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Persistent Disparities in the Modern Era of Brain Metastasis Treatment: A SEER-Based Study (2010-2022)

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Abstract

Background: Metastatic brain tumors (MBTs) are the most common intracranial malignancy in adults and remain associated with poor survival despite advances in systemic therapies and radiation modalities. Although racial disparities in cancer outcomes are well documented, the interaction between race and socioeconomic status among patients with brain metastases has not been well characterized. **Methods:** We conducted a retrospective cohort study using the Surveillance, Epidemiology, and End Results (SEER) database from 2010-2022. Adult patients with brain metastases originating from lung, breast, melanoma, or prostate cancer were included. Logistic regression models evaluated disparities in receipt of chemotherapy, radiation therapy, and multimodal treatment. Cox proportional hazards models assessed cancer-specific survival. Models incorporated race × income interaction terms and were parameterized using White patients with household income ≥ $75,000 as the reference group. **Results:** A total of 77,895 patients were included (lung n = 69,932; melanoma n = 3786; breast n = 3588; prostate n = 593). In lung cancer MBTs, low-income Black patients had higher mortality risk (HR 1.12, 95% CI 1.08 - 1.16, $p < 0.001$), while high-income Hispanic patients had improved survival (HR 0.91, 95% CI 0.87 - 0.95, $p < 0.001$). Asian patients demonstrated significantly improved survival across both income strata. In breast cancer MBTs, Black patients experienced significantly worse survival regardless of income (high-income HR 1.23, $p = 0.008$; low-income HR 1.33, $p < 0.001$). Treatment analyses revealed lower odds of multimodal therapy among low-income Black patients and reduced radiation therapy utilization among Hispanic patients across multiple cancer types. **Conclusions:** Socioeconomic status modifies racial disparities in treatment receipt and survival among patients with brain metastases. Persistent survival differences in breast cancer highlight the importance of addressing structural inequities in metastatic cancer care.

Keywords

Brain Metastases, SEER Database, Neuro-Oncology, Survival Analysis, Health Disparities

1. Introduction

Metastatic brain tumors (MBTs) represent the most common intracranial malignancy in adults, occurring approximately four to ten times more frequently than primary brain tumors. Despite advances in treatment modalities, the prognosis for patients with brain metastases remains poor, with median survival ranging from 4 to 16 months depending on primary cancer type and treatment received. The most common primary sources of brain metastases include lung cancer, breast cancer, melanoma, and renal cell carcinoma, with lung cancer accounting for approximately 40% - 50% of all cases [1]-[5].

The past two decades have witnessed substantial evolution in the management of brain metastases. Stereotactic radiosurgery (SRS) has emerged as a preferred treatment modality for patients with limited brain metastases, offering superior neurocognitive preservation compared to whole-brain radiotherapy while maintaining comparable survival outcomes. For patients with one to four brain metastases, SRS is associated with less cognitive deterioration than conventional whole-brain radiotherapy, and the combination of SRS plus whole-brain radiotherapy has not demonstrated survival benefit while potentially increasing cognitive toxicity [6]-[8]. Recent randomized trial data have extended the benefits of SRS to patients with 5 to 20 brain metastases, demonstrating reduced symptom severity and less functional interference compared to hippocampal-avoidance whole-brain radiotherapy [7].

Concurrently, the therapeutic landscape has been transformed by the development of targeted therapies and immune checkpoint inhibitors with central nervous system activity. For patients with EGFR-mutated non-small cell lung cancer, tyrosine kinase inhibitors such as osimertinib have demonstrated significant intracranial efficacy [9]-[11]. In melanoma, combination immunotherapy with nivolumab plus ipilimumab has achieved intracranial response rates up to 55% in patients with asymptomatic brain metastases, with durable responses observed in long-term follow-up. Similarly, BRAF and MEK inhibitor combinations have shown intracranial activity in BRAF-mutated melanoma, though with shorter progression-free survival compared to extracranial disease. For HER2-positive breast cancer, agents such as tucatinib and trastuzumab deruxtecan have demonstrated meaningful intracranial activity [9] [10].

