially in the metabolically active tissues like the liver which are directly responsive to insulin and glucose [11]. Knowing these pathways is essential for developing tailored prevention and treatment approaches for cancer among individuals with diabetes.

Liver Cancer Emphasis

Hepatocellular Carcinoma (HCC), the most prevalent form of primary liver cancer, has traditionally been associated with precursor viral hepatitis, especially HBV and HCV whose combined contribution accounts for nearly 55 percent of global prevalence of HCC [12]. However, this is changing with better vaccination and antiviral treatment strategies, as other metabolic risk factors such as Type 2 Diabetes Mellitus (T2DM) and Non-Alcoholic Fatty Liver Disease (NAFLD) are now considered to be contributing close to 30 percent of new HCC cases, particularly in economically developed regions. T2DM is responsible for the accumulation of fat in the liver, inflammation as seen in NAFLD and NASH, but also works together with other insults to accelerate liver carcinogenesis. In a certain meta-analysis, diabetic individuals who suffered from HCV had a HCC development risk 2.31 times greater than non-diabetic HCV-sufferers, showcasing the added risk burden of metabolic and viral factors [13]. With the increasing rates of obesity and diabetes globally, the number of people suffering from metabolically driven HCC is expected to increase, changing the epidemiology of liver cancer and highlighting the importance of managing metabolic risks in liver cancer prevention [14].

AI in Laboratory Medicine

Artificial Intelligence in Diagnostic Applications

AI is transforming laboratory medicine, especially with regard to diagnostic procedures like cancer detection. Within medical imaging, the use of deep learning neural networks has greatly enhanced the precision of diagnostics [15]. In radiology, deep models have been able to detect breast cancer from mammograms with up to 94% accuracy (Figure 1).

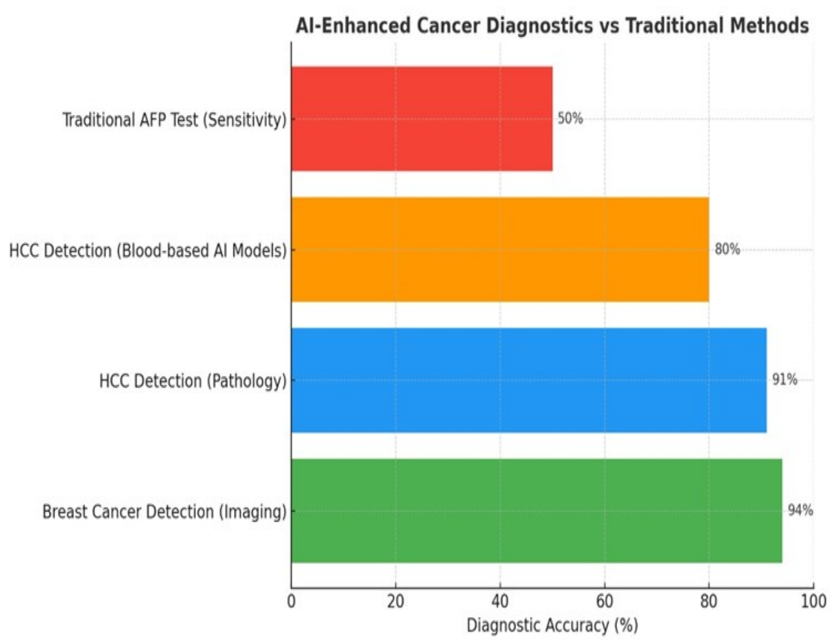

Figure 1: AI-Enhanced Diagnostic Accuracy in Cancer Detection.

Similar to this, AI systems in digital pathology have shown 91% sensitivity and 87% specificity in identifying hepatocellular carcinoma (HCC) from histopathological slides, facilitating quicker and more reliable diagnoses. Additionally, AI has great promise for blood-based diagnostics [16]. The sensitivity of traditional alpha-fetoprotein (AFP) testing is limited, particularly in cases of liver cancer that are still in the early stages. However, compared to AFP testing alone, machine learning models that combine several biomarkers, including AFP, des-γ-carboxy prothrombin (DCP), and imaging data, have improved the early detection of HCC by as much as 30%. By analyzing intricate data patterns that traditional methods frequently overlook, these models improve prognosis and enable earlier interventions.

Personalized Medicine

Particularly in oncology, artificial intelligence (AI) is greatly helping to advance tailored medicine. AI systems can stratify patients based on molecular profiles and project individualized treatment responses by combining data from genomics, transcriptomic, proteomics, and clinical records [17]. This lessens trial-and-error prescribing and allows more focused treatments. IBM Watson for Oncology is one prominent example; it generates evidence-based treatment recommendations by analyzing patient data alongside a lot of clinical literature. Watson's dependability as a decision-support tool has shown in clinical settings when Watson has shown up to 90% concordance between decisions made by expert oncologists for lung and colorectal cancers [18]. Moreover, based on genetic mutations (EGFR, KRAS), AI algorithms are being applied to forecast adverse drug reactions, maximize dosages, and identify patients probably benefiting from immunotherapy or targeted agents. By avoiding useless treatments, these tools not only enhance results but also help to lower expenses. AI-driven personalization will keep changing cancer treatment as precision oncology develops, so improving treatment efficacy, efficiency, and customizing to every patient's individual biological composition [19].

