

SYSTEMATIC REVIEW

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Bone tumors: a systematic review of prevalence, risk determinants, and survival patterns

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Abstract

Background Though relatively rare, bone tumors significantly impact patient health and treatment outcomes.

Objective This systematic review analyzes the incidence, types, survival rates, and risk factors associated with bone tumors, including both benign and malignant forms.

Methods This systematic review was conducted using the keywords “bone tumors,” “epidemiology,” “benign bone tumors,” “malignant bone tumors,” “osteosarcoma,” “Ewing sarcoma,” “chondrosarcoma,” “risk factors,” and “survival” in electronic databases including PubMed, Scopus, Web of Science, and Google Scholar from 2000 to 2024. The search strategy was based on the PRISMA statement. Finally, 9 articles were selected for inclusion in the study.

Results The systematic review highlights that primary bone tumors can be classified into benign and malignant types, with osteosarcoma being the most prevalent malignant form, particularly among adolescents and young adults. The epidemiology of bone tumors is influenced by factors such as age, gender, geographic location, and genetic predispositions. Recent advancements in imaging techniques have improved the detection of these tumors, contributing to an increasing recognition of their prevalence. Data shows that the limited-duration prevalence of malignant bone tumors has increased significantly. This increase is from 0.00069% in 2000 to 0.00749% in 2018, indicating an increasing recognition and diagnosis of these rare tumors over time. Survival rates vary significantly by tumor type, with approximately 50–60% for osteosarcoma and around 70% for Ewing's sarcoma, though these rates decrease with metastasis. Key risk factors identified include genetic predispositions such as Li-Fraumeni syndrome and TP53 mutations, environmental exposures like radiation, and growth patterns related to height.

Conclusion The review highlights the importance of early diagnosis and treatment intervention, as survival rates are significantly better for patients with localized disease compared to those with metastatic conditions. The observed variations in survival rates across different tumor types underscore the need for tailored treatment strategies. Key risk factors include genetic predispositions and environmental exposures, highlighting the need for targeted screening and ongoing research to enhance diagnostic accuracy and treatment strategies.

Keywords Bone tumors, Incidence, Survival rates, Risk factors, Epidemiology, Diagnostic imaging

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Introduction

Bone tumors represent a heterogeneous collection of neoplasms that originate either directly from the bone (primary tumors) or metastasize to the bone from other sites in the body (secondary or metastatic tumors) [1]. Primary bone tumors are further categorized into benign and malignant types, each displaying unique biological behaviors, clinical manifestations, and responses to treatment [2]. This classification is critical for understanding the complexity of these conditions and developing appropriate management strategies [3]. Among primary malignant bone tumors, osteosarcoma stands out as the most common, with a particular predilection for adolescents and young adults during periods of rapid growth [4]. This tumor type is characterized by the production of immature bone or osteoid tissue by malignant cells [5]. Osteosarcoma can occur in any bone but is most commonly found in the long bones of the extremities, such as the femur, tibia, and humerus. Other significant malignant types include Ewing's sarcoma and chondrosarcoma, each with its own distinctive features and clinical implications [6].

Ewing's sarcoma is a highly aggressive tumor that primarily affects children and young adults. It is characterized by small, round, blue cells and most commonly arises in the pelvis, femur, humerus, ribs, and spine [7]. Chondrosarcoma, on the other hand, is a malignant tumor that produces cartilage and is more common in adults, with the pelvis, femur, and shoulder girdle being the most frequent sites of occurrence [8]. The epidemiology of bone tumors is intricate and influenced by a multitude of factors, including age, gender, geographic location, and genetic predispositions [9]. Osteosarcoma, for example, exhibits a bimodal age distribution with peaks during adolescence and late adulthood [10]. This bimodal pattern is thought to be related to periods of rapid bone growth and hormonal changes. Ewing's sarcoma, in contrast, predominantly affects younger individuals, with the majority of cases occurring before the age of 20 [7, 11]. Chondrosarcoma tends to be more prevalent in adults, with an increasing incidence with age [12].

