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AIMS AND SCOPE

The primary aim of *World Journal of Diabetes* (*WJD*, *World J Diabetes*) is to provide scholars and readers from various fields of diabetes with a platform to publish high-quality basic and clinical research articles and communicate their research findings online.

WJD mainly publishes articles reporting research results and findings obtained in the field of diabetes and covering a wide range of topics including risk factors for diabetes, diabetes complications, experimental diabetes mellitus, type 1 diabetes mellitus, type 2 diabetes mellitus, gestational diabetes, diabetic angiopathies, diabetic cardiomyopathies, diabetic coma, diabetic ketoacidosis, diabetic nephropathies, diabetic neuropathies, Donohue syndrome, fetal macrosomia, and prediabetic state.

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SCIENTOMETRICS

Global trends and hotspots of type 2 diabetes in children and adolescents: A bibliometric study and visualization analysis

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Abstract

BACKGROUND

Epidemiological surveys indicate an increasing incidence of type 2 diabetes mellitus (T2DM) among children and adolescents worldwide. Due to rapid disease progression, severe long-term cardiorenal complications, a lack of effective treatment strategies, and substantial socioeconomic burdens, it has become an urgent public health issue that requires management and resolution. Adolescent T2DM differs from adult T2DM. Despite a significant increase in our understanding of youth-onset T2DM over the past two decades, the related review and evidence-based content remain limited.

AIM

To visualize the hotspots and trends in pediatric and adolescent T2DM research and to forecast their future research themes.

METHODS

This study utilized the terms "children", "adolescents", and "type 2 diabetes", retrieving relevant articles published between 1983 and 2023 from three citation databases within the Web of Science Core Collection (SCI, SSCI, ESCI). Utilizing CiteSpace and VoSviewer software, we analyze and visually represent the annual output of literature, countries involved, and participating institutions. This allows us to predict trends in this research field. Our analysis encompasses co-cited authors, journal overlays, citation overlays, time-zone views, keyword analysis,

and reference analysis, *etc.*

RESULTS

A total of 9210 articles were included, and the annual publication volume in this field showed a steady growth trend. The United States had the highest number of publications and the highest H-index. The United States also had the most research institutions and the strongest research capacity. The global hot journals were primarily diabetes professional journals but also included journals related to nutrition, endocrinology, and metabolism. Keyword analysis showed that research related to endothelial dysfunction, exposure risk, cardiac metabolic risk, changes in gut microbiota, the impact on comorbidities and outcomes, *etc.*, were emerging keywords. They have maintained their popularity in this field, suggesting that these areas have garnered significant research interest in recent years.

CONCLUSION

Pediatric and adolescent T2DM is increasingly drawing global attention, with genes, behaviors, environmental factors, and multisystemic interventions potentially emerging as future research hot spots.

Key Words: Child; Adolescent; Type 2 diabetes mellitus; Bibliometrics; Knowledge mapping; Visualization; CiteSpace; VOSviewer

Core Tip: A total of 9210 articles were enrolled to explore the development of type 2 diabetes mellitus (T2DM) in children and adolescents from 1983-2023. Based on analysis of the relevant indices, this study determined the development and changes of T2DM in children and adolescents as well as the characteristics of the published papers and the author's origin. Furthermore, we conducted a visualization analysis of keywords and co-cited references. The results showed that genes, behavior, psychology, environment, and integrated diagnosis and treatment of multiple systems may constitute significant areas of future research.

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INTRODUCTION

Diabetes is common, complex, and chronic. This syndrome, characterized by hyperglycemia, is a manifestation of glucose and lipid metabolism disorders, resulting from defects in insulin secretion or insulin action. Symptoms of significantly elevated blood glucose include polyuria, thirst, and weight loss. Sometimes these symptoms are accompanied by polyphagia and blurred vision.

In children, the disease may be associated with growth disorders and susceptibility to certain infections, and severe cases can lead to diabetic ketoacidosis or nonketotic hyperosmolar syndrome. The persistent state of hyperglycemia, a common feature of diabetes, holds the potential to inflict damage on a multitude of organs. Notably, the eyes, kidneys, nerves, heart, and blood vessels are particularly susceptible, a condition that could precipitate organ dysfunction or even failure. This can result in conditions such as vision loss, renal failure, foot ulcers, autonomic neuropathy, and atherosclerosis[1]. Diabetes chiefly comprises type 1 diabetes mellitus, an outcome of autoimmune destruction of β cells typically resulting in absolute insulin deficiency, inclusive of latent autoimmune diabetes in adults. Also included is type 2 diabetes mellitus (T2DM), frequently linked with inadequate β cell insulin secretion amid insulin resistance. Gestational diabetes, a condition diagnosed during the second or third trimester of pregnancy that was not evidently overt diabetes prior to gestation, is another form. Specific types of diabetes due to other causes, such as monogenic diabetes syndromes like neonatal diabetes and maturity-onset diabetes of the young, are also encompassed in this category[2].

T2DM, constituting 90%-95% of all diabetes cases, distinctively characterized by the absence of autoimmune destruction of β-cells. The underlying etiology could potentially be the progressive decline in β-cell insulin secretion against a backdrop of chronic insulin resistance[1]. The Professional Practice Committee of the American Diabetes Association (ADA) has explicitly stated that the traditional paradigm, which considered T2DM to be exclusive to adults and type 1 diabetes to children, is no longer accurate. Both diseases occur across both age groups, and misdiagnoses are common in children and adolescents in clinical settings[2].

The recent clinical guidelines from the ADA state that tests for glycated hemoglobin, fasting plasma glucose, or a 2-hour oral glucose tolerance test can be used to detect prediabetes or T2DM in children and adolescents, similar to adults. Diagnostic criteria include glycated hemoglobin ≥ 6.5% (≥ 48 mmol/mol), fasting plasma glucose ≥ 126 mg/dL (7.0 mmol/L), 2-hour oral glucose tolerance test ≥ 200 mg/dL (11.1 mmol/L), or for patients with typical hyperglycemia or

hyperglycemic crisis symptoms and random blood glucose > 200 mg/dL (11.1 mmol/L). Notably, the guidelines recommend that all adolescents with clinical features of T2DM undergo testing for pancreatic autoantibodies. This test should include GAD65 and IA2 antibodies as well as insulin autoantibodies in individuals not yet exposed to exogenous insulin. Additionally, genetic testing for monogenic diabetes should be conducted to determine the subtype of diabetes in adolescents and to guide treatment plans[3].

According to the 10th edition of the International Diabetes Federation Diabetes Atlas, there are 537 million adults (20-79-years-old) with diabetes in 2021 globally, and this number is expected to rise to 643 million by 2030. Diabetes has caused at least $966 billion in health expenditures, an increase of 316% from 2006 to 2021 and has imposed a significant economic burden on healthcare. The incidence of T2DM has been growing at an astonishing rate in all age groups over the past two decades[4,5]. Diabetes management has become a significant part of national healthcare systems in both developed and developing countries.

From 2002 to 2012, the overall annual growth rate of T2DM in adolescents was 4.8%. In the United States, it is predicted that if the incidence continues to increase, the number of adolescents with T2DM could rise to 30000-84000 by 2050[6]. In other countries, the incidence of T2DM in adolescents is also increasing similarly. For example, a cohort study in Israel showed that the incidence of T2DM in Israeli adolescents increased from 0.63 per 100000 people in 2008 to 3.41 per 100000 people in 2019[7]. Another report in 2021 on T2DM in East Asia estimated that the age-adjusted prevalence of diabetes in China and India was 10.6% and 9.6%, respectively, with 145 million and 74 million people, which accounts for 41% of the global adult diabetes population.

The incidence rate among young people is increasing rapidly[8]. There is evidence that the progression of T2DM in the adolescent population is faster than in adults with β cell function declining by 20%-35% per year[9], and adolescents have stronger insulin resistance than adults[10,11] and a poorer response to hypoglycemic drugs[12]. Despite the fact that our understanding of youth-onset T2DM has greatly increased over the past two decades, reliable and evidence-based data are still limited in terms of diagnosis and treatment methods, prevention of complications, mechanisms and risk factors of adolescent T2DM, the differences between adolescent and adult T2DM, and intervention and prevention strategies for adolescents[3].

Bibliometrics represents a statistical approach, both qualitative and quantitative, to the analysis of research publications. This analytical tool offers an accurate representation of the present status of investigations within specified fields. Its application extends, but is not confined to, the delineation of research topics, the tracking of their evolution, identification of emerging themes, and discernment of publishing trends[13,14]. Comprehensive indexes (such as journals, authors, countries, and institutions) can be used for in-depth evaluation of research trends and focus on specific topics[15,16]. Authors with a high citation count indicate that their scientific achievements have garnered substantial interest from their peers or recognition for their quality[17]. At present, the pathogenesis and intervention strategies of adolescent T2DM are attracting more and more attention from scholars, and the number of related research is also increasing. It is necessary to analyze the content and direction of research on childhood and adolescent T2DM to understand the overall situation, trends, and hotspots of current related research and to predict its future research directions and hotspots.

MATERIALS AND METHODS

Data retrieval strategy

In this study, we used the Science Citation Index Core Collection for bibliometric analysis because it encompasses a large volume of biomedical research and has previously been reported to track older citations and categorize journals more accurately than Scopus[18]. Furthermore, we employed VOSviewer and CiteSpace for bibliometric analysis and related graphic representation. These software tools are capable of visualizing key features, hotspots, and trends in a particular field based on bibliographic information, citation frequency, collaboration strength, and keyword frequency and emergence. Further details on the software used will be provided later in the text.

After multiple rounds of data preprocessing and analysis, the final literature search and collection were completed within 1 day (December 16, 2023), to ensure data accuracy. The main themes focused on "children", "adolescents", and "type 2 diabetes" research. The final search formula was constructed using these terms to form subject words and free words for searching, with the detailed search strategy provided in Supplementary Table 1. We searched three citation databases in the Web of Science (WOS) Core Collection (Science Citation Index Expanded from 1900 to present, Social Sciences Citation Index from 1900 to present, Emerging Sources Citation Index from 2005 to present), with publication dates ranging from inception to December 16, 2023. The primary types of literature selected for this study were articles and reviews. The initial data search was independently conducted by two researchers, Zhang FS and Song YP, who subsequently identified and resolved any potential discrepancies, thereby ensuring the exclusion of such inconsistencies. Ultimately, we analyzed 9210 articles for our study. The detailed screening process is displayed in Figure 1. We also arranged the guidelines related to T2DM in children and adolescents over the years according to the timeline and revision changes. The specific search formula and related Supplementary Tables 1-3 can be found in the Supplementary material.

Literature selection and data extraction

To ensure a visual representation of the global landscape of child and adolescent-related research and to extract hot topics from highly emerged and impactful literature in this field, the literature was filtered according to the following inclusion criteria. The included studies met all the following criteria: (1) The main content focused on related research on children, adolescents, and T2DM; and (2) The study was an article or a review paper. The literature was screened, and the original data were extracted through the core database of the Scientific Network. The information gathered primarily encom-

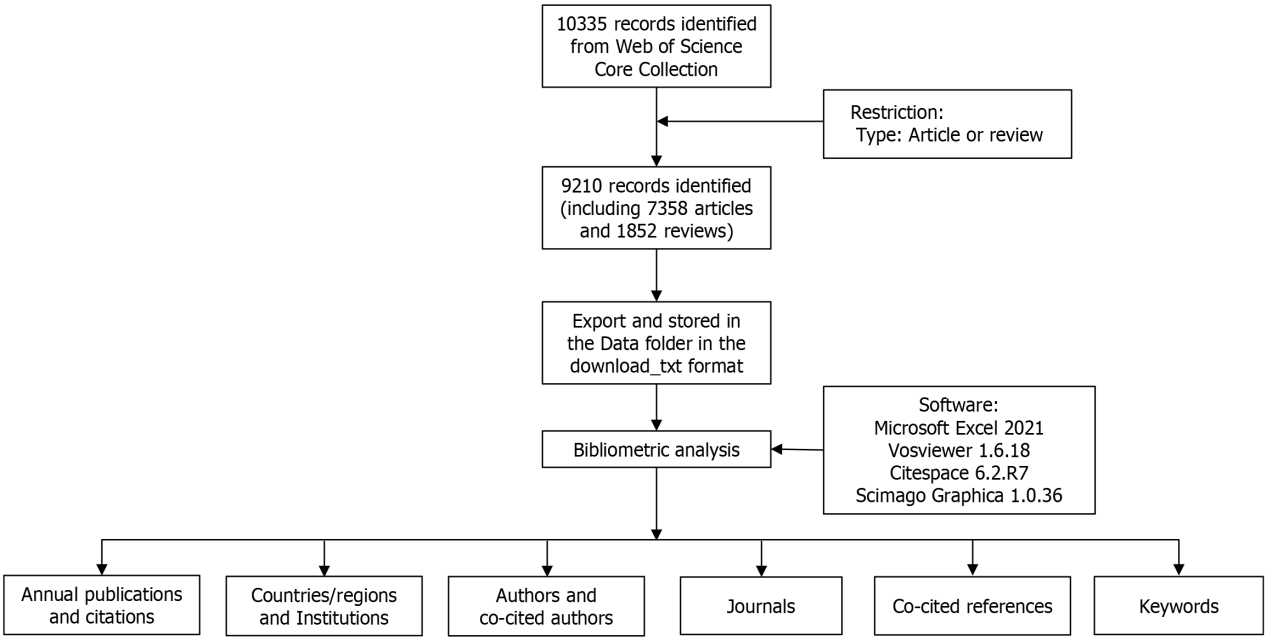


Figure 1 Detailed process for literature screening.

passes the number of publications, year of publication, citation frequency, volume of articles from each country along with H-index, authors of the publications, institutions, journals, keywords, and references.

