

ORIGINAL ARTICLE

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Global research trends in chondroblastoma: A bibliometric analysis from 2000 to 2025 **Batuhan Ayhan¹**,  **Samet Batuhan Yogurt²**¹*Haymana State Hospital, Department of Orthopedics, Ankara, Türkiye*²*Kahta State Hospital, Department of Orthopedics, Adiyaman, Türkiye*

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**Abstract**

Chondroblastoma is a rare, benign but locally aggressive bone tumor that predominantly affects the epiphyses of skeletally immature patients. Despite its clinical importance, a comprehensive bibliometric analysis of the global chondroblastoma literature has never been performed. This study aimed to quantify and characterize the global scientific output on chondroblastoma over a 25-year period. A systematic search of the Web of Science Core Collection (WoSCC) was conducted for publications on chondroblastoma from January 2000 to December 2025. Bibliometric indicators including publication trends, citation metrics, country/institution/author/journal distributions, Bradford's law, and keyword co-occurrence networks were analyzed using Python and VOSviewer (version 1.6.20). A total of 740 publications (601 articles, 107 reviews, 32 records with combined/early-access designations) accumulated 14,407 citations (mean 19.47 per document; H-index = 56). Annual output increased from 13 in 2000 to 47 in 2025, with a compound annual growth rate (CAGR) of 3.8% and a marked acceleration after 2013. The United States (n = 226), China (n = 94), and Japan (n = 74) led in productivity. Harvard University (n = 58) and Mayo Clinic (n = 56) were the most productive institutions. Skeletal Radiology was the leading journal (n = 38; Bradford Zone 1). The most cited article (665 citations) reported H3F3B driver mutations in chondroblastoma. VOSviewer network analysis identified five keyword clusters and three distinct journal co-citation clusters spanning pathology, radiology, and orthopedic surgery. Global chondroblastoma research has grown substantially over 25 years, with acceleration following the landmark H3F3B mutation discovery in 2013. Emerging research hotspots include epigenetic pathogenesis, radiofrequency ablation, and craniofacial involvement. This first comprehensive bibliometric analysis provides an evidence-based roadmap for future research.

Keywords: Chondroblastoma; bibliometrics; bone neoplasms; histones; mutation; biomedical research**Introduction**

Chondroblastoma is a rare benign but locally aggressive neoplasm of bone, first described by Jaffe and Lichtenstein in 1942 [1]. It accounts for less than 1-2% of all primary bone tumors and characteristically arises in the epiphysis or apophysis of long bones in skeletally immature patients, with the proximal humerus, distal femur, and proximal tibia representing the most commonly affected sites [2-4]. Histologically, the tumor is composed of chondroblast-like mononuclear cells with characteristic nuclear grooves, pericellular “chicken-wire” calcifications, and scattered osteoclast-type giant cells [5]. The standard of care for most lesions is intralesional curettage with or without bone grafting, which achieves local control in the majority of cases [6-9]. However, local recurrence following curettage has been reported in 10-35% of cases [10], and rare

but documented instances of pulmonary metastasis highlight the tumor's unpredictable biological potential [11].

The molecular landscape of chondroblastoma was fundamentally transformed in 2013, when Behjati et al. reported that the vast majority of chondroblastomas harbor missense mutations in H3F3B (encoding histone H3.3K36M), distinguishing this tumor at the molecular level from all other bone neoplasms [12]. Subsequent work by Fang et al. demonstrated that this K36M mutation reprograms the epigenome by inhibiting histone methyltransferases polycomb repressive complex 2 and nuclear receptor-binding SET domain protein 2 [13], while Cleven et al. established immunohistochemistry (IHC) for H3.3K36M as a highly sensitive and specific diagnostic tool [14]. These discoveries catalyzed a wave of translational research exploring oncohistone biology and potential targeted therapies, with the

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epigenomics of sarcoma — including chondroblastoma — reviewed comprehensively by Nacev et al. [15]. Meanwhile, the clinical literature has evolved toward less invasive treatment paradigms, particularly radiofrequency ablation (RFA) for lesions in challenging anatomic locations [16].

Despite this growing interest, the global landscape of chondroblastoma research has never been characterized in a systematic and quantitative manner. Bibliometric analysis offers an objective, quantitative framework for mapping the intellectual structure of a research field, identifying leading contributors, tracing emerging themes, and forecasting future research directions. Tools such as VOSviewer enable visualization of co-authorship, keyword co-occurrence, and co-citation networks [17]. These methods have been increasingly applied to orthopedic oncology topics in recent years, encompassing malignant tumors such as chondrosarcoma [18-20] and osteosarcoma [21], as well as benign bone lesions including osteoblastoma [22] and osteochondroma [23]. However, to the best of our knowledge, no bibliometric study has comprehensively analyzed the chondroblastoma literature.

The present study aims to fill this gap by performing a comprehensive bibliometric analysis of the global scientific output on chondroblastoma over a 25-year period (2000-2025) using the Web of Science Core Collection (WoSCC). Our specific objectives were to: (1) quantify annual publication trends and growth rates; (2) identify the most productive countries, institutions, journals, and authors; (3) characterize the citation landscape and most influential publications; (4) map VOSviewer network visualizations for keyword co-occurrence, co-citation, bibliographic coupling, and country co-authorship; and (5) provide evidence-based recommendations for future research directions.

