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Effective Cancer Recurrence Prediction using Healthcare Data Analytics with Machine Learning and Artificial Intelligence

Jinesh Kumar Chinnathambi

Subject Matter Expert(SME)//4x AWS Certified Technologist, Leading Health Insurance Company, Richmond, Virginia, United States

Abstract: ***Empowered with health data, artificial intelligence (AI) and data analytics demonstrate transformative potential in cancer recurrence prediction and treatment. This paper explores the potential of AI in predicting cancer recurrence incidences, enabling earlier interventions, and potentially improving patient outcomes. Currently, limitations such as late diagnosis or misdiagnosis often result in suboptimal patient outcomes and increased healthcare costs, emphasizing a crucial requirement for an efficient prediction system in the initial stage of Cancer. AI, particularly machine learning (ML) and deep learning (DL), coupled with health data analytics, provides a promising platform for developing predictive models in cancer care. Harnessing patients' demographic, genetic, clinical, and lifestyle data, these intelligent models can identify risk factors and patterns associated with various types of Cancer. These insights assist healthcare providers in predicting susceptibility to specific cancer types in the early stages when intervention can significantly improve prognosis. Additionally, AI's ability to continually learn allows the models to become more accurate, adapting to new findings and trends in cancer care. Implementing AI in healthcare for cancer prediction also enables personalized medicine, ensuring that each patient's unique genetic makeup and lifestyle factors are considered in determining treatment plans. This paper delves into the comprehensive role of data analytics and AI in reshaping cancer care, acting as invaluable tools in predictive oncology.***

Keywords: Healthcare data analytics, Artificial intelligence in healthcare, Cancer Recurrence Prediction, Predictive Models, Machine Learning Cancer Recurrence Prediction, AI Integration in Clinical Practice, Social Determinants of Health, Behavioral Aspects of Cancer, Health Data Empowerment

1. Introduction

The frightening scale and complexity of Cancer, responsible for millions of deaths worldwide each year, demand elevated levels of innovation, particularly in early detection and diagnosis. Late-stage cancer diagnosis often results in less favorable prognoses and more aggressive treatment plans, further reinforcing the compelling need for efficient early detection. New technological strides are bringing us closer to revolutionizing how we predict, diagnose, and treat various forms of Cancer. The confluence of healthcare data analytics and artificial intelligence (AI) offers unprecedented opportunities for medical breakthroughs in oncology.

The healthcare industry is no stranger to big data, with massive amounts of vital information constantly generated from various sources such as clinical tests, electronic health records (EHRs), genetic studies, and radiological images. This tremendous data store has vast potential but needs to be more utilized due to its complexity. Here is where AI, specifically machine learning (ML) and deep learning (DL), plays a transformative role. It captures the core behavioral aspects of Cancer and identifies sophisticated patterns amidst vast and diverse data that might not be discernible to the human eye.

This white paper explores how integrating Artificial Intelligence, Machine Learning, and big data analytics can be a potent tool to predict Cancer at an early stage, thereby significantly improving patient outcomes and recalibrating the future of cancer care. It also delves into the potential of AI to continuously enhance its learning, making it an invaluable asset in the field of cancer prediction and diagnostics. Through real-world examples and evidence, this white paper will illustrate the role of now within-reach technology in overcoming the global challenge of Cancer.

2. Background

Cancer continues to place enormous strain on global health systems, representing one of the leading causes of morbidity and mortality worldwide. The International Agency for Research on Cancer reported[1] an astounding 19.3 million new cancer cases and nearly 10 million cancer deaths globally in 2020.[2] Despite advances in genomics and personalized medicine, early detection and prediction of Cancer remains a significant challenge in the healthcare sector. There is a pressing need for efficient, scalable, and accurate methods for early identification of potential cancer patients, refining prognostic predictions, and guiding therapeutic decisions.