Bibliometric analysis methods

In the current investigation, an analysis of the literature was performed, and pertinent graphical depictions were produced employing tools such as VOSviewer (version 1.6.18), CiteSpace (version 6.2.R7), Pajek64, Microsoft Excel 2021, and Scimago Graphica (version 1.0.36). Specifically, VOSviewer was utilized for bibliographic coupling, presenting heat maps of national distribution, highly cited literature, and the plotting and analysis of keyword hotspots and cluster distributions. CiteSpace was employed for author, co-cited author, and research strength information characteristics, journal and citation dual map overlay, crucial node literature emergence timeline and time zone view, and visual presentation of emerging keywords. Scimago Graphica was used for the visualization of article distribution on a global map. Pajek64 was applied for the plotting of keyword clusters. Microsoft Excel 2021 was used for the creation of tables and bar charts.

VOSviewer1.6.18 and CiteSpace 6.2.5 were used for statistical analysis of literature extraction and visualization of scientific knowledge, including a comprehensive bibliographic coupling analysis of journals, an exhaustive co-occurrence examination of all keywords, and a thorough co-citation analysis of journals cited in references[19,20].

CiteSpace is a JAVA-based citation visualization software that provides an experimental platform for researching new theories and comparing existing methods. Due to its rich functionality, it has become an effective method for analyzing big data today[21]. It is primarily employed for the visual representation and forecast of the latest research trends in the field. It encompasses a diverse range of features, including the identification of key authors and co-cited authors, journal statistics and dual-map overlays of citations, a chronological review of keywords and citations, as well as an analysis of the emergence intensity of keywords and citations[21]. In this study, we employed CiteSpace software to analyze the temporal and emergent strength of authorship and citation information, high-impact research institutions, core journals of popularity, cited references, and high-frequency keywords[22,23]. In the visualized image, the size of the nodes signifies the quantity of literature or the frequency of keyword occurrences. The relationships between the nodes, such as coexistence, co-occurrence, or co-citation, are represented by their connections[23,24]. The purple outer ring of the nodes represents centrality, with a wider purple ring indicating higher centrality. Nodes of significant importance, characterized by a centrality greater than 0.1, are prominently highlighted with a purple ring[25].

In this study, we also conducted a cluster analysis on the reference citations and summarized the top 10 papers with the highest citation frequency and outbreak intensity. The co-citation clusters of references were generated using a log-likelihood ratio (LLR) approach[22,24]. In terms of keyword analysis, we collated the top ten most frequently occurring keywords and the fifty keywords with the highest emergence intensity.

RESULTS

Annual quantitative analysis of publications

A comprehensive search yielded a total of 9210 scholarly outputs, encompassing 7358 articles and 1852 reviews. As per the records in the WOS database, these identified articles collectively received 254565 non-self-citations, averaging 43.57 citations per article. The combined H-index for all these publications stood at 247. Figure 2 shows the annual number of

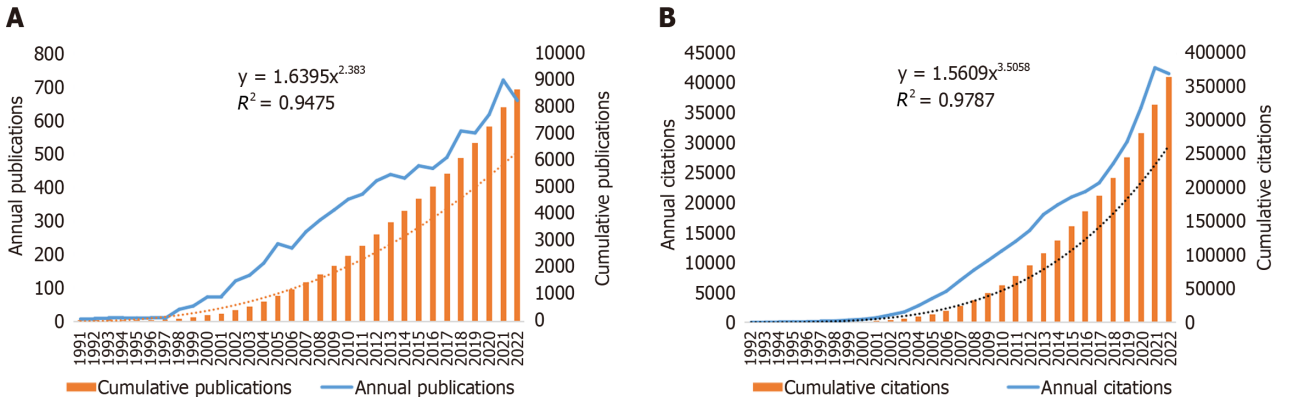


Figure 2 Articles related to the study of type 2 diabetes mellitus in children and adolescents. A: Annual number of publications; B: Annual number of citations.

published articles and the annual number of co-citations related to childhood and adolescent T2DM research (data for 2023 was not included due to incomplete year and data lag, affecting overall curve fitting and trend judgement).

Since the 1983 report by Lovrencic *et al*[26] on the phagocytic activity of diabetic children, the annual number of research articles on childhood and adolescent T2DM has fluctuated slightly, but overall it has shown an upward trend with a peak in the past decade. Based on the ascending trend of publication volume and research advancements, we can categorize this into four temporal stages: The rise (1991-2001); the first outbreak (2001-2005); fluctuating rise (2006-2016); and the second outbreak (2017-2022). There were no relevant articles between 1983 and 1991. Therefore, these years were not shown in the figure to display the overall growth trend. The steady increase in the patient population, the continuous investment in investigative research by various countries, the breakthroughs and applications of advanced technologies or theories, and the continuous deepening of interdisciplinary research may be key factors influencing the growth of articles in each period. We analyzed and reported the characteristics and causes of each stage in the subsequent discussion section.

The function fitting curves of the annual growth trends in publication volume, as shown in the data (R^2 = 0.9475), significantly correlate with the year of publication. This suggests a continuous increase in research input and growing attention in this field. Overall, after nearly 40 years of development, research in this field has gradually matured. Simultaneously, the annual citation frequency exhibits a smooth upward curve, indicating a significant correlation with the year of publication (R^2 = 0.9787). This suggests that the attention and importance accorded to research in related fields are steadily increasing. Particularly, there has been a notable surge in citations from 2017 to the present, indicating an explosive growth in interest.

Based on the content of the WOS database, the top 15 research directions in this field are endocrine metabolism (3600), pediatrics (1360), general internal medicine (867), nutrition (857), public environmental occupational health (671), experimental medicine (351), cardiovascular system cardiology (297), pharmacology (295), other topics in science and technology (273), biochemistry (230), genetics (196), obstetrics and gynecology (188), psychology (153), neuroscience (144), and psychiatry (143), showing the interdisciplinary collaboration in the research on childhood and adolescent T2DM.

National and regional distribution

In the past four decades of research on T2DM in children and adolescents, articles related to this field have been published in 137 countries, as shown in Figure 3A and Table 1. Among all the countries, the United States has published the most articles (3669), followed by the United Kingdom (1008) and China (705). The time zone map (Figure 3B) revealed that publication distribution data over the past decade indicates a shift in the field from a pattern dominated by developed countries, predominantly the United States and the United Kingdom, towards a model of multipoint collaboration involving developing countries such as China and Iran, along with a host of other nations.

In terms of collaboration intensity (Figure 3C and D), the total connection strength of the United States was the highest (1775), indicating its frequent collaboration with other countries in conducting research in this field., followed by the United Kingdom (1373) and Germany (820). In terms of total citations (Figure 3E), articles from the United States were cited the most (213955), followed by those from the United Kingdom (79435) and Australia (31856). In recent years, there has been a growing reliance on the H-index as a tool for assessing scholarly contributions and forecasting future scientific accomplishments[27,28]. The United States had the highest H-index (205), followed by the United Kingdom (136), and then Australia (80) (Figure 3F). Collectively, the United States, Europe, and Asia emerge as the principal countries and regions contributing to the publication of articles. Notably, the United States and the United Kingdom stand at the forefront in this particular field of research.

Authors and co-cited authors

Since the first paper on pediatric and adolescent T2DM was published in 1983[26], 1240 authors have conducted related research. A visualization analysis of the authors was carried out using CiteSpace, where each node represents an author, with larger nodes indicating a higher number of publications. The links between nodes represented collaborations between authors, with thicker lines indicating closer collaborations. The map (Figure 4A) showed 1240 nodes and 2246

Table 1 Top ten countries with the highest number of published studies on type 2 diabetes mellitus in children and adolescents

Rank	Country	Publications	Total citations	Average citation	H-index	Total link strength
1	United States	3669	213955	58.3143	205	1775
2	United Kingdom	1008	79435	78.8046	136	1373
3	China	705	20189	28.6369	62	457
4	Canada	543	27089	49.8877	76	530
5	Australia	528	31856	60.3333	80	692
6	Germany	497	22072	44.4105	76	820
7	Italy	469	20230	43.1343	67	635
8	India	320	16025	50.0781	53	240
9	Spain	294	11425	38.8605	51	670
10	Sweden	284	13807	48.6162	60	539

edges, with a network density of 0.0029. Dabelea D (115) had the most publications (Table 2 and Figure 4B), followed by Lawrence JM (76), Nadeau KJ (69), Dolan LM (58), and Bacha F (57).

Co-citation of authors refers to the phenomenon where two or more authors are simultaneously cited by at least one article. The higher the frequency of co-citation between two authors, the closer their academic relationship and research direction are likely to be. Excluding institutional group authors and anonymous authors, Figure 4C shows the network of co-cited authors displayed intuitively by CiteSpace. The citation counts of the top 10 co-cited authors exceeded 450 (Table 3, Figure 4D). Among the top 10 co-cited authors, Dabelea D (1186) ranked first, followed by Ogden CL (773), Weiss R (632), Matthews DR (626), and Reeves ND (538). This implies that these authors have significant research influence and play a bridging role in this field. From a comprehensive survey of the volume of publications, citations, and the intensity of emerging trends, it is evident that core authors such as Dabelea D have enriched the international scientific knowledge base on pediatric and adolescent T2DM. Their robust evidence supports and supplements the fundamental mechanisms, disease course characteristics, and treatment plans for this condition. Their work provides a solid foundation and reliable evidence for a large number of researchers to further their studies and implement clinical treatments.

Active institutions

We conducted an institutional symbiotic network analysis using CiteSpace to identify relatively mature organizations or institutions involved in the research. Table 4 lists the top 10 institutions in terms of the number of publications and centrality rankings in the field of T2DM research in children and adolescents. In the visual graph (Figure 5), nodes represent the institutions with their size corresponding to the number of articles published; the larger the node, the greater the number of publications. Connections between nodes indicate collaborations between institutions, and the thickness of the line signifies the strength of the collaboration; the thicker the line, the stronger the collaboration.

The University of Colorado System (403) led in the number of publications, followed by the University of Colorado Anschutz Medical Campus (353) and Harvard University (352). The top three institutions in terms of centrality rankings were Case Western Reserve University (0.48), George Washington University (0.34), and Howard Hughes Medical Institute (0.29). As shown in the figure, the thicker lines between the key nodes representing each institution indicate relatively close collaboration between these institutions. The research collaboration of the University of Colorado and its associated hospitals has resulted in a substantial number of publications in this field. However, the collaborative strength among higher education institutions and organizations in the United States, represented by Case Western Reserve University, Harvard University, and George Washington University, is even more solid, providing a powerful joint research force. In addition, in Europe, collaborative networks have been formed, which are represented by Queen Mary University and the European collaboration network represented by Karolinska Institutet.

Journals

Analysis of the sources of the included literature indicated that *Diabetes Care* (351) was the journal with the most articles published in this field, followed by *Pediatric Diabetes* (293) and *Journal of Clinical Endocrinology & Metabolism* (213) (Table 5 and Figure 6A). The majority of the top 10 journals with the most publications had a Journal Citation Report division of Q1 or Q2 (only one was Q4), suggesting that the quality of the publications included is fundamentally reliable, and the impact and representativeness of the related research findings are robust.