Material and Methods

Data source and search strategy

This bibliometric study was conducted using the WoSCC database. A comprehensive literature search was performed on April 26, 2026. Because all records indexed for the full study period (through December 31, 2025) were available and stabilized at the time of extraction, the search captured the complete 2000–2025 calendar window rather than a projection of partial-year data. The following topic search string was used:

TS = (“chondroblastoma” OR “chondroblastomas” OR “epiphyseal chondroblastoma”)

The search was restricted to publications from January 1, 2000 to December 31, 2025. The document-type filter targeted Articles and Reviews; the retained set also included a small number of records (n = 32, 4.3%) carrying combined WoSCC document-type designations (16 “Article; Proceedings Paper”, 14 “Article; Book Chapter”, and 2 “Article; Early Access”), which were retained because their primary classification corresponded to an original article or review. Only English-language publications

were included. All data were exported in tab-delimited format (Full Record and Cited References) for analysis.

Data extraction and analysis

Bibliometric data were analyzed using Python (v3.11) with the pandas library, applying the methodological framework established by Aria and Cuccurullo for comprehensive science mapping [24]. Key scientometric indicators included: total publication count, compound annual growth rate (CAGR), total and average citations, H-index, and Bradford’s law zones for journal concentration. The CAGR was computed as $(N_{end} / N_{start})^{(1/\Delta t)} - 1$, where N_{start} and N_{end} are the annual publication counts of the first and last year and Δt is the number of intervening years. Bradford’s zones were derived by ranking all source journals in descending order of publication count and partitioning the cumulative output into three zones each containing approximately one-third ($\approx 33.3\%$) of total publications; the set of journals required to reach the first one-third constituted the core (Zone 1). The topic search string combined the controlled disease term with its plural and the principal anatomical synonym to maximize recall while avoiding the truncated wildcard “chondroblast*”, which would have introduced false-positive matches to “chondroblast” as a cell-biology descriptor; the formal sensitivity and specificity of this retrieval against an external reference standard were not quantified. Network visualization was performed with VOSviewer (v1.6.20) [17] to generate: (1) keyword co-occurrence maps (minimum keyword frequency: 5); (2) country co-authorship networks (minimum publications per country: 5); (3) co-citation networks of cited journals (minimum co-citations: 10); and (4) bibliographic coupling of documents (minimum coupling strength: 10). No ethical approval was required as all data were derived from publicly available bibliographic sources.

Inclusion and exclusion criteria

Inclusion criteria: (1) WoSCC-indexed publications; (2) year 2000-2025; (3) document type: article or review (including records with combined or early-access designations primarily classified as such); (4) English language. Exclusion criteria: (1) non-English publications; (2) duplicate records; (3) publications outside the specified date range; (4) document types whose primary classification was neither article nor review (e.g., letters, editorial material, meeting abstracts).

Results

General overview

After applying all inclusion and exclusion criteria, 740 publications were retained for analysis. Comprehensive bibliometric indicators are presented in Table 1. The 740 publications accumulated 14,407 total citations, with a mean of 19.47 citations per document and a field H-index of 56. Eighty-eight documents (11.9%) received no citations. The average number of authors per document was 5.50 (range 1-29). Of all publications, 617 (83.4%) were indexed in the Science Citation Index Expanded (SCIE) and 113 (15.3%) in the Emerging Sources Citation Index (ESCI).

Table 1. General bibliometric characteristics of chondroblastoma literature (2000-2025)

Parameter	Value
Total publications (2000-2025)	740
Articles	601 (81.2%)
Reviews	107 (14.5%)
Combined/early-access designations	32 (4.3%)
Total citations	14,407
Average citations per document	19.47
H-index of the field	56
Documents with zero citations	88 (11.9%)
Annual growth rate (CAGR)	3.8%
Average authors per document	5.50 (range: 1-29)
Total source journals	312
Bradford's law core journals (Zone 1)	22 journals / 246 papers (33.2%)
SCIE-indexed publications	617 (83.4%)
ESCI-indexed publications	113 (15.3%)
Study period	2000-2025
Database	Web of Science Core Collection

Combined/early-access designations (n = 32) denote records whose WoSCC document-type field carried a combined tag (16 “Article; Proceedings Paper”, 14 “Article; Book Chapter”, and 2 “Article; Early Access”) but whose primary classification corresponded to an original article or review; these were retained in the analyzed set. Abbreviations: CAGR, compound annual growth rate; ESCI, Emerging Sources Citation Index; SCIE, Science Citation Index Expanded; WoSCC, Web of Science Core Collection.

Annual publication trends

Annual publications increased from 13 in 2000 to 47 in 2025 (CAGR 3.8%), with a notable peak of 64 publications in 2021 (Figure 1). Output remained comparatively stable between 2000 and 2013 (range 11-34 per year). A clear inflection point emerged

after 2013-2014, coinciding with the landmark discovery of H3F3B mutations by Behjati et al. [12]. Total output in the final five years (2020-2024, n = 216) was 184% greater than in the first five years (2000-2004, n = 76).