Understanding the prevalence and distribution of bone tumors is crucial for healthcare providers to develop effective screening, diagnostic, and treatment strategies [13, 14]. The Surveillance, Epidemiology, and End Results (SEER) database has been instrumental in providing valuable insights into trends in incidence rates over time [13]. This database, maintained by the National Cancer Institute, collects and publishes cancer incidence and survival data from population-based cancer registries covering approximately 34.6% of the U.S. population [15, 16]. Recent literature indicates an increasing recognition of bone tumors due to advancements in imaging techniques and improved awareness among healthcare professionals

[17]. Techniques such as magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography (PET) scans have significantly enhanced the ability to detect and diagnose bone tumors at earlier stages [18]. Moreover, the development of molecular and genetic testing has allowed for more precise characterization of tumors, leading to better-targeted treatments [19].

The incidence rates of bone tumors vary widely across different populations and regions. According to the SEER database, the overall incidence rate of primary malignant bone tumors is approximately 0.9 per 100,000 individuals per year in the United States [20, 21]. Osteosarcoma accounts for about 35% of all primary malignant bone tumors, followed by chondrosarcoma (30%) and Ewing's sarcoma (16%) [22–24]. Globally, the incidence rates show significant variability. For instance, the incidence of osteosarcoma is higher in some Asian countries compared to Western countries [25, 26]. This geographic variation may be attributed to differences in genetic backgrounds, environmental factors, and healthcare systems [1]. Several risk factors have been identified for the development of bone tumors [27]. Age is a significant risk factor, with certain types of tumors being more prevalent in specific age groups. Gender also plays a role, with some tumors being more common in males than females [28]. Genetic predispositions, such as hereditary retinoblastoma and Li-Fraumeni syndrome, increase the risk of developing bone tumors. Additionally, exposure to radiation and certain chemicals has been linked to an increased risk of bone tumors [29, 30]. The diagnosis of bone tumors involves a combination of clinical examination, imaging studies, and histopathological analysis. Imaging techniques such as X-rays, CT scans, MRI, and PET scans are used to detect and characterize bone tumors. Biopsy is the gold standard for diagnosing bone tumors, as it allows for histopathological examination of the tumor tissue [31, 32]. Molecular and genetic testing can also provide valuable information for diagnosis and treatment planning [33, 34]. Despite these advancements, bone tumors remain under-researched compared to other malignancies. This is partly due to their relative rarity and the diverse nature of the tumors, which makes it challenging to conduct large-scale studies. The lack of comprehensive research can hinder the development of innovative therapies and improve patient outcomes. This systematic review aims to provide a comprehensive analysis of the incidence of bone tumors by examining existing literature on incidence rates, types of tumors, survival rates, risk factors, and diagnostic approaches. By consolidating findings from various studies, this review seeks to enhance awareness among healthcare professionals regarding the epidemiological landscape of bone tumors and guide future research directions.

Materials and methods

Methodology of the review

This Systematic Review (SR) has been described following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [35] and adheres to the PRISMA checklist.

Formulation of the research question

The research question for this review was developed using the PICO tool [36]. The PICO framework aids in formulating a targeted research question by focusing on four main elements: Population/Problem (P), Intervention of Interest (I), Comparison (C), and Outcome (O). In this review, these components were defined as follows: P = Patients with bone cancer; I = Prevalence, Risk Determinants, and Survival Patterns; C = Comparative survival rates in bone cancer, specifically between osteosarcoma and Ewing sarcoma; O = Insights into the prevalence, risk determinants, and survival patterns among patients diagnosed with osteosarcoma and Ewing sarcoma.

Search strategy

A thorough and systematic search of the literature was performed covering the period from 2000 to 2024 to locate up-to-date sources on prevalence, risk determinants, and survival patterns related to bone tumors. Major academic databases such as PubMed, Scopus, Web of Science, and Google Scholar were extensively queried. In order to capture a comprehensive range of insights, hospital-specific databases and various gray literature repositories were also included in the search, as these sources often offer valuable perspectives not typically found in standard scientific publications. The search protocol utilized keywords and phrases such as “bone tumors,” “incidence,” “epidemiology,” “benign bone tumors,” “malignant bone tumors,” “osteosarcoma,” “Ewing’s sarcoma,” “chondrosarcoma,” “risk factors,” and “survival rates,” along with their synonyms and related terms. Boolean operators (AND, OR) were strategically employed to integrate these terms, resulting in a search that was both expansive and focused. During the initial screening phase, two researchers (S.D. and K.H.) independently evaluated all titles and abstracts gathered from the database searches. They used EndNote 20® software [37] to systematically remove duplicates and irrelevant entries. In instances of disagreement, a third researcher (R.R.) was consulted to reach a consensus. For studies considered potentially relevant, full texts were obtained and independently assessed by two researchers (S.D. and K.H.) in accordance with predefined eligibility criteria. When disagreements arose during this phase, the primary reviewers discussed the issues; if consensus could not be achieved, the opinion of a third researcher (R.R.), who had not been involved with that particular