In Figure 6B, co-citation analysis of the journals shows that *Diabetes Care* (28311) was the most frequently cited journal, followed by *Journal of Clinical Endocrinology & Metabolism* (13795) and *The Lancet* (13383). *The American Journal of Clinical Nutrition* (0.65) had the highest centrality, followed by *Diabetes* (0.59) and *The American Journal of Medicine* (0.56), indicating that these journals have a higher influence in this field (Table 5). Journals such as *Diabetes Care*, which is pivotal in the field of diabetes, have published a plethora of significant research on the fundamentals and clinical aspects of diabetes in the past, establishing their formidable influence in this discipline. They are the preferred references for clinical

Table 2 Top 10 authors with the most publications on type 2 diabetes mellitus in children and adolescents

Rank	Author	Institutions	Publications
1	Dana Dabelea	Colorado School of Public Health	115
2	Jean M Lawrence	NIH National Institute of Diabetes & Digestive & Kidney Diseases	76
3	Kristen J Nadeau	University of Colorado Anschutz Medical Campus	69
4	Lawrence M Dolan	University of Cincinnati	58
5	Fida Bacha	Baylor College of Medicine	57
6	Sonia Caprio	Baylor College of Medicine	56
7	Elizabeth J Mayer-Davis	Centers for Disease Control & Prevention – United States	56
8	Giuseppina Imperatore	Centers for Disease Control & Prevention - United States	54
9	Catherine Pihoker	University of Washington	53
10	Silva Arslanian	University of Pittsburgh	47

Table 3 Top 10 most commonly co-cited authors in the field of type 2 diabetes mellitus in children and adolescents

Rank	Author	Institutions	Count
1	Dabelea D	Colorado School of Public Health	1186
2	Ogden CL	George Washington University	733
3	Weiss R	Rambam Health Care Campus	632
4	Matthews DR	University of Oxford	626
5	Zeitler P	University of Colorado Anschutz Medical Campus	538
6	Reinehr Thomas	Witten Herdecke University	516
7	Knowler WC	George Washington University	514
8	Barker DJP	Dep Hort & Crop Sci	497
9	Mayer-Davis EJ	Centers for Disease Control & Prevention – United States	491
10	Cole TJ	University College London	489

Table 4 Top ten institutions in terms of number of publications and centrality ranking in the field of type 2 diabetes mellitus research in children and adolescents

Rank	Institutions	Count	Rank	Institutions	Centrality
1	University of Colorado System	403	1	Case Western Reserve University	0.48
2	University of Colorado Anschutz Medical Campus	353	2	George Washington University	0.34
3	Harvard University	352	3	Howard Hughes Medical Institute	0.29
4	University of California System	293	4	University of California San Diego	0.27
5	Pennsylvania Commonwealth System of Higher Education	271	5	Yale University	0.25
6	University of Pittsburgh	231	6	Queen Mary University London	0.24
7	Cincinnati Children's Hospital Medical Center	231	7	Harvard University	0.22
8	University System of Ohio	230	8	Assistance Publique Hopitaux Paris	0.2
9	National Institutes of Health – United States	230	9	Erasmus University Rotterdam - Excl Erasmus MC	0.2
10	University of London	206	10	Northwestern University	0.19

Table 5 Top 10 most commonly cited journals in the field of type 2 diabetes mellitus in children and adolescents

Rank	Journal	Count	JCR Partitions	Rank	Journal	Centrality	JCR Partitions
1	*Diabetes Care*	351	Q1	1	*The American Journal of Clinical Nutrition*	0.65	Q1
2	*Pediatric Diabetes*	293	Q1	2	*Diabetes*	0.59	Q1
3	*Journal of Clinical Endocrinology & Metabolism*	213	Q1	3	*American Journal of Medicine*	0.56	Q1
4	*Journal of Pediatric Endocrinology & Metabolism*	166	Q4	4	*Lancet*	0.5	Q1
5	*Diabetologia*	155	Q1	5	*Journal of the American Dietetic Association*	0.46	Q1
6	*PLoS One*	144	Q2	6	*New England Journal of Medicine*	0.41	Q1
7	*Diabetic Medicine*	134	Q2	7	*Preventive Medicine*	0.28	Q1
8	*Nutrients*	112	Q1	8	*American Journal of Physiology-Cell Physiology*	0.23	Q1
9	*Diabetes Research and Clinical Practice*	111	Q2	9	*Annals of Internal Medicine*	0.22	Q1
10	*Current Diabetes Reports*	105	Q2	10	*American Journal of Obstetrics and Gynecology*	0.21	Q1

JCR: Journal Citation Reports.

practitioners, and the preferred outlet for authors worldwide to submit their important research findings for academic recognition and understanding.

The dual map of CiteSpace can reflect the development of different disciplinary research. As depicted in Figure 6C, the left side represents the citing articles while the right side illustrates the cited articles. The colored curved paths in the middle signify the citation relationships among articles from diverse fields. Yellow, green, or blue citation paths indicate that molecular/biological/immunological, medical/clinical, and psychological/educational/sociological research is often cited by health, nursing, and genetics journals. Meanwhile, the peripheral areas of the overlay map showed veterinary/animal/science, systems/computing/computer, and environmental/toxicology/nutrition also contributed to the research in this field. This indicates the continuous deepening of interdisciplinary collaborative research in this field.

Co-citations of references

The interrelatedness and relevance among references can be discerned through their co-citations. Utilizing VOSviewer, we have organized the five most frequently co-cited references within this field (Figure 7A and B, Table 6). Among them, the five articles with the most citations are cited by the author Matthews *et al*[29]; Zeitler *et al*[12]; Knowler *et al*[30]; Sinha *et al*[31] and Cole *et al*[32] in sequence. The most frequently cited paper was authored by Matthews *et al*[29] and evaluated the ability of a computer steady-state model to assess the effects of insulin resistance and β cell functional defects on fasting hyperglycemia. They determined its clinical predictive utility.

We employed CiteSpace for further analysis of co-cited references, with parameters set as follows: Time slices (1983-2023); number of slices per year (1); node type (cited references); selection criteria (k = 25); and pathfinder pruning. Anonymous author nodes were deleted. The results, as shown in Figure 7C, yielded a symbiotic network with 2184 nodes, 4666 connections, and a density of 0.002. We then performed cluster analysis of the cited references based on the LLR, with the top 13 clusters shown in Figure 7D and E. The cluster modularity Q = 0.8103 and the average silhouette score S = 0.9107 indicated reasonable clustering and significant cluster structure. The numerical value assigned to each cluster signifies the degree of attention that the specific topic garners within the discipline. A lower cluster value denotes a heightened level of attention.

These clusters mainly focused on four aspects: (1) The conceptual typing of T2DM in children and adolescents, including: {0} youth-onset type, {1} metabolic syndrome, {3} diabetes mellitus, {12} pediatric diabetologists, and {14} epidemiological definition; (2) The related risk factors of T2DM in children and adolescents, including: {2} obese youth, {4} weight loss surgery, {6} fat mass, {7} gestational age, {8} sugary-sweetened beverage, {9} gestational diabetes mellitus, {10} gestational diabetes, {17} hypertension, and {18} health; (3) The widely concerned diseases related to adolescent T2DM, including: {5} cardiovascular risk, {11} coronavirus disease 2019 (COVID-19) pandemic, {13} polycystic ovary syndrome, and {19} macrovascular complications; and (4) The related drug research of adolescent T2DM, including: {15} atypical antipsychotics and {16} vitamin D parathormone.

The emergence of cited references often signifies the advent of new research topics and shifts in research focus within a field. We have employed CiteSpace to filter the 25 most citation-bursting references (minimum duration = 2, γ = 1) to aid in our interpretation and prediction of the evolution of this field (Figure 7F).

Table 6 Top five most-cited references in literature related to type 2 diabetes mellitus in children and adolescents

Rank	First author	Journal	Year	Citations	TLS
1	Matthews DR	*Diabetologia*	1985	575	5056
2	Zeitler P	*The New England Journal of Medicine*	2012	396	6525
3	Knowler WC	*The New England Journal of Medicine*	2002	393	5296
4	Sinha R	*The New England Journal of Medicine*	2002	354	6324
5	Cole TJ	*British Medical Journal*	2000	341	3720

The five most-cited articles are taken from references[12,29-32]. TLS: Total link strength.

The strongest citation burst was a 2017 paper (91.19)[33]. The study reported a significant increase in the incidence of type 1 diabetes and T2DM among youths during 2002-2012, especially among minority and ethnic minority youths.

Keyword analysis

The co-occurrence network of keywords illuminates the hot research topics in this field and their evolution over time. In this study, we employed VOSviewer software for keyword extraction and analysis, resulting in the identification of 1001 hot topic words with a frequency of occurrence greater than 10. Table 7 and Figure 8A display the top 10 ranked keywords and the network diagram, respectively. Further clustering analysis of the keywords (Figure 8B and C) yielded seven clusters, representing six research directions and fields. The largest cluster, cluster 1 (red), contained 252 keywords, including obesity, insulin resistance, glucose tolerance, weight, development, adipose tissue, metabolism, oxidative stress, and others. The second largest, cluster 2 (green), contained 205 keywords, including adolescents, prevalence, T2DM, childhood obesity, prevention, health, nutrition, exercise, diet, lifestyle, and others. This was followed by cluster 3 (blue) with 136 keywords, cluster 4 (yellow) with 132 keywords, cluster 5 (purple) with 125 keywords, cluster 6 (cyan) with 125 keywords, and cluster 7 (orange) with 25 keywords, each with their respective keyword content.

Clusters 1 and 3 primarily reflected the pathophysiology of T2DM in children and adolescents. Cluster 2 primarily reflected the main risk factors and management strategies for T2DM in children and adolescents. Cluster 4 primarily reflected epidemiological and genetic research on diabetes within the population of children and adolescents. Cluster 5 primarily reflected the main topics of T2DM in the cardiovascular field in children and adolescents. Cluster 6 primarily reflected hotspot keywords in the clinical treatment of T2DM in children and adolescents. Cluster 7 primarily reflected comorbidities related to T2DM in children and adolescents.

Utilizing CiteSpace, we have devised a visual representation of the keyword network, yielding a map comprising 701 nodes, 1099 links, and a density of 0.0045. Subsequently, we have identified and organized the 50 most frequently mentioned keywords through keyword emergence (Figure 8D and E). The blue line serves as a timeline, with the red segments denoting the periods of keyword surges. The figure shows that before 2000, a large number of emerging keywords were related to the epidemiology, risk factors, and physiological pathogenic mechanisms of diabetes in children and adolescents. After 2000, the focus began to shift towards the comprehensive impact of diabetes on the organ systems and functions of adolescent populations, the interaction between genetics and environment, and the specific impact and outcome on comorbidities and related organ systems.

In recent years, research related to endothelial dysfunction in the pathogenesis of diabetic vascular complications, the impact of prenatal exposure on T2DM in adolescents, cardiac metabolic risk and changes in gut microbiota in the adolescent T2DM population, and the impact and outcomes on comorbidities have been emerging keywords maintaining prevalence in this field (Figure 8E). This indicates that these areas are recent research hotspots and implies future research directions.

Review of guidelines related to pediatric and adolescent T2DM

The release and revision of international standard guidelines often reflect the updated knowledge of researchers of a particular disease globally. We used "guideline" and "diabetes" as search terms to search the WOS and PubMed databases, and compiled the unique entries in the guidelines over the years for the prevention and treatment of diabetes in children and adolescents.

We found that around the turn of the century (approximately 2000 CE), screening and specific diagnosis and treatment for diabetes in children and adolescents have been included in major guideline recommendations gradually. Guidelines for specialized diagnosis and treatment of adolescent diabetes, standards for social support organizations, *etc.*, have also been introduced. In the past decade, the discussion in the guidelines on T2DM in children and adolescents has been expanded significantly, with new recommendations proposed in many areas, including screening and diagnosis, lifestyle management, medication management, and care transition to adult providers. New recommendations have also been added for blood glucose targets, metabolic surgery, kidney disease, neuropathy, and socio-psychological factors. However, due to the great difficulty of conducting surveys and research among children and adolescents in general, a large number of clinical treatments available to these populations have yet to be supported by high-quality evidence. The revised entries of the guidelines highlight the urgency of obtaining solid and sufficient evidence of the efficacy of new or adult-established treatments in children, the environmental and psychological factors in the growth process of children

Table 7 Top 10 Keywords in the field of type 2 diabetes mellitus in children and adolescents by frequency of appearance

Rank	Keywords	Occurrences	TLS
1	Children	2859	23174
2	Obesity	2489	21968
3	Adolescents	1952	16891
4	Prevalence	1505	13030
5	Insulin-resistance	1465	12960
6	Mellitus	1296	10322
7	Type 2 diabetes	1275	11416
8	Metabolic syndrome	1242	11545
9	Risk	1173	9567
10	Body-mass index	870	7903

TLS: Total link strength.

and adolescents, and the necessary screening and diagnosis methods for children's diabetes. The release dates, issuing organizations, and main content or updated content related to children and adolescents in the 30 guidelines mentioned above are provided in the Supplementary material.

DISCUSSION

International research trends in childhood and adolescent T2DM are moving towards genes, behavior, environment, and multisystem integrated interventions. This study provided an overview of the direction of research related to childhood and adolescent T2DM from 1983 to 2023, with a total of 9210 articles and reviews included. Based on the ascending trend of publication volume and research advancements, we can categorize this into four temporal stages: The rise period (1991-2000); the first outbreak period (2001-2005); the fluctuating rise period (2006-2016); and the second outbreak period (2017-2023).

In the 1980s and earlier, T2DM was still widely considered an adult disease, as it was rare in the pediatric population. From 1991 to 2001 (the rise period), a large number of researchers from around the world, led by the United States and the United Kingdom, reported on the increasing incidence of T2DM in children and adolescents based on the results of clinical epidemiological surveys[34-37]. It was stated that this increase was becoming an unignorable public health problem that urgently needed to be managed and solved[38-41]. In this decade, researchers focused on risk factors for childhood and adolescent T2DM that included overweight/obesity[42,43], blood pressure/lipid abnormalities[44,45], poor diet/lifestyle[46], infant and young child growth and development abnormalities[47-49], and maternal obesity/hyperglycemia[48,50]. They emphasized the comprehensive impact of the gene-nutrition interaction on childhood diabetes. Glucokinase (*MODY2*), hepatocyte nuclear factor-1α (*HNF-1a* or *MODY3*), *HNF-4a* (*MODY1*), insulin promoter factor 1 (*MODY4*), and *HNF-1β* (*MODY5*) gene mutations[51], genetic programmed defects of β cell function[52,53] leading to glucose and lipid metabolism disorders[54] were proposed as important mechanisms for the occurrence and development of childhood T2DM at this stage. Published articles advocated for improving lifestyle factors[55], increasing exercise[56], and prescribing the necessary medications[57-59].

