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Prognostic trends of malignant cardiac tumors: insights from the Surveillance, Epidemiology, and End Results (SEER) registry

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Abstract

Aim: This study aims to evaluate how demographic and treatment variables, including age, tumor type, resectability, and metastasis, affect survival outcomes across prognostic subgroups of primary malignant cardiac tumors (PMCTs).

Methods: PMCT cases diagnosed between 2000 and 2021 were identified from Surveillance, Epidemiology, and End Results (SEER) 18 registries. 730 patients were analyzed and categorized into prognosis groups based on 5-year survival (< 50%, 50–95%, > 95%). Demographic, histologic, and treatment varieties were examined using descriptive statistics, Kaplan-Meier estimates, and Cox proportional hazards models.

Results: Among 730 patients, most were middle-aged (56.6%), male (52.5%), and White (60.1%). Soft tissue sarcomas predominated in the poorest-prognosis group (80.3%), while hematologic malignancies were most common in intermediate prognosis (52.0%). Younger age significantly reduced mortality risk [hazard ratio (HR) 0.49–0.52; $p < 0.01$]. Brain and lung metastases increased mortality (HR 2.04 and 1.89; $p < 0.05$). Surgical resection improved survival in sarcoma-dominant tumors, while systemic metastasis predicted poorer outcomes in hematologic malignancies. Chemotherapy improved survival in sarcomas ($\rho = 0.457$; $p < 0.0001$) but was associated with poorer outcomes in hematologic cancers ($\rho = -0.337$; $p < 0.0001$).

Conclusions: PMCT prognosis is primarily influenced by histologic subtype and resectability. Sarcoma-dominant tumors benefit from aggressive surgical and chemotherapeutic management, conversely systemic control is key for hematologic malignancies. Younger age and absence of metastasis consistently predict better outcomes. Histology-specific and early intervention strategies are critical to improving survival in this rare malignancy.

Keywords

prognosis, resectability, metastasis, survival analysis, histopathology, age

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Introduction

Primary malignant cardiac tumors (PMCTs) are a rare group of disorders that are associated with a poor prognosis [1]. While less common than metastatic cardiac tumors, the average annual incidence of PMCTs has increased with time, rising from 25.1 in 1973–1989 to 46.6 in 2000–2011 [2]. Despite their rarity, these tumors carry devastating consequences, with the 1, 3, and 5-year survival rates being 45.6%, 18.8%, and 11.2%, respectively, pointing to the poor prognosis of the disease [3]. Overall, the histopathologic subtypes with the highest rate of mortality include mesotheliomas and sarcomas, whereas the lowest rate of mortality includes lymphomas.

Clinically, most PMCTs are asymptomatic, often being found incidentally. However, systemic or cardiac signs and symptoms are also possible, depending on the location and size. These findings can include new arrhythmias, congestive heart failure, new-onset dyspnea, or murmurs [4]. Consequently, diagnosis is often delayed until the tumor has reached an advanced stage, which further complicates treatment methods [5]. Advances in diagnostic imaging modalities such as echocardiography, computed tomography (CT), magnetic resonance imaging (MRI), positron emission tomography (PET), cardiac catheterization, and biopsy may have increased diagnoses and earlier identification. Despite these imaging advances, the survival rate of these cancers continues to be abysmal [6].

The rarity of PMCTs has limited the generalizability of current literature, as most data have come from case reports, retrospective analyses, or single-institution findings. National registries, such as Surveillance, Epidemiology, and End Results (SEER) database, offer a unique opportunity for wider applicability due to the broad range of populations and long time periods of evaluation. Past analyses have shown that age, histopathological subtype, and method of treatment have been strong indicators of outcomes [7]. However, systematic stratification of these tumors by prognosis category remains somewhat underexplored.

This study seeks to explore survival analysis of PMCTs using 18 registries from the SEER database between 2000 and 2021. By doing so, we aim to provide new insight into how tumor biology and treatments influence overall survival (OS) outcomes in this rare but clinically significant disease.

Preliminary findings from this study were previously presented as a meeting abstract at the American College of Cardiology Annual Scientific Session and published in the Journal of the American College of Cardiology abstract supplement.

Materials and methods

Study population

We queried SEER*Stat (November 2023 update) to extract cases from the SEER 18 registries diagnosed between 2000 and 2021 [8]. Eligible records had the primary site coded as heart using the ICD-O-3 topography code C38.0. A total of 784 cases of PMCTs were initially identified in the SEER database between 2000 and 2021. After excluding 54 cases with missing survival information, the final analytic cohort consisted of 730 patients. Variables were harmonized using a project data dictionary. Demographic covariates included age at diagnosis, categorized as youth (< 45 years), middle (45–64 years), and elderly (≥ 65 years); sex; race/ethnicity; neighborhood median household income (quartiles) based on the national median during 2022 ($75,000); and rural-urban continuum code. These various groupings intentionally reflected factors that are associated with inequities in healthcare, including race, socioeconomic status, and population density. These populations are often less likely to have equal access to healthcare and thus, cardiac imaging and other diagnostic modalities in comparison to their counterparts [9]. Clinical and histologic covariates included tumor size (continuous), ICD-O-3 histology, a prespecified prognosis group, cancer subtype (Soft tissue, Hematologic, Embryonal, Other), and indicators of distant metastases to bone, brain, liver, and lung.

Prognosis groups were designated based on literature-derived estimates of percent survival at 5 years [7, 10, 11]. Prognosis I defines tumors with a prognosis worse than 50% at 5 years, Prognosis II defines tumors with a prognosis between 50–95% at 5 years, and Prognosis III defines tumors with > 95% survival at 5 years. Cancer subtype was determined by literature-derived histological proximity based on author consensus (> 2 authors agreeing). Stratification by author consensus was pursued in an effort to further describe pre-existing biology-driven classification of cardiac malignancy that continues to be useful but limited [12, 13]. This investigation categorized cardiac tumors by literature-derived estimates of 5-year percent survival to ascertain similarities in clinical significance over histology as a distinct tumor niche in primary cardiac tumors to elucidate large, therapeutically informative trends that address the gaps in histology-driven studies.

Treatment covariates included surgery of the primary site (SEER RX Summ—Surg Prim Site [1998+]), radiation type, and chemotherapy (yes/no). These therapies were administered as part of the first course of treatment following the initial cancer diagnosis; subsequent treatments given after disease progression or recurrence were not comprehensively captured within the database. Cases coded as "unknown/death" under the surgery variable represent death certificates that had the treatment information listed as unavailable; thus, it is unknown whether surgical treatment was performed.