Workflow Automation

AI is streamlining operations in laboratory medicine by automating complex tasks and optimizing clinical workflows. AI-integrated lab systems have been shown to reduce diagnostic turnaround time by 35–50%, particularly in high-throughput molecular and genetic testing [20]. Automated sample handling, result interpretation, and quality control minimize human error and improve consistency in test processing [21]. In addition, predictive analytics powered by electronic health record (EHR) data can identify patterns linked to cancer recurrence (Table 2).

Table 2: Roles of AI in Oncology and Lab Automation

Area	AI Application	Impact	Reference
Personalized Care	Patient stratification via omics data	Enables targeted therapies	Uddin *et al*., [17].
	Treatment recommendation systems	90% match with expert decisions	Sakil *et al*., [18].
	Mutation-based drug prediction	Personalized, effective treatment	Ahmed *et al*., [19].
Lab Automation	Faster molecular/genetic test processing	35–50% reduced turnaround time	Rahman *et al*., [20].
	Automated interpretation and quality control	Minimizes errors, boosts efficiency	Xu et al., [21].
	Recurrence risk prediction	Early detection for better planning	Alum *et al*., [22].
	Smart sample triaging	Prioritizes critical cases, optimizes workload	Noorbakhsh, *et al*., [23].

Machine learning models have demonstrated the ability to forecast recurrence risk 6–12 months in advance, enabling earlier surveillance and intervention strategies. These systems evaluate variables such as tumor markers, imaging trends, and clinical history to support decision-making [22].AI also supports workload management by prioritizing critical samples, flagging abnormal results for review, and allocating resources more efficiently. As lab demands increase, especially in oncology, AI-driven automation is proving essential for maintaining speed, accuracy, and scalability [24]

Multifactorial Integration for Cancer Prevention

Effective cancer prevention relies on integrating clinical, molecular, and technological strategies. AI offers powerful tools for risk stratification, particularly in high-risk populations. For instance, diabetic patients over age 50 with elevated ALT, insulin resistance, and NAFLD have been shown to carry a 3.5-fold increased risk of developing HCC [25, 26]. AI-driven models can identify these individuals early by analyzing complex patterns across lab values, medical history, and lifestyle data. In terms of therapeutic synergy, combining resveratrol, a natural polyphenol, with metformin, a widely used antidiabetic drug, has demonstrated up to 70% reduction in tumor cell proliferation in vitro. This highlights the potential of integrating phytochemicals with standard treatments to enhance anticancer effects, especially in metabolically compromised patients. Real-time monitoring using AI-enabled wearable biosensors further strengthens prevention. These devices can continuously track glucose levels, inflammatory markers, and liver function, offering dynamic insights into patient status [27]. By alerting clinicians to early deviations, such systems support proactive care and timely intervention. This multifactorial approach blending lifestyle, pharmacological, and AI-assisted strategies holds promise for shifting cancer care from reactive to preventive, particularly in populations at metabolic and oncologic risk.

Challenges and Future Directions

Despite promising advances, several challenges hinder the full integration of multifactorial approaches in cancer prevention and diagnosis. A key barrier is clinical translation while resveratrol shows strong anticancer potential in preclinical studies, robust human trial data remains limited. Similarly, AI adoption in laboratory medicine is inconsistent due to variability in data quality, infrastructure, and algorithm transparency. Data privacy and security also pose significant concerns [28, 29]. With over 80% of AI systems relying on sensitive patient data, adherence to ethical guidelines, such as GDPR, and robust cybersecurity measures are essential to maintain public trust and ensure responsible AI deployment. Moreover, meaningful progress demands multidisciplinary collaboration. The integration of oncology, endocrinology, bioinformatics, and systems biology is crucial for building predictive models and personalized care pathways. Shared platforms, standardized protocols, and cross-sector partnerships will be vital for advancing precision medicine [30]. Moving forward, efforts must focus on large-scale validation studies, transparent AI design, and ethical frameworks to ensure safe, equitable, and effective use of these innovations in real-world clinical settings.

CONCLUSION

Cancer prevention and diagnosis benefit from multifactorial strategies that integrate clinical risk factors, natural compounds, and emerging technologies. Diabetes mellitus increases cancer risk, especially for hepatocellular carcinoma, through metabolic and inflammatory pathways. Resveratrol offers promise as a chemo preventive agent due to its antioxidant and anti-carcinogenic properties. Artificial intelligence enhances diagnostic accuracy and supports personalized care through data-driven insights. Together, these elements enable a proactive, patient-specific approach to cancer care. Future success will depend on interdisciplinary collaboration, ethical AI implementation, and robust clinical validation to ensure safe, effective, and personalized cancer prevention and diagnostic solutions.

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