From 2001-2005, the attention and research on childhood and adolescent T2DM began to spread globally, with 63 countries participating in the research and publishing articles in the field (nearly double the 37 countries in the previous period). More than 15 countries published more than 10 research papers or reports in these 5 years. The depth and breadth of the content of related epidemiological surveys were further enriched[60], and topics such as adolescent racial factors[61-62], birth environment[63-65], and lifestyle[66] were mentioned multiple times in addition to obesity. Notably, Raubenheimer[67] reported that offspring with insulin resistance in T2DM patients have impaired mitochondrial activity. A large number of studies systematically reviewed and summarized health management issues for the child and adolescent population[68,69], including weight control[70], nutrition structure[70,71], and exercise design[72]. In addition, various prevention management and treatment methods for T2DM in this population began to emerge. Topics included target exploration and drug use[73-77], weight loss surgery[78], and dietary structure adjustment[70].

From 2006-2016, the attention and research on childhood and adolescent T2DM maintained a relatively even and steady growth rate, with occasional growth fluctuations. During this period, the understanding and management of childhood and adolescent T2DM began to mature and stabilize. According to WOS data, the top 10 disciplines included endocrinology and metabolism (1582), pediatrics (647), nutrition (389), general internal medicine (361), public environmental occupational health (302), cardiovascular system cardiology (162), research papers experimental medicine (150), pharmacology (132), obstetrics and gynecology (116), and science and technology and other topics (114). It can be seen that the cross-disciplinary cooperation in research on childhood and adolescent T2DM began to form.

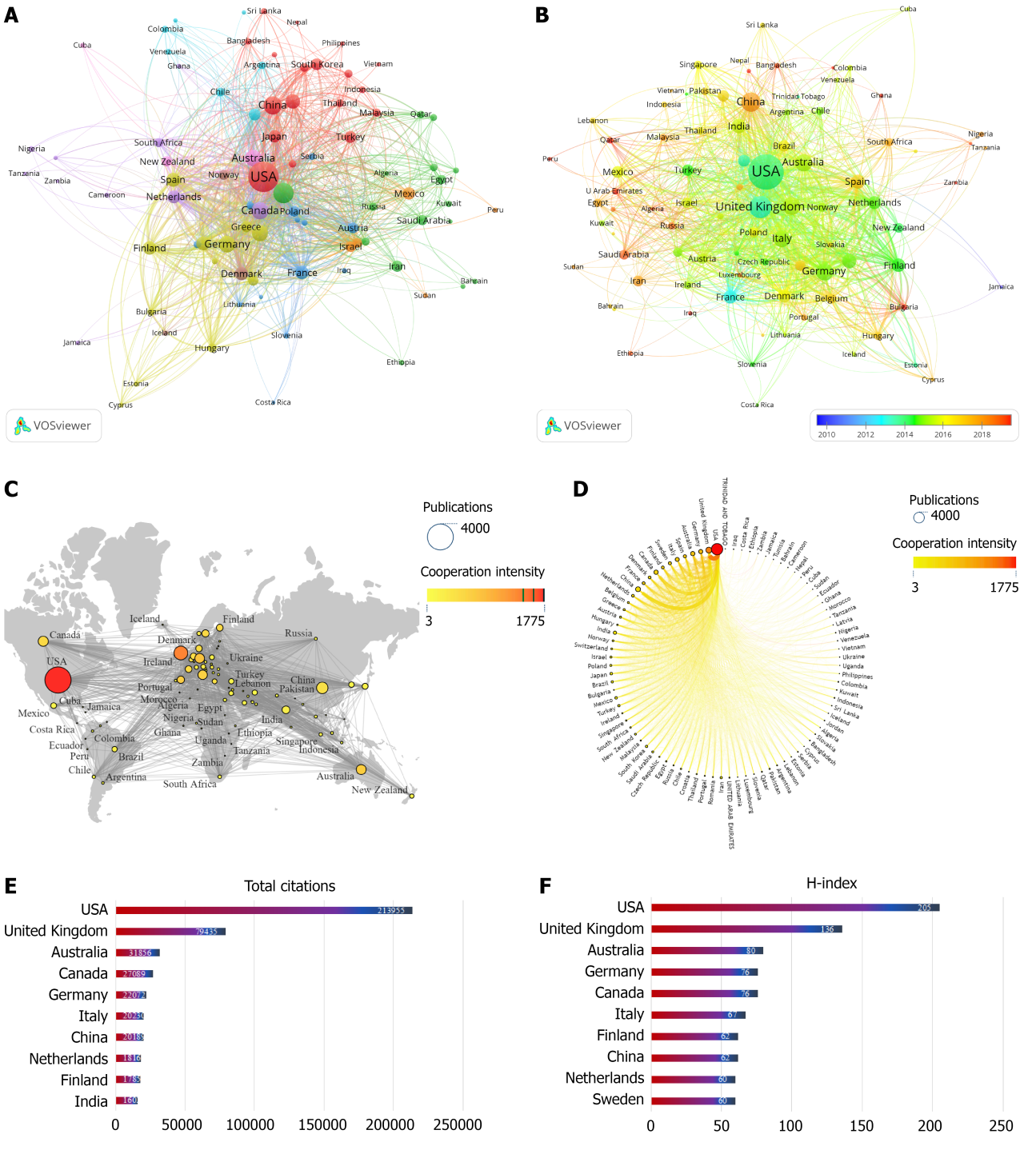


Figure 3 Contribution of different countries to the study of type 2 diabetes mellitus in children and adolescents. A: Map of country collaborations related to type 2 diabetes mellitus in children and adolescents. The circles in the graph represent countries and the lines between the circles represent collaborations between countries; B: Timeline of national policy issuance; C: World map of the intensity of cooperation between countries; D: A circle diagram that evaluates international collaboration between clusters; E: Top 10 in terms of co-citation frequency; F: Top 10 countries for H-index.

The risk factors for adolescent T2DM are innate genetic inheritance[79,80], multisystem functional changes[81-83], and behavioral environmental factors[84-87] and their interactions[88]. The physiological pathological development process was explored in multiple pathways and targets[85,89-91]. The related theories and methods for its prevention and management were more systematic and perfect in the cross-disciplinary contribution[92-98]. In this period, a large number of researchers focused on the impact of breastfeeding, sugary drinks, sedentary behavior, and physical activity on childhood and adolescent T2DM[80,84,86,87,92].

Genetic inheritance was a focus of researchers, which specifically included the *FTO* gene IRX3 target, the *KCNJ11* gene E23K variant, and genome-wide association studies[79,91,99,100]. Puberty-induced insulin resistance, interleukin-1[89] and vitamin D levels[96,101], adipocyte number and differentiation[102-104], gut microbiota[105], and mitochondrial function[83] were newly proposed pathological mechanisms and quickly gained attention. In addition, cardiovascular diseases[81], liver changes[82], diabetic nephropathy[97], and depression[106,107] were indicated as comorbidities. A

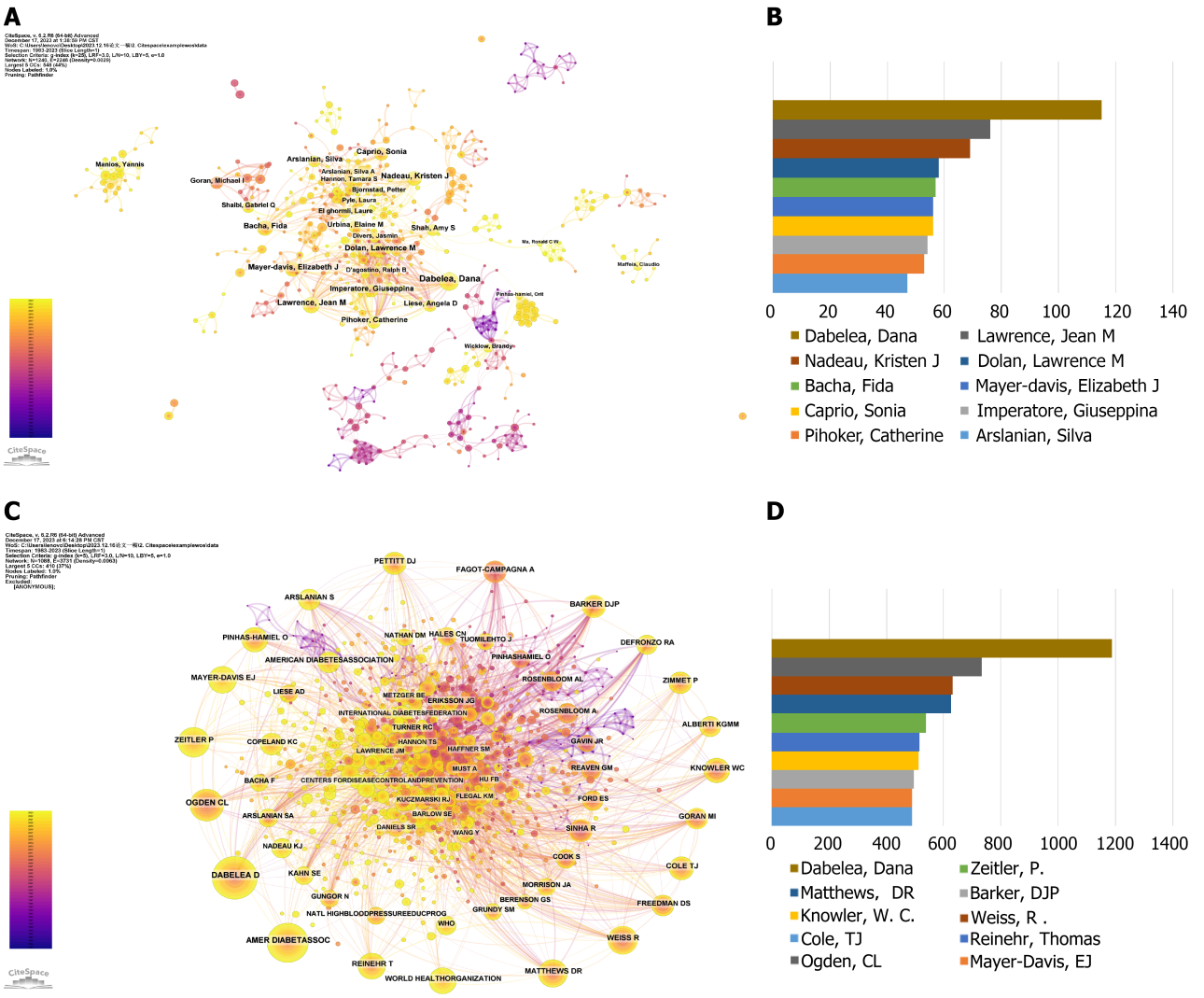


Figure 4 Authors involved in the study of type 2 diabetes mellitus in children and adolescents. A: Co-occurrence of authors; B: Top 10 authors in terms of number of publications; C: CiteSpace visualization of co-cited authors. The outer circle is the key cited author with more than 400 articles, the middle 300-400, and the inner circle less than 300; D: Top 10 authors in terms of co-citations. The size of the circles in the diagram represents the number of articles posted by authors; the connecting lines represent communication and interaction between authors.

large number of studies still recommended physical activity and fitness[80,93,98], diet structure adjustment[105,108], and necessary drug or weight loss surgery interventions[109,110] (such as metformin plus rosiglitazone, insulin, *etc.*) for the treatment of this population.

In recent years, research on childhood and adolescent T2DM has entered a new outbreak period (2017-2023), and the citation frequency of related publications has significantly exploded. Due to advances in research methods and technology, a large number of high-quality evidence-based medical designs[111-115] and large-scale clinical epidemiological reports[33,116-118] have emerged. The different symptom characteristics and responses to intervention of adults and adolescents with T2DM are increasingly being valued[119]. At the same time, retrospective reviews based on past theories and methods[120-123], research on the latest physiological pathological mechanisms[124-126], and new intervention methods for childhood and adolescent diabetes[127-129] are also increasing. Interestingly, the proportion of review publications from 2017-2023 was 25% (n = 1001) compared to 17% (n = 721) in the 11 years prior.

In addition to metformin and insulin, which are standard drugs in the guidelines, other drugs have also been approved for the treatment of T2DM in young people, such as liraglutide[130], exenatide[131], and dapagliflozin[132-134]. In the latest mechanism research, the association between DNA methylation and the serum metabolome[135], the role of the microbiome[136], serum free fatty acids and muscle mitochondrial dysfunction[126], the adipose tissue expansion hypothesis[137], ectopic fat accumulation and adipose inflammation[138], psychological adversity affecting cardiac metabolism[122], sleep deprivation[139], and other contents have been proposed. Psychological behavioral intervention [128,140,141], surgical intervention[142-144], omics treatment[145], and anakinra therapy[146] have been evaluated for prevention and intervention. Due to the COVID-19 pandemic, the interaction and outcome of adolescent T2DM and COVID-19 has emerged[147-149].