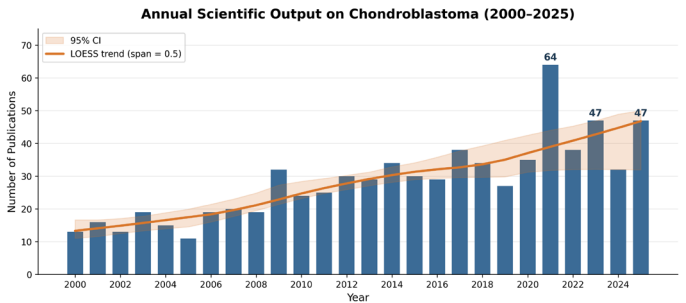


Figure 1. Annual scientific output on chondroblastoma (2000-2025). Bars represent yearly publication counts; the solid curve represents a locally estimated scatterplot smoothing (LOESS) trend (span = 0.5), with the shaded band indicating the 95% confidence interval. A clear inflection point is visible after 2013, coinciding with the landmark discovery of H3F3B driver mutations.

Geographic distribution

Publications originated from over 60 countries. Country-level output data are presented in Table 2. The United States was the most productive country (n = 226, 30.5%), followed by China (n = 94, 12.7%) and Japan (n = 74, 10.0%). Asian countries collectively accounted for approximately 30% of total output. Türkiye ranked seventh globally (n = 27, 3.6%). Country co-authorship network analysis (Figure 2) identified the United States as the dominant collaboration hub, with strong bilateral links to Japan, England, Italy, Canada, and Germany. China and India, despite high individual output, exhibited comparatively sparse international co-authorship links, suggesting predominantly domestic research activity.

Table 2. Top 15 countries by publication output

Rank	Country	n	% of total
1	USA	226	30.5%
2	China	94	12.7%
3	Japan	74	10.0%
4	India	65	8.8%
5	Italy	48	6.5%
6	Germany	31	4.2%
7	Türkiye	27	3.6%
8	France	26	3.5%
9	Netherlands	26	3.5%
10	Canada	25	3.4%
11	South Korea	24	3.2%
12	Switzerland	14	1.9%
13	Egypt	12	1.6%
14	Spain	11	1.5%
15	Iran	9	1.2%

Abbreviations: USA, United States of America.

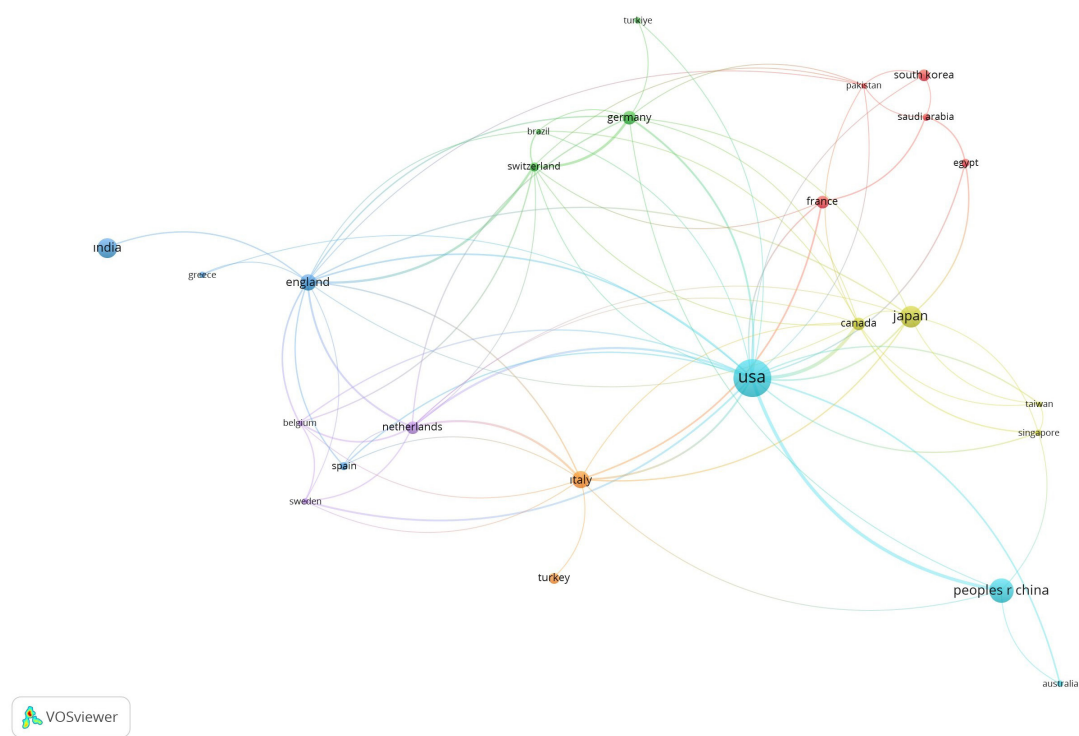


Figure 2. Country co-authorship network generated by VOSviewer (minimum publications per country ≥ 5). Node size represents publication volume; line thickness indicates collaboration intensity. Colors denote distinct collaboration clusters.