Enter the promising domain of big data, health care analytics, artificial intelligence (AI), and machine learning (ML). Within healthcare, enormous amounts of data are routinely collected - clinical or pathological data, electronic health records, genetic data, and imaging data, to name a few. Each data offers select pieces of a yet-unfinished puzzle, private glimpses into intricate relationships between genetic markers, lifestyle variables, environmental factors, and cancer risk.

We can combine these puzzle pieces by harnessing AI and machine learning. Machine learning, a subset of AI, empowers computers to learn directly from data, identify patterns, and make predictions, all without being explicitly programmed. In cancer prediction, machine learning models can be trained and validated on large sets of clinical and genetic data, enabling them to predict a patient's cancer risk based on their unique profile. These predictions can facilitate early detection and timely, personalized treatment interventions, significantly augmenting the probability of better patient outcomes.

As AI and machine learning technologies become more sophisticated, healthcare data analytics' potential in cancer prediction is gradually being unleashed, offering new hope in our global fight against Cancer. This white paper will explore how these promising technologies can transform cancer care.

3. Sample Machine Learning Cancer Recurrence Prediction Score

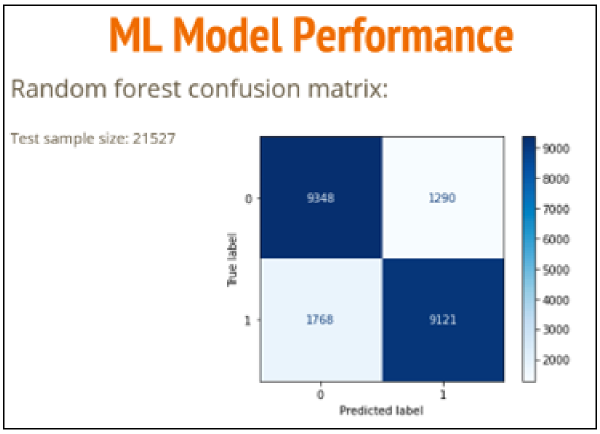

Figure 1: Cancer prediction score

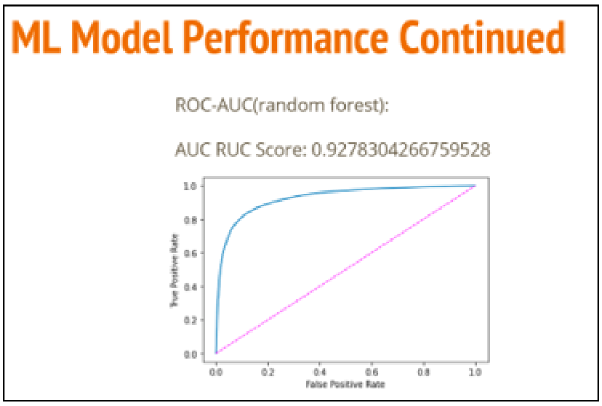

Figure 2: ML prediction with true vs false positive

pland_trtmnt_strt_dt	pland_trtmnt_end_dt	recr_ind	mbr_age	gndr_cd	site	cancr_stage_cd	height_msr	weight_msr	zip_cd	BMI
2018-04-09 00:00:00	2018-10-15 00:00:00	N	43	M	Colon	02	1.8542000	103.418976000	62884	30.08064053
2017-02-21 00:00:00	2018-02-21 00:00:00	Y	75	F	Colon	04	1.6510000	82.100152000	63124	30.11964263
2018-06-19 00:00:00	2019-06-11 00:00:00	N	76	F	Colon	04	1.6510000	74.842680000	63124	27.45713278
2018-07-03 00:00:00	2018-10-16 00:00:00	N	76	F	Colon	04	1.6764000	74.389088000	63124	26.46999931
2018-10-30 00:00:00	2019-02-12 00:00:00	N	76	F	Colon	04	1.6510000	72.574720000	63124	26.62509846
2020-01-13 00:00:00	2020-03-14 00:00:00	NA	62	F	Rectum	01	1.7018000	92.079176000	63017	31.79394258
2018-12-13 00:00:00	2019-06-20 00:00:00	N	61	M	Rectum	04	1.6764000	71.213944000	63144	25.34018227
2019-01-11 00:00:00	2019-06-21 00:00:00	N	62	M	Rectum	04	1.7018000	70.760352000	63144	24.43278346
2019-03-06 00:00:00	2019-08-14 00:00:00	N	62	M	Rectum	04	1.7018000	76.657048000	63144	26.46884875
2019-05-16 00:00:00	2020-02-13 00:00:00	N	62	M	Rectum	04	1.7018000	79.832192000	63144	27.5651916
2015-12-15 00:00:00	2016-03-29 00:00:00	N	58	M	Colon	04	1.7526000	81.192968000	63011	26.43338628