OS in months and vital status were obtained from SEER, and death from any cause was considered an event. OS in months began at the time of initial diagnosis and considered death from all causes, not exclusively cancer-related. Because metastasis indicators in SEER are consistently available from 2010 forward, models that included bone/brain/liver/lung metastasis were restricted to diagnoses from 2010–2021, with complete-case analysis for those covariates.

Statistical analysis

We described cohort characteristics with standard descriptive statistics and summarized annual counts (2000–2021) for incidence visualization. To screen hypothesis-generating associations between covariates and survival time, we computed Pearson correlation between continuous variables (e.g., tumor size vs OS months) and Spearman correlation for ordinal or categorical variables vs OS (months); two-sided *p*-values < 0.05 were considered statistically significant. Unadjusted survival was estimated with the Kaplan-Meier (KM) methods overall and within prespecified strata (All tumors; Prognosis I; Prognosis II; Hematologic; Soft tissue; Embryonal; Other). We reported median OS and KM survival probabilities at 12, 24, and 60 months, and compared curves with log-rank tests. We then fit Cox proportional hazards models separately within each stratum with covariates including age group, sex, race/ethnicity, surgery type, radiation, chemotherapy, household income relative to the median household income in 2022 (above or below $75,000), rural-urban code, tumor size in millimeters (mm), and the four metastasis indicators (when available). Cox proportional hazards regression was used to explore factors associated with OS. Because proportional hazards diagnostics were not formally assessed, the results should be interpreted as exploratory. Given the rarity of PMCTs and small cell counts in some subgroups (particularly embryonal histologies), results from sparse strata were interpreted cautiously. Indeed, results from the embryonal and origins of other types were excluded from the final explorative analysis. Metastasis was also excluded in the subgroup correlational analysis due to low outcome variability. All analyses were conducted in Python within the Jupyter Notebook environment using pandas for data management and lifelines for survival analyses; figures were generated with matplotlib. Two-sided α was set at 0.05.

Results

Descriptive results

All tumor types

The overall cohort (*n* = 730) was mostly middle-aged (56.6%), male (52.5%), and White (60.1%). Soft-tissue sarcomas were the most frequent histology as seen in Table 1, followed by hematological malignancies, embryonal tumors, and other rare histologies. Half of the patients did not have surgery (49.2%), with a larger majority not having radiotherapy (83.8%). A small majority of patients had chemotherapy (53.7%).

Table 1. Frequency of demographic and therapeutic factors of all non-categorized primary malignant cardiac tumors.

Variable	Category	Count	Percent
Age group	Middle (45–64 years)	413	56.58
Age group	Elderly (≥ 65 years)	256	35.07
Age group	Youth (< 45 years)	61	8.35
Sex	Male	383	52.47
Sex	Female	347	47.53
Race	White	439	60.13
Race	Other	220	30.14
Race	Black	71	9.73
Surgery	None	359	49.17
Surgery	Simple/partial surgical removal of the primary site	105	14.38
Surgery	Excisional biopsy	99	13.56
Surgery	Local tumor excision, NOS	68	9.32
Surgery	Debulking surgery	35	4.79
Surgery	Enucleation	18	2.47
Surgery	Radical surgery	16	2.19
Surgery	Local tumor excision, partial/total removal, laser excision	14	1.92
Surgery	Surgery, NOS	9	1.23
Surgery	Unknown/death	4	0.55
Surgery	Local tumor destruction, NOS	1	0.14
Surgery	Local tumor excision, partial/total removal, cryosurgery	1	0.14
Surgery	Polypectomy	1	0.14
Radiation	None	612	83.84
Radiation	Radiation	118	16.16
Chemotherapy*	Yes	392	53.70
Chemotherapy*	None	338	46.30
Income	Above median household income (≥ $75,000)	538	73.70
Income	Below median household income (< $75,000)	192	26.30
Rural-urban	Urban	662	90.68
Rural-urban	Rural	68	9.32
Prognosis group	I (< 50% survival at 5 years)	366	50.14
Prognosis group	II (50–95% survival at 5 years)	356	48.76
Prognosis group	III (> 95% survival at 5 years)	8	1.10
Cancer subtype	Soft tissue	458	62.74
Cancer subtype	Heme	212	29.04
Cancer subtype	Other	53	7.26
Cancer subtype	Embryonal	7	0.96
Metastasis—bone	N/A	370	50.68
Metastasis—bone	No	326	44.66
Metastasis—bone	Yes	34	4.66
Metastasis—brain	N/A	373	51.10
Metastasis—brain	No	343	46.99
Metastasis—brain	Yes	14	1.91
Metastasis—liver	N/A	372	50.96
Metastasis—liver	No	334	45.75
Metastasis—liver	Yes	24	3.29
Metastasis—lung	N/A	370	50.68
Metastasis—lung	No	306	41.92
Metastasis—lung	Yes	54	7.40
Tumor size (per mm)	Median	65	
Tumor size (per mm)	IQR	36.75	

*The type of Chemotherapy was not provided in the SEER data. N/A: not applicable; NOS: not otherwise specified; IQR: interquartile range.

Table 2. Frequency of demographic and therapeutic factors of poor prognosis primary malignant cardiac tumors.

Variable	Category	Count	Percent
Age group	Middle (45–64 years)	250	68.31
Age group	Elderly (≥ 65 years)	85	23.22
Age group	Youth (< 45 years)	31	8.47
Sex	Male	195	53.28
Sex	Female	171	46.72
Race	White	213	58.20
Race	Other	107	29.23
Race	Black	46	12.57
Surgery	None	161	43.99
Surgery	Simple/partial surgical removal of the primary site	57	15.57
Surgery	Excisional biopsy	50	13.66
Surgery	Local tumor excision, NOS	44	12.02
Surgery	Debulking surgery	20	5.46
Surgery	Enucleation	13	3.55
Surgery	Local tumor excision, partial/total removal, laser excision	7	1.91
Surgery	Radical surgery	7	1.91
Surgery	Surgery, NOS	4	1.09
Surgery	Unknown/death	2	0.55
Surgery	Polypectomy	1	0.27
Radiation	None	302	82.51
Radiation	Radiation	64	17.49
Chemotherapy	Yes	188	51.37
Chemotherapy	None	178	48.63
Income	Above (≥ $75,000)	270	73.77
Income	Below (< $75,000)	96	26.23
Rural-urban	Urban	326	89.07
Rural-urban	Rural	40	10.93
Prognosis group	I (< 50% survival at 5 years)	366	100.00
Cancer subtype	Soft tissue	294	80.33
Cancer subtype	Other	45	12.30
Cancer subtype	Heme	24	6.56
Cancer subtype	Embryonal	3	0.82
Metastasis—bone	No	191	52.19
Metastasis—bone	N/A	147	40.16
Metastasis—bone	Yes	28	7.65
Metastasis—brain	No	206	56.28
Metastasis—brain	N/A	150	40.98
Metastasis—brain	Yes	10	2.73
Metastasis—liver	No	198	54.10
Metastasis—liver	N/A	149	40.71
Metastasis—liver	Yes	19	5.19
Metastasis—lung	No	173	47.27
Metastasis—lung	N/A	147	40.16
Metastasis—lung	Yes	46	12.57
Tumor size (per mm)	Median	65	
Tumor size (per mm)	IQR	35	

N/A: not applicable; NOS: not otherwise specified; IQR: interquartile range.