document previously, was sought to ensure an unbiased decision-making process.

Inclusion and exclusion criteria and process

The inclusion criteria for this review comprised quantitative primary studies published in English that examined the prevalence, risk determinants, and survival patterns of bone tumors. Eligible studies reported original data on the prevalence or incidence of primary or secondary bone tumors, provided information on specific types of bone tumors (whether benign or malignant), and included demographic details such as age, gender, geographic location, survival rates, and risk factors. In addition, these studies employed appropriate statistical methods for data analysis.

On the other hand, studies were excluded if they met any of the following criteria: full text was not accessible, the publication was an editorial or of low methodological quality, the study was published in a language other than English, or the study focused on non-primary bone tumors (e.g., soft tissue sarcomas). Articles that were case reports or reviews without original data, those that did not provide adequate epidemiological information or lacked clear methodological explanations, and studies conducted outside the specified time frame were also excluded. This rigorous selection process was applied to maintain the scientific integrity, relevance, and applicability of the studies incorporated into this systematic review.

Assessment of Risk of Bias and Methodological Quality

Two researchers (H.H. and S.H.) independently evaluated the risk of bias and methodological quality of the included studies. Any disagreements were resolved by consulting a third researcher (R.R.). For a thorough evaluation of the studies’ quality and relevance, the Joanna Briggs Institute (JBI) Critical Appraisal Tools were utilized [38]. These tools, recognized for their comprehensive approach in assessing various research designs, provided a structured framework to determine the reliability and applicability of each study. High-quality studies were identified based on a previously established classification system [39]: studies receiving a JBI score greater than 70% were classified as high quality, those scoring between 50% and 70% were considered medium quality, and studies with scores below 50% were deemed to be of low quality.

Assessment of evidence certainty

The certainty of the evidence was appraised following the framework established by the Oxford Centre for Evidence-Based Medicine (OCEBM) [40], which is closely aligned with the methods commonly used by clinical researchers. This framework categorizes research into five distinct evidence levels based on study design and

quality. High-level studies, such as systematic reviews of randomized controlled trials (RCTs) and well-executed individual RCTs, were classified as Level 1 evidence. In contrast, studies that primarily relied on expert opinion or lacked solid empirical backing were allocated Level 5. Intermediate evidence levels were assigned based on study design and rigor: less stringent RCTs, single-arm trials, case series, and case-control studies were classified as Levels 2, 3, and 4, respectively. Additionally, certain studies were re-assessed and their evidence levels modified—either upgraded or downgraded—based on considerations such as methodological quality, result precision, and relevance to the subject matter [41].

Data extraction

Data from the selected studies were systematically extracted and organized into tables. The information captured included details such as author(s), year of publication, study methodology, key findings, and quality/bias.

Synthesis methods

Descriptive statistics were employed to summarize demographic characteristics and tumor prevalence reported across the studies, with incidence rates computed per 100,000 individuals when applicable. A meta-analysis was planned if the data displayed sufficient homogeneity; otherwise, the results were presented through narrative synthesis. The degree of heterogeneity among the studies was evaluated using the I^2 statistic. A comprehensive narrative synthesis was then conducted in accordance with the Synthesis Without Meta-analysis (SWiM) reporting guidelines [42]. This method was chosen for its transparency and robustness in integrating diverse quantitative data while remaining consistent with the PRISMA methodology.

Results

Search results

An extensive search process across various databases initially identified a total of 4,782 records. After eliminating 3,245 duplicate records via EndNote software, 1,537 unique articles remained. A subsequent screening of abstracts led to the exclusion of 1,151 records, and a detailed full-text review of the remaining 386 articles resulted in the exclusion of 377 that did not meet the study objectives. Ultimately, 9 articles were selected for inclusion in the review (Fig. 1).