2016-02-02 00:00:00	2016-03-29 00:00:00	N	59	M	Colon	04	1.7526000	81.192968000	63011	26.43338628
2016-03-21 00:00:00	2016-07-04 00:00:00	N	59	M	Colon	04	1.7526000	78.017824000	63011	25.39967844
2016-03-30 00:00:00	2016-07-13 00:00:00	N	59	M	Rectum	04	1.7526000	78.017824000	63011	25.39967844
2016-06-21 00:00:00	2016-07-30 00:00:00	N	59	M	Rectum	04	1.7526000	71.667536000	63011	23.33226275
2016-11-30 00:00:00	2017-03-15 00:00:00	N	59	M	Rectum	04	1.7526000	74.842680000	63011	24.3659706
2016-01-07 00:00:00	2016-04-21 00:00:00	N	55	M	Colon	03	1.8542000	127.912944000	63555	37.20500276
2016-01-28 00:00:00	2016-06-23 00:00:00	N	55	M	Colon	04	1.8542000	122.469840000	63555	35.62181116
2020-04-14 00:00:00	2020-10-20 00:00:00	NA	62	F	Colon	03	1.7526000	111.130040000	65804	36.17977452
2016-09-20 00:00:00	2017-02-14 00:00:00	N	47	F	Rectum	03	1.8796000	78.471416000	63123	22.21163953
2016-09-26 00:00:00	2017-04-03 00:00:00	N	47	F	Rectum	03	1.7526000	77.110640000	63123	25.10433334

Figure 3: Dataset referred in the ML model

Feature	Possible Values
Patient Symptoms	None, Incidental, Local, or Systemic
Histology from the Biopsy	None, Chromophobe, Conventional, or Papillary
T Stage	pT1, pT2, pT3a, pT3b, or pT3c
Tumor size	Must be between 0.001 and 20 cm

Figure 4: Key factors

4. Cancer Types and Relapse Percentage

Cancer is a complex group of diseases characterized by uncontrolled cell growth, and it can occur in different parts of the body, resulting in numerous types of Cancer. Here are some common types of Cancer and their associated relapse percentages:

Breast Cancer: This is one of the most common types of Cancer among women. While advancements in early detection and treatment have significantly improved survival rates, approximately 20% - 30% of women diagnosed with early-stage breast cancer can develop metastatic disease, which is considered a relapse.

Prostate Cancer: This is a leading type of Cancer among men. While many men with prostate cancer will never experience a relapse following initial treatment, some studies suggest that biochemical recurrence (rising prostate-specific antigen levels) can occur in approximately 15% - 40% of patients within five years - although this does not necessarily mean symptomatic disease return.

Lung Cancer: This is the leading cause of cancer deaths globally. Approximately 30% - 55% of non-small cell lung cancers can relapse after surgery, mainly depending upon the Cancer's stage at the time of operation.

Leukemia: The relapse rate for leukemia varies greatly depending on the subtype and other factors, such as age at diagnosis. For example, for children with acute lymphoblastic leukemia (ALL), the most common type of Cancer in children, current treatment strategies result in cure rates of 80% - 85%, leaving a relapse rate of around 15% - 20%.