Prognosis I

A total of 366 patients were included in the Prognosis I cohort (prognosis worse than 50% in 5 years) (Table 2). The majority were middle-aged (68.3%), male (53.3%), and White (58.2%). Soft tissue tumors were the overwhelming majority (80.3%), followed by tumors of other origin (12.3%). And 44.0% of patients did not pursue any type of surgery, with a significant majority not pursuing radiation (82.5%). A small majority continued with chemotherapy (51.4%).

Prognosis II

There were 356 patients included in the improved prognosis cohort (50–95% survival in 5 years) (Table 3). A small majority were elderly (47.5%), male (51.1%), and White (62.4%). The majority were hematological cancers (52.0%). A small majority did not have surgery (53.9%), with a significant majority not having radiotherapy (85.4%). A majority of patients had chemotherapy (55.9%).

Table 3. Frequency of demographic and therapeutic factors of improved prognosis primary malignant cardiac tumors.

Variable	Category	Count	Percent
Age group	Elderly (≥ 65 years)	169	47.5
Age group	Middle (45–64 years)	157	44.1
Age group	Youth (< 45 years)	30	8.4
Sex	Male	182	51.1
Sex	Female	174	48.9
Race	White	222	62.4
Race	Other	111	31.2
Race	Black	23	6.4
Surgery	None	192	53.9
Surgery	Excisional biopsy	48	13.5
Surgery	Simple/partial surgical removal of primary site	47	13.2
Surgery	Local tumor excision, NOS	24	6.7
Surgery	Debulking surgery	15	4.2
Surgery	Radical surgery	9	2.5
Surgery	Local tumor excision, partial/total removal, laser excision	7	2.0
Surgery	Enucleation	5	1.4
Surgery	Surgery, NOS	5	1.4
Surgery	Unknown/death	2	0.6
Surgery	Local tumor destruction, NOS	1	0.3
Surgery	Local tumor excision, partial/total removal, cryosurgery	1	0.3
Radiation	None	304	85.4
Radiation	Radiation	52	14.6
Chemotherapy	Yes	199	55.9
Chemotherapy	None	157	44.1
Income	Above (≥ $75,000)	261	73.3
Income	Below (< $75,000)	95	26.7
Rural-urban	Urban	328	92.1
Rural-urban	Rural	28	7.9
Prognosis group	II (50–95% survival at 5 years)	356	100.0
Cancer subtype	Heme	185	52.0
Cancer subtype	Soft tissue	159	44.7
Cancer subtype	Other	8	2.2
Cancer subtype	Embryonal	4	1.1
Metastasis—bone	N/A	217	61.0
Metastasis—bone	No	133	37.4
Metastasis—bone	Yes	6	1.7
Metastasis—brain	N/A	217	61.0
Metastasis—brain	No	135	37.9
Metastasis—brain	Yes	4	1.1

Table 3. Frequency of demographic and therapeutic factors of improved prognosis primary malignant cardiac tumors. (*continued*)

Variable	Category	Count	Percent
Metastasis—liver	N/A	217	61.0
Metastasis—liver	No	134	37.6
Metastasis—liver	Yes	5	1.4
Metastasis—lung	N/A	217	61.0
Metastasis—lung	No	131	36.8
Metastasis—lung	Yes	8	2.2
Tumor size (per mm)	Median	66	
Tumor size (per mm)	IQR	48.5	

N/A: not applicable; NOS: not otherwise specified; IQR: interquartile range.

Correlational analysis

All tumor types

Small correlations were found between several factors and survival in months, as seen in Table 4. Notably, tumors characterized by the study as having poor prognosis were associated with fewer months of survival ($\rho = -0.181$; $p < 0.0001$). Chemotherapy was associated with fewer survival in months ($\rho = -0.397$; $p < 0.0001$) while radiotherapy was associated with increased months of survival ($\rho = 0.117$; $p < 0.01$).

Table 4. Correlational analysis of demographic factors and therapeutic strategies, and survival in all tumor types.

Variable	Type	Correlation	*p*-value
Tumor size (per mm)	Continuous	0.250476579	0.0043
Age recode with < 1 year old and 90+	Categorical	–0.075815532	0.0406
Sex	Categorical	0.036647961	0.3228
Race and origin recode (NHW, NHB, NHAIAN, NHAPI, Hispanic)	Categorical	0.005393235	0.8843
RX Summ—Surg Prim Site (1998+)	Categorical	0.002661549	0.9428
Radiation recode	Categorical	0.117303122	0.0015
Chemotherapy recode (yes, no/unknown)	Categorical	–0.396603804	0.0000
Median household income inflation-adjusted to 2022	Categorical	–0.02628622	0.4783
Rural-urban continuum code	Categorical	0.004912835	0.8946
ICD-O-3 Hist/behavior	Categorical	0.120800191	0.0011
Prognosis (I, II, III)	Categorical	–0.180536742	0.0000
Cancer subtype	Categorical	0.086727803	0.0191
SEER Combined Mets at DX-bone (2010+)	Categorical	0.117700998	0.0014
SEER Combined Mets at DX-brain (2010+)	Categorical	0.075304502	0.0419
SEER Combined Mets at DX-liver (2010+)	Categorical	0.104129826	0.0049
SEER Combined Mets at DX-lung (2010+)	Categorical	0.094516858	0.0106
Sequence number	Categorical	0.052458979	0.1568

NHAIAN: non-Hispanic American Indian/Alaska Native; NHAPI: Non-Hispanic Asian/Pacific Islander; NHB: non-Hispanic Black; NHW: non-Hispanic Whites; SEER: Surveillance, Epidemiology, and End Results.

