

Does Research Activity Reflect the Burden of Scoliosis? A Bibliometric Analysis of Etiologic Subtypes

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Abstract

Purpose

Whether research output is distributed across scoliosis subtypes in proportion to their burden of disease is unknown. We characterized the scoliosis literature published from 2010 to 2025 by etiologic subtype and compared scholarly output with disease prevalence.

Methods

We searched the Scopus database for articles and reviews on scoliosis published between January 1, 2010, and December 31, 2025. Records were classified by a predefined keyword algorithm into AIS, congenital, neuromuscular, degenerative/adult, syndromic, and non-adolescent idiopathic categories. The dataset was analyzed in R with the bibliometrix package.

Results

The search returned 27,190 documents (24,335 articles [89.5%] and 2,855 reviews [10.5%]) from 79,475 authors, with annual output rising from 858 in 2010 to 2,811 in 2025. Adolescent Idiopathic Scoliosis (AIS) was the largest named subtype, accounting for 6,818 documents (25.1% of the corpus and 43.8% of all output); 42.8% of documents could not be classified by etiology. Degenerative/adult scoliosis was second (4,176; 15.4%), grew the fastest, and had the highest mean citations per document (23.4), whereas AIS had a comparatively low mean citation rate (18.1). The AIS share of annual output remained between 20.2% and 27.2%, with no sustained directional change. Neuromuscular (11.4%), syndromic (6.0%), and congenital (3.6%) scoliosis remained comparatively small.

Conclusions

The distribution of scoliosis research across etiologic subtypes doesn't mirror disease prevalence. Despite the substantially greater prevalence of degenerative scoliosis in adults, publication volume remained lower than that of AIS throughout the study period. These findings suggest congenital, neuromuscular, and degenerative scoliosis as priorities for future investigation.

Introduction

Scoliosis comprises a heterogeneous group of spinal deformities characterized by coronal curvature and vertebral rotation.⁽¹⁾ Although all scoliosis subtypes have similar radiographic appearances, they present with significant differences in etiology, presentation age, natural history, treatment options, and operative risks. Adolescent idiopathic scoliosis (AIS) is the most common form, affecting approximately 2% to 3% of adolescents.⁽²⁾ Its origin is multifactorial and remains incompletely defined, with proposed

etiologies from genetic predisposition, abnormal skeletal growth, and disordered neuromuscular factors. (2) Congenital scoliosis results from a defect of vertebral formation, segmentation, or both during embryogenesis, in which asymmetric vertebral growth from a hemivertebra or unsegmented bar drives curve progression.(1, 3) Neuromuscular scoliosis develops secondary to disorders such as cerebral palsy, Duchenne muscular dystrophy, and spinal muscular atrophy, in which muscular weakness, spasticity, and asymmetric trunk-muscle imbalance produce long, sweeping vertebral curves and pelvic obliquity.(4) Degenerative scoliosis arises in the aging spine, where asymmetric intervertebral disc degeneration, facet arthropathy, and vertebral osteoporosis drive an asymmetric segmental collapse that progresses to coronal and sagittal malalignment.(5, 6) It affects more than 30% of adults, with prevalence increasing substantially after 60 years of age.(6) Syndromic scoliosis occurs in association with systemic conditions including Marfan syndrome and neurofibromatosis type 1, in which the connective-tissue or bony dysplasia underlying the syndrome predisposes to spine deformity.(1)

Despite these distinct clinical profiles, the literature on scoliosis has historically been dominated by studies of adolescent idiopathic scoliosis, with comparatively less attention to other subtypes.(7)

To our knowledge, no study has examined how research activity is distributed among major scoliosis etiologies or whether that distribution corresponds to the relative burden of disease represented by each subtype. The purpose of this study was to characterize the scoliosis literature published between 2010 and 2025 according to etiologic subtypes.

Methods

A search was conducted of the Scopus Core Collection for articles and reviews on scoliosis published between January 1, 2010, and December 31, 2025. The search was limited to the title, abstract, and keyword fields. Document type was restricted to "article" and "review" and excluded conference papers, editorials, letters, notes, errata, and other non-research document types. To prevent undercounting degenerative scoliosis, scoliosis terms were combined with the terms under which that literature appears, including "degenerative scoliosis," "de novo scoliosis," and "adult spinal deformity."

Classification of each record was done by etiologic subtype using a predefined keyword algorithm applied to the combined title, abstract, author keyword, and indexing-term text. AIS was defined by the explicit term "adolescent idiopathic scoliosis," or by "idiopathic scoliosis" together with an adolescent qualifier. The congenital, neuromuscular, degenerative/adult, syndromic, and non-adolescent idiopathic categories were defined by their corresponding disease-specific terms.