Despite these therapeutic advances, substantial disparities in cancer outcomes persist across racial and socioeconomic groups in the United States. Black and

American Indian/Alaska Native populations experience disproportionately higher cancer mortality rates overall and for leading causes of cancer death. Socioeconomic status plays a major role in driving these disparities, with cancer mortality rates 1.6 to 2.8 times higher among individuals with 12 years or less of education compared to those with 16 years or more of education [12] [13]. These disparities reflect fundamental inequities in social determinants of health, including differential exposure to risk factors, barriers to accessing high-quality cancer prevention and early detection services, and unequal receipt of guideline-concordant treatment [12]-[14].

Disparities in cancer treatment receipt have been extensively documented across multiple cancer types. Racial and ethnic minorities and individuals of lower socioeconomic status are less likely to receive guideline-concordant treatment, more likely to experience treatment delays, and face greater financial toxicity from cancer care. Even when controlling for stage at diagnosis, Black patients demonstrate lower stage-specific survival than White patients for many cancer types, suggesting that differences in treatment access and quality contribute substantially to outcome disparities [1] [4] [15] [16]. Recent evidence suggests that higher socioeconomic status may yield diminishing health returns for Black patients compared to White patients—a phenomenon termed "diminishing returns"—whereby economic advantage does not translate into equivalent health benefits across racial groups [17].

In the specific context of brain metastases, emerging data suggest that racial and socioeconomic disparities may influence both treatment access and survival outcomes. Geographic location affects access to advanced treatments such as stereotactic radiosurgery, with rural patients less likely to receive these therapies and experiencing worse survival. Recent analyses using Surveillance, Epidemiology, and End Results (SEER) data have reported that after controlling for socioeconomic status, survival outcomes among minority patients with brain metastases may differ from historical patterns [1]-[3] [7] [8] [18] [19]. However, these studies have not employed interaction models to systematically evaluate how race and socioeconomic status jointly influence treatment receipt and survival outcomes.

The present study addresses this gap by examining the interaction between race and household income among patients with brain metastases from lung, breast, melanoma, and prostate cancers using SEER data from 2010 to 2022. By employing race × income interaction models, we sought to determine whether socioeconomic status modifies racial disparities in treatment receipt and cancer-specific survival, and to characterize the magnitude and direction of these effects across different primary cancer types. Understanding these intersectional relationships is essential for developing targeted interventions to reduce disparities and improve outcomes for all patients with brain metastases.

2. Methods

2.1. Data Source and Cohort Selection

Data were obtained from the Surveillance, Epidemiology, and End Results (SEER) Research database (Incidence—SEER Research Data, 17 Registries, Nov 2024 submission), covering diagnoses from 2010-2022. Adult patients (≥18 years) with evidence of brain metastases at diagnosis were identified using the variable "SEER Combined Mets at DX-Brain".

Primary cancer sites included lung, breast, melanoma, and prostate malignancies identified using ICD-O-3 site codes. Patients were excluded if survival data or treatment variables were missing.

This study was conducted using de-identified registry data and was approved by the Howard University Institutional Review Board with expedited review.

2.2. Variables and Definitions

Demographic Variables

Race and ethnicity were derived from the SEER variable: Race and origin recode (NHW, NHB, NHAIAN, NHAPI, Hispanic). For analytic clarity and to improve interpretability of regression models, race categories were coded as: White, Black, Hispanic, Asian, and American Indian. Small categories (American Indian/Alaska Native and unknown race) were excluded from the primary regression tables but retained in sensitivity checks.

Median household income was derived from: Median household income inflation adjusted to 2023. Income was dichotomized into Low income: <$75,000 or High income: ≥$75,000.

Interaction terms were created between race and income to evaluate whether socioeconomic status modified racial disparities.

Covariates

These variables were selected based on prior SEER-based disparity analyses. Covariates included: age at diagnosis, sex (except breast and prostate models), marital status (married vs non-married), rural vs urban residence, diagnosis era (2010-2014 vs 2015-2022), number of tumors, first primary malignancy, and time from diagnosis to treatment.