Prognosis I

Table 5 lists all correlations between factors and survival in months. Chemotherapy was moderately associated with improved survival in months ($\rho = 0.457$; $p < 0.0001$) while radiotherapy was loosely associated with increases in survival in months ($\rho = 0.137$; $p < 0.01$).

Prognosis II

Table 6 describes all the significant correlations found in the improved prognosis group. Increasing tumor size was associated with improved survival ($\rho = 0.504$; $p < 0.01$). Chemotherapy was associated with decreases in survival months ($\rho = -0.337$; $p < 0.0001$).

Table 5. Correlational analysis of demographic factors and therapeutic strategies, and survival in poor-prognosis tumor types.

Variable	Type	Correlation	*p*-value
Tumor size (per mm)	Continuous	–0.14908	0.1632
Age recode with < 1 year old and 90+	Categorical	–0.16054	0.0021
Sex	Categorical	–0.03116	0.5524
Race and origin recode (NHW, NHB, NHAIAN, NHAPI, Hispanic)	Categorical	0.016637	0.7511
RX Summ—Surg Prim Site (1998+)	Categorical	–0.01497	0.7753
Radiation recode	Categorical	0.136765	0.0088
Chemotherapy recode (yes, no/unknown)	Categorical	0.457487	0.0000
Median household income inflation-adjusted to 2022	Categorical	–0.03	0.5673
Rural-urban continuum code	Categorical	–0.01419	0.7867
ICD-O-3 Hist/behavior	Categorical	–0.01315	0.8020
Cancer subtype	Categorical	–0.07452	0.1548
SEER Combined Mets at DX-bone (2010+)	Categorical	0.0276	0.5987
SEER Combined Mets at DX-brain (2010+)	Categorical	–0.01508	0.7737
SEER Combined Mets at DX-liver (2010+)	Categorical	0.00000685	0.9999
SEER Combined Mets at DX-lung (2010+)	Categorical	–0.0039	0.9407
Sequence number	Categorical	–0.10017	0.0555

NHAIAN: non-Hispanic American Indian/Alaska Native; NHAPI: Non-Hispanic Asian/Pacific Islander; NHB: non-Hispanic Black; NHW: non-Hispanic Whites; SEER: Surveillance, Epidemiology, and End Results.

Table 6. Correlational analysis of demographic factors and therapeutic strategies, and survival in improved prognosis tumor types.

Variable	Type	Correlation	*p*-value
Tumor size (per mm)	Continuous	0.5044	0.0011
Age recode with <1 year old and 90+	Categorical	–0.1227	0.0206
Sex	Categorical	0.1013	0.0561
Race and origin recode (NHW, NHB, NHAIAN, NHAPI, Hispanic)	Categorical	–0.0521	0.3267
RX Summ—Surg Prim Site (1998+)	Categorical	–0.0009	0.9862
Radiation recode	Categorical	0.1174	0.0268
Chemotherapy recode (yes, no/unknown)	Categorical	–0.3372	0.0000
Median household income inflation-adjusted to 2022	Categorical	–0.0129	0.8078
Rural-urban continuum code	Categorical	0.0479	0.3679
ICD-O-3 Hist/behavior	Categorical	0.1924	0.0003
Cancer subtype	Categorical	0.1714	0.0012
SEER Combined Mets at DX-bone (2010+)	Categorical	0.1485	0.0050
SEER Combined Mets at DX-brain (2010+)	Categorical	0.1144	0.0309
SEER Combined Mets at DX-liver (2010+)	Categorical	0.1454	0.0060
SEER Combined Mets at DX-lung (2010+)	Categorical	0.1030	0.0522
Sequence number	Categorical	0.0980	0.0647

NHAIAN: non-Hispanic American Indian/Alaska Native; NHAPI: Non-Hispanic Asian/Pacific Islander; NHB: non-Hispanic Black; NHW: non-Hispanic Whites; SEER: Surveillance, Epidemiology, and End Results.

Cox proportional hazards model

Table 7 depicts statistically significant predictors of hazard from explorative Cox proportional hazards models stratified by cohort.

In the All tumors cohort, younger age was protective [middle vs elderly hazard ratio (HR) 0.69 (0.50–0.95); $p = 0.019$; youth vs elderly HR 0.52 (0.35–0.78); $p = 0.003$] while brain and lung metastases conferred higher hazard (HR 2.04 and 1.89; $p = 0.047$ and $p = 0.011$, respectively).

Table 7. Statistically significant results in an explorative multivariable Cox proportional hazards regression model.

Cohort	Predictor	Hazard ratio (95 % CI)	*p*-value
All tumors (*n* = 730)	Age—middle (45–64 years; *n* = 413) vs elderly (≥ 65 years; *n* = 256)	0.69 (0.50–0.95)	0.019
	Age—youth (< 45 years; *n* = 61) vs elderly (≥ 65 years; *n* = 256)	0.52 (0.35–0.78)	0.003
	Brain metastases (yes; *n* = 14 vs no; *n* = 343)	2.04 (1.01–4.11)	0.047
	Lung metastases (yes; *n* = 54 vs no; *n* = 306)	1.89 (1.15–3.10)	0.011
Prognosis I (*n* = 366)	Tumor size (per mm)	1.01 (1.00–1.02)	0.031
	Age—middle (45–64 years; *n* = 250) vs elderly (≥ 65 years; *n* = 85)	0.56 (0.37–0.83)	0.005
	Age—youth (< 45 years; *n* = 31) vs elderly (≥ 65 years; *n* = 85)	0.49 (0.32–0.75)	0.004
	Surgery—local tumour excision (*n* = 44)	0.63 (0.40–1.00)	0.050
	Surgery—partial resection (*n* = 57)	0.44 (0.23–0.82)	0.021
Prognosis II (*n* = 356)	Age—middle (45–64 years; *n* = 157) vs elderly (≥ 65 years; *n* = 169)	0.59 (0.42–0.83)	0.003
	Age—youth (< 45 years; *n* = 30) vs elderly (≥ 65 years; *n* = 169)	0.52 (0.34–0.80)	0.004
	Surgery—excisional biopsy (*n* = 48)	0.50 (0.25–0.99)	0.049
	Surgery—unknown or death (*n* = 2)	1.54 (1.15–2.07)	0.004
	Brain metastases (yes; *n* = 4 vs no; *n* = 135)	2.43 (1.16–5.09)	0.017
	Lung metastases (yes; *n* = 8 vs no; *n* = 131)	1.93 (1.17–3.18)	0.010
Hematological (*n* = 212)	Age—middle (45–64 years; *n* = 72) vs elderly (≥ 65 years; *n* = 134)	0.30 (0.17–0.55)	0.001
	Age—youth (< 45 years; *n* = 6) vs elderly (≥ 65 years; *n* = 134)	0.13 (0.04–0.38)	0.000
	Race—NHAPI (*n* = 29) vs others (*n* = 183)	0.41 (0.18–0.90)	0.026
	Race—Hispanic (*n* = 33) vs non-Hispanic (*n* = 179)	0.38 (0.17–0.85)	0.020
	Surgery—excisional biopsy (*n* = 10)	0.44 (0.20–0.97)	0.047
	Surgery—unknown/death (*n* = 3)	2.18 (1.26–3.78)	0.006
Soft tissue (*n* = 458)	Tumor size (per mm)	1.02 (1.00–1.03)	0.017
	Age—middle (45–64 years; *n* = 311) vs elderly (≥ 65 years; *n* = 99)	0.46 (0.33–0.65)	0.000
	Age—youth (< 45 years; *n* = 48) vs elderly (≥ 65 years; *n* = 99)	0.30 (0.20–0.44)	0.000
	Surgery—enucleation (*n* = 14)	0.39 (0.20–0.77)	0.003
	Surgery—excisional biopsy (*n* = 83)	0.36 (0.20–0.65)	0.001
	Surgery—local tumour excision (*n* = 54)	0.35 (0.23–0.53)	0.000
	Surgery—partial resection (*n* = 90)	0.44 (0.27–0.71)	0.000
Other (*n* = 53)	Race—NHAPI (*n* = 5) vs others (*n* = 48)	0.12 (0.03–0.52)	0.004
	Race—Hispanic (*n* = 8) vs non-Hispanic (*n* = 45)	0.17 (0.04–0.65)	0.009
	Surgery—partial resection (*n* = 4)	0.37 (0.18–0.76)	0.007
	Income—upper quartile (*n* = 41)	1.73 (1.09–2.75)	0.022