Bibliometric Analysis

Records were imported into R (version 4.5.3) and analyzed with the bibliometrix package.(8) We captured the total study count, the count, and proportion of records in each subtype, and the mean and median citations per document for each subtype. Annual document counts were computed for the full dataset and for each subtype. AIS output was expressed both as an annual count and as a share of total

annual scoliosis output. The dataset was characterized by source, by author, and by country of author affiliation. To address the study question, the proportion of output devoted to each subtype was compared against published estimates of that subtype's prevalence.

Statistical Analysis

Continuous bibliometric measures, including citations per document, were summarized with the mean and standard deviation and with the median and interquartile range, and while categorical characteristics, including subtype membership and document type, were summarized with frequencies and percentages. Citation counts were those recorded in Scopus at the time of export. All analyses were performed in R (version 4.5.3).

Results

Included Studies

The search returned 27,190 documents after deduplication and removal of records dated outside the study window. After removing duplications, there were 24,335 articles (89.5%) and 2,855 reviews (10.5%) contributed by 79,475 authors. The mean number of citations per document was 18.2, the mean number of co-authors per document was 7.1, and 19.5% of documents had international co-authorship. The annual growth rate of output was 8.2%. **(Table 1)** Annual production rose from 858 documents in 2010 to 2,811 in 2025. **(Fig. 1)**

Distribution of Output by Subtype

AIS was the largest named subtype, accounting for 6,818 documents, constituting approximately one quarter of all scoliosis publications and nearly twice the volume of degenerative scoliosis research, despite the latter affecting a substantially larger adult population. The remaining 20,372 documents (74.9%) addressed all other forms. A total of 11,639 documents (42.8%) could not be assigned an etiology from indexed text. Among the 15,551 documents that carried an identifiable etiology, AIS accounted for 43.8%. Within the other subtypes, degenerative/adult scoliosis was second at 4,176 documents (15.4%), followed by neuromuscular scoliosis (3,106; 11.4%), syndromic scoliosis (1,632; 6.0%), congenital scoliosis (990; 3.6%), and non-adolescent idiopathic forms (328; 1.2%). **(Table 2)**

Citation Impact by Subtype

Mean citations per document were highest for degenerative/adult scoliosis (23.4; median, 10) and lowest among the named subtypes for AIS (18.1; median, 9). Syndromic (21.2), neuromuscular (20.4), and non-adolescent idiopathic (20.4) scoliosis fell between these values, and congenital scoliosis had the lowest mean (16.0). **(Table 2)**

The 20 most-cited documents in the publication dataset included 4 adult spinal deformity classification and alignment publications, 2 AIS bracing and epidemiology studies, 4 neuromuscular disease

management guidelines, and several syndromic disease reviews in which scoliosis was a described feature rather than the primary topic. **(Table 3)**

Temporal Trends

Annual AIS output rose from 173 documents in 2010 to 754 in 2025. Across the same period, the AIS share of total annual scoliosis output remained between 20.2% and 27.2%, with no sustained directional change. **(Table 4)** Degenerative/adult scoliosis showed the steepest absolute growth of any subtype, rising from fewer than 100 documents annually in 2010 to approximately 500 in 2025, and surpassed neuromuscular output by the mid-2010s. **(Fig. 2)** Neuromuscular, syndromic, congenital, and non-adolescent idiopathic output rose more gradually. Keyword trend analysis identified machine learning, deep learning, artificial intelligence, and vertebral body tethering as the most recent emerging terms, while degenerative scoliosis, adult spinal deformity, and proximal junctional kyphosis were introduced into the literature earlier and have sustained output through 2025. **(Fig. 3)**

Sources and Journals

The 27,190 documents appeared across 3,387 unique journals. The three most prolific were Spine (1,580 documents; 5.8%), Spine Deformity (1,523; 5.6%), and the European Spine Journal (1,413; 5.2%). The Journal of Pediatric Orthopaedics ranked fourth (569; 2.1%), and the Spine Journal fifth (515; 1.9%). Together, the top 20 sources accounted for 35.2% of total output. **(Table 5)**

Most Prolific Authors

The most prolific authors by raw article count were Lafage V (526 articles), Smith JS (453), and Qiu Y (402). When output was weighted by fractionalized authorship, Wang Y (50.6), Qiu Y (50.3), and Lenke LG (48.7) ranked highest, reflecting greater first- or sole-authorship contributions. The most prolific authors separated into two recognizable communities: one centered on adult spinal deformity (Lafage, Smith, Shaffrey, Ames, Bess, Schwab) and one on pediatric idiopathic and congenital deformity (Qiu, Zhu, Wang, Liu, Newton, Lenke). **(Table 6)**

Geographic Distribution

By author affiliation, the United States contributed the most author-affiliation appearances (30,733), followed by China (9,059), Japan (5,981), France (5,026), and Italy (4,454) **(Table 7, Fig. 3)**. European countries collectively matched or exceeded Japan and China individually. Output from Asian, Middle Eastern, and South American countries remained lower than that of North American and Western European institutions across the study period. **(Table 7)**