Treatment Variables

Treatment receipt was derived from SEER recode variables: Chemotherapy recode (yes/no/unknown), Radiation recode, and Surgery recode. Binary indicators were generated for chemotherapy, radiation, surgery, and multimodal therapy (receipt of ≥2 modalities).

Because SEER chemotherapy variables combine "no" and "unknown", treatment variables were separated where possible. A sensitivity analysis excluding cases with unknown treatment status was conducted to evaluate potential misclassification bias.

Survival Outcomes

Two survival endpoints were evaluated: Overall survival (OS)—primary endpoint, and Cancer-specific survival (CSS)—secondary endpoint. Survival time was measured in months from diagnosis until death or last follow-up.

Cause of death was obtained from: COD to site recode (ICD-O-3 2023 revision).

2.3. Statistical Analysis

Regression Parameterization

All regression models used the following reference group: White patients with household income ≥ $75,000.

Interaction models included indicator variables for race × income categories: White low income, Black high income, Black low income, Hispanic high income, Hispanic low income, Asian high income, Asian low income, American Indian high income, American Indian low income.

This parameterization allowed direct estimation of disparities relative to the reference group.

Treatment Models

Binary logistic regression models estimated the odds of receiving each treatment modality. Three model tiers were evaluated: unadjusted, adjusted (covariates listed above), race × income interaction models. Results are presented as odds ratios (ORs) with 95% confidence intervals.

Survival Models

Survival outcomes were modeled using Cox proportional hazards regression. Separate models were run for each cancer type. Hazard ratios (HR) and 95% confidence intervals were estimated for each race × income subgroup relative to the reference group.

Model Diagnostics

Proportional hazards assumptions were evaluated using Schoenfeld residual tests and graphical inspection of scaled residual plots. No substantial violations were detected for primary predictors. In models where minor deviations were observed, sensitivity analyses using stratification by diagnosis era produced comparable estimates.

Marginal Effects

To facilitate interpretation of interaction terms, marginal predicted probabilities of treatment receipt and adjusted survival probabilities at 12 and 24 months were estimated for race-income groups.

Software

All analyses were conducted in R version 4.5 using the packages: survival, emmeans, broom, dplyr.

3. Results

3.1. Cohort Description

Descriptive statistics of each cohort are summarized in Table 1. The total number of patients was 77,895. The overall mean age was approximately 65 years. Approximately 40% of patients fell into the low-income group (household income < $75,000), and 71.5% resided in urban areas. The average time between diagnosis and treatment was 21 days overall. Mean survival across the cohort was approximately 15 months. All regression models used White patients with household income ≥ $75,000 as the reference group.

Given the large volume of data generated from the analysis, we decided to limit the results of this paper to the interaction model and focus on race and income differences. Other notable findings will be mentioned briefly below and explored in a subsequent report.

Table 1. Cohort summary.

Variable	Lung	Melanoma	Breast	Prostate
Cases	69,932	3786	3588	593
Mean Age	66	65	60	70
Sex, Male	36,270	2731	43	593
Sex, Female	33,662	1055	3545	0
Income < $75,000	29,294	1385	1296	225
Income ≥ $75,000	40,634	2401	2292	368
Income Unknown	4	0	0	0
Hispanic	5119	210	570	89
White	49,686	3484	2118	373
Black	8066	27	589	95
Asian	6509	44	274	32
American Indian	449	14	274	4

3.2. Survival Outcomes

Lung Cancer (see Table 2)

In the adjusted interaction model evaluating cancer-specific survival, several race-income groups demonstrated significant differences compared with the reference group (White ≥ $75,000).

Low-income White patients had significantly worse cancer-specific survival (HR 1.18, 95% CI 1.16 - 1.21, $p < 0.001$).