Particularly, the differences in hotspots of T2DM research from different periods can better reflect the potential development trends and research tasks in this field. The period from 1991 (initial rise) to approximately 2005 (the first outbreak period), prompted by the initial proposal of the global prevalence of T2DM, showed that researchers focused on

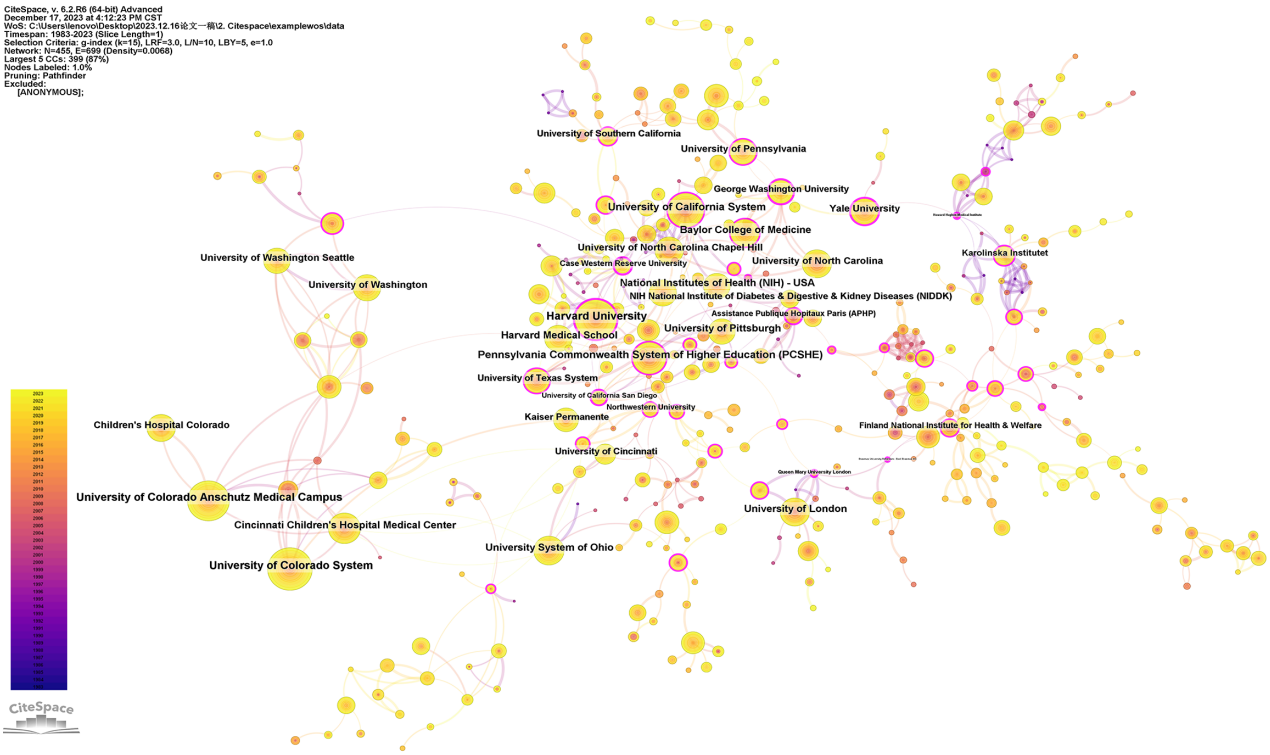


Figure 5 Visualization of institutions conducting research related to type 2 diabetes mellitus in children and adolescents.

the characteristic analysis of the adolescent T2DM population[36,38] (*e.g.*, race, environment, obesity, *etc.*, as well as the derived lifestyle intervention methods[55,71]) to explain the prevalent reasons for adolescent T2DM and try to prevent and manage T2DM by changing acquired behavioral habits. In this period, the screening for adolescent T2DM also gradually improved[46]. As shown in Figure 7F, several diabetes-related epidemiological survey articles emerged in this period, such as those reporting on the prevalence of overweight and obesity in the United States and significantly obese children[150] and on the prevalence of impaired glucose tolerance in adolescents[31], *etc.* As shown in Figure 8E, the emerging keywords in this period include "family history", "Indians", "birth weight", "nutritional survey", among others. During the fluctuating rise period (2006-2016 CE), after more in-depth surveys of the disease population characteristics and the formation of a screening system, when a large number of children had received management and treatment, researchers had begun to notice the unique challenges of managing adolescent T2DM compared to those of adults[151]; for example, some of the lines of inquiry that arose were how to control the continuously rising incidence, how to manage the faster development of adolescent T2DM, and how to make diagnosis and treatment more accurate and efficient. Researchers began to form consensus guidelines for targeted prevention and management in conjunction with multiple disciplines[3]. Therefore, the deep mechanisms of disease occurrence and development, specific prevention and management methods, and control of complications became topics of greater concern in this period. As shown in Table 6, the research by Zeitler *et al*[12] comparing methods of treatment for adolescent T2DM was also published in this period and received much attention, evidenced by its ranking first in total link strength. As shown in Figure 7F, a large number of management guidelines[152,153] had the highest emergence intensity in this period, and as shown in Figure 8E, the emerging keywords in this period included "whole genome", "vitamin D", and "endothelial function", among others. During the second outbreak period (2017-2023 CE), on the basis of the release of specific guidelines, researchers focused on tackling the problems that the current guidelines could not solve and the needs that were not met[154]; these include the pathogenesis of adolescent T2DM in order to assist in the development of new drugs and disease prevention, evaluation of a large number of clinical trials to increase clinical treatment options and improve the best management of adolescent T2DM, and improving multi-modal interventions to solve psychological, social and environmental barriers beyond the disease itself. Interestingly, this also indicates the research tasks of the current period to some extent. As shown in Figure 7F and Figure 8E, articles related to high-quality clinical trial evidence[116,130] had the strongest emergence force in this latest period, with emerging keywords including "prenatal exposure", "gut microbiota", and "cardiac metabolism", among others.

Hotspot distribution of national institutions studying pediatric and adolescent T2DM was centered in the United States and radiated globally

The number of publications from the United States in this field accounted for over 40% of the total number of articles published by the top 10 countries, reflecting a strong research capability and leading role in the development of this field. The top 10 countries in terms of publication volume included developed countries such as the United States, the United Kingdom, and Canada as well as developing countries such as China and India. As shown in the time zone map, the research focus in the past decade has shifted from developed countries to developing countries, indicating that T2DM in

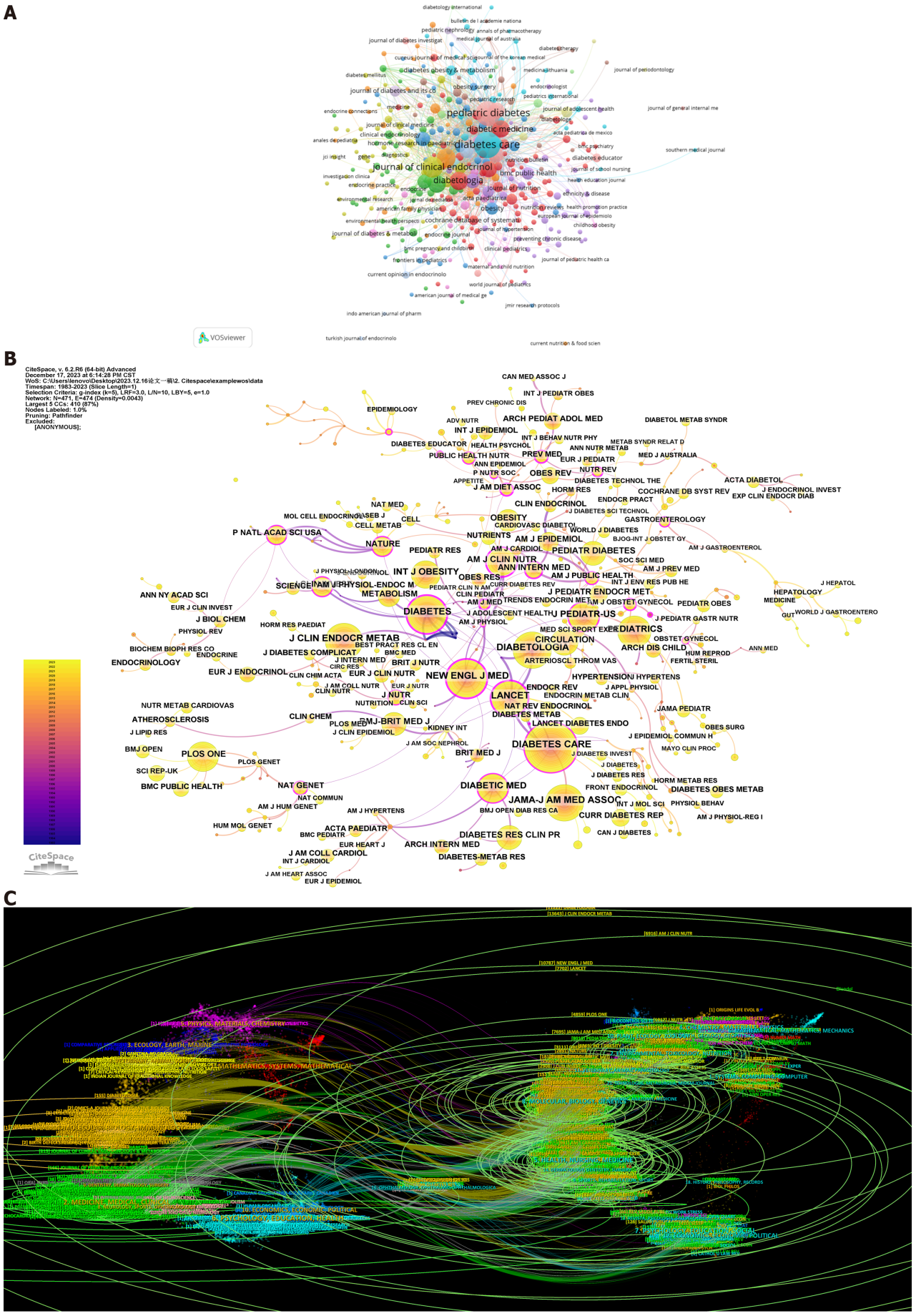


Figure 6 Visualisation of source journal and co-cited journals on type 2 diabetes mellitus in children and adolescents. A: Map of source

journal related to type 2 diabetes mellitus (T2DM) in children and adolescents; B: Visualisation of co-cited journals on T2DM in children and adolescents. Co-cited journals are indicated by circles in the graph; interactions between journals are indicated by connecting lines; C: A biplot overlay of journals on T2DM in children and adolescents (left side represents areas covered by citing journals, right side represents areas covered by cited journals).

children and adolescents is a significant issue faced by both developed and developing countries. This issue holds immense socioeconomic value and potential for future development. Furthermore, the United States, as the central country in this field of research, also serves as a core collaborator for other countries. Research sharing and collaboration led by developed countries, primarily the United States, have to some extent stimulated the attention and research development in developing countries towards adolescent T2DM.

Among research institutions, the University of Colorado System (403) had the highest number of published articles, demonstrating its strong academic environment and research foundation in the fields of pediatrics and diabetes. Collaborations in this field were primarily distributed in Western countries and formed a cooperative network represented by institutions such as Case Western Reserve University, Harvard University, and George Washington University. This network enabled the integration and amplification of research capabilities. Additionally, in Europe, there were cooperative networks represented by Queen Mary University and Karolinska Institutet.

Despite the large populations in China and India, research on diabetes in children and adolescents is still in its infancy, and there is a lack of inter-institutional collaboration. There were no representatives from Asian countries among the top 10 institutions in this field, which may be a future development goal for Asian countries and research institutions. Hence, we propose increased efforts to foster collaborations between research institutions in Asia and those in Europe and America. This approach could effectively leverage the advanced technological capabilities of developed countries and the resource support of developing countries, thereby enhancing the intensity of international cooperation.