Conceptual and Thematic Structure

Co-occurrence analysis of author keywords resolved the literature into two principal clusters. One cluster grouped operative and deformity terms, including adolescent idiopathic scoliosis, spinal deformity,

spinal fusion, pedicle screw, adult spinal deformity, proximal junctional kyphosis, sagittal alignment, and pedicle subtraction osteotomy. A second cluster grouped pediatric and neuromuscular terms, including spinal muscular atrophy, cerebral palsy, pain, quality of life, and magnetic resonance imaging. Intellectual disability appeared as a peripheral node. **(Fig. 4)**

On the thematic map, adult spinal deformity occupied the motor-theme quadrant, defined by high centrality and high density; adolescent idiopathic scoliosis fell near the boundary between developed and central themes; scoliosis occupied the basic-theme quadrant; and congenital scoliosis and osteoporosis fell in the emerging-or-declining quadrant. **(Fig. 5)**

Discussion

This study reviewed 27,190 scoliosis publications from 2010 to 2025 by etiologic subtype. AIS accounted for one-quarter of the publication dataset and nearly half of all output that could be assigned to an etiology, yet its annual share held steady across the period. Degenerative scoliosis was the second-largest subtype, grew the fastest, and drew the most citations per document. To our knowledge, this is the first analysis to divide the scoliosis literature by etiology and to weigh that division against disease prevalence.

AIS produced 6,818 documents, 25.1% of the publication dataset and 43.8% of all output with an identifiable etiology. Its research footprint is large relative to the size of the surgically relevant adolescent population. For instance, only 2% to 3% of adolescents carry a measurable curve, only a fraction reaches the magnitude at which treatment is indicated.(2, 9) Degenerative scoliosis, by contrast, affects a far larger and expanding population, with reported prevalence above 30% in adults and near 68% in those older than 60 years, yet it generated 4,176 documents (15.4%) within the publication dataset.(5, 6) This data suggests that the output devoted to AIS exceeds what its absolute disease burden alone would predict, whereas the degenerative literature remains disproportionately small relative to the affected population. One explanation is that AIS has historically served as the principal model for deformity research, shaping the development of curve classification, bracing, and posterior instrumentation, thereby attracting sustained scholarly attention.(10) Neuromuscular (11.4%) and congenital (3.6%) scoliosis accounted for a small proportion of the literature despite their operative complexity and high complication rates, highlighting a need for additional high-quality research.(11, 12) Nearly half of all retrieved records lacked sufficient etiologic terminology for classification. Many represented general deformity, imaging, biomechanics, navigation, instrumentation, or basic-science studies that transcend specific scoliosis etiologies. Consequently, the subtype-specific counts should be interpreted as minimum estimates rather than complete representations of the literature.

The absolute volume of AIS research rose more than fourfold over the study window, but its share of total scoliosis output stayed between 20% and 27% with no sustained directional change. Degenerative scoliosis followed a different trajectory, rising from the lowest annual counts among the subtypes in 2010 to surpass neuromuscular output by the mid-2010s and to approach AIS volume by 2025. This

acceleration parallels the aging of the surgical population, the expansion of adult deformity surgery, and the maturation of adult spinal deformity classification and alignment frameworks over the same interval. (5) Keyword trend analysis showed that adult deformity terms, including adult spinal deformity and proximal junctional kyphosis, emerged earlier and maintained sustained output, whereas machine learning, deep learning, and vertebral body tethering appeared predominantly after 2020. This shift reflects growing interest in motion-sparing treatment of AIS and artificial intelligence–based approaches to curve measurement and progression prediction.(13–16)

This study also found the publication volume was not always associated with its respective citation impact. Although AIS was the largest subtype by publication count, it had the lowest mean citations per document (18.1), whereas degenerative scoliosis had the highest (23.4). This difference suggests that adult deformity research exerts influence disproportionately to its share of total output. The citation data mirrored this pattern. Adult spinal deformity classification and alignment papers by Schwab and Lafage accounted for 4 of the 11 most-cited publications, whereas the BRAIST trial by Weinstein et al., the highest-ranked AIS-specific study, ranked seventh overall.(7, 10) In contrast, the citation performance of the syndromic and neuromuscular categories should be interpreted cautiously, as these groups included highly cited disease-overview articles in which scoliosis was a secondary feature rather than the primary focus, potentially inflating both publication counts and citation averages.(4, 17)