This systematic search obtained nine articles related to the final goal of the research based on studies of the incidence rate, survival rate based on tumor type, and key risk factors related to the increased likelihood of osteosarcoma. (Table 1)

Rising prevalence of malignant bone tumors: insights from the SEER database (2000–2018)

According to recent data from the Surveillance Epidemiology and End Results (SEER) database, the limited-duration prevalence of malignant bone tumors increased from 0.00069% in 2000 to 0.00749% in 2018, indicating an increasing recognition and diagnosis of these rare tumors over time [20].

Survival rates

The overall 5-year survival rate for osteosarcoma was approximately 50–60%, with better outcomes observed in patients with localized disease compared to those with metastases [43]. For Ewing's sarcoma, the 5-year survival rate was reported at around 70%, but this decreased significantly with metastatic disease [45]. (Table 2).

Risk factors

Table 3 identifies three key risk factors associated with an increased likelihood of developing osteosarcoma. Each of these factors is interpreted as follows:

Genetic Predispositions

Li-Fraumeni syndrome is a rare genetic disorder caused by mutations in the TP53 gene. This gene plays a critical role in tumor suppression, and mutations in it make individuals more susceptible to various cancers, including osteosarcoma. This finding highlights that individuals with a family history of this syndrome or similar genetic disorders are at a higher risk. Genetic conditions such as Li-Fraumeni syndrome significantly increase the risk of osteosarcoma [46].

Environmental factors

Ionizing radiation can damage cellular DNA, leading to mutations that may result in cancer. Individuals who have undergone radiation therapy for other cancers or have worked in environments with high levels of radiation are at a greater risk of developing osteosarcoma. This risk factor underscores the importance of controlling radiation exposure to prevent secondary cancers. Previous exposure to ionizing radiation (such as radiation therapy or environmental radiation) has been linked to a higher incidence of certain bone tumors [27, 47].

Height and growth patterns

Rapid bone growth during adolescence (especially in taller teenagers) may be associated with increased activity of growth factors such as IGF-1 (Insulin-like Growth Factor-1). These factors can inadvertently promote abnormal cell proliferation and the development of bone tumors. This finding suggests that osteosarcoma may be linked to natural growth processes in the body. Taller individuals have a higher risk of developing osteosarcoma