Spinal Cancer: I am currently studying spinal Cancer, which is a relatively uncommon condition, occurring in about 1 in 140 men and 1 in 180 women over their lifetime. Metastatic spinal tumors refer to those that have spread to the spine from other parts of the body. The ability of a tumor to spread generally indicates malignancy. It is estimated that between 30% and 70% of cancer patients will develop metastatic spine cancer at some point during the progression of their disease.

Colorectal Cancer: Recurrence rates of colorectal Cancer depend significantly on the stage at diagnosis. While early-stage colorectal cancers have a relatively low recurrence rate (around 5% for Stage I), up to 25% of Stage III colorectal cancer patients will experience a relapse.

Table 5: ICD-9/10 colorectal mappings

Diagnosis	ICD-9 code	ICD-10 code
Right colon (ascending colon)		
Hepatic flexure	153	C18.3
Cecum	153.4	C18.0
Ascending colon	153.6	C18.2
Transverse colon		
Transverse colon	153.1	C18.4
Left colon (descending colon)		
Descending colon	153.2	C18.6
Sigmoid colon	153.3	C18.7
Splenic flexure	153.7	C18.5
Rectosigmoid junction	154	C19

Unspecified colon site		
Colon unspecified	153.9	C18.9
Malignant neoplasm of appendix vermiformis	153.5	N/A
Malignant neoplasm of appendix	N/A	C18.1
Malignant neoplasm of other specified sites of large intestine	153.8	N/A
Malignant neoplasm of overlapping sites of colon	N/A	C18.8

Note: It is important to remember that these are estimated averages. Individual prognosis can vary widely based on factors such as overall health, specific genetic features of the Cancer, and the treatment strategy employed.

5. Social Determinants of Health (SDOH) role in cancer recurrence

The term "Social Determinants of Health (SDOH)" encompasses the environmental and social factors in which individuals live, learn, work, play, worship, and age, impacting various health, well-being, and quality of life. SDOH can play a significant role in effective cancer recurrence prediction when paired with healthcare data analytics and Artificial Intelligence (AI).

In the context of predicting cancer recurrence, here is how SDOH could fit into the picture:

Incorporate SDOH Data: Including SDOH data like education level, income, employment status, and neighborhood characteristics in the AI models can enhance the accuracy and effectiveness of cancer recurrence predictions. Socioeconomic factors can directly or indirectly influence health outcomes, including the likelihood of cancer recurrence.

Improve Risk Stratification: Evaluating SDOH factors alongside health-related data can help identify high-risk populations and individuals who might be more prone to cancer recurrence due to socioeconomic or environmental stressors. It can enhance the risk stratification process, enabling more targeted interventions.

Personalize Risk Communication: Understanding the SDOH allows healthcare providers to personalize risk communication and increase the chances of adherence to prevention and treatment plans. This can be particularly beneficial in reducing the risk of cancer recurrence.

Tailored Interventions: Taking SDOH into account allows for designs of interventions that consider lifestyle, economic, and societal factors that might affect whether an individual can participate in specific treatment regimens.

By analyzing SDOH, we can identify systemic issues that lead to poorer outcomes for specific populations. This understanding can serve as a valuable asset in shaping public and healthcare policy decisions, enabling us to create a positive influence on healthcare policies.

Applied thoughtfully, an approach integrating SDOH with healthcare data analytics and AI can revolutionize cancer care and management. It ensures that healthcare is equitable, personalized, and capable of considering the individual's comprehensive life situation. However, the responsible handling of such sensitive data is essential in preserving equity and trust in healthcare, reassuring us of its ethical considerations.

