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A Bibliometric Analysis of Botulinum Toxin in Cerebral Palsy from 2005 to 2024

2005-2024 Yılları Arasında Serebral Palsi'de Botulinum Toksinin Bibliyometrik Analizi

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Abstract: This study presents a comprehensive bibliometric analysis of the literature on botulinum toxin A (BoNT-A) applications in cerebral palsy (CP) between 2005 and 2024. A search conducted in the Web of Science Core Collection identified 690 publications (550 original research articles and 140 reviews). An overall increase in publication output was observed over the years, peaking in 2018, with a temporary decline noted in 2020–2021. The United States, Australia, and Italy were the leading contributors, with Australia achieving the highest average citation rate. Desloovere K was identified as the most productive author, while Graham HK received the highest number of citations. Keyword analysis revealed that “cerebral palsy,” “botulinum toxin,” and “spasticity” were central themes, while concepts such as “rehabilitation,” “gait analysis,” and “quality of life” also stood out. In recent years, the use of technological terms such as “ultrasound” and “electromyography” has increased. In addition, intraglandular BoNT-A applications for the treatment of “sialorrhea” have been highlighted. The study also noted that BoNT-A in the upper limb is recommended to be combined with rehabilitation in order to achieve functional gains. The literature emphasizes that data on long-term efficacy remain limited and that there is a need for multicenter, prospective studies.

Keywords: Bibliometric analysis, botulinum toxin, cerebral palsy, spasticity

Özet: Bu çalışma, 2005–2024 yılları arasında serebral palside (SP) botulinum toksin A (BoNT-A) uygulamalarıyla ilgili literatürü değerlendiren kapsamlı bir bibliyometrik analiz sunmaktadır. Web of Science Core Collection veri tabanında yapılan tarama sonucunda 690 yayın (550 araştırma makalesi, 140 derleme) incelenmiştir. Yayın sayısında yıllar içinde genel bir artış gözlenmiş, 2018’de en yüksek üretim gerçekleşmiş, 2020–2021’de geçici bir düşüş yaşanmıştır. Araştırmalara en fazla katkı sağlayan ülkeler ABD, Avustralya ve İtalya olurken, Avustralya en yüksek ortalama atıf oranına ulaşmıştır. En üretken yazar Desloovere K, en çok atıf alan yazar ise Graham HK olarak belirlenmiştir. Anahtar kelime analizinde “cerebral palsy”, “botulinum toxin”, “spasticity” merkezde yer almış; “rehabilitation”, “gait analysis” ve “quality of life” gibi kavramlar ön plana çıkmıştır. Son yıllarda “ultrasound” ve “electromyography” gibi teknolojik kavramların kullanımı artmıştır. Ayrıca “sialorrhea” tedavisine yönelik intraglandüler BoNT-A uygulamaları vurgulanmıştır. Çalışmada, üst ekstremitede BoNT-A’nın fonksiyonel kazanımlar için rehabilitasyonla birlikte uygulanmasının önerildiği belirtilmiştir. Literatürde uzun dönem etkinlik verilerinin sınırlı olduğu ve çok merkezli, prospektif çalışmalara ihtiyaç duyulduğu vurgulanmıştır.

Anahtar Kelimeler: Bibliyometrik analiz, botulinum toksin, serebral palsi, spastisite

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1. Introduction

Cerebral palsy (CP) is a neurological disorder that affects muscle tone, movement, and posture, primarily resulting from abnormal brain development or damage during early development (1). Spasticity is part of a condition known as the upper motor neuron syndrome, characterized by a velocity-dependent increase in muscle tone and reflex activity (2). Spasticity is considered the most common cause of motor impairment in children with CP, affecting approximately 80% of patients. In addition to impaired mobility, it can lead to serious complications such as contractures and pressure sores (3,4).

Intramuscular administration of botulinum toxin type A (BoNT-A) is a widely preferred treatment modality for focal or segmental spasticity (4). By targeting specific muscles, BoNT-A can temporarily reduce spasticity, enhance functional abilities, relieve pain, and contribute to the rehabilitation process. There is no single standardized treatment strategy for BoNT-A administration in CP, and the dosages used have varied over the years (5–7).

The continuous increase in the number of scientific publications and the increasingly fragmented nature of studies make it challenging to organize the existing body of knowledge. Bibliometrics is an important method for systematically evaluating and quantifying the literature. It enables us to assess various indicators of scientific publications by transforming them into numerical data (8,9). Furthermore, it assists researchers in identifying areas that require attention (10–12). In this way, aspects such as scientific productivity, collaboration networks, research impact, and emerging trends become objective and measurable. The Web of Science Core Collection (WOSCC) is one of the most frequently used and user-friendly databases for bibliometric analyses, providing key information for researchers aiming to measure scientific output and impact (13). Tools such as VOSviewer and Bibliometrix, an R-based package, are commonly employed in bibliometric analyses (14). These tools enhance the effectiveness of bibliometric studies through features such as citation network analysis, mapping of collaborative relationships, and visualization of key concepts in the literature.

Bibliometric analyses of studies on BoNT-A administration in CP are valuable for understanding the role of this treatment in clinical practice and evaluating its development over time. These analyses can provide insights into the efforts aimed

at developing improved therapeutic strategies. This study aims to present a comprehensive bibliometric analysis of research on BoNT-A injections in CP, providing an overview of the evolution and impact of global research in this field and summarizing emerging trends in the application of BoNT-A in CP.

2. Materials and Methods

On December 24, 2024, the WoSCC was used to search for published articles on BoNT-A applications in CP. The search strategy was: AB = (“cerebral palsy” OR “spastic cerebral palsy” OR “spasticity in cerebral palsy”) AND AB = (“Botulinum toxin” OR “Botox” OR “botulinum neurotoxin” OR “BoNT” OR “Botulinum”). The results were refined by publication year (2005–2024), English language, and document type (articles, review articles, and proceeding papers). The remaining 690 results were sorted by citation count, with the most cited article listed first. As the data in this study were obtained from previously published studies, ethical approval was not required.

For each article, the following data were recorded: title, total number of authors and their names (corresponding author and first author), publication year, citation count and citation index, journal name, h-index, impact factor, authors’ countries, article type, and funding sources. When authors were from different countries, the country of the first listed author was recorded. To perform comprehensive bibliometric analyses, the open-source Bibliometrix R package (<http://www.bibliometrix.org/>) and VOSviewer software (version 1.6.20, Leiden University, Leiden, the Netherlands) were used. Bibliometrix is an R-based software used for bibliometric analysis and visualization (15). Subsequently, VOSviewer was employed to perform co-occurrence analysis of abstracts and keywords to identify the most frequently associated terms in this field. The citation index was calculated as the total number of citations a paper received divided by the number of years since its publication.

3. Results

a. Publication Outputs

In this study, a total of 690 publications meeting the inclusion criteria (550 research articles and 140 review articles) were analysed (Figure 1). The total number of citations for these publications was 15.734, with an average of 22.7 citations per article.

Figure 2 shows the distribution of publications by year, revealing a general upward trend in publication output between 2005 and 2024. The year 2018 saw the highest number of publications, with a total of 44

articles released. A temporary decline in publication numbers was observed in 2021–2022; however, this was followed by a recovery in 2023 and 2024. The annual growth rate was calculated as 5.01%.

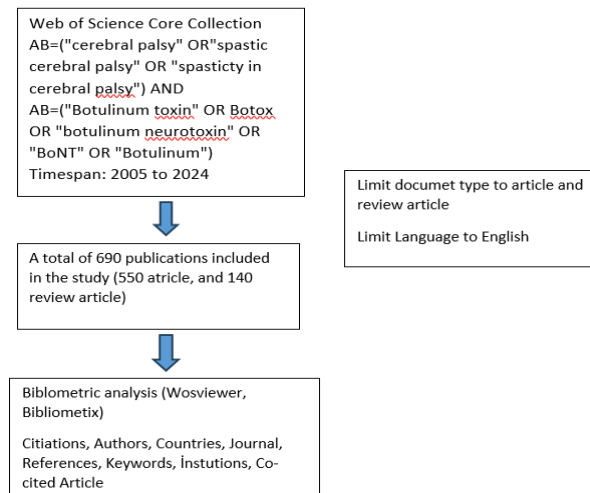


Figure 1. A flowchart of searching literature and analysis process

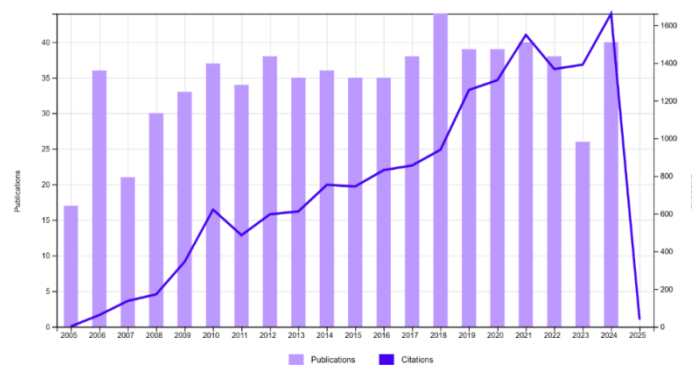


Figure 2. Annual scientific production

b. Countries/Regions

Based on the results of the bibliometric analysis, scientific publications were contributed by a total of 66 countries from 2005 to 2024. The United States (USA) ranked first in publication count with 115 publications, followed by Australia with 86 publications and Italy with 54 publications. In terms

of average citation counts, Australia demonstrated the highest citation performance (Table 1). Regarding international collaboration, the most significant contributions were made by the USA, France, and the United Kingdom (UK) (Figure 3).

Table 1. Top 10 Countries by Number of Publications (2005–2024)

Ranking	Countries/ Regions	Publications (P)	TC	AAC	H-index
1	USA	115	3244	28.1	29
2	Australia	86	4639	53.9	37
3	Italy	54	1238	22.8	19
4	South Korea	47	704	14.9	16
5	UK	47	1478	31.4	25
6	Turkey	45	723	16.0	13
7	France	44	1213	27.5	18
8	The Netherlands	44	1364	31	20
9	Belgium	41	1392	33.9	18
10	Canada	38	1089	26.6	14

USA: The United States of America, UK: The United Kingdom TC: Times Cited, AAC: Avarage Article Citation