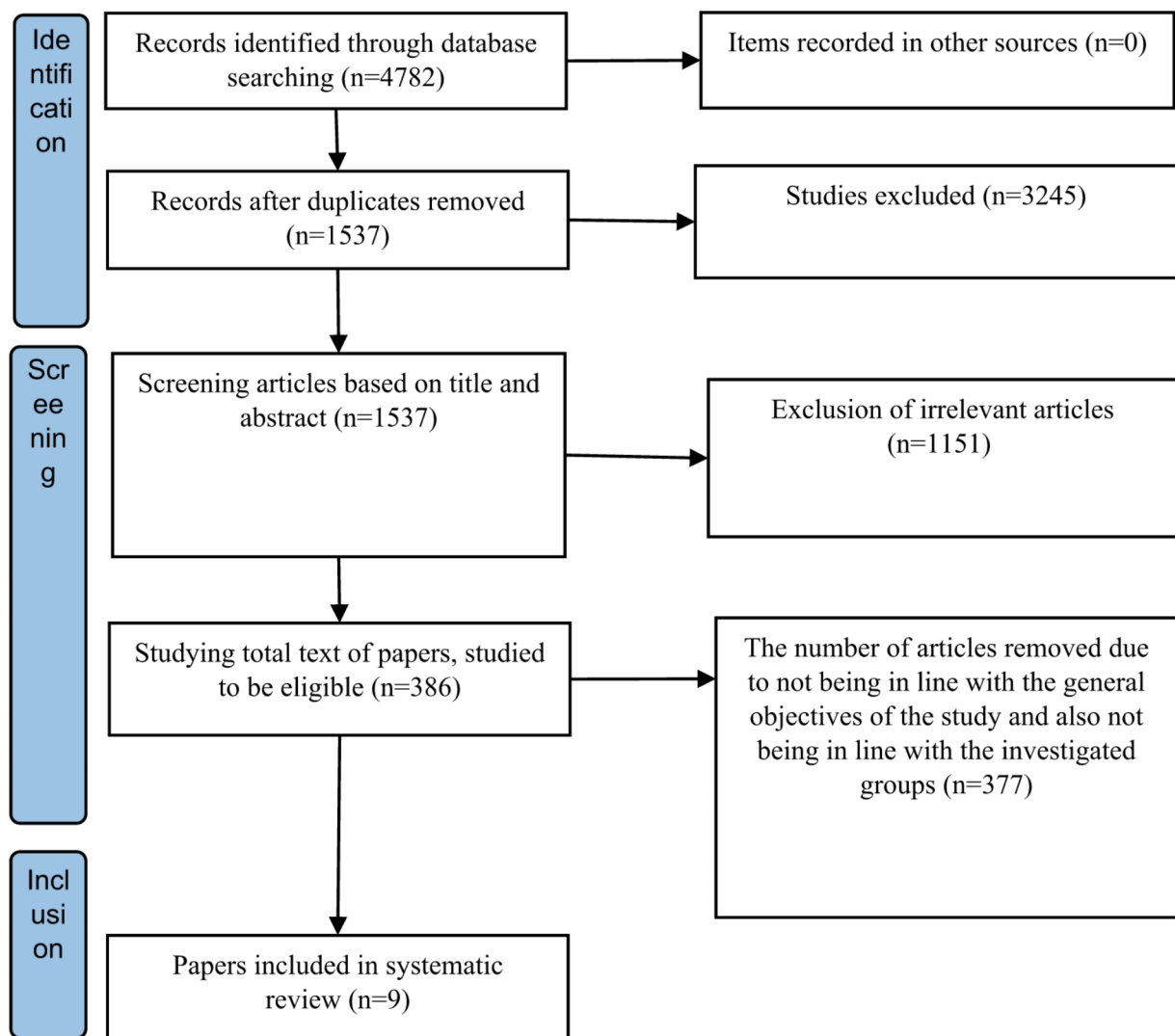


Fig. 1 The process of searching and screening selected articles based on PRISMA guidelines

due to growth factors that may influence tumorigenesis [44, 48, 49].

Table 3 demonstrates that osteosarcoma is a multifactorial disease, with a combination of genetic, environmental, and physiological factors contributing to its risk. To prevent and manage this disease, it is essential to consider genetic history, reduce exposure to harmful radiation, and better understand the role of growth factors in tumorigenesis. These findings can help design targeted preventive and therapeutic strategies.

Discussion

This systematic review highlights significant findings regarding the incidence and epidemiology of bone tumors globally. The observed bimodal age distribution indicates that different mechanisms may underlie tumor development in adolescents compared to older adults.

The predominance of osteosarcoma in younger populations suggests a potential link with growth spurts during adolescence when rapid cell division may increase susceptibility to genetic mutations leading to malignancy. The increasing prevalence noted over recent years may reflect improvements in diagnostic capabilities rather than an actual rise in incidence. Enhanced imaging techniques such as MRI and CT scans have improved detection rates for both benign and malignant lesions that may have previously gone undiagnosed [50–52]. Furthermore, awareness campaigns targeting healthcare professionals about potential symptoms associated with bone tumors may contribute to earlier detection. The variations in survival rates underscore the importance of early diagnosis and treatment intervention. Patients with localized disease have significantly better outcomes than those presenting with metastases at diagnosis;