6. Data requirements to predict cancer recurrence using machine learning

Utilizing healthcare data analytics and Artificial Intelligence (AI) for effective cancer recurrence prediction requires a wide range of data. These data sets are typically collected from different sources, each contributing to a comprehensive view of a patient's health status. Here are some types of data that might be needed:

1) **Patient Demographics:** Information such as age, sex, race, and geographic location can contribute to a patient's risk profile for certain types of Cancer.
   Electronic Health Records (EHRs): These records contain critical data, including medical history, diagnoses, medications, treatment plans, immunization dates, allergies, radiology images, and laboratory test results.
   Pathology Reports provide specific details about the diagnosed Cancer's type, stage, and characteristics.
2) **Genetic and Genomic Data:** Information regarding genetic mutations or variants can offer insight into a patient's cancer risk or potential responses to treatment.
   Radiology and Imaging Data: Images such as MRI, CT scans, PET scans, and X-rays are critical in monitoring the Cancer's progress and the effectiveness of treatments.
   Lifestyle Data: Data reflecting lifestyle choices such as smoking, alcohol consumption, diet, and exercise can also significantly impact cancer recurrence risk.
   Treatment Data: Detailed data on treatments a patient has undergone - such as surgery, radiation, or chemotherapy, including treatment duration and the drugs used.
3) **Follow-up Data:** Regular follow-ups can provide information about the patient's health post-treatment and any signs of recurrence.
   Real-Time Monitoring Data: Wearable devices can provide real-time data on various health metrics and help monitor a patient's vital signs and symptoms.
4) **Clinical Trial Data:** Data from clinical trials, including outcomes for individuals who have undergone experimental treatments.
   Compiling and analyzing these extensive datasets with AI and data analytics tools can enable healthcare providers to predict potential cancer recurrence more accurately, providing a solid foundation for personalized and timely treatment planning.

7. Breast cancer recurrence prediction using machine learning

Recurrence: Breast cancer ranks as the most prevalent type of Cancer among women on a global scale. The highest risk of recurrence occurs within the first 2–3 years after the initial diagnosis and subsequently decreases. An estimated 8-10% of women diagnosed with breast cancer will experience locoregional recurrences, while 15-30% will develop distant metastases. Various factors, including the initial tumor characteristics, the presence of estrogen and progesterone

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receptors, the presence of HER2, previous treatments, smoking habits, alcohol consumption, and metabolic syndrome influence the incidence and location of recurrence.

Figure 5: Development Methodology

Feature Selection:
- Identified predictors of breast cancer recurrence within the dataset.
- Extracted breast cancer treatment regimens and medications from the dataset.
- Categorized the regimens as recurrent or non-recurrent using the following criteria: The subsequent regimen should be administered at least 180 days after the prior regimen, or the subsequent regimen should indicate a progressive diagnosis compared to the prior regimen at the same site.

Data Preprocessing: The following transformations were applied to the numeric and categorical features within the raw dataset.

Numerical Features:
- Missing values imputation
- Standard Scaling
- Discretization

Categorical Features
- Missing values imputation
- One Hot Encoding

Model Training:
- The dataset exhibited a class imbalance. About 46,000 regimens had no recurrence, and about 4000 regimens had recurrence.
- Oversampled the minority class observations using the SMOTE algorithm.
- The dataset was split into training and test datasets in the ratio of 75:25. The dataset was trained using the following classifiers: LogisticRegression, RandomForestClassifier, and XGBClassifier (Gradient Boosting).
- Models were trained by splitting the data into several folds and using cross-validation techniques to obtain the best choice of hyperparameters.