NHAPI: Non-Hispanic Asian/Pacific Islander.

In Prognosis I, larger tumor size was associated with a small per-mm increase in hazard (HR 1.01; $p = 0.031$). Younger age was protective (middle HR 0.56; $p = 0.005$; youth HR 0.49; $p = 0.004$). Limited surgical interventions were associated with lower hazard, including local excision (HR 0.63; $p = 0.050$) and partial resection (HR 0.44; $p = 0.021$).

In Prognosis II, younger age again, reduced hazard (middle HR 0.59; $p = 0.003$; youth HR 0.52; $p = 0.004$). Excisional biopsy was protective (HR 0.50; $p = 0.049$), whereas “unknown/death” surgical status was associated with increased hazard (HR 1.54; $p = 0.004$). Brain and lung metastases remained adverse (HR 2.43 and 1.93; $p = 0.017$ and $p = 0.010$).

In Hematological cancers, the age gradient was pronounced (middle HR 0.30; $p = 0.001$; youth HR 0.13; $p < 0.0001$). Non-Hispanic Asian/Pacific Islander (NHAPI) race and Hispanic ethnicity were associated with lower hazard (HR 0.41; $p = 0.026$ and HR 0.38; $p = 0.020$). Excisional biopsy was protective (HR 0.44; $p = 0.047$), while unknown/death surgical status increased hazard (HR 2.18; $p = 0.006$).

In Soft tissue tumors, size showed a modest per-mm hazard increase (HR 1.02; $p = 0.017$). Younger age was protective (middle HR 0.46; $p < 0.0001$; youth HR 0.30; $p < 0.0001$). Several procedures were associated with reduced hazard, including enucleation (HR 0.39; $p = 0.003$), excisional biopsy (HR 0.36; $p = 0.001$), local excision (HR 0.35; $p < 0.0001$), and partial resection (HR 0.44; $p < 0.0001$).

In Other tumors, NHAPI race and Hispanic ethnicity were associated with lower hazard (HR 0.12; p = 0.004 and HR 0.17; p = 0.009). Partial resection was protective (HR 0.37; p = 0.007), whereas upper-quartile income was associated with higher hazard (HR 1.73; p = 0.022).

Kaplan-Meier survival curves across all tumor types

As seen in Table 8, the statistical significance in survival probability was noted by prognosis grouping and cancer subtype most definitively across time points ($p < 0.001$). Prognosis II maintains consistently improved survival compared to Prognosis I at 30, 60, and 120 months time points. Chemotherapy status also showed strong separation of survival curves at 30, 60, and 120 months ($p < 0.001$). Brain metastasis was consistently associated with poorer survival at all evaluated intervals (30 months: p = 0.017; 60 months: p = 0.017; 120 months: p = 0.017), while bone metastasis was associated with poorer short- and intermediate-term survival (30 months: p = 0.017; 60 months: p = 0.028) with attenuation by 120 months (p = 0.084). Lung metastasis was associated with poorer short-term survival at 30 months (p = 0.046), but was not sustained over time. Liver metastasis did not significantly separate survival curves at any interval examined. Sex, age, race, tumor size category, income, and rural-urban status were not associated with durable long-term differences in unadjusted survival.

Table 8. Results of Kaplan-Meier survival curve for all tumors summarized.

Variable	30-month log-rank *p*-value	60-month log-rank *p*-value	120-month log-rank *p*-value
Age group	0.117	0.178	0.061
Sex	0.123	0.101	0.069
Race	0.729	0.637	0.543
Radiation	0.036	0.105	0.067
Chemotherapy	< 0.001	< 0.001	< 0.001
Tumor size category	0.310	0.243	0.169
Income	0.478	0.673	0.554
Rural-urban status	0.818	0.889	0.767
Prognosis group (II vs I)	< 0.001	< 0.001	< 0.001
Cancer subtype	< 0.001	< 0.001	< 0.001
Bone metastasis	0.017	0.028	0.084
Brain metastasis	0.017	0.017	0.017
Liver metastasis	0.786	0.786	0.631
Lung metastasis	0.046	0.101	0.145

Discussion

This study utilizes the SEER data regarding PMCTs and provides prognostic stratifications, specifically Prognosis I (< 50% 5-year survival) and Prognosis II (50–95% 5-year survival). While these two groups were similar in size, their demographic, histologic, and treatment-related characteristics were notably different, suggesting distinct disease processes that may require different therapeutic strategies.