Institutional distribution

Institutional output data are presented in Table 3. Harvard University (n = 58) and Mayo Clinic (n = 56) led global output, followed by Harvard University Medical Affiliates (n = 48)

and Leiden University Medical Center (LUMC; n = 38). The IRCCS Istituto Ortopedico Rizzoli (Italy, n = 36) was the most productive single-site orthopedic oncology center outside North America.

Table 3. Top 15 most productive institutions

Rank	Institution	Country	n
1	Harvard University	USA	58
2	Mayo Clinic	USA	56
3	Harvard University Medical Affiliates	USA	48
4	Leiden University Medical Center	Netherlands	38
5	University of California System	USA	37
6	IRCCS Istituto Ortopedico Rizzoli	Italy	36
7	Assistance Publique Hopitaux de Paris	France	31
8	Massachusetts General Hospital	USA	28
9	Universite Paris Cite	France	25
10	University College London	UK	23
11	Seoul National University	South Korea	20
12	Nagoya University	Japan	18
13	University of Toronto	Canada	17
14	MD Anderson Cancer Center	USA	16
15	Chinese University of Hong Kong	China	15

Abbreviations: IRCCS, Istituto di Ricovero e Cura a Carattere Scientifico; LUMC, Leiden University Medical Center; UK, United Kingdom; USA, United States of America.

Journal analysis and Bradford’s law

Chondroblastoma research was published across 312 unique journals. Application of Bradford’s law identified a core zone (Zone 1) of 22 journals responsible for 246 publications (33.2% of total output). The top 15 journals are presented in Table 4. Skeletal Radiology was the leading source (n = 38). Journal co-citation

network analysis (Figure 3) revealed three distinct clusters: (1) a green cluster of orthopedic clinical journals centered on Clinical Orthopaedics and Related Research; (2) a blue/teal cluster of radiology/imaging journals centered on Skeletal Radiology; and (3) a red cluster of pathology journals including Modern Pathology and American Journal of Surgical Pathology.

Table 4. Top 15 source journals ranked by publication count

Rank	Journal	n	Bradford Zone
1	Skeletal Radiol	38	1
2	Clin Orthop Relat Res	20	1
3	Mod Pathol	14	1
4	Histopathology	14	1
5	Hum Pathol	13	1
6	Am J Surg Pathol	12	1
7	Diagn Cytopathol	12	1
8	Virchows Arch	11	1
9	World J Surg Oncol	10	1
10	J Foot Ankle Surg	10	1
11	Cureus	10	2
12	Orthopedics	8	2
13	J Bone Oncol	8	2
14	Acta Cytol	8	2
15	Int J Surg Pathol	9	2

Journals listed using PubMed/Index Medicus abbreviations. Bradford Zone 1: core journals accounting for the first third of total publications.

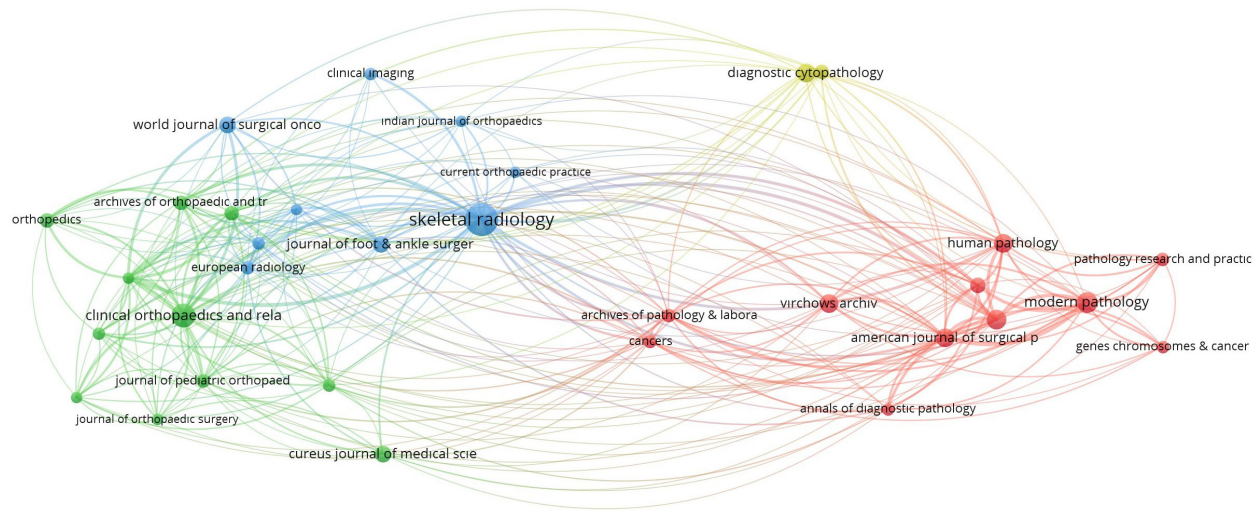


Figure 3. Co-citation network of journals generated by VOSviewer (minimum co-citations ≥ 10). Three distinct clusters are identified: orthopedic clinical journals (green), radiology/imaging journals (blue/teal), and pathology journals (red). Node size represents co-citation frequency; line thickness indicates co-citation strength.