Figure 6: Random Forest Classifier

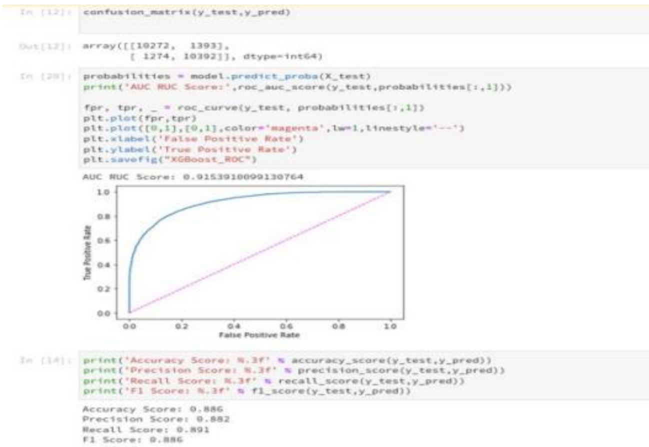

Figure 7: XGB Classifer

Limitations: The following patient data which is critical to the recurrence of breast cancer wasn't available in the dataset.
- Patient Lifestyle Data
- Smoking status, Alcohol consumption status
- Metabolic Syndrome
- Patient Biopsy data (Tumor size, Auxiliary Nodal involvement)

The models would have a better precision if the features listed above were made available in the training dataset from the electronic medical records of the patient.

Financial Advantages cancer recurrence prediction

Integrating healthcare data analytics and AI for effective cancer recurrence prediction can provide significant financial advantages. Here are some ways these technologies can lead to cost savings:

Early Detection and Intervention: Accurately predicting cancer recurrence at an early stage allows for timely treatment, which can be more effective. It can also improve patient outcomes and survival rates, reducing long-term care costs.

Optimized Treatment Plans: Leveraging AI, healthcare providers can recommend the most effective treatment plans, reducing [4] the trial-and-error approach sometimes used in cancer treatment. This can save costs by reducing wasted resources on less effective treatments.

Hospitalization Costs: Curbing hospital readmission rates through effective prediction and management of cancer recurrence can result in significant savings in hospitalization costs.

Targeted Surveillance: Using AI to identify patients with a high risk of recurrence can allow healthcare providers to conduct targeted surveillance on these patients, maximizing cost-effectiveness.

Reduction in Unnecessary Testing: AI predictive models can reduce unnecessary testing and treatments by providing a more accurate picture of a patient's risk [5] of cancer recurrence.

Improved Resource Allocation: AI can help optimize healthcare resource allocations by determining which patients need the most care and when leading to overall cost savings in the healthcare system.

R&D costs Reduction: AI-based algorithms can drastically decrease the time and cost linked to cancer-related research by identifying patterns and predicting outcomes swiftly and more accurately.

By employing healthcare data analytics and AI to predict cancer recurrence, healthcare systems can provide more effective, personalized patient care while significantly reducing costs.

How can providers mitigate cancer recurrence risks?

Healthcare providers are critical in leveraging healthcare data analytics and AI for effective cancer recurrence prediction. They can ensure these advanced technologies are used to their full potential in mitigating recurrence risks. Here is how:

Data Collection: Providers are the backbone of this process, responsible for accurately collecting and recording patient data—medical histories, test results, treatment responses, and follow-up care details. Their meticulous work is crucial for training reliable AI models. Integrating AI into Clinical Practice: Healthcare providers must integrate these solutions into their daily patient assessments, diagnoses, and treatment plans. This might involve using AI-driven tools to identify at-risk patients, determine the best treatment protocols, or monitor patient responses over time.

Interpreting and Acting on Predictions: AI can provide predictions and probabilities, but providers must interpret these in each patient's unique case context. Providers need to consider the results from AI tools with other critical factors (like patient preferences) to form a comprehensive treatment plan.

Patient Education and Communication: Providers are essential in informing patients about how their data is used and what predictive insights mean for their health and treatment plans. Managing patient expectations is critical in this respect.

Continuous Learning and Improvement: Healthcare providers are at the forefront of this journey, closely monitoring and assessing the accuracy and relevance of AI predictions over time. Their feedback is instrumental in enhancing the models, empowering them to contribute to the evolution of healthcare. Ethics and Privacy: Providers are responsible for ensuring the ethical use of AI and patient data. This includes securing patient consent, ensuring transparency in how and why patient data is used, and maintaining strict data privacy and security standards.