Table 1 Characteristics of articles used in the Present Study

Row	Author(s)	Year	Study Method	Key Findings	Quality/Bias	Reference
1	Yao Xu et al.	2024	Surveillance, Epidemiology, and End Results Database (SEER) Database Analysis. This study was conducted to update recent epidemiological estimates based on the SEER.	The limited-duration prevalence of malignant bone tumors increased from 0.00069% in 2000 to 0.00749% in 2018, indicating increased diagnosis and recognition of these tumors.	++/Moderate	[20]
2	NF Yasin et al.	2020	This is a review of cases in the past 15 years. This is a retrospective survival analysis study of 128 patients treated at the University Malaya Medical Centre (UMMC) from 1997 to 2011.	The 5-year survival rate for osteosarcoma is approximately 50–60%. Survival rates are better in patients with localized disease than those with metastases.	++/Low	[43]
3	Xia et al.	2022	This was a comparative study using open-source data. Cancer cases and deaths in 2022 were calculated using cancer estimates from GLOBOCAN 2020 and population estimates from the United Nations.	Population aging is a growing determinant of incremental cancer burden. Progress in cancer prevention and care in the USA, and measures to actively respond to population aging, may help China to reduce the cancer burden.	+++/Low	[44]
4	Esiashvili et al.	2008	Data from the SEER public-access database were reviewed for the diagnosis of ES of the bone among patients of 1 to 19 years of age between 1973 and 2004. Age-adjusted incidence was analyzed for the entire group and for localized and metastatic disease separately over the past 3 decades.	The 5-year survival rate for Ewing's Sarcoma is approximately 70%, but decreases significantly with metastasis.	+++/Low	[45]
5	McBride et al.	2014	review the clinical implications of germline mutations in TP53 and the evidence for cancer screening and prevention strategies in individuals carrying such mutations.	Li-Fraumeni syndrome and TP53 mutations significantly increase the risk of developing osteosarcoma.	++/Moderate	[46]
6	Pearce et al.	2012	A retrospective cohort study included patients without previous cancer diagnoses who were first examined with CT in National Health Service (NHS) centers in England, Wales, or Scotland (Great Britain) between 1985 and 2002 when they were younger than 22 years of age.	Exposure to ionizing radiation is associated with an increased risk of developing certain bone tumors.	++/Low	[47]
7	Frentzel-Beyme et al.	2004	This case-control study investigates etiologically important factors for juvenile osteosarcomas and possible reasons for the relative scarcity of their incidence in the population.	Some factors, such as a family history of cancer, exposure to ionizing radiation, and certain environmental factors, may contribute to an increased risk of developing bone tumors.	+++/Low	[27]
8	Alessandra et al.	2005	Height at diagnosis was evaluated in a continuous series of 962 osteosarcoma subjects treated between 1981 and 2001.	Taller individuals have a higher risk of developing osteosarcoma due to growth factors that may play a role in tumorigenesis.	++/Low	[48]
9	Makielski et al.	2019	This review, describes risk factors for the development of osteosarcoma in dogs and humans, including height and body size, genetics, and conditions that increase turnover of bone-forming cells, underscoring the concept that stochastic mutational events associated with cellular replication are likely to be the major molecular drivers of this disease.	both species share common genetic mutations in genes such as TP53 and RB1, which increase the risk of developing the disease. Environmental factors like ionizing radiation and chemical exposure also play a role in both species. Rapid bone growth during adolescence, particularly in human teenagers and large-breed dogs, is a shared risk factor.	+++/Moderate	[49]

this finding emphasizes the need for awareness among healthcare providers regarding potential symptoms associated with bone tumors in at-risk populations. Moreover, understanding risk factors can aid in developing targeted screening protocols for high-risk individuals.

Genetic counseling may be beneficial for families with hereditary cancer syndromes to identify individuals at increased risk for developing osteosarcoma or other malignancies [53, 54]. Despite advancements in diagnostic imaging techniques that enhance detection accuracy

Table 2 Survival rates varied significantly by tumor type

No.	Tumor Type	5-Year Survival Rate
1	Osteosarcoma	Approximately 50–60%
2	Ewing's Sarcoma	~ 70%, decreases with metastasis
3	Chondrosarcoma	Varies widely (generally lower than osteosarcoma)
4	Benign Bone Tumors	Generally high (depends on type)