Author analysis

Author productivity data are presented in Table 5. The most productive author was Marco Gambarotti (IRCCS Rizzoli, Italy; n = 10), followed by Alberto Righi (n = 9) and Judith V.M.G. Bovee (LUMC, Netherlands; n = 9). Three of the five most productive authors were pathologists, underscoring the centrality of histopathological and molecular pathological expertise in the field.

Table 5. Top 10 most productive authors

Rank	Author	n	Affiliation
1	Gambarotti M	10	IRCCS Istituto Ortopedico Rizzoli, Italy
2	Righi A	9	IRCCS Istituto Ortopedico Rizzoli, Italy
3	Bovee JVMG	9	Leiden University Medical Center, Netherlands
4	Baumhoer D	8	University of Basel, Switzerland
5	Szuhai K	7	Leiden University Medical Center, Netherlands
6	Hogendoorn PCW	7	Leiden University Medical Center, Netherlands
7	Folpe AL	6	Mayo Clinic, USA
8	Fang D	5	National Cancer Institute, USA
9	Gulia A	5	Tata Memorial Centre, India
10	Botchu R	5	Royal Orthopaedic Hospital, UK

Abbreviations: IRCCS, Istituto di Ricovero e Cura a Carattere Scientifico; LUMC, Leiden University Medical Center; UK, United Kingdom; USA, United States of America.

Citation analysis and most cited articles

The ten most cited articles are presented in Table 6. The most cited publication was Behjati et al. (2013) in Nature Genetics (n = 665 citations), which reported H3F3B K36M mutations as the molecular hallmark of chondroblastoma [12]. Gelderblom et al. (2008) ranked second (n = 543), reflecting the diagnostic challenge of differentiating chondroblastoma from malignant chondroid neoplasms [25]. Eefting et al. (2009, n = 160) provided a methodological framework for grading central cartilaginous tumors [26], and Cleven et al. (2015, n = 156) established IHC H3.3K36M testing as a diagnostic tool [14]. Bibliographic coupling network analysis (Figure 4) revealed three parallel research streams: molecular/genetic studies, clinical/surgical outcome series, and imaging characterization studies.

Table 6. Top 10 most cited articles in chondroblastoma research

Rank	Authors (year)	Title (abbreviated)	Journal	Citations
1	Behjati et al (2013)	Distinct H3F3A and H3F3B driver mutations define chondroblastoma and giant cell tumor of bone	Nat Genet	665
2	Gelderblom et al (2008)	The clinical approach towards chondrosarcoma	Oncologist	543
3	Murphey et al (2003)	Imaging of primary chondrosarcoma: radiologic-pathologic correlation	Radiographics	346
4	Oliveira et al (2004)	USP6 and CDH11 oncogenes identify the neoplastic cell in primary aneurysmal bone cysts	Am J Pathol	292
5	Aoki et al (2001)	FDG PET of primary benign and malignant bone tumors	Radiology	240
6	Fang et al (2016)	The histone H3.3K36M mutation reprograms the epigenome of chondroblastomas	Science	213
7	Chai et al (2010)	Radiologic diagnosis of osteoid osteoma: from simple to challenging findings	Radiographics	169
8	Nacev et al (2020)	The epigenomics of sarcoma	Nat Rev Cancer	166
9	Eefting et al (2009)	Assessment of interobserver variability in classification of central cartilaginous tumors	Am J Surg Pathol	160
10	Cleven et al (2015)	Mutation analysis of H3F3A and H3F3B as a diagnostic tool for giant cell tumor and chondroblastoma	Am J Surg Pathol	156

Abbreviations: Am J Pathol, American Journal of Pathology; Am J Surg Pathol, American Journal of Surgical Pathology; Nat Genet, Nature Genetics; Nat Rev Cancer, Nature Reviews Cancer.