Low-income Black patients also had increased cancer-specific mortality (HR 1.12, 95% CI 1.08 - 1.16, $p < 0.001$), whereas high-income Black patients did not significantly differ from the reference group (HR 1.02, 95% CI 0.98 - 1.06, $p = 0.37$).

Hispanic patients demonstrated income-dependent differences. High-income Hispanic patients had improved cancer-specific survival (HR 0.91, 95% CI 0.87 - 0.95, $p < 0.001$), while low-income Hispanic patients had slightly worse survival (HR 1.07, 95% CI 1.01 - 1.13, $p = 0.017$).

Asian/Pacific Islander patients demonstrated significantly improved survival in both income strata. High-income Asian patients had HR 0.72 (95% CI 0.69 - 0.74, $p < 0.001$) and low-income Asian patients had HR 0.81 (95% CI 0.75 - 0.87, $p < 0.001$).

American Indian/Alaska Native patients had worse survival in both income groups (high income HR 1.14, 95% CI 1.00 - 1.31, $p = 0.044$; low income HR 1.22, 95% CI 1.04 - 1.44, p = 0.014).

Table 2. Lung cancer-adjusted hazard ratios for cancer-specific survival.

Race-Income Group	HR	95% CI	p
White < 75 k	1.18	1.16 - 1.21	<0.001
AIAN ≥ 75 k	1.14	1.00 - 1.31	0.044
AIAN < 75 k	1.22	1.04 - 1.44	0.014
Asian ≥ 75 k	0.72	0.69 - 0.74	<0.001
Asian < 75 k	0.81	0.75 - 0.87	<0.001
Black ≥ 75 k	1.02	0.98 - 1.06	0.37
Black < 75 k	1.12	1.08 - 1.16	<0.001
Hispanic ≥ 75 k	0.91	0.87 - 0.95	<0.001
Hispanic < 75 k	1.07	1.01 - 1.13	0.017

Reference group: White ≥ $75 k (HR: 1).

Melanoma (see Table 3)

Most race-income groups did not demonstrate statistically significant differences in cancer-specific survival relative to the reference group. Low-income White patients had worse cancer-specific survival compared with the reference group (HR 1.13, 95% CI 1.03 - 1.23, p = 0.009). High-income American Indian/Alaska Native patients demonstrated improved survival relative to the reference group (HR 0.34, 95% CI 0.14 - 0.81, p = 0.016). Other race-income groups did not demonstrate statistically significant differences.

Table 3. Melanoma-Adjusted hazard ratios for cancer-specific survival.

Race-Income Group	HR	95% CI	p
White < 75 k	1.13	1.03 - 1.23	0.009
AIAN ≥ 75 k	0.34	0.14 - 0.81	0.016
AIAN < 75 k	0.68	0.17 - 2.71	0.58
Black ≥ 75 k	1.26	0.68 - 2.36	0.46
Black < 75 k	1.26	0.67 - 2.34	0.47
Hispanic ≥ 75 k	1.07	0.87 - 1.32	0.50
Hispanic < 75 k	1.10	0.83 - 1.45	0.50
Asian ≥ 75 k	1.21	0.82 - 1.80	0.34

Breast (see Table 4)

Significant disparities in cancer-specific survival were observed among Black patients. High-income Black patients had increased cancer-specific mortality (HR 1.23, 95% CI 1.06 - 1.43, p = 0.008). Low-income Black patients demonstrated even higher mortality risk (HR 1.33, 95% CI 1.14 - 1.54, p < 0.001). Low-income

White patients also had significantly worse survival relative to the reference group (HR 1.15, 95% CI 1.03 - 1.29, p = 0.010). Hispanic and Asian patients did not demonstrate statistically significant differences in cancer-specific survival.

Table 4. Breast cancer-adjusted hazard ratios for cancer-specific survival.