Categorical analysis

Demographic characteristics

Across all tumors (Table 1), the majority of patients were middle-aged (56.6%), male (52.5%), and White (60.1%). Prognosis I (Table 2) skewed younger, with 68.3% middle-aged, while Prognosis II (Table 3) skewed older, with 47.5% ≥ 65 years old. The Cox analysis (Table 7) confirmed younger age as consistently protective, with HRs of 0.52–0.69 compared to elderly patients. Older patients in Prognosis II may be more limited by comorbidities, influencing both treatment selection and survival outcomes. These results are consistent with prior studies demonstrating that younger patients tolerate aggressive multimodality treatment better and are more likely to undergo and survive large surgeries [2, 14].

Race and ethnicity distributions also differed. White patients made up the majority in both groups, but were not significantly correlated with outcomes within Prognosis I or II. Prognosis II had a higher proportion of Hispanic patients compared with Prognosis I. Findings from the hematologic tumor cohort in Table 7 suggested that NHAPI had a lower hazard of death compared to all of the other races included in the cohort (HR = 0.41). Hispanic patients had a lower hazard of death compared to non-Hispanic Whites (HR = 0.38). Similar findings were found in the "Other" tumor cohort in Table 7, where lower HRs were observed for NHAPI compared to other races (HR = 0.12) and for Hispanic patients compared to non-Hispanic Whites (HR = 0.17). While surface-level observation of this data may be of interest, these subgroups included only a small number of patients. As a result, these findings should be interpreted carefully, as small sample sizes may cause HRs that are skewed and not representative of the generalized population. Therefore, these findings should be used as an exploratory idea rather than a definitive finding.

Histologic characteristics and treatment modalities

Prognosis I tumors were predominantly soft tissue sarcomas (80.3%), while Prognosis II was composed primarily of hematologic malignancies (52.0%). These findings may reflect the locally aggressive nature of sarcomas compared to the systemic effects of hematologic malignancies. This distinction is consistent with contemporary institutional series of primary cardiac sarcoma, which report aggressive local invasion, high rates of early metastasis, and median survival often less than two years despite treatment [15].

In Prognosis I, surgical resection was strongly associated with improved survival, with partial resection (HR 0.44, $p = 0.021$) and local excision (HR 0.63, $p = 0.050$) demonstrating protective effects. Chemotherapy also correlated with longer survival ($\rho = 0.457$, $p < 0.0001$), consistent with prior reports where multimodal therapy extended survival in cardiac sarcomas despite high recurrence rates [16, 17]. Importantly, larger tumor size predicted worse outcomes (HR 1.01 per mm, $p = 0.031$), emphasizing the value of early diagnosis and surgical referral to maximize resectability.

In Prognosis II, surgery played a limited role, with only excisional biopsy showing benefit (HR 0.50, $p = 0.049$). Prognosis in this group was instead dominated by systemic progression, specifically brain metastasis (HR 2.43, $p = 0.017$) and lung metastasis (HR 1.93, $p = 0.010$). Chemotherapy was conversely associated with poorer survival ($\rho = -0.337$, $p < 0.0001$), likely reflecting confounding with advanced disease, but also emphasizing the limited strength of current chemotherapeutic regimens for primary cardiac lymphomas [18].

These findings highlight that Prognosis I outcomes are highly influenced by resectability, while Prognosis II outcomes depend on systemic disease control. Even partial resections in sarcomas may provide prolonged survival. This differs from the hematologic tumors that dominated Prognosis II, where systemic therapy would provide improved prognosis outcomes. Our analysis reflects a nuanced histopathological understanding of current standards regarding prognosis categories, thus helping inform the etiology of PMCT outcome stratifications within the SEERs database.

Tumor size and metastasis

Interestingly, tumor size carried opposite implications across prognosis groups. In Prognosis I, larger tumor size predicted increased hazard (HR 1.01, $p = 0.031$, Table 7), reinforcing that early diagnosis improves resectability and outcomes. In Prognosis II, however, tumor size paradoxically correlated with improved survival ($\rho = 0.50$, $p = 0.001$, Table 6). This is likely a measurement artifact: Hematologic malignancies may present diffusely, appearing "larger" without conferring worse outcomes, whereas small sarcomas may already reflect aggressive biology.

Metastasis emerged as a dominant determinant of survival. Across all tumors (Table 7), brain (HR 2.04, $p = 0.047$) and lung metastases (HR 1.89, $p = 0.011$) were associated with significantly worse survival. This pattern was especially pronounced in Prognosis II, reflecting the systemic nature of hematologic disease. These findings reinforce the importance of comprehensive staging at diagnosis, including advanced imaging modalities such as cardiac MRI and PET/CT, to assess for systemic spread [19].

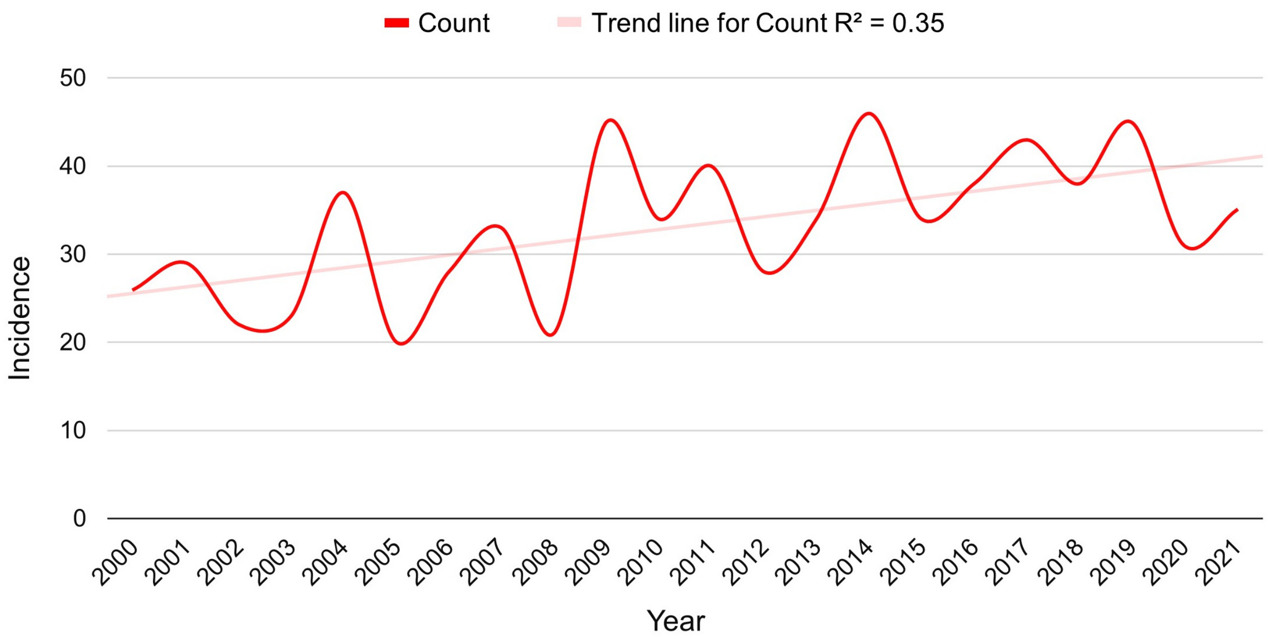

Figure 1. Incidence of all primary malignant cardiac tumors between 2000 and 2021.