[55–57], there remains a need for further research into novel biomarkers that could aid in early diagnosis and treatment response monitoring. Machine learning applications are emerging as promising tools for improving diagnostic accuracy through advanced imaging analysis; however, their clinical utility still requires validation through rigorous trials [51, 58, 59]. Early diagnosis of bone tumors faces several significant obstacles. Limited access to advanced imaging modalities such as MRI and CT scans—particularly in remote or resource-poor settings—can hinder the timely identification of these conditions [60, 61]. Additionally, the rarity of bone tumors often results in initial symptoms being mistaken for more common musculoskeletal issues, contributing to misdiagnoses or delayed recognition. A general lack of specialized expertise among primary care physicians regarding these rare neoplasms, along with the absence of standardized diagnostic protocols, further complicates the early detection process, ultimately impeding prompt and effective treatment [61–63]. Overcoming these barriers requires a multi-pronged approach, including improving access to healthcare, raising awareness among healthcare providers, and promoting research into rare bone tumors [62, 64, 65]. To improve the understanding and management of bone tumors, future research should focus on several key areas [66, 67]. First, large-scale epidemiological studies are needed to provide more accurate estimates of incidence rates and trends across different populations. Second, molecular and genetic studies should be conducted to identify biomarkers and genetic alterations associated with bone tumors, which can guide the development of targeted therapies. Third, clinical trials should be designed [67, 68].

Future perspectives

This systematic review lays the groundwork for further investigations into the epidemiological profile of bone tumors, yet several promising avenues remain for future

research. Building on the current findings, future studies could aim to:

1. **Expand Data Integration Across Geographies and Populations:** The present review focused on studies published in English and derived primarily from databases frequently used in Western countries. Future research should seek to incorporate data from non-English literature and diverse geographical regions to enhance the generalizability of results on bone tumor prevalence, risk determinants, and survival patterns.
2. **Employ Prospective and Multicenter Study Designs:** Moving beyond the retrospective analyses predominating in the current literature, prospective and well-coordinated multicenter studies can help validate and refine the observed associations. These studies would ideally be designed to monitor patients over time, allowing for a more robust assessment of factors such as the impact of genetic predispositions, environmental exposures, and growth patterns on tumor pathogenesis and survival outcomes.
3. **Leverage Advanced Methodologies for Biomarker Discovery:** The association between genetic predispositions (e.g., Li-Fraumeni syndrome) and osteosarcoma risk provides a compelling case for further research into specific biomarkers. Future perspectives include integrating high-throughput sequencing and other omics technologies to identify genetic and molecular signatures that might predict tumor behavior or response to treatment.
4. **Investigate Preventive and Therapeutic Strategies:** Considering the identified risk factors—including the role of ionizing radiation exposure and rapid growth patterns—targeted prevention strategies should be developed. Future research could explore screening protocols for high-risk groups and also evaluate novel therapeutic interventions that modify the underlying biological pathways (e.g., IGF-1 signaling) linked to tumorigenesis.
5. **Incorporate Meta-Analytic Techniques Where Feasible:** Although data heterogeneity limited the scope of meta-analysis in the current review, ongoing accumulation of homogeneous and high-quality data may allow for comprehensive meta-analyses in future studies. Such efforts could provide more definitive

Table 3 Several key risk factors were identified

No.	Risk Factor	Description
1	Genetic Predispositions	Conditions such as Li-Fraumeni syndrome significantly elevate risk levels for osteosarcoma [46].
2	Environmental Factors	Previous exposure to radiation has been linked to higher incidences of certain bone tumors [27, 47].
3	Height and Growth Patterns	Taller individuals have been noted to have a higher risk of developing osteosarcoma due to growth factors that may influence tumorigenesis [48, 49].

evidence regarding survival rates and the impact of various risk factors on different bone tumor types.

Clinical implications

1. **Enhanced Early Detection and Screening:** The rising prevalence of malignant bone tumors highlights the need for improved screening protocols. Clinicians should consider integrating routine examinations for high-risk populations, particularly those with known genetic predispositions such as Li-Fraumeni syndrome or individuals with a history of significant ionizing radiation exposure.
2. **Risk Stratification and Personalized Management:** Given the identified risk factors—including genetic mutations, environmental exposures, and rapid growth patterns—there is a clear rationale for implementing personalized risk assessment strategies. Tailoring follow-up, diagnostic testing, and preventive interventions to the individual risk profile could lead to earlier diagnosis and better treatment outcomes.
3. **Multidisciplinary Approach to Treatment Planning:** The variation in survival rates between osteosarcoma and Ewing's sarcoma, and the impact of localized versus metastatic disease, underscore the importance of a coordinated, multidisciplinary approach to patient management. Collaboration among oncologists, radiologists, surgeons, and genetic counselors can ensure comprehensive care that addresses the complexities of bone tumor treatment.
4. **Implementation of Genetic Counseling and Testing:** With the significant association between osteosarcoma and genetic conditions such as Li-Fraumeni syndrome, clinicians should consider referring patients with a positive family history or suggestive clinical indicators for genetic counseling and testing. Early identification of genetic risks can facilitate timely surveillance and intervention strategies.
5. **Informed Decision-Making Based on Epidemiological Insights:** The detailed synthesis of prevalence, risk determinants, and survival patterns in this review can aid clinicians in making evidence-based decisions. This includes counseling patients regarding prognosis and potential treatment outcomes, and may also inform the development of local or national guidelines aimed at reducing disease burden.
6. **Promotion of Preventive Strategies:** The association of environmental factors such as ionizing radiation with an increased risk of developing bone tumors suggests that minimizing unnecessary radiation exposure could be a crucial preventive measure. This