Race-Income Group	HR	95% CI	p
White < 75 k	1.15	1.03 - 1.29	0.010
Black ≥ 75 k	1.23	1.06 - 1.43	0.008
Black < 75 k	1.33	1.14 - 1.54	<0.001
Hispanic ≥ 75 k	0.88	0.77 - 1.02	0.091
Hispanic < 75 k	1.01	0.83 - 1.23	0.91
Asian ≥ 75 k	0.92	0.77 - 1.10	0.35
Asian < 75 k	1.05	0.76 - 1.44	0.77

Prostate

In the prostate cancer cohort, no race-income subgroup demonstrated statistically significant differences in cancer-specific survival relative to the reference group.

3.3. Treatment Type

Lung Cancer

Chemotherapy

Low-income White patients had slightly lower odds of receiving chemotherapy compared with the reference group (OR 0.95, 95% CI 0.92 - 0.98, p = 0.002). High-income Black patients had lower odds of receiving chemotherapy (OR 0.75, 95% CI 0.69 - 0.81, p < 0.001). Low-income Black patients, however, were more likely to receive chemotherapy relative to the reference group (OR 1.23, 95% CI 1.11 - 1.37, p < 0.001).

Hispanic patients had lower odds of receiving chemotherapy across both income groups. High-income Hispanic patients had an OR of 0.84 (95% CI 0.74 - 0.96, p = 0.009), while low-income Hispanic patients had an OR of 0.81 (95% CI 0.69 - 0.95, p = 0.010). Asian patients demonstrated increased chemotherapy utilization among high-income individuals (OR 1.54, 95% CI 1.42 - 1.66, p < 0.001).

Marginal predicted probabilities indicated chemotherapy receipt rates of approximately 52% for the reference group, compared with 48% for high-income Black patients and 58% for high-income Asian patients.

Radiation Therapy

Low-income White patients had lower odds of receiving radiation therapy compared with the reference group (OR 0.94, 95% CI 0.90 - 0.98, p = 0.005). High-income Asian patients had reduced odds of radiation therapy (OR 0.88, 95% CI 0.81 - 0.96, p = 0.004). Hispanic patients had slightly reduced odds of radiation therapy regardless of income status.

Multimodal Treatment (Chemotherapy + Radiation + Surgery)

Low-income White patients had lower odds of receiving multimodal therapy (OR 0.91, 95% CI 0.86 - 0.97, p = 0.005). Low-income Black patients were significantly less likely to receive multimodal treatment (OR 0.85, 95% CI 0.76 - 0.94, p = 0.001). Hispanic patients had reduced odds of multimodal treatment regardless of income level: high-income Hispanic patients: OR 0.78 (95% CI 0.69 - 0.88, p < 0.001), low-income Hispanic patients: OR 0.76 (95% CI 0.63 - 0.90, p = 0.002) (Table 5).

Table 5. Lung cancer-adjusted odds ratios for treatment receipt.

Race-Income Group	Chemotherapy OR (95% CI)	p	Radiation OR (95% CI)	p	Multimodal Treatment OR (95% CI)	p
White < 75 k	0.95 (0.92 - 0.98)	0.002	0.94 (0.90 - 0.98)	0.005	0.91 (0.86 - 0.97)	0.005
Black ≥ 75 k	0.75 (0.69 - 0.81)	<0.001	0.96 (0.89 - 1.04)	0.32	0.89 (0.79 - 0.99)	0.04
Black < 75 k	1.23 (1.11 - 1.37)	<0.001	0.93 (0.86 - 1.01)	0.08	0.85 (0.76 - 0.94)	0.001
Hispanic ≥ 75 k	0.84 (0.74 - 0.96)	0.009	0.91 (0.80 - 1.03)	0.13	0.78 (0.69 - 0.88)	<0.001
Hispanic < 75 k	0.81 (0.69 - 0.95)	0.01	0.90 (0.76 - 1.07)	0.23	0.76 (0.63 - 0.90)	0.002
Asian ≥ 75 k	1.54 (1.42 - 1.66)	<0.001	0.88 (0.81 - 0.96)	0.004	0.95 (0.87 - 1.03)	0.20

Breast Cancer

Radiation Therapy

Low-income Hispanic patients were significantly less likely to receive radiation therapy (OR 0.61, 95% CI 0.41 - 0.90, p = 0.01). Low-income Black patients also had lower odds of receiving radiation therapy (OR 0.79, 95% CI 0.64 - 0.98, p = 0.03). Marginal predicted probabilities indicated radiation receipt rates of approximately 60% in the reference group compared with 51% among low-income Hispanic patients (Table 6).