Advocating for Better Resources: Providers are not just users but also advocates for the resources necessary for incorporating AI and data analytics into healthcare settings. Their influence can shape the future of healthcare, emphasizing the long-term benefits of these advancements in improving patient outcomes and reducing healthcare costs. By actively participating in each stage, healthcare providers become the crucial link between AI potential and improved patient care. They ensure that AI and data analytics serve their purpose - offering patients better and more timely care.

8. Implementation in other industries

Data analytics and artificial intelligence (AI) principles utilized in "Effective Cancer Recurrence Prediction" can be leveraged in multiple industries. Here is how:

Banking and Finance: Banks can use AI and data analytics to predict potential frauds or credit defaults. AI can analyze spending patterns, previous transaction history, and market trends to highlight potential risky behavior.

Retail: These technologies can predict shopping trends and customer preferences. Retailers can use this data to manage inventory, improve customer relationships, and maximize sales.

Supply Chain Management: Predictive analytics and AI can identify potential disruptions, optimize routes, and improve delivery times. Machine learning algorithms can predict supply and demand patterns, enabling businesses to manage their resources more efficiently.

Telecommunication: Telecom companies can use AI and data analytics to predict customer churn, enabling them to make proactive interventions to retain customers. These tools can also help in network optimization and anomaly detection in real-time.

Energy: In the energy sector, these technologies can help predict energy usage trends, identify inefficiencies, optimize energy distribution, and improve grid reliability. Furthermore, they can assist in predicting equipment failures, enabling preventive maintenance, and avoiding costly outages.

Agriculture: Farmers can use AI and data analytics to predict crop yields, monitor plant health, and optimize irrigation and fertilization, increasing efficiency and productivity.

Although each industry differs from healthcare, they can all benefit from data analytics and AI to predict future trends. By leveraging historical and real-time data, companies can anticipate and strategize future actions, enhancing efficiency, reducing costs, and improving outcomes. Privacy and data security must be paramount as businesses implement these technologies.

9. Conclusion

Healthcare data analytics and artificial intelligence demonstrate transformative potential in cancer recurrence prediction and treatment. With the integration of AI, particularly machine learning and deep learning, and big data analytics, healthcare providers have the opportunity to revolutionize cancer care. The ability to harness patients' demographic, genetic, clinical, and lifestyle data allows for the identification of risk factors and patterns associated with various types of cancer. This insight assists in predicting susceptibility to specific cancer types in the early stages when intervention can significantly improve prognosis.

Furthermore, the continuous learning ability of AI models allows for increased accuracy and adaptation to new findings and trends in cancer care. Implementing AI in healthcare for cancer prediction also enables personalized medicine, ensuring that each patient's unique genetic makeup and lifestyle factors are considered in determining treatment plans. The implications of this are an early prediction of cancer recurrence, leading to improved patient outcomes and associated cost savings.

The potential financial advantages of utilizing healthcare data analytics and AI for cancer recurrence prediction include the reduction of long-term care costs through early detection and intervention, optimized treatment plans, decreased hospitalization costs, targeted surveillance, reduced unnecessary testing, improved resource allocation, and decreased research and development costs.

In addition, it's essential for providers to play a critical role in leveraging these advanced technologies for effective cancer recurrence prediction. They are responsible for accurate data collection, integration of AI into clinical practice, interpretation and action on predictions, patient education and communication, continuous learning and improvement, ethics and privacy, and advocating for better resources.

Lastly, the principles of data analytics and AI employed in effective cancer recurrence prediction can be leveraged in multiple industries including banking and finance, retail, supply chain management, telecommunication, energy, and agriculture, where predictive analytics and AI can help predict potential fraud, manage inventory, optimize supply chain routes, predict customer churn, optimize energy distribution, and predict crop yields, among other applications.

Overall, the transformative potential of AI and data analytics in cancer recurrence prediction offers promising opportunities for medical breakthroughs in oncology, emphasizing the need for the integration of these advanced technologies in healthcare systems to improve patient outcomes and reduce healthcare costs.

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