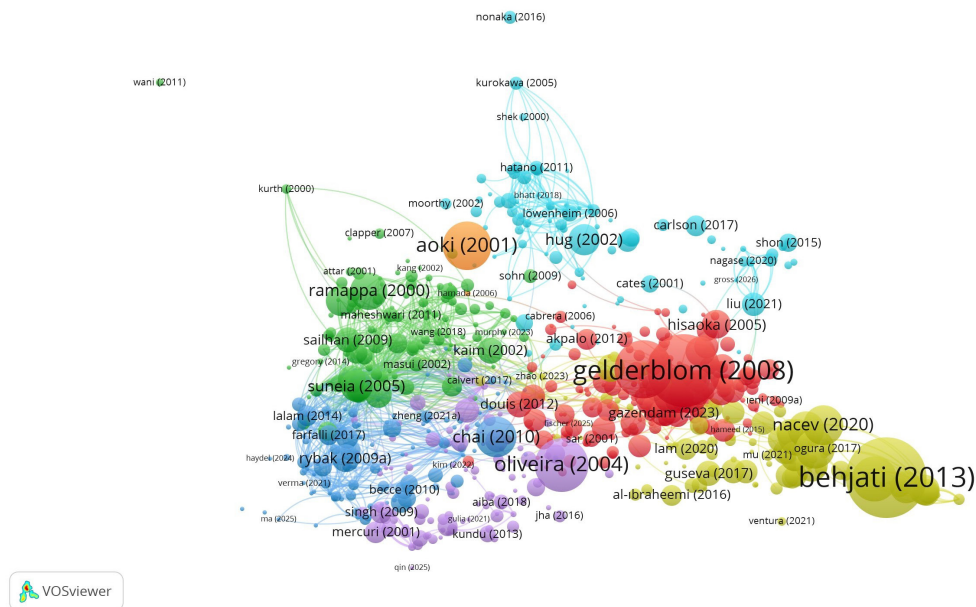


Figure 4. Bibliographic coupling network of documents generated by VOSviewer (minimum coupling strength ≥ 10). Node size indicates citation count; colors represent distinct research clusters. Three major research streams are visible: molecular/genetics studies (yellow-green), clinical/surgical outcome series (green), and imaging characterization studies (blue/teal).

Keyword analysis and research hotspots

The top 15 author keywords by frequency are presented in Table 7. The VOSviewer keyword co-occurrence network (Figure 5) identified five major thematic clusters: (1) molecular pathology and differential diagnosis (IHC, giant cell tumor of bone, H3F3A, osteosarcoma, denosumab); (2) imaging and diagnosis (magnetic resonance imaging (MRI), computed tomography

(CT), clear cell chondrosarcoma); (3) surgical treatment and outcomes (curettage, surgery, recurrence, RFA); (4) anatomic location (femoral head, proximal femur, foot, ankle); (5) pediatric and epiphyseal features (epiphysis, children). The high co-occurrence frequency of RFA ($n = 16$) and the prominence of temporal bone ($n = 21$) and temporomandibular joint ($n = 16$) indicate significant emerging interest in minimally invasive ablation [16] and craniofacial anatomic variants.

Table 7. Top 15 author keywords in chondroblastoma research (excluding ‘chondroblastoma’)

Rank	Keyword	Frequency	Thematic cluster
1	Bone tumor	41	Surgical/clinical
2	Chondrosarcoma	39	Differential diagnosis
3	Immunohistochemistry	36	Molecular pathology
4	Aneurysmal bone cyst	30	Differential diagnosis
5	Osteosarcoma	27	Differential diagnosis
6	MRI	27	Imaging
7	Curettage	24	Surgical treatment
8	Chondromyxoid fibroma	23	Differential diagnosis
9	Recurrence	23	Surgical/clinical
10	Temporal bone	21	Anatomic location
11	Giant cell tumor of bone	20	Differential diagnosis
12	Radiofrequency ablation	16	Surgical treatment
13	Temporomandibular joint	16	Anatomic location
14	CT	16	Imaging
15	Clear cell chondrosarcoma	17	Differential diagnosis

Keyword clusters identified by VOSviewer co-occurrence network analysis (minimum keyword frequency ≥ 5). Abbreviations: CT, computed tomography; MRI, magnetic resonance imaging.

Discussion

To the best of our knowledge, this is the first comprehensive bibliometric analysis of the global chondroblastoma literature. Our analysis of 740 publications spanning 25 years reveals a progressively growing research field with a CAGR of 3.8%, total citations exceeding 14,000, and a field H-index of 56. These metrics compare favorably with analogous bibliometric analyses of other rare bone tumors: Yilmaz and Kurt reported 679 publications and a CAGR of approximately 3.2% for osteoblastoma over a similar period, [22] while chondrosarcoma bibliometric analyses have described markedly higher absolute volumes reflective of its greater clinical prevalence [18-20].

The most striking finding in our temporal analysis is the inflection in publication output beginning in 2013-2014, temporally coincident with the Behjati et al. discovery of H3F3B K36M mutations [12]. Although bibliometric data cannot establish causation, several lines of evidence support a directly attributable rather than merely coincidental relationship. First, the change is temporally specific: mean annual output rose from 21.4 publications in the decade preceding the discovery (2003–2012) to 37.6 in the decade following it (2014–2023), a 76% increase that is discontinuous with the gradual pre-2013 trend rather than a continuation of it. Second, the change is mechanistically plausible and category-specific: the discovery did not merely add citations but generated a concrete, deployable diagnostic tool—H3.3K36M IHC [14]—that was rapidly adopted across pathology laboratories, which explains why Pathology is the second-most-represented subject category (23.5%) and why three of the five most productive authors are pathologists. Third, the effect is thematically traceable in our own data: molecular terms (H3F3A, IHC, denosumab) and the corresponding red cluster of the keyword network are populated almost entirely by post-2013 records, whereas the surgical/clinical clusters draw on the full study period. Competing explanations—a general secular rise in bibliometric indexing, the broader growth of orthopedic oncology output, or improved imaging access—would predict a smooth, field-wide increase rather than the abrupt, molecularly concentrated shift observed here. The convergence of temporal specificity, a tangible diagnostic mechanism, and theme-specific clustering therefore makes the 2013 discovery the most parsimonious driver of the inflection. This single landmark publication (n = 665 citations, the highest in our dataset) fundamentally reoriented the field from clinical characterization toward molecular pathogenesis and epigenetic biology. The subsequent Science paper by Fang et al. [13] (n = 213 citations) established the mechanistic basis of H3.3K36M-driven epigenomic reprogramming, making chondroblastoma a paradigm for the emerging class of oncohistone-driven neoplasms — a class comprehensively reviewed by Nacev et al. [15]. This molecular revolution is directly reflected in our keyword co-occurrence network, where H3F3A, denosumab, and IHC form a prominent cluster linked to differential diagnosis with giant cell tumor of bone.