Table 6. Breast cancer-adjusted odds ratios for radiation therapy.

Race-Income Group	OR	95% CI	p
White <75 k	0.93	0.81 - 1.07	0.32
Black ≥ 75 k	0.88	0.71 - 1.09	0.25
Black < 75 k	0.79	0.64 - 0.98	0.03
Hispanic ≥ 75k	0.82	0.63 - 1.07	0.14
Hispanic < 75 k	0.61	0.41 - 0.90	0.01
Asian ≥ 75 k	0.91	0.68 - 1.22	0.53

Melanoma

Radiation Therapy

High-income Hispanic patients were less likely to receive radiation therapy relative to the reference group (OR 0.64, 95% CI 0.42 - 0.98, p = 0.03). Low-income

White patients had increased odds of receiving multimodal therapy compared with the reference group (OR 1.36, 95% CI 1.03 - 1.78, p = 0.02) (**Table 7**).

Table 7. Melanoma-adjusted odds ratios for radiation therapy.

Race-Income Group	OR	95% CI	p
White < 75 k	1.36	1.03 - 1.78	0.02
Black ≥75 k	0.72	0.38 - 1.36	0.31
Black < 75 k	0.64	0.34 - 1.22	0.17
Hispanic ≥ 75k	0.64	0.42 - 0.98	0.03
Hispanic < 75 k	0.71	0.46 - 1.10	0.12

Prostate Cancer

Systemic Therapy

High-income Hispanic patients were significantly less likely to receive systemic therapy compared with the reference group (OR 0.36, 95% CI 0.15 - 0.86, p = 0.02). No other race-income groups demonstrated statistically significant differences in treatment receipt.

3.4. Sensitivity Analysis

Because the SEER chemotherapy variable combines "No" and "Unknown", treatment models were re-estimated after excluding cases with unknown treatment status.

The sensitivity analysis demonstrated no meaningful change in odds ratio estimates or statistical significance for race-income associations, suggesting that potential misclassification of treatment status did not materially affect the results.

4. Discussion

This study demonstrates that socioeconomic status significantly modifies racial disparities in treatment receipt and survival among patients with brain metastases, with effects varying substantially by primary cancer type. The findings reveal persistent inequities in both access to multimodal therapy and survival outcomes, particularly among Black patients with breast cancer and low-income patients across multiple cancer types. These results underscore the complex interplay between race, income, and cancer outcomes in the modern era of brain metastasis treatment.

4.1. Survival Disparities and the Modifying Effect of Income

The most striking finding was the persistent survival disadvantage among Black patients with breast cancer brain metastases regardless of income level (high-income HR 1.23, low-income HR 1.33), suggesting that socioeconomic advantage does not fully mitigate racial disparities in this population. This pattern aligns with the "diminishing returns" hypothesis, which posits that higher socioeconomic status yields fewer health benefits for Black individuals compared to White individuals [1]. Recent analyses have found strong evidence of diminishing returns among Black women, particularly for breast and uterine cancers, where higher neighborhood socioeconomic status failed to eliminate survival disparities [1] [2]. The persistence of breast cancer disparities even among high-income Black patients in our cohort suggests that factors beyond economic resources—including structural racism, differential access to high-quality care, implicit bias in treatment recommendations, and biological differences in tumor characteristics—contribute to worse outcomes [2]-[6].

In contrast, lung cancer brain metastases demonstrated income-dependent disparities, with low-income Black patients experiencing elevated mortality (HR 1.12) while high-income Black patients showed no significant difference from the reference group. This pattern suggests that for lung cancer, socioeconomic factors may play a more dominant role in driving racial disparities than for breast cancer. The differential impact of income across cancer types highlights the importance of cancer-specific approaches to addressing disparities rather than applying uniform interventions across all malignancies [2] [6] [7] [20].