Scoliosis research is concentrated to a small number of dedicated spine and deformity journals. Spine, Spine Deformity, and the European Spine Journal together contributed 16.6% of total output, a pattern consistent with prior spine bibliometric work.(7, 18) The presence of the American Journal of Medical Genetics Part A among the top 10 sources, ranking eighth with 447 documents, reflects the volume of syndromic and congenital literature indexed under genetics rather than orthopaedics, and is a partial explanation for that subtype's citation inflation. The separation of authors into adult deformity and pediatric idiopathic deformity communities mirrors the division of fellowship training in spine surgery and may contribute to the persistence of distinct research agendas within each domain. The United States led national output by a margin that exceeded all other countries combined, consistent with prior analyses of orthopaedic and spine literature.(18–20) The strong representation of China and Japan, particularly after fractional weighting of authorship, reflects sustained regional investment in AIS research and aligns with the high AIS surgical volume reported from East Asian centers.(21–23)

Keyword analysis demonstrated that scoliosis research is organized around two principal domains, namely operative deformity surgery and pediatric/neuromuscular care. The co-occurrence network separated a surgical deformity cluster (which combined AIS and adult spinal deformity terms) from a distinct neuromuscular and pediatric cluster, indicating that the two highest-volume subtypes share a common operative vocabulary while neuromuscular work forms a separate literature with its own terminology. On the thematic map, adult spinal deformity occupied the motor-theme quadrant, the position of a well-developed and central topic that drives a field, consistent with its rapid growth and high citation impact. Adolescent idiopathic scoliosis appeared as a developed theme, and scoliosis itself anchored the basic-theme quadrant as the foundational term of the field.(7) Congenital scoliosis fell in

the emerging-or-declining quadrant, a position consistent with its small and slowly growing output and with its identification here as an underrepresented subtype.(24)

Limitations

There were a few limitations in this study that should be addressed. First, classification depended on indexed text, and 42.8% of documents carried no etiologic term the algorithm could read. Second, surgical technique, imaging, and basic-science reports are overrepresented in this unspecified group, so every named subtype is undercounted, and the absolute counts should be read as conservative estimates. Thirdly, the named subtype categories overlap, so a single document may contribute to more than one group, and only the AIS versus non-AIS partition is mutually exclusive. Finally, the geographic figures reflect author-affiliation appearances rather than documents and therefore it is presented here as authorship volume rather than national document counts.

Conclusions

Between 2010 and 2025, scoliosis research expanded substantially, with adolescent idiopathic scoliosis remaining the dominant etiologic subtype despite accounting for a relatively small proportion of the overall disease burden. Degenerative scoliosis demonstrated the greatest growth in publication volume and the highest citation impact, reflecting its increasing importance within the deformity literature. In contrast, congenital and neuromuscular scoliosis remained comparatively underrepresented despite their clinical complexity. These findings indicate that the distribution of scholarly output across scoliosis subtypes does not fully mirror disease prevalence and suggest opportunities for increased research attention to underrepresented deformity populations.

Declarations

Author Contribution

R.R., M.A.S., A.B., and A.K. conceptualized and designed the study. R.R., B.M., and K.T.-F. performed the search, data extraction, and bibliometric analyses in R. R.R., M.A.S., and A.B. drafted the main manuscript text. R.C.G., R.C.C., A.B. (Allan Beebe), S.T., K.T.-F., and A.K. critically revised the manuscript for important intellectual content. All authors reviewed and approved the final manuscript.

Data Availability

Data Availability Statement: The bibliometric data used in this study were retrieved from the Scopus database (Elsevier) spanning publications from January 1, 2010, to December 31, 2025. The extracted literature metadata, search strings, and R analysis scripts are available from the corresponding author upon reasonable request