Global hotspots in publishing were dominated by diabetes-specific journals with involvement from journals in the fields of nutrition and endocrinology and metabolism

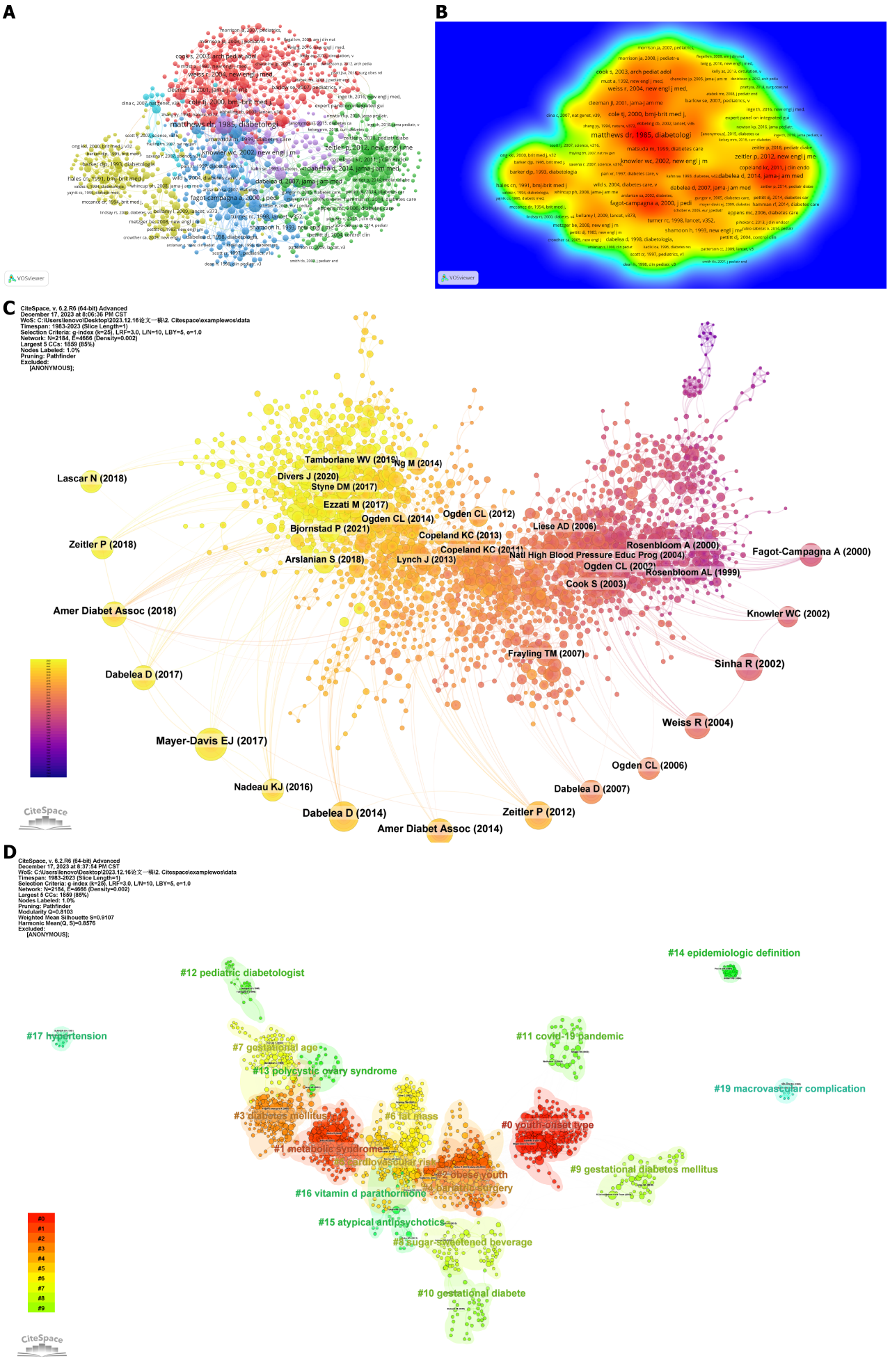
The top three journals in terms of the number of published articles in this field were *Diabetes Care* (351), *Pediatric Diabetes* (293), and *The Journal of Clinical Endocrinology & Metabolism* (213). *Diabetes Care*, a journal under the auspices of the influential ADA, provides clinicians with the latest advances in disease treatment and clinical basic research, with the goal of better management for diabetes patients. Its main research area is medical endocrinology and metabolism, and it has significant impact in diabetes research, providing many new methods and evidence for the study of mechanisms and prevention interventions for T2DM in children and adolescents over the past four decades.

Pediatric Diabetes, a bimonthly journal, is dedicated to disseminating new research regarding the epidemiology, etiology, pathogenesis, management, complications, and prevention of diabetes in children and adolescents. The journal aims to be a major medium for the international dissemination of research and practice in adolescent diabetes. Additionally, *The American Journal of Clinical Nutrition* (0.65), the highest-ranking central journal, is a leading research journal in nutrition and dietetics, publishing the latest research on nutrition topics related to human and clinical nutrition, such as obesity, vitamins and minerals, nutrition and disease, and energy metabolism. Given the multidisciplinary intersections involved in pediatric and adolescent T2DM, there is an extraordinarily close relationship among diabetes-specific journals and endocrinology and metabolism-related journals. This aligns with the comprehensive and multidisciplinary research and interpretation needed for pediatric and adolescent T2DM from mechanisms to clinical applications. High-quality articles that hold significant implications for the development of the field are likely to be studied and referenced by many scholars through core journals such as *Diabetes Care*. The journals listed in this study, with their publication volumes and centrality rankings, can provide some reference for authors who can consider the dynamics of these journals in future research.

Research hotspots reflected by authors and co-cited articles demonstrated increased scholarly attention to the epidemiological characteristics, clinical prediction methods, and interventions for T2DM in children and adolescents

Based on the number of articles published by the authors and the number of co-citations, influential authors, including Dabelea D, Lawrence JM, Nadeau KJ, Ogden CL and Weiss R are listed in Table 2 and Table 3. The author with the highest number of publications and citations was Dabelea D from the Colorado School of Public Health, who has made significant contributions to the study of the population characteristics and risk factors of diabetes in children and adolescents, the pathophysiological mechanisms related to metabolomics, and the impacts on various systems of the human body. This provides important reference evidence for the prevention and basic research of T2DM in children and adolescents.

Lawrence JM is from the National Institutes of Health National Institute of Diabetes & Digestive & Kidney Diseases and primarily studies the clinical epidemiology and related basics of diabetes in American adolescents. Ogden CL from George Washington University has made significant contributions to research related to child obesity. It is noteworthy that the cross-linking strength between important nodes, particularly among a few authors such as Dabelea D and Lawrence JM, is dense, facilitating the enhancement of research strength and quality through collaborations between institutions and authors (Figure 4). Meanwhile, the co-citation author map (Figure 4C) demonstrates the dense connections between nodes represented by Ogden CL and Weiss R and a multitude of other nodes. The research achievements of these individuals (as displayed by the dozens of important nodes on the outer ring of the map) provide a solid foundation and reliable evidence for further research and clinical implementation by a large number of researchers from various perspectives.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Timespan: 1983-2023 (Slice Length=1)
Selection Criteria: g-index (k=25), LRF=3.0, L/N=10, LBY=5, e=1.0
Network: N=2184, E=4666 (Density=0.002)
Largest 5 CCs: 1659 (85%)
Nodes Labeled: 1.0%
Pruning: Pathfinder
Excluded:
[ANONYMOUS];
Tamborlane WV (2015)
Ng M (2014)
Lascar N (2018)
Divers J (2020)
Styne DM (2017)
Ezzati M (2017)
Ogden CL (2014)
Ogden CL (2012)
Liese AD (2006)
Bjornstad P (2021)
Copeland KC (2013)
Zeitler P (2018)
Copeland KC (2011)
Natl High Blood Pressure Educ Prog (2004)
Rosenbloom A (2000)
Fagot-Campagna A (2000)
Arslanian S (2018)
Lynch J (2013)
Ogden CL (2002)
Rosenbloom AL (1999)
Cook S (2003)
Amer Diabet Assoc (2018)
Knowler WC (2002)
Frayling TM (2007)
Sinha R (2002)
Dabelea D (2017)
Weiss R (2004)
Mayer-Davis EJ (2017)
Ogden CL (2006)
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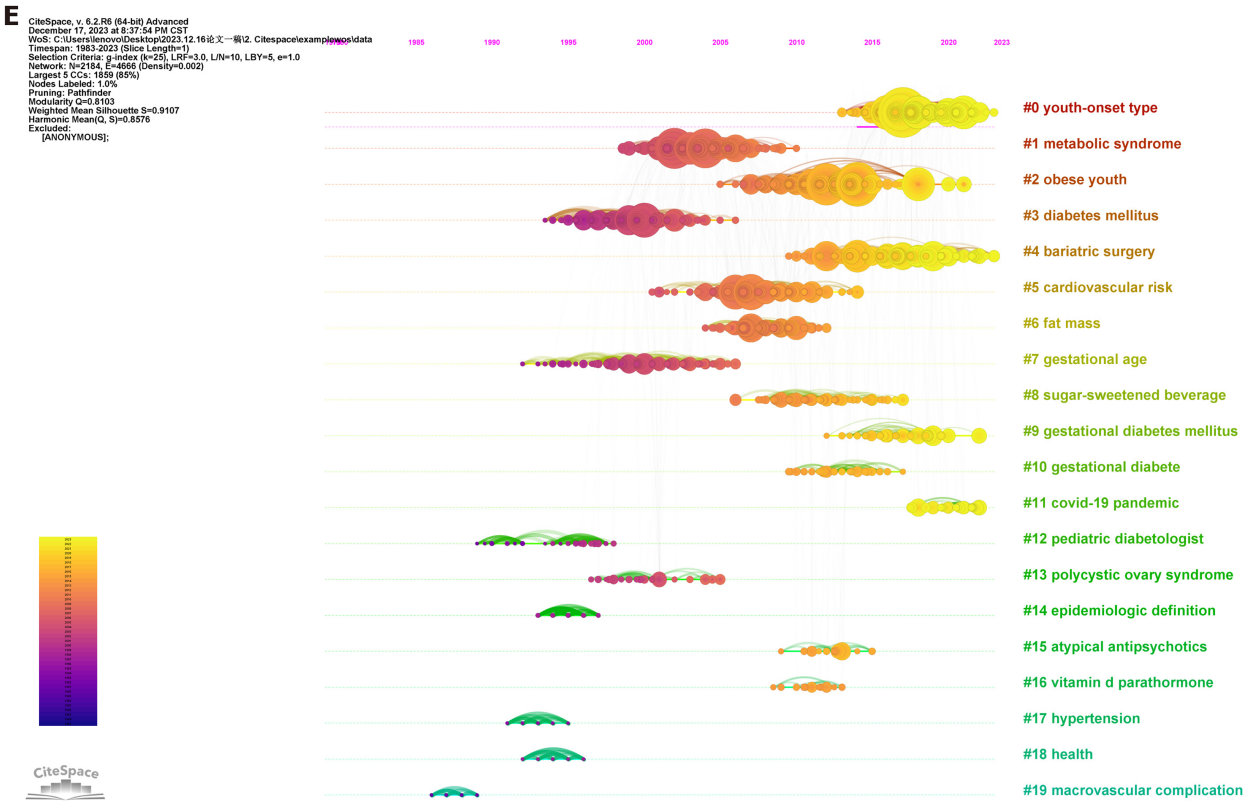
Timespan: 1983-2023 (Slice Length=1)
Selection Criteria: g-index (k=25), LRF=3.0, L/N=10, LBY=5, e=1.0
Network: N=2184, E=4666 (Density=0.002)
Largest 5 CCs: 1859 (85%)
Nodes Labeled: 1.0%
Pruning: Pathfinder
Modularity Q=0.8103
Weighted Mean Silhouette S=0.9107
Harmonic Mean(Q, S)=0.8576
Excluded:
[ANONYMOUS];
#14 epidemiologic definition
#12 pediatric diabetologist
#17 hypertension
#11 covid-19 pandemic
#7 gestational age
#13 polycystic ovary syndrome
#19 macrovascular complication
#3 diabetes mellitus
#6 fat mass
#0 youth-onset type
#1 metabolic syndrome
#9 gestational diabetes mellitus
#2 obese youth
#4 bariatric surgery
#16 vitamin d parathormone
#15 atypical antipsychotics
#8 sugar-sweetened beverage
#10 gestational diabete



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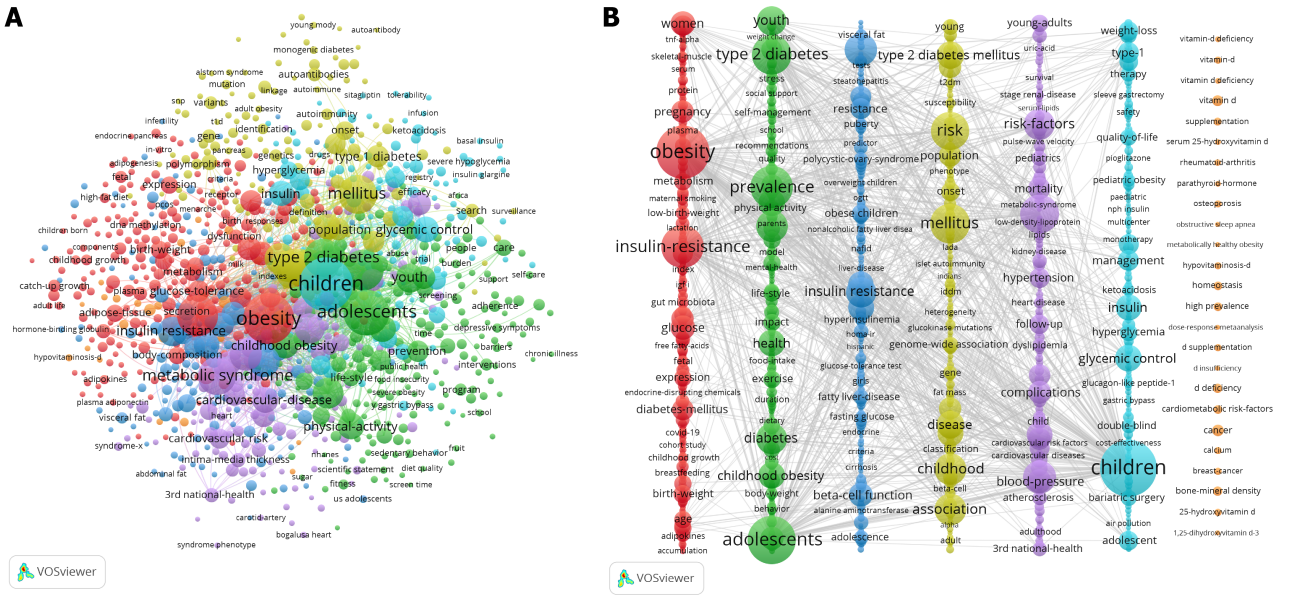
Top 25 References with the strongest citation bursts