4.2. The Asian Survival Advantage

Asian patients demonstrated significantly improved survival across both income strata in lung cancer brain metastases (high-income HR 0.72, low-income HR 0.81), consistent with prior literature documenting superior cancer outcomes in Asian populations [8] [9]. Multiple mechanisms may contribute to this survival advantage. Asian patients with lung cancer have higher rates of EGFR mutations, which respond favorably to targeted tyrosine kinase inhibitors with excellent CNS penetration [8] [10]. Additionally, Asian patients may present with less aggressive tumor biology, receive more comprehensive treatment, and benefit from cultural factors such as stronger social support networks and adherence to treatment [8] [9]. However, it is important to note that the "Asian" category encompasses diverse ethnic subgroups with varying cancer outcomes, and aggregation may mask disparities within this heterogeneous population [11] [21].

4.3. Treatment Disparities across Cancer Types

Significant disparities in treatment receipt were observed across multiple cancer types, with particularly concerning patterns in multimodal therapy utilization. Among lung cancer patients, low-income Black patients had 15% lower odds of receiving multimodal treatment (OR 0.85), while Hispanic patients demonstrated reduced odds regardless of income level (high-income OR 0.78, low-income OR 0.76). These findings align with extensive literature documenting racial and socioeconomic disparities in receipt of guideline-concordant cancer treatment [22]. Black and Hispanic patients are more likely to experience treatment delays, receive care at lower-volume hospitals, and face financial toxicity that limits treatment completion [7] [12] [13] [23].

The reduced radiation therapy utilization among low-income Hispanic patients with breast cancer (OR 0.61) is particularly concerning given the established role of radiation in local control and survival for breast cancer brain metastases. Geographic barriers, language concordance issues, medical mistrust, and lack of culturally tailored patient navigation may contribute to these disparities. Studies have shown that Hispanic patients are less likely to receive provider referrals for cancer screening and treatment, and face unique barriers related to immigration status and health insurance coverage [7] [15].

Interestingly, high-income Asian patients with lung cancer demonstrated increased chemotherapy utilization (OR 1.54) but reduced radiation therapy receipt (OR 0.88), suggesting potential differences in treatment preferences or physician recommendations that warrant further investigation. This pattern may reflect cultural preferences for systemic over local therapy, differential access to clinical trials of novel systemic agents, or physician bias in treatment recommendations [9] [16].

4.4. Structural Determinants of Disparities

The observed disparities must be understood within the broader context of structural racism and social determinants of health that shape cancer outcomes [2] [6] [7] [24]. Historical policies such as redlining have resulted in residential segregation, concentrated poverty, and underinvestment in communities of color, creating downstream effects on cancer risk, diagnosis, and treatment. These structural inequities manifest as differential exposure to carcinogens, limited access to high-quality cancer centers, lower rates of health insurance coverage, and reduced availability of advanced treatments such as stereotactic radiosurgery in underserved areas [12] [17]-[19].

Even when controlling for socioeconomic status, Black patients experience worse cancer survival than White patients for most cancer types, suggesting that race-specific factors beyond income—including chronic stress from discrimination, differential quality of care even within the same healthcare systems, and underrepresentation in clinical trials—contribute to outcome disparities [2] [6] [25]. A recent study found that structural racism, measured by a composite index of racial gaps in social determinants, was associated with increased treatment delays among Black patients with breast cancer, with neighborhood socioeconomic status accounting for a substantial portion of the Black-White survival disparity [25] [26].

4.5. Implications for Brain Metastasis Care

The treatment of brain metastases has evolved substantially over the study period (2010-2022), with increasing use of stereotactic radiosurgery, hippocampal-avoidance whole-brain radiotherapy, and CNS-penetrant systemic therapies [10] [17] [27]-[29]. However, our findings suggest that not all patients have benefited equally from these advances. Geographic disparities in access to stereotactic radiosurgery have been previously documented, with rural and low-income patients less likely to receive this treatment modality [12] [17] [18] [30]. The lower rates of multimodal therapy among minority and low-income patients in our cohort suggest that barriers to accessing comprehensive, guideline-concordant care persist despite therapeutic innovations [18] [19].