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Tables

Tables 1 to 8 are available in the supplementary files section

Figures

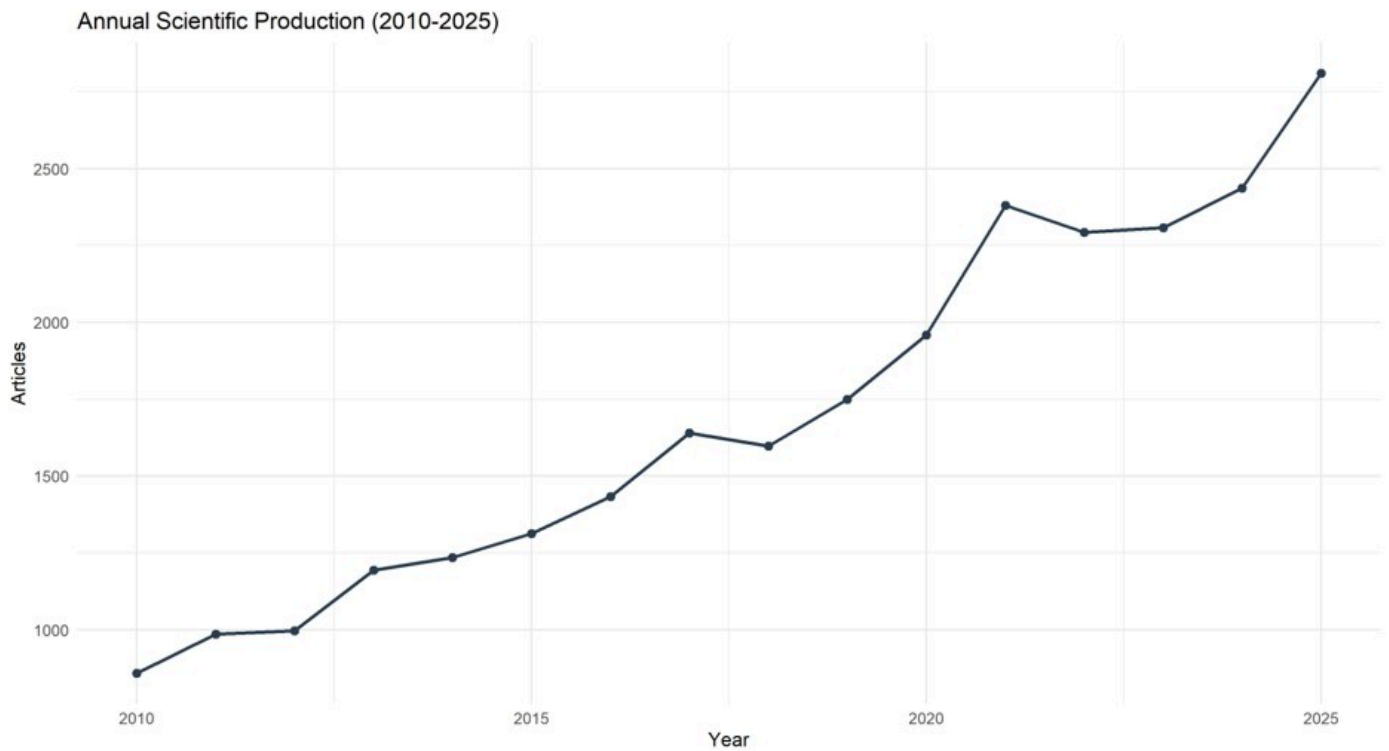


Figure 1

Annual scientific production across the full scoliosis publication dataset, 2010 to 2025. Total scoliosis documents published per year. Output grew at a compound annual rate of 8.2%, rising from 858 documents in 2010 to 2,811 in 2025, with steady growth through the mid-2010s, a plateau around 2020, and accelerated growth from 2021 onward.