The geographic distribution of chondroblastoma research reflects well-established patterns in global orthopedic oncology output. The United States' dominant position is consistent with its infrastructure of dedicated sarcoma centers, large patient volumes, and robust funding mechanisms. The strong performance of European institutions — particularly LUMC, IRCCS Istituto Ortopedico Rizzoli, and centers in France, Germany, and Switzerland — reflects the historical leadership of European bone tumor pathology and the coordinating role of consortia such as the European Musculoskeletal Oncology Society and the Connective Tissue Oncology Society [27]. Absolute counts, however, are strongly confounded by population and research-system size, and a population-normalized perspective alters the ranking substantially. When output is normalized per 10 million inhabitants (2025 population estimates), the ranking changes markedly: small, high-output nations move to the front—Switzerland (≈15.6 publications per 10 million), the Netherlands (≈14.7), and Italy (≈8.2)—whereas the population giants fall to the bottom (China ≈0.7; India ≈0.4). The United States, despite its first-place absolute count, ranks only mid-table per capita (≈6.5), comparable to Japan (≈6.0) and Canada (≈6.2) and far below the leading European centers. A second normalization—mean citations per document—points in the same direction: the small European centers also lead on per-paper impact (Switzerland ≈85.6, the Netherlands ≈61.8, and England ≈45.5 citations per document), whereas the highest-volume Asian producers show the lowest per-paper impact (India ≈4.8; China ≈12.2), with the United States mid-field (≈25.0). Both the population- and document-normalized metrics therefore converge on the same conclusion: absolute output overstates the relative research intensity and per-paper influence of the largest producers, while the dense concentration of expertise in a few European centers represents the field's true per-capita and per-document research intensity. Türkiye's seventh-place global ranking (n = 27; ≈3.1 publications per 10 million inhabitants, within the mid-tier European range alongside Germany (≈3.7) and France (≈3.9)) is a notable finding that aligns with the broader growth trajectory of Turkish orthopedic oncology research documented in the literature [22,23]. Several structural factors plausibly underlie this position: a large skeletally immature population with correspondingly high case volumes for an epiphyseal tumor of childhood and adolescence, a concentrated network of high-volume university and training-and-research hospitals performing musculoskeletal oncology surgery, and the rapid expansion of doctoral thesis output and indexed national journals over the past decade. Türkiye's per-capita comparability with established Western European producers, despite a shorter modern research history, suggests that its contribution to the chondroblastoma literature is now structural rather than incidental, even though—consistent with the collaboration analysis below—much of this output remains predominantly domestic and would benefit from deeper integration into international multicenter consortia.

Our country co-authorship network analysis (Figure 2) reveals a nuance beyond simple publication counts: China and India, despite ranking second and fourth in absolute output, exhibit comparatively sparse international collaboration networks. This suggests a predominantly domestic research ecosystem — a pattern that may reflect language barriers and the early stage of international integration for emerging research economies. In contrast, the dense transatlantic collaboration network linking the United States, United Kingdom, Netherlands, Italy, and Germany reflects established institutional partnerships within the World Health Organization/International Agency for Research on Cancer bone tumor working groups [27].

A critical reading of the most-cited articles (Table 6) is more informative than their raw citation counts. Influence in this corpus is of two distinct kinds. The first is genuinely field-transforming: Behjati et al. (2013, $n = 665$) and Fang et al. (2016, $n = 213$) did not merely accumulate citations but redefined the diagnostic and biological identity of the tumor, converting chondroblastoma from a histologically defined lesion into a molecularly defined, oncohistone-driven entity and seeding an entirely new research stream; Cleven et al. (2015, $n = 156$) translated that insight into routine practice through a validated immunohistochemical assay. These three papers are causally upstream of the post-2013 inflection. The second kind of influence is borrowed rather than intrinsic: several of the highest-ranked items—Gelderblom et al. on chondrosarcoma ($n = 543$), Murphey et al. on chondrosarcoma imaging ($n = 346$), Oliveira et al. on aneurysmal bone cysts ($n = 292$), Aoki et al. on fluorodeoxyglucose positron emission tomography of bone tumors ($n = 240$), and Chai et al. on osteoid osteoma ($n = 169$)—are not chondroblastoma-specific studies at all. They are captured by the search because chondroblastoma appears within their differential-diagnosis discussions, and their high counts reflect the citation economy of the more prevalent neoplasms they primarily address. This distinction has a concrete implication: citation magnitude in a rare-tumor bibliometric dataset is a biased proxy for topical impact, systematically inflating the apparent importance of adjacent-entity references while a discovery's true field-shaping role is better evidenced by the new thematic clusters and research streams it nucleates, as the molecular cluster in our keyword network demonstrates.