References	Year	Strength	Begin	End	1983 - 2023
Fagot-Campagna A, 2000, J PEDIATR-US, V136, P664, DOI 10.1067/mpd.2000.105141, DOI	2000	61.79	2000	2005	
Rosenbloom A, 2000, DIABETES CARE, V23, P381	2000	46.39	2000	2005	
Rosenbloom AL, 1999, DIABETES CARE, V22, P345, DOI 10.2337/diacare.22.2.345, DOI	1999	44.42	2000	2004	
Sinha R, 2002, NEW ENGL J MED, V346, P802, DOI 10.1056/NEJMoa012578, DOI	2002	73.22	2002	2007	
Knowler WC, 2002, NEW ENGL J MED, V346, P393, DOI 10.1056/NEJMoa012512, DOI	2002	47.86	2002	2007	
Ogden CL, 2002, JAMA-J AM MED ASSOC, V288, P1728, DOI 10.1001/jama.288.14.1728, DOI	2002	47.55	2003	2007	
Cook S, 2003, ARCH PEDIAT ADOL MED, V157, P821, DOI 10.1001/archpedi.157.8.821, DOI	2003	44.86	2004	2008	
Weiss R, 2004, NEW ENGL J MED, V350, P2362, DOI 10.1056/NEJMoa031049, DOI	2004	63.17	2005	2009	
Ogden CL, 2006, JAMA-J AM MED ASSOC, V295, P1549, DOI 10.1001/jama.295.13.1549, DOI	2006	50.23	2007	2011	
Dabelea D, 2007, JAMA-J AM MED ASSOC, V297, P2716	2007	55.69	2008	2012	
Amer Diabet Assoc, 2014, DIABETES CARE, V37, PS81, DOI 10.2337/dc13-S011, DOI	2014	53.11	2014	2019	
Copeland KC, 2011, J CLIN ENDOCR METAB, V96, P159, DOI 10.1210/jc.2010-1642, DOI	2011	39.39	2012	2016	
Ogden CL, 2012, JAMA-J AM MED ASSOC, V307, P483, DOI 10.1001/jama.2012.40, DOI	2012	38.57	2012	2017	
Zeitler P, 2012, NEW ENGL J MED, V366, P2247, DOI 10.1056/NEJMoa1109333, DOI	2012	79	2013	2017	
Copeland KC, 2013, PEDIATRICS, V131, P364, DOI 10.1542/peds.2012-3494, DOI	2013	35.17	2013	2018	
Ogden CL, 2014, JAMA-J AM MED ASSOC, V311, P806, DOI 10.1001/jama.2014.732, DOI	2014	43.68	2014	2019	
Dabelea D, 2014, JAMA-J AM MED ASSOC, V311, P1778, DOI 10.1001/jama.2014.3201, DOI	2014	84.7	2015	2019	
Nadeau KJ, 2016, DIABETES CARE, V39, P1635, DOI 10.2337/dc16-1066, DOI	2016	46.68	2017	2021	
Mayer-Davis EJ, 2017, NEW ENGL J MED, V376, P1419, DOI 10.1056/NEJMoa1610187, DOI	2017	91.19	2018	2023	
Dabelea D, 2017, JAMA-J AM MED ASSOC, V317, P825, DOI 10.1001/jama.2017.0686, DOI	2017	53.22	2018	2023	
Zeitler P, 2018, PEDIATR DIABETES, V19, P28, DOI 10.1111/pedi.12719, DOI	2018	43.71	2019	2023	
Lascar N, 2018, LANCET DIABETES ENDO, V6, P69, DOI 10.1016/S2213-8587(17)30186-9, DOI	2018	43.71	2019	2023	
Arslanian S, 2018, DIABETES CARE, V41, P2648, DOI 10.2337/dci18-0052, DOI	2018	41.17	2019	2023	
Tamborlane WV, 2019, NEW ENGL J MED, V381, P637, DOI 10.1056/NEJMoa1903822, DOI	2019	35.44	2020	2023	
Divers J, 2020, MMWR-MORBID MORTAL W, V69, P161, DOI 10.15585/mmwr.mm6906a3, DOI	2020	34.86	2021	2023	

Figure 7 Visualisation of co-cited literature on type 2 diabetes mellitus in children and adolescents. A: References co-citation network. Circles represent co-cited literature; B: Density visualization of co-cited references; C: CiteSpace visualization of co-cited references, the outer circle refers to articles that have been cited more than 100 times and have the highest connection strength, while the inner refers to articles that have been cited less than 100 times and have the highest connection strength; D: Cluster analysis of co-cited references; E: Timeline graph of cluster analysis; F: Timeline distribution of top 25 references with the strongest citation bursts.

According to the top five co-cited references listed earlier, combined with the citation frequency and the ranking of emerging strength, the key research publications in this field can be identified. This allows for an analysis of the basic knowledge and disciplinary framework of research on T2DM in children and adolescents. The most frequently cited article in this field was authored by Matthews *et al*[29], who evaluated the ability of a computer steady-state model to assess the impact of insulin resistance and β cell functional defects on fasting hyperglycemia. They also evaluated its clinical predictive value and validated the theory that steady-state basal plasma glucose and insulin concentrations are determined by their interaction in the feedback loop.


A
B
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VOSviewer
CiteSpace
women
youth
type 2 diabetes
type 2 diabetes mellitus
obesity
prevalence
insulin-resistance
insulin resistance
risk
population
mellitus
children
adolescents
diabetes
childhood obesity
metabolic syndrome
cardiovascular-disease
physical-activity
glycemic control
beta cell function
bone mineral density
association
low birth weight
hypertension
coronary heart disease

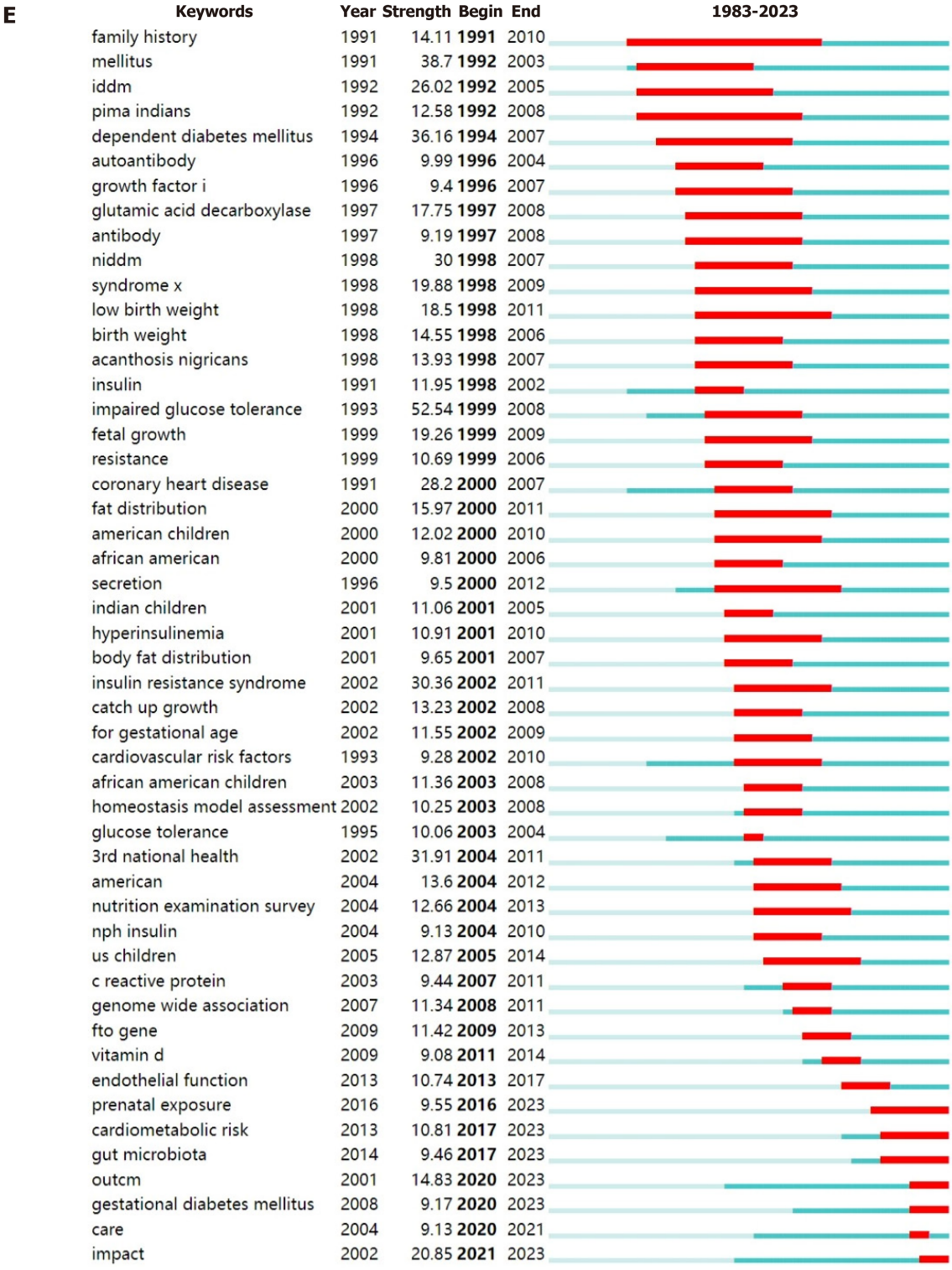

Figure 8 The mapping on keywords of type 2 diabetes mellitus in children and adolescents. A: Network diagram of 1000 keywords appearing more than 10 times; B: Keyword clustering graph: Divided into 7 clusters by different colors: Cluster 1 red, cluster 2 green, cluster 3 blue, cluster 4 yellow, cluster 5 purple, cluster 6 light blue, and cluster 6 brown. The size of the nodes in the graph represents the frequency of keyword occurrences; C: Density visualization of keyword clustering; D: CiteSpace visualization of keyword; E: Timeline distribution of top 50 keywords with the strongest citation bursts.

Another highly cited article included Zeitler *et al*[12]. They compared the efficacy of three treatment regimens for newly diagnosed T2DM in children and adolescents to achieve sustained glycemic control. The article reports an association between monotherapy with metformin and sustained glycaemic control. Combined therapy with metformin and rosiglitazone is superior to metformin alone or in combination with lifestyle interventions.

Knowler *et al*[30] reported through a randomized controlled trial that changes in lifestyle and metformin treatment can reduce the incidence of diabetes in high-risk populations. Lifestyle interventions were more effective than metformin. Sinha *et al*[31] reported that impaired glucose tolerance was very common in severely obese children and adolescents of various races. Severe T2DM was associated with β cell failure. Cole *et al*[32] recommended internationally acceptable

definitions of overweight and obesity in children with specific measurement indicators, reference populations, and specific cutoff points for age and sex, providing a basis for international comparisons of the prevalence of overweight and obesity in children.

The top three articles in terms of emerging strength were a 2012 report on the three treatment regimens for newly diagnosed T2DM in children and adolescents to achieve sustained glycemic control, with metformin combined with rosiglitazone being the best[12], a 2014 report on the increased prevalence of type 1 diabetes and T2DM in children and adolescents in five regions of the United States from 2001 to 2009[155], and a 2017 report on the significant increase in the incidence of type 1 diabetes and T2DM among American youth from 2002-2012, especially among minority youth in the Americas[33]. It can be seen that the epidemiological characteristics, clinical prediction methods, and interventions for T2DM in children and adolescents have always been hot topics of concern in academia.

In addition, a chronological display of the most recent 10 high-emergence, high-impact factor articles to predict hotspot trends shows that in 2013, Copeland *et al*[153] provided evidence-based recommendations for managing patients diagnosed with T2DM and aged 10 years to 18 years [impact factor (IF) 6.2]. In 2014, Ogden *et al*[156] investigated the annual (2011-2012 CE) prevalence of obesity among children and adults in the United States, finding that the prevalence of obesity in the relevant population remained unchanged but still high, concluding that continued monitoring is important (IF 63.1). In that same year, Dabelea *et al*[155] published the results of a 8-year (2001-2009 CE) survey on the prevalence of T1DM and T2DM in children and adolescents; they found that in five regions of the United States, the prevalence of T1DM and T2DM among children and adolescents had increased, with T1DM increasing by 21.1% in 8 years and T2DM increasing by 30.5% overall (IF 63.1). In 2016, Nadeau *et al*[152] retrospectively described the characteristics of T2DM in children, assessed the fundamental differences between children and adult diseases, and discussed the current treatment plans and the challenges and methods of developing new treatments (IF 14.8). In 2017, Mayer-Davis *et al*[33] found that the incidence of T1DM and T2DM among adolescents significantly increased during 2002-2012, especially among adolescents in minority racial and ethnic groups (IF 96.2). In that same year, Dabelea *et al*[116] reported that among adolescents and young people diagnosed with diabetes during childhood or adolescence, the prevalence of complications and comorbidities was higher in patients with T2DM than in those with T1DM but was common in both groups (IF 63.1). In 2018, Lascar *et al*[121] reviewed and described the pathophysiology, risk factors, complications, and management of T2DM in adolescents and young people, as well as the epidemiology and existing knowledge (IF 44). In that same year, Arslanian *et al*[3] from the ADA enriched the understanding of T2DM in youth, its risk factors, pathophysiology, management, and prevention of related complications (IF 14.8). In 2019, Tamborlane *et al*[130] reported that in children and adolescents with T2DM, liraglutide administration at 1.8 mg/day (added to metformin, with or without basal insulin) effectively improved blood glucose control within 52 weeks; this efficacy, unfortunately, came at the expense of an increased frequency of gastrointestinal adverse events. In 2020, Divers *et al*[157] reported that from 2011 to 2015, the incidence of T1DM and T2DM among adolescents continued to increase in the five United States sites included in the SEARCH for Diabetes in Youth study, especially among minority racial and ethnic groups (IF 25.4).