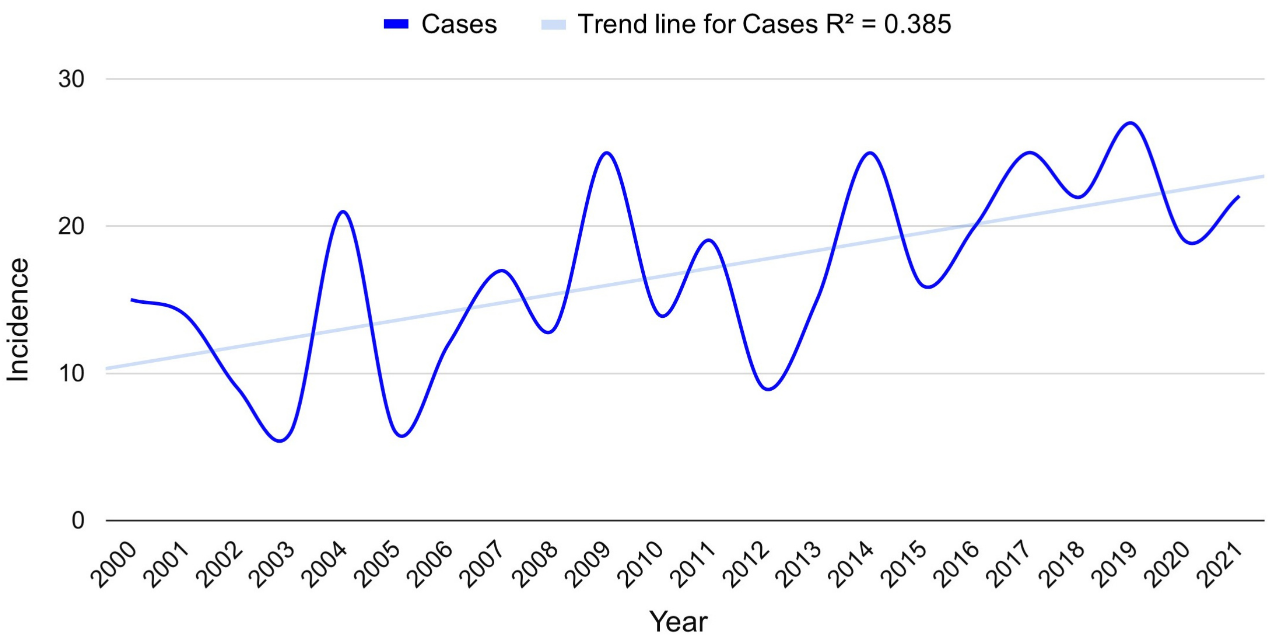

Figure 2. Incidence of poor-prognosis primary malignant cardiac tumors between 2000 and 2021.

Incidence trends

Figures 1 and 2 demonstrate a gradual increase in PMCT incidence over time, representing overall incidence and poor-prognosis incidence, respectively. While this could reflect a true biological increase, it is more likely due to improved detection through advanced imaging and greater diagnostic awareness. This parallels trends in other rare tumors, where incidence rates have risen with increased imaging utilization [2]. The continual uptick in reported cases emphasizes the importance of earlier implementation of cardiac imaging, such as echocardiography or cardiac MRI, in patients presenting with unexplained cardiopulmonary symptoms. When examining Figure 3, rates increased and plateaued in the 2010s compared with the 2000s, followed by a gradual decline in the later years of the dataset. This trend contrasts with the patterns observed in poor-prognosis and overall PMCT incidence. These findings may suggest a shift in the distribution of PMCT prognostic categories over the study period, with potentially fewer improved-prognosis tumors being diagnosed in recent years. This may be related to surveillance factors, such as increased reporting, clinical recognition of more aggressive tumors, or improvements in diagnostic tests that enhance identification of higher-risk tumors. Overall, the trends shown in the figures likely reflect evolving diagnostic and reporting practices that may influence observed incidence patterns rather than reflecting true changes in tumor biology.

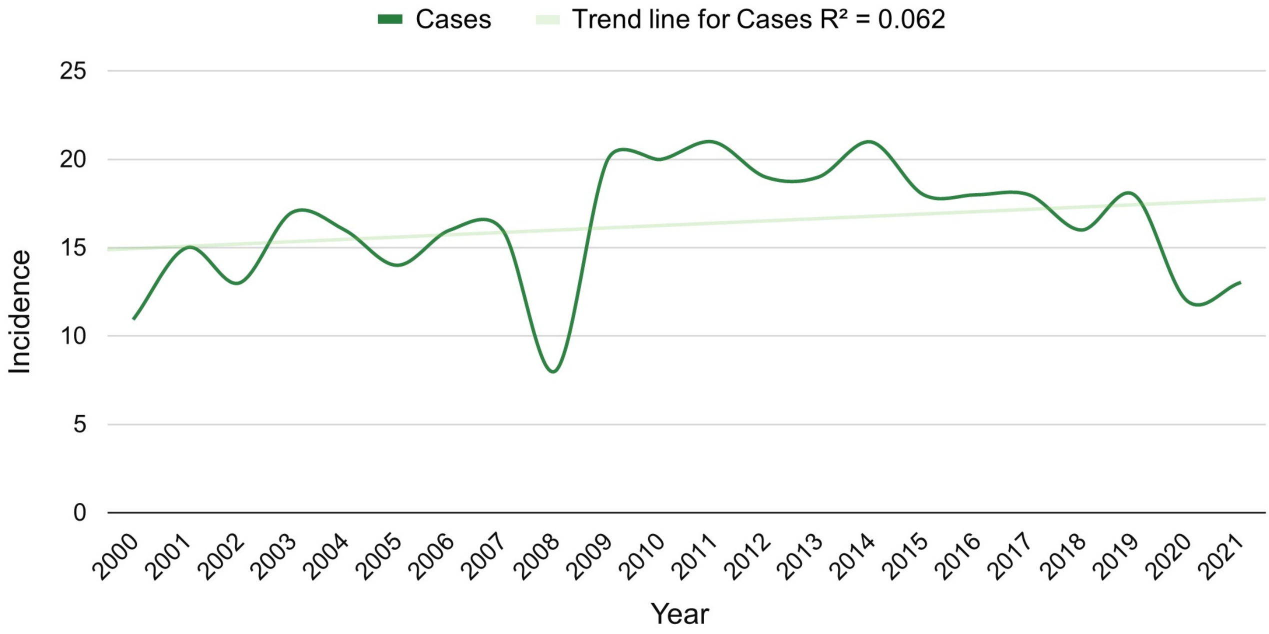

Figure 3. Incidence of improved prognosis primary malignant cardiac tumors between 2000 and 2021.