Financial toxicity represents a significant barrier to optimal brain metastasis treatment, as patients must navigate costs associated with multiple treatment modalities, frequent imaging surveillance, supportive medications, and potential loss of income during treatment. The high cost of novel targeted therapies and immunotherapies, combined with increasing cost-sharing requirements in private insurance plans, may exacerbate existing disparities. Patients with limited financial resources may face nonmedical barriers such as lack of transportation to specialized treatment centers, inability to take time off work, and inadequate social support—all of which can delay or prevent receipt of optimal care [7] [12] [18].

4.6. Limitations and Strengths

This study has several limitations. The SEER database lacks detailed information on treatment quality, specific radiation modalities (e.g., stereotactic radiosurgery vs. whole-brain radiotherapy), molecular tumor characteristics, performance status, and individual-level socioeconomic factors beyond area-level median income. The chemotherapy variable combines "no" and "unknown" responses, potentially introducing misclassification bias, although sensitivity analyses excluding unknown cases showed consistent results. Additionally, SEER does not capture information on treatment intent, completion of planned therapy, or reasons for treatment non-receipt, limiting our ability to distinguish between patient preference, physician recommendation, and systemic barriers.

Despite these limitations, this study has important strengths. The large, population-based cohort spanning 2010-2022 provides contemporary data on brain metastasis outcomes in the era of modern systemic therapies and radiation techniques. The use of race × income interaction models allows for nuanced examination of how socioeconomic status modifies racial disparities, moving beyond simple additive models. The inclusion of multiple primary cancer types reveals important heterogeneity in disparity patterns, highlighting the need for cancer-specific interventions.

4.7. Future Directions

Addressing the disparities identified in this study will require multilevel interventions targeting individual, healthcare system, and policy levels [1] [31] [32]. At the individual level, patient navigation programs have demonstrated effectiveness in improving treatment receipt and reducing delays among minority patients, particularly when culturally tailored and addressing both medical and nonmedical barriers [1] [33] [34]. Community-based participatory research approaches that engage affected communities in intervention design and implementation may enhance acceptability and effectiveness.

At the healthcare system level, interventions should focus on improving implicit bias training for providers, implementing tracking dashboards to monitor and address disparities in real-time, ensuring adequate representation of minority populations in clinical trials, and expanding access to advanced treatment modalities such as stereotactic radiosurgery in underserved areas [1] [2] [31] [35]. Hospitals serving higher proportions of minority patients should receive targeted support to offer comprehensive cancer treatment services comparable to those available at academic medical centers [12] [13].

Policy interventions are essential for addressing the structural determinants of disparities. Expanding health insurance coverage through Medicaid expansion and eliminating cost-sharing for cancer treatment could substantially reduce financial barriers to care [18]. Policies that address social determinants of health—including housing assistance, food security programs, transportation vouchers, and paid medical leave—may have significant downstream effects on cancer outcomes [7] [18]. Additionally, increased research funding for cancers that disproportionately affect minority populations and requirements for diversity in clinical trial enrollment are needed to ensure that therapeutic advances benefit all patients equitably [2] [18] [31] [36].

5. Conclusion

This study demonstrates that socioeconomic status modifies racial disparities in treatment receipt and survival among patients with brain metastases, with effects varying by primary cancer type. The persistent survival disadvantage among Black patients with breast cancer regardless of income level, coupled with reduced multimodal therapy utilization among low-income Black patients and Hispanic patients across cancer types, highlights the urgent need for multilevel interventions addressing structural inequities in metastatic cancer care. Future research should focus on identifying specific mechanisms driving these disparities and evaluating interventions to ensure that all patients benefit equitably from advances in brain metastasis treatment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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