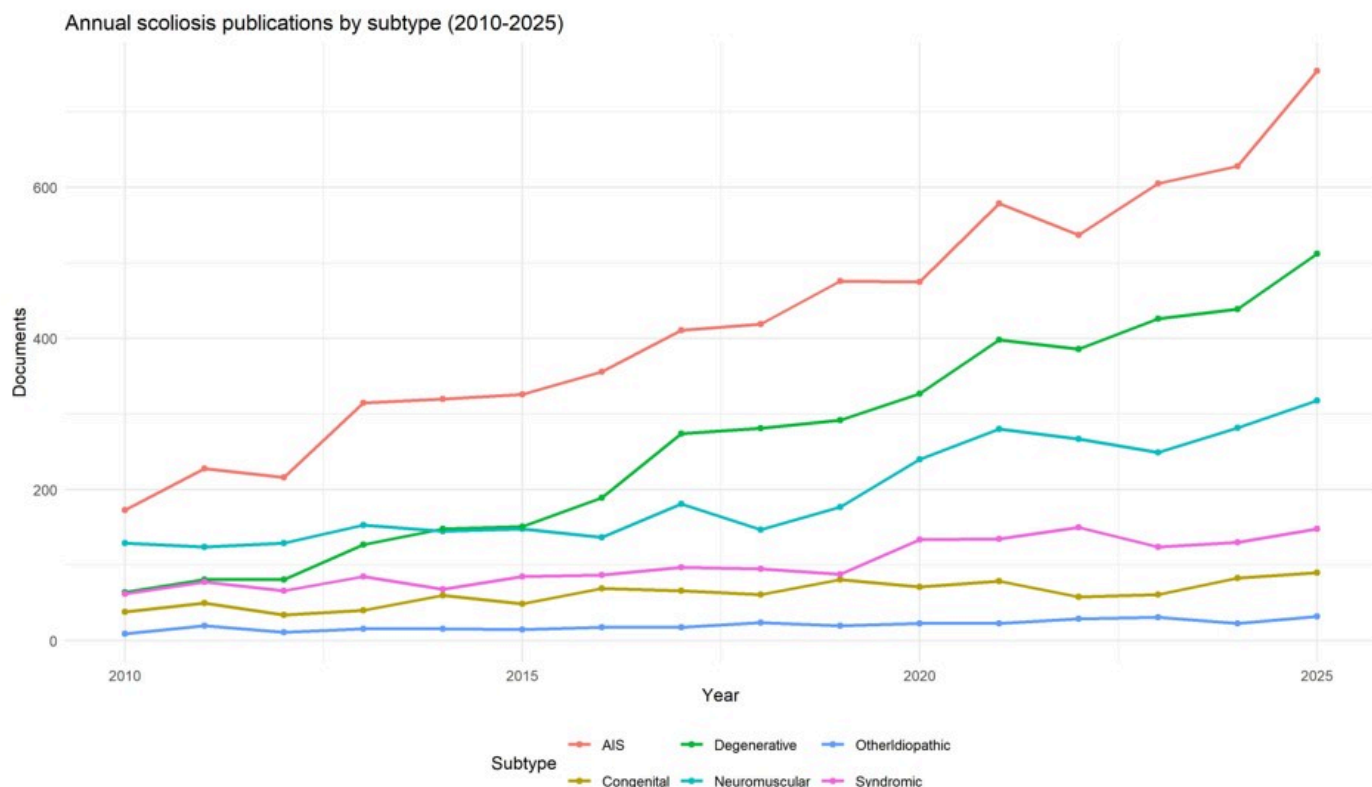


Figure 2

Annual scoliosis output by etiologic subtype, 2010 to 2025. AIS led in absolute volume throughout the study period. Annual document counts for each named subtype plotted as separate color-coded lines. AIS led in absolute volume throughout the period. Degenerative/adult scoliosis showed the steepest growth, surpassing neuromuscular output by the mid-2010s. Neuromuscular, syndromic, congenital, and other idiopathic subtypes rose more gradually.

Trend Topics

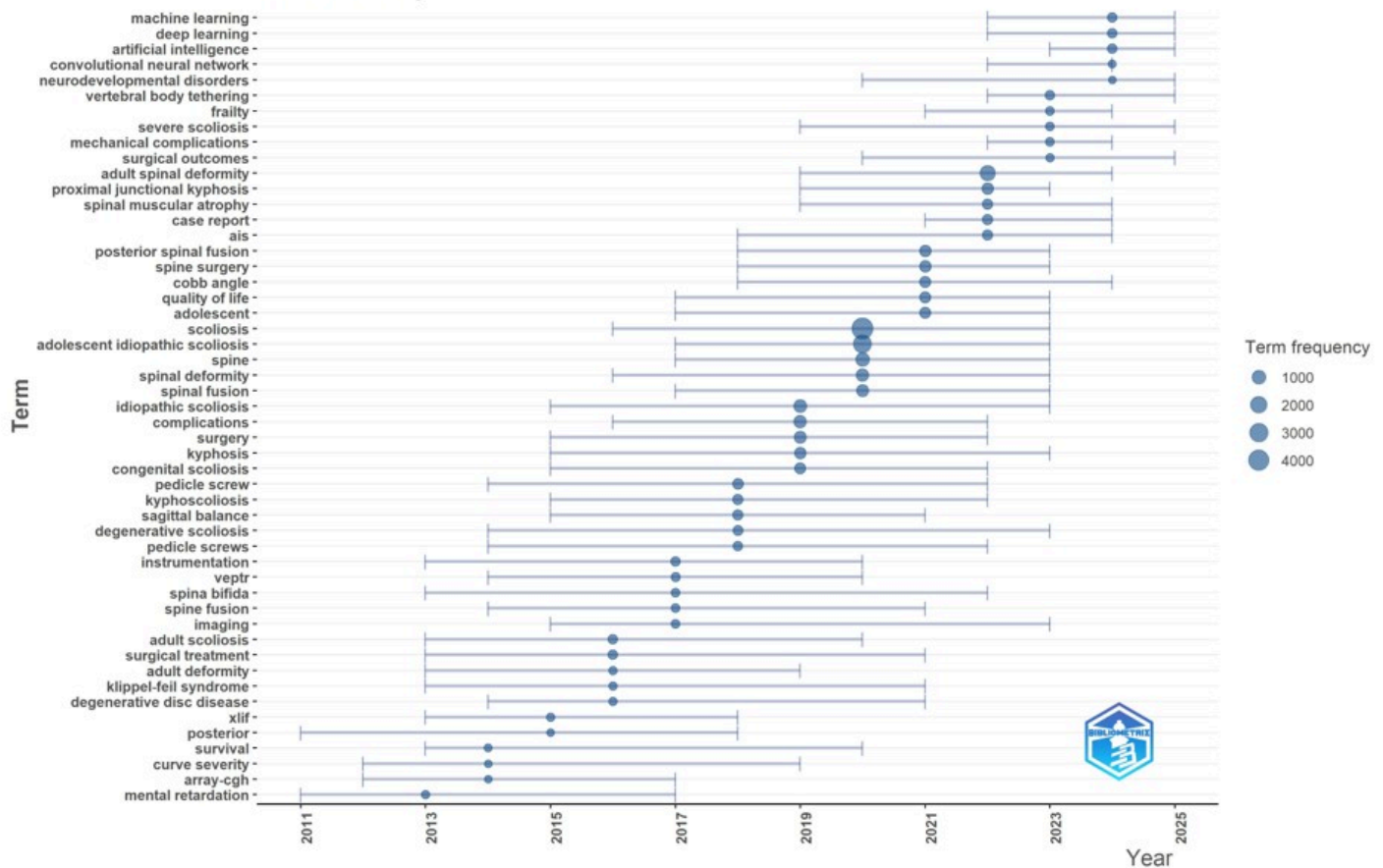


Figure 3

Keyword Trend Analysis of the 50 Most Frequent Author Keywords, 2010 to 2025. Bubble chart displaying the median publication year (x-axis) and temporal span (horizontal lines) of the 50 most frequent author keywords. Bubble size reflects term frequency. Machine learning, deep learning, artificial intelligence, and vertebral body tethering cluster in the most recent years; degenerative scoliosis, adult spinal deformity, and proximal junctional kyphosis span the full study window.

Co-word Network (Author Keywords)

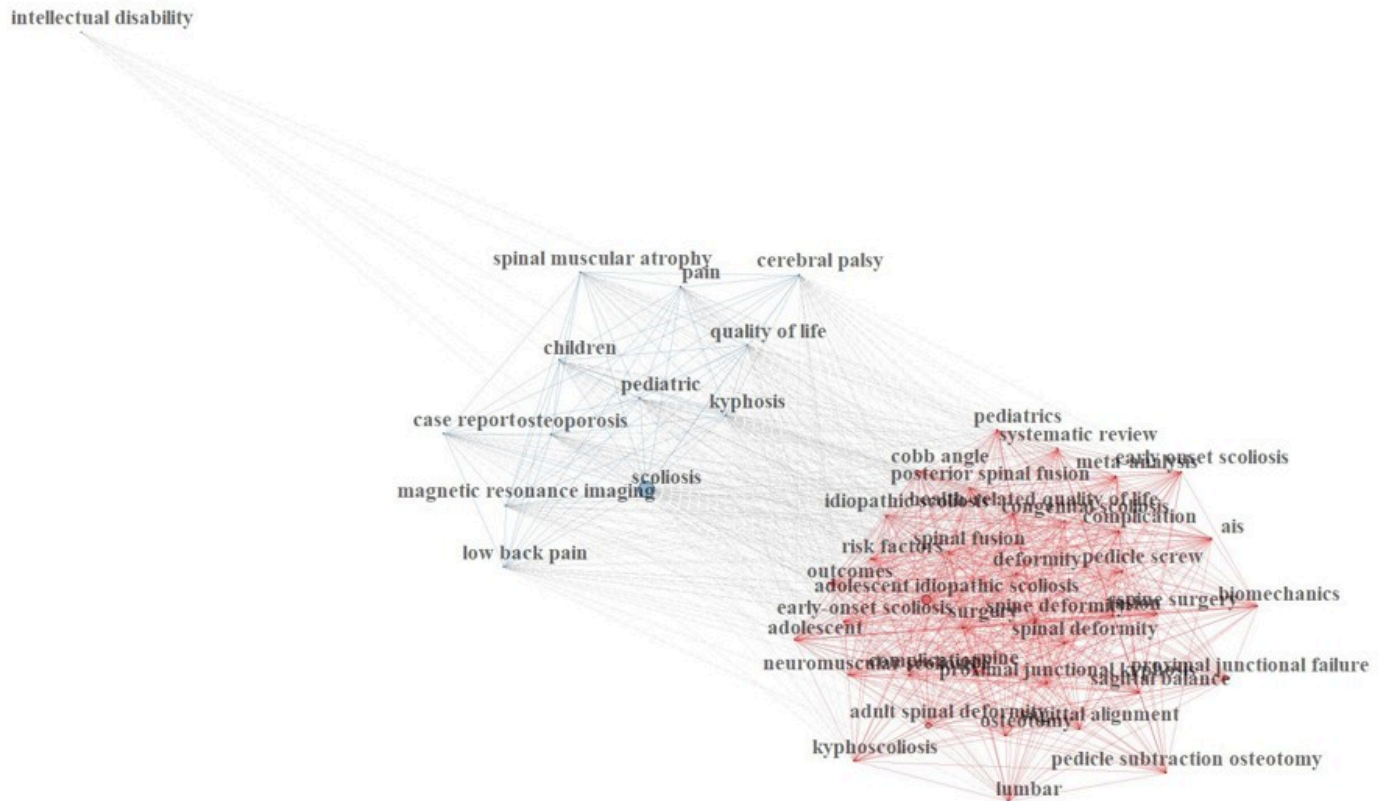


Figure 4

Co-occurrence network of the 50 most frequent author keywords, 2010 to 2025. Network visualization in which node size reflects keyword frequency and edges reflect co-occurrence strength. A dense surgical deformity cluster groups AIS and adult spinal deformity terms with operative terminology. A separate pediatric and neuromuscular cluster groups spinal muscular atrophy, cerebral palsy, and quality of life. Intellectual disability appears as a peripheral node.