The journal co-citation network (Figure 3) identified a tripartite landscape — orthopedic surgery, radiology, and pathology — mirroring the multidisciplinary diagnostic framework required for chondroblastoma management. The bibliographic coupling network (Figure 4) further clarified the field's internal structure by revealing three parallel research streams: molecular/genetic, clinical/surgical, and imaging. Beyond cataloguing these clusters, their relative positions and interconnections are themselves informative. In the keyword network (Figure 5) the molecular-pathology cluster (red) and the imaging cluster (blue/purple) are not adjacent but are bridged consistently through the differential-diagnosis vocabulary—giant cell tumor of bone, aneurysmal bone cyst, chondromyxoid fibroma, and clear cell chondrosarcoma—indicating that the field's intellectual

cohesion is organized around the diagnostic problem of distinguishing chondroblastoma from its mimics rather than around any single technique. The surgical/treatment cluster (green) occupies a comparatively peripheral position with weaker links to the molecular cluster, signalling a persistent translational gap between the epigenetic understanding of the tumor and its day-to-day surgical management. The clusters also carry a temporal signature: the molecular nodes constitute the field's current research front, whereas the surgical and imaging nodes—curettage, recurrence, and the core imaging descriptors—form its stable knowledge base. The emergent craniofacial (temporal bone, temporomandibular joint) and minimally invasive (RFA) sub-clusters appear at the network margins with recent, sparsely connected nodes, identifying them as nascent frontiers that have not yet been integrated into the established co-citation core. This co-evolution—a molecular front grafted onto a durable clinical and radiologic foundation—captures how the H3.3K36M discovery reorganized, rather than replaced, the pre-existing structure of the field. The prominent clustering of treatment outcome studies (Ramappa et al. [6], Suneja et al. [8], Farfalli et al. [9]) in the clinical/surgical stream confirms the clinical importance of long-term joint preservation outcomes, particularly given the young age of affected patients and the risk of arthritis after proximal femoral curettage [9].

Keyword analysis (Figure 5, Table 7) identifies several actionable research frontiers. RFA has emerged as a viable minimally invasive alternative to curettage, particularly for lesions in difficult anatomic locations such as the femoral head and talus [16]. The craniofacial cluster (temporal bone, temporomandibular joint) reflects a biologically and surgically distinct subset requiring dedicated multicenter study. The denosumab node in the molecular cluster reflects emerging interest in receptor activator of nuclear factor-kappa B (RANK)/RANK ligand (RANKL)-targeted therapy for refractory or recurrent cases, analogous to its established role in giant cell tumor of bone, where it targets the osteoclast-like giant cell component shared with chondroblastoma [28].

Several limitations warrant acknowledgment. First, restriction to WoSCC may exclude publications indexed only in PubMed, Embase, or Scopus; because Scopus and PubMed provide broader coverage of regional, lower-impact, and non-English-source journals, their omission likely under-represents output from emerging research economies and may modestly deflate the absolute counts of high-volume but less internationally indexed contributors such as China and India, although the relative concentration of the field in established North American and European centers is unlikely to be reversed. The absence of a cross-database comparison is itself a limitation, and the formal sensitivity and specificity of our WoSCC search strategy were not benchmarked against an independent reference set of known chondroblastoma publications. Second, citation counts favor older publications irrespective of contemporary impact. Third, country assignment based on corresponding author affiliation may underestimate multinational contributions, and our country and institutional rankings are based on absolute publication

counts rather than normalized indicators; population-adjusted output (publications per capita) and citation-per-document metrics would reposition several small but highly productive nations (e.g., the Netherlands and Switzerland) far higher, as discussed above, so absolute rankings should be interpreted as measures of total scholarly volume rather than per-capita research intensity. Fourth, keyword analysis is constrained by inconsistent indexing terminology across journals and time periods. Fifth, the restriction to English-language publications excludes potentially significant case series and clinical reports published in the national languages of highly productive countries such as China and Japan; given that these two nations rank second and third in absolute output, the true geographic distribution of chondroblastoma scholarship—particularly its clinical, as opposed to molecular, literature—may be incompletely captured by an English-only sample. Despite these limitations, WoSCC remains the gold standard for bibliometric research given its comprehensive citation data and robust field classification.

Conclusion

This first comprehensive bibliometric analysis of the global chondroblastoma literature (2000-2025) demonstrates a progressively growing research field with a CAGR of 3.8% and a marked acceleration since the molecular revolution of 2013. The United States, China, and Japan lead in publication output; Harvard University and Mayo Clinic are the most productive institutions; Skeletal Radiology is the field's core journal. VOSviewer network analyses identify three parallel research streams (molecular pathology, clinical/surgical, imaging) and five keyword thematic clusters, with emerging hotspots in epigenetic pathogenesis, RFA, craniofacial involvement, and denosumab therapy. These findings provide an evidence-based roadmap for researchers and clinicians seeking to navigate and contribute to this evolving field.

Ethical Approval

This study utilized only publicly available bibliometric data from the WoSCC. No patient data were used and no ethical approval was required.

Patient Consent

Not applicable. This bibliometric study analyzed only publicly available bibliographic records; no human participants or patient data were involved, and informed consent was therefore not required.

Conflict of Interest

The authors confirm the absence of any conflicts associated with this work.

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