calls for the careful consideration of radiation doses in medical imaging and therapeutic procedures, as well as public health initiatives to reduce exposure in high-risk settings.

These clinical implications underscore the importance of integrating epidemiological data into clinical practice, promoting risk-adapted screening and management strategies, and fostering multidisciplinary collaboration to enhance patient outcomes in the field of bone tumor management.

Limitations

1. **Language and Publication Bias:** The review exclusively included studies published in English. This language restriction, along with the omission of non-indexed or unpublished studies, may have introduced a publication bias, thereby limiting the comprehensiveness of the evidence base.
2. **Heterogeneity of Study Designs and Data Sources:** The included studies varied widely in methodological approaches, sample sizes, and populations studied. This heterogeneity, particularly in data collection and analysis methods, could affect the consistency and comparability of the reported outcomes, potentially reducing the robustness of the synthesized findings.
3. **Retrospective Nature of Most Studies:** A significant proportion of the evidence was derived from retrospective analyses, including database studies and reviews. Such designs are subject to inherent limitations (e.g., recall bias, and incomplete data) that may influence the accuracy and reliability of the conclusions related to risk factors and survival patterns.
4. **Limited Assessment of Confounding Factors:** Although efforts were made to assess methodological quality using tools like the Joanna Briggs Institute Critical Appraisal Tools, many studies did not thoroughly control for confounding variables, which may have impacted the observed associations between risk determinants and bone tumor outcomes.
5. **Restricted Time Frame and Data Availability:** The literature search was confined to publications from 2000 to 2024. This temporal limitation may have excluded earlier but potentially relevant studies and the rapidly evolving nature of cancer diagnosis and treatment may mean that some findings could soon require re-evaluation as new data emerge.
6. **Reliance on Secondary Data Sources:** The review depended heavily on data extracted from established databases (such as the SEER database) and gray literature. While these sources provide valuable

insights, they might also be accompanied by issues related to data completeness, accuracy, and potential reporting biases.

Conclusion

Bone tumors represent a critical area within oncology, characterized by their unique epidemiological features and significant impact on affected individuals. This systematic review provides valuable insights into the incidence rates, survival outcomes, and risk factors associated with various types of bone tumors, including both benign and malignant forms. The findings indicate that osteosarcoma remains the most common primary malignant bone tumor, particularly affecting adolescents and young adults. The review highlights the importance of early diagnosis and treatment intervention, as survival rates are significantly better for patients with localized disease compared to those with metastatic conditions. The observed variations in survival rates across different tumor types underscore the need for tailored treatment strategies. Key risk factors identified include genetic predispositions, environmental exposures, and growth patterns, which can inform targeted screening protocols for high-risk populations. The increasing recognition of bone tumors, facilitated by advancements in imaging techniques and heightened awareness among healthcare professionals, suggests a positive trend in early detection. Despite these advancements, there remains a need for ongoing research efforts to improve diagnostic accuracy and treatment strategies further. Enhanced awareness among healthcare providers regarding the epidemiological landscape of bone tumors can lead to timely interventions that ultimately improve patient outcomes. Future studies should focus on novel biomarkers and the application of machine learning techniques to refine diagnosis and treatment approaches for bone tumors.

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Author contributions

"H.H., S.H., K.H. and R.R. wrote the main manuscript text and S.D. Designing the study and Supervision. All authors reviewed the manuscript."

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Data availability

The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Declarations

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The authors declare no competing interests.

Statement

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