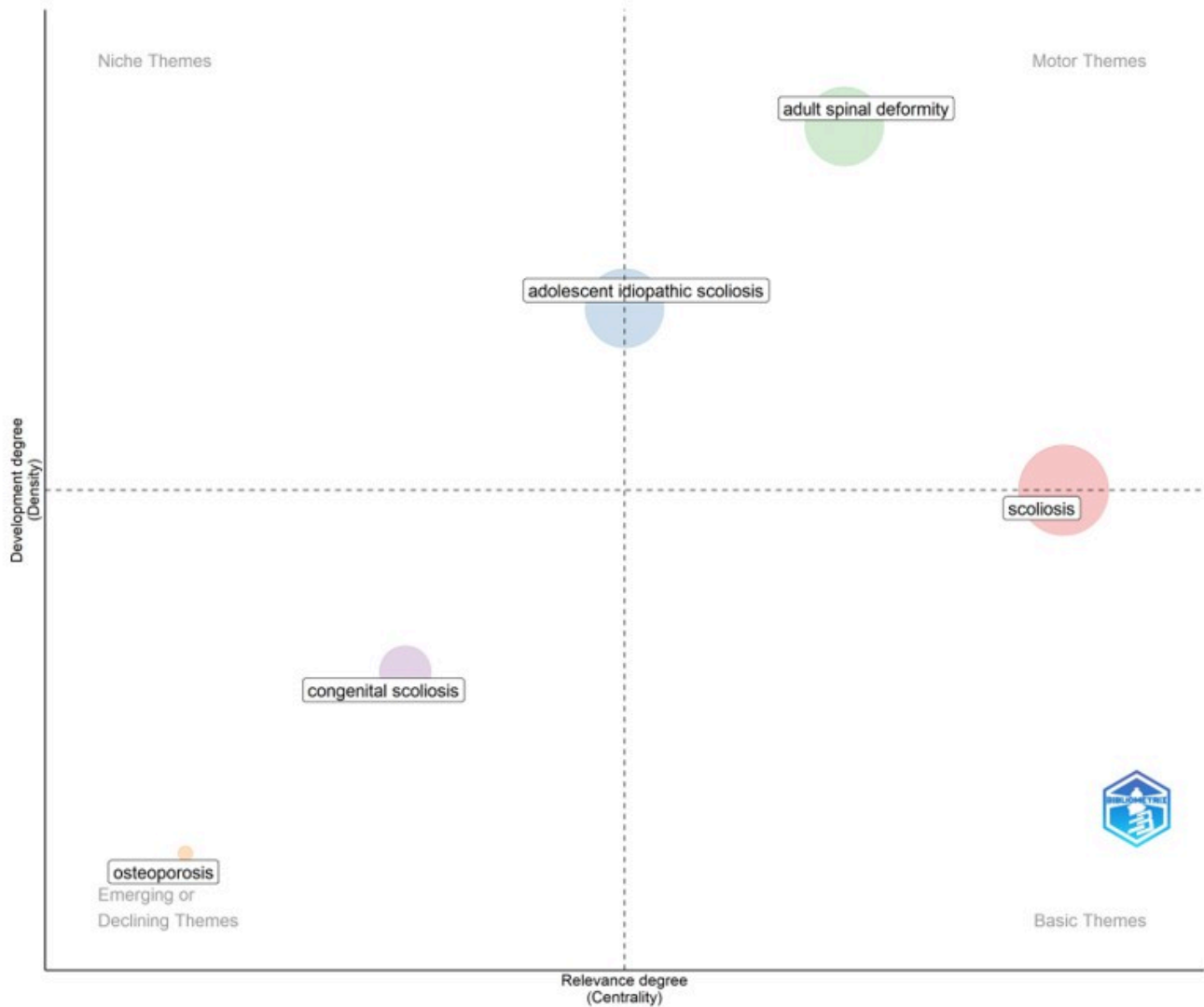


Figure 5

Thematic map of author keywords positioned by centrality (relevance) and density (development), 2010 to 2025. Diagram plotting keyword clusters by centrality (relevance) and density (internal development) across four quadrants. Adult spinal deformity occupies the motor-theme quadrant (high centrality, high density). Adolescent idiopathic scoliosis falls near the niche/motor-theme boundary. Scoliosis anchors the basic-theme quadrant. Congenital scoliosis and osteoporosis fall in the emerging-or-declining quadrant.

Supplementary Files

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