Among the high-impact papers that have emerged over the years, the top comprise the following: (1) In a study by Tamborlane *et al*[130], the clinical efficacy of liraglutide in the pediatric and adolescent population was evaluated. The study demonstrated that a daily dosage of 1.8 mg of liraglutide significantly improved glycemic control over a 52-week treatment period. However, this therapeutic benefit was accompanied by a notable increase in the incidence of gastrointestinal adverse events, highlighting the importance of a balanced assessment of treatment benefits and risks in this patient demographic. (IF 96.2); (2) A survey by Mayer-Davis *et al*[33] on the incidence of T1DM and T2DM in adolescents, which showed a significant increase in the incidence of both types of diabetes, especially among minority racial and ethnic groups (IF 96.2); (3) A clinical trial by Zeitler *et al*[12] comparing metformin, rosiglitazone and lifestyle interventions for maintaining blood glucose control in young people with T2DM, with metformin plus rosiglitazone proving most effective (IF 96.2); (4) A study by Weiss *et al*[158] on the impact of varying degrees of obesity on the prevalence of metabolic syndrome in children and adolescents and its relationship with insulin resistance, C-reactive protein and adiponectin levels, which showed that the prevalence of metabolic syndrome increases with the severity of obesity, reaching 50% in severely obese adolescents, and that C-reactive protein levels increase and adiponectin levels decrease with increasing obesity (IF 96.2); (5) A clinical trial by Knowler *et al*[30] on reducing the incidence of T2DM through lifestyle intervention or metformin, which showed that both methods can reduce the incidence of diabetes in high-risk populations (IF 96.2); (6) A survey by Sinha *et al*[31] on the prevalence of impaired glucose tolerance in significantly obese children and adolescents, which showed that impaired glucose tolerance is very common in severely obese children and adolescents of all races, and that oral glucose tolerance is related to insulin resistance, while β-cell function is relatively preserved (IF 96.2); (7) A multi-center observational study by Dabelea *et al*[116] on the association between T1DM and T2DM diagnosed in childhood and adolescence and complications in adolescence and young adulthood, which showed that the rate of complications and comorbidities is higher in patients with T2DM than in those with T1DM (IF 63.1); (8) A survey by Dabelea *et al*[155] on the incidence of T1DM and T2DM in children and adolescents in five regions of the United States, which showed a 21.1% increase in T1DM and a 30.5% overall increase in T2DM over 8 years (IF 63.1); and (9) Three surveys by Ogden *et al*[150,156,159] on the prevalence of obesity in children and adults in the United States, which showed a continued increase in the prevalence of obesity and overweight in children and adolescents since the beginning of the 20th century (IF 63.1).

A synthesis of the aforementioned high-profile, high-impact articles reveals that influential papers have primarily provided new, reliable evidence on the prevalence and correlation of diseases and complications in adolescents and children, the efficacy and risk assessment of new treatment methods, and clinical diagnosis and management methods. Overall, this provides clinical practice with more reliable preventive management information (*e.g.*, obesity prevention and complication control), more individualized treatment options (*e.g.*, selection of new drugs and addition of lifestyle interventions), and more systematic management plans (*e.g.*, clinical management guidelines and drug use guides).

Currently, however, we still need more high-quality epidemiological and clinical trial evidence to support and refine the prevention, treatment, and management of T2DM in children and adolescents.

Hotspots and frontiers

Employing co-occurrence of keywords and co-citation analysis, we can ascertain the present research emphasis in this field and forecast future research trajectories. Utilizing density diagrams, temporal graphs, and emergence intensity based on keywords, we have summarized and projected the research hotspots and development directions of studies related to T2DM in children and adolescents, as detailed below.

The most frequently appearing keywords can be divided into four categories according to their content. The first category was the concept of disease: Children (2859); adolescents (1952); diabetes (1296); and T2DM (1275). The second category was important topics: Prevalence (1505) and risk (1173). The third category was important related factors: Obesity (2489) and body mass index (870). The fourth category was disease pathophysiology: Insulin resistance (1465) and metabolic syndrome (1242).

According to the VOSviewer clustering (Figure 8B and C), all keywords were further subdivided into the following six major modules: (1) Pathophysiology of T2DM in children and adolescents; (2) Major risk factors and management strategies for T2DM in children and adolescents; (3) Epidemiological and genetic studies of diabetes in children and adolescent populations; (4) Major topics in the field of cardiovascular disease in children and adolescents with T2DM; (5) Hotspot words in the clinical treatment of T2DM in children and adolescents; and (6) Comorbidities associated with T2DM in children and adolescents.

The connections depicted between keywords and clusters in Figure 8B and D demonstrated a robust link from risk factors to population characteristics, from fundamental mechanisms to clinical strategies, and associated comorbidities in children and adolescents with T2DM. This further highlighted the need for a multifaceted, multistep, and multidisciplinary approach in the research and management of T2DM in children and adolescents. Notably, the tight linkage of keywords from a vast amount of basic theoretical research with clinical prevention and intervention methods indicates a strong focus on the translation of basic findings to clinical applications among numerous scholars.

Further, according to the time map of keyword emergence, as the research on T2DM in children and adolescents deepens, the current stage of research has begun to produce more articles in the direction of the comprehensive impact of diabetes on all organs and functions of the adolescent population, the interaction of genetics and environment, and the specific impact and outcome of comorbidities and related organ systems.

Mechanisms of T2DM in children and adolescents extended across multiple systems and pathways, with potential new areas of focus including DNA/RNA methylation, pediatric vitamin D deficiency and vitamin D receptor gene polymorphism, and gut microbiota: The etiology of T2DM in children and adolescents often aligns with that of adult diabetes, but due to the distinctive growth and developmental characteristics of children and adolescents as well as environmental influences that significantly differ from adults caution is required when extrapolating the mechanisms of T2DM from adults to this younger population. With the advent of genetic technology, epigenetic modifications, particularly DNA/RNA methylation, have been recognized as playing a significant role in the onset and progression of T2DM [160-162].

Polymorphisms in the vitamin D receptor gene[163] and the *FTO* gene[164], as well as iron overload-related genes [165], have been implicated in obesity and may contribute to T2DM in children and adolescents. Changes in the hypothalamic developmental circuitry during early neurodevelopment, under the influence of exposure factors, may be a primary cause of impaired metabolic programming[166]. Factors such as vitamin D deficiency[163], β nutritional factors [167], gut microbiota[168], mechanisms of adipose tissue expansion in children[169], oxidative stress/inflammation[170, 171], and changes in insulin degradation[172] are considered potential key mechanisms triggering T2DM.

Primary risk factors and management strategies for pediatric and adolescent T2DM increasingly focused on the interplay of psychological, behavioral, and environmental factors, necessitating higher standards for the scale and quality of research and design: In recent years, more studies on the major risk factors for pediatric and adolescent T2DM have shifted their focus from basic factors, such as overweight and obesity, sedentary lifestyle, unhealthy diet including cured meats/sugary drinks, and adverse exposure during pregnancy[117], to environmental exposure and psychological behavior, with keywords such as sleep deprivation[173], immigration changes[174], family stress[175], depressive states [176], and personality and psychological changes[177] emerging. Notably, with the advancement of clinical research techniques and methods, the requirements for the scale and quality of research and design have become more stringent [178].

Focus on prevention and treatment of T2DM in children and adolescents differed from adults, with the effects of nutritional, behavioral, and psychological interventions and new interventions targeting the pathogenesis of T2DM lacking high-quality evidence: The basic pharmacological treatment for clinical diabetes includes metformin and insulin as recommended in the guidelines. In recent years, new drugs for adolescent-onset T2DM have begun to be promoted, including liraglutide[130], exenatide[131], and dapagliflozin-flozins[132-134], which have been proven effective in studies. Metabolic surgery is a method that has emerged in the past decade and has good evidence of effectiveness[5,142-144]. However, due to the uniqueness of the child and adolescent population, the focus of prevention and treatment of T2DM in children and adolescents should differ from adults.

Lifestyle interventions such as physical exercise and dietary adjustments are still recommended for this group, supplemented by medication and surgical interventions when necessary[179-181]. The specific prescription and effects of exercise therapy is a topic to be further explored. In addition, psychological and behavioral interventions[129,140,141], mindfulness-based interventions (including meditation)[182,183], probiotic interventions based on updated T2DM mechanisms[168], omics therapy[145], and anakinra therapy[146] are in the early stages of evaluation.

It is worth noting that high-quality evidence is still lacking for the clinical effectiveness and effects of nutritional, behavioral, and psychological interventions and new interventions targeting the pathogenesis of T2DM. Various clinical trials are currently evaluating potential new therapies and trying to solve the problem of examination and treatment compliance in this special population to meet the needs of optimal management of T2DM in children and adolescents [154]. On the other hand, T2DM in children and adolescents often involves a variety of comorbidities related to endocrinology and metabolism, such as heart disease, kidney disease, and depression. The mechanism and intervention plan of multiple diseases are also important issues to be resolved[94].

Strengths and limitations

This study investigated the progress and trends of global scientific research on T2DM in children and adolescents based on bibliometrics and visual analysis. Comprehensive analysis and visual literature network presentations were conducted using CiteSpace and VOSviewer software to achieve co-occurrence and co-citation. Moreover, researchers can now quickly grasp the current survey status, hot topics, and development trends in this field by visualizing the top 10 most frequently cited references.

Despite this, limitations are inevitable. First, we placed great emphasis on publications only from the WOS core database, which may exclude some key research. Despite the widespread use of the WOS in scientometrics, it is advisable to incorporate data from multiple databases for a more robust aggregation and analysis. The exclusion of articles not indexed in the WOS database may introduce publication bias into the present study. In the course of this study, we observed that research trends and hotspots in adolescent and adult T2DM become increasingly distinct as the research deepens. The protection of children and adolescents, a unique group, and meeting their special treatment needs are issues that urgently need deeper discovery and greater resolution. Multidisciplinary integration and cooperation may be an effective way to address these issues, and research and organization in this direction are important tasks for our future work. Moreover, given the rapid development of research related to T2DM in children and adolescents, there may be a lag in citation data for the most recent high-quality articles, potentially leading to lower citation frequencies. This could result in discrepancies between the research findings and the actual situation. We have employed bibliometric methods to collate and analyse the existing literature, but it should be noted that bibliometrics is merely a tool. While its results can aid us in understanding and predicting topic shifts within this field, they may not always align perfectly with the real-world outcomes. Therefore, it is essential to interpret and judge these results in the context of the actual situation.

CONCLUSION

In a pioneering effort, this study employs the WOS database, CiteSpace, and VOSviewer software to conduct bibliometric and visualized analysis of international research on T2DM in children and adolescents. It provides a relatively scientific and intuitive overview of the included studies. We have collated and analyzed the research landscape across various countries, institutions, author groups and high-impact journals. Further, we have performed a deep dive analysis of articles, referenced literature and co-occurrence networks. This enables us to trace the research progress, guideline changes, and future needs in this field. Combining the content of existing research, we forecast future development trends and provide information on the primary research hotspots and frontiers. The number of published studies in the field of T2DM in children and adolescents has significantly increased. The international trend for research on T2DM in children and adolescents is focused on genes, behaviors, environment, and multisystem integrated interventions. The related mechanisms indicate that DNA/RNA methylation, children's vitamin D deficiency and vitamin D receptor gene polymorphisms, gut microbiota, and other microbiomes may be the new hot keywords. The main risk factors and management plans focus on the combined effects of behavior and environment. The prevention and treatment of T2DM for children and adolescents are different from adults with nutrition, behavior, and psychological interventions at the forefront of future research directions.

FOOTNOTES

Author contributions: Yu X and Song YP contributed to the literature search and screening, data analysis and visualization, and manuscript drafting; Ren YF contributed to study conception and draft review; Qian XZ contributed to literature searching and screening; Liu JL contributed to study conception and methodology, and data verification; Li WX contributed to data curation; All authors revised and approved the final version of this manuscript. Zhang FS and Li HJ are co-first authors of this manuscript due to their equal contributions to conception and design of the study, acquiring and analyzing data from the experiments, writing of the manuscript, and making critical revisions for important intellectual content; Huang YR and Gao K are co-corresponding authors of this manuscript according to their equal contributions in design of the study, guidance in software, critical revision of the manuscript for important intellectual content, and providing approval of the final version.

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