Implications and future directions

These findings reinforce that prognostic grouping carries clinical significance:

- Prognosis I (sarcoma-dominant): Aggressive multimodality therapy is warranted, with early surgical referral emphasized. Partial resections provide tangible benefit, and chemotherapy should be integrated into multimodal treatment planning. Early imaging to detect resectable disease is also essential.
- Prognosis II (hematologic-dominant): Systemic therapy, not surgery, should be prioritized. The poor outcomes associated with chemotherapy highlight the need to adapt hematologic oncology advances like rituximab-based regimes or CAR-T into cardiac manifestations of hematologic malignancies.
- Across all PMCTs: Younger age and absence of metastasis are the strongest consistent predictors of survival. This emphasizes the importance of earlier diagnosis, comprehensive staging, and targeted therapeutics for optimal survival outcomes.

Limitations

This study design has various limitations. First, the rarity of PMCTs, as well as the use of SEER data collection, introduces inherent selection and reporting biases that may have affected the generalizability of the findings. Given that this is the largest database that includes this tumor type, it is the best current understanding of PMCTs, but it is worth noting that as more data becomes available, the results could shift. Another key limitation of using the SEER database is the potential for confounding variables inherent in its retrospective design. Treatment modalities such as radiation, surgical resection, or chemotherapy cannot be interpreted as independently or collectively effective due to unmeasured confounders and lack of randomization. Also, the heterogeneity in the collection of data into the SEER database, such as institution-to-institution diagnostic criteria, follow-up, or treatment approaches, may have indirectly skewed the results. Furthermore, survival outcomes may have been further influenced by unmeasured variables such as referral patterns, supportive care differences, among others, all of which may have played a role in the variables measured in the paper. Next, the sample size for some of the variables, such as people who received radiotherapy, was very small, which may have played a role in the statistically significant findings noted. Another limitation revolves around the fact that since metastasis data only became consistently available in the SEER database starting in 2010 until 2021, analyses based on metastatic data would reflect only a subset of the overall study population, which spanned from 2000 to 2021. Thus, analyses done between metastatic burden and the overall study population may not be directly comparable due to various shifts in medicine, including diagnostic practices, staging accuracy, and treatment patterns during these 10 extra years. These potential shifts in medicine and PMCT care may influence the interpretation of any results and skew potential relationships investigated. The improved survival associated with surgery and chemotherapy in sarcomas may reflect selection bias, as those eligible for surgery and/or chemotherapy could have had a less severe manifestation of PMCTs to be eligible for said treatment options. Finally, because proportional hazards diagnostics were not formally assessed, interpretation of the Cox regression findings should be considered exploratory. Still, our results provide hypothesis-generating factors that contribute to primary cardiac tumor therapy and survival.

Conclusions

PMCTs remain an exceptionally rare cancer that is functionally challenging to manage. This study, using the SEER database, serves as a large analysis of this tumor type, offering insight into trends in incidence, demographic patterns, histologic distributions, and survival predictors. Prognosis I tumors, which were predominantly soft tissue sarcomas, were largely influenced by size and resectability, whereas Prognosis II tumors, which were often hematologic, were more strongly affected by metastases. Younger ages consistently conferred survival advantages for both groups, and select surgical interventions and chemotherapy helped improve outcomes in Prognosis I. Both groups were severely affected by metastases, especially to the lung and brain. Furthermore, PMCTs are very heterogeneous, where tumor biology not only affects prognosis, but also the ability to intervene surgically and the presence of metastatic spread.

While limited by the retrospective nature of the SEER database and incomplete areas of data collection, the results indicate an important principle of early diagnosis, screening, and tailored treatment strategies. Moving forward, prospective multicenter studies and genomic profiling may refine the classification of these tumor types, identify strong therapeutic targets, and ultimately improve outcomes for this rare but devastating group of tumors.

Abbreviations

CT: computed tomography

HR: hazard ratio

KM: Kaplan-Meier

MRI: magnetic resonance imaging

NHAPI: Non-Hispanic Asian/Pacific Islander

OS: overall survival

PET: positron emission tomography

PMCTs: primary malignant cardiac tumors

SEER: Surveillance, Epidemiology, and End Results

Supplementary materials

The supplementary table for this article is available at: https://www.explorationpub.com/uploads/Article/file/1012107_sup_1.xlsx.

Declarations

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Author contributions

RM: Conceptualization, Investigation, Writing—original draft, Writing—review & editing, Project administration, Supervision. ZM: Investigation, Data curation, Writing—original draft, Writing—review & editing. SK: Data curation, Formal analysis, Resources, Validation, Writing—original draft, Writing—review & editing. JJ: Writing—original draft, Writing—review & editing. TA: Supervision, Project administration. All authors read and approved the submitted version.

Conflicts of interest

The authors declare no conflicts of interest.

Ethical approval

This study utilized de-identified data from the publicly available Surveillance, Epidemiology, and End Results (SEER) Program database. As the dataset contains no identifiable patient information and involves no direct interaction with human participants, this study was considered exempt from Institutional Review Board review and the requirement for informed consent was waived, consistent with the ethical principles outlined in the Declaration of Helsinki.

Consent to participate

This study utilized de-identified data from the publicly available Surveillance, Epidemiology, and End Results (SEER) Program database. As the dataset contains no identifiable patient information and involves no direct interaction with human participants, the informed consent was waived, consistent with the ethical principles outlined in the Declaration of Helsinki.

Consent to publication

Informed consent was waived because this study used publicly available, de-identified data from the Surveillance, Epidemiology, and End Results (SEER) Program database, which contains anonymized cancer registry information collected for public health surveillance. No identifiable patient information was accessed.

Availability of data and materials

Data is publicly available and submitted with the manuscript as supplemental materials. The data analyzed in this study were obtained from the SEER database. Requests for access to these datasets should be directed to https://seer.cancer.gov/data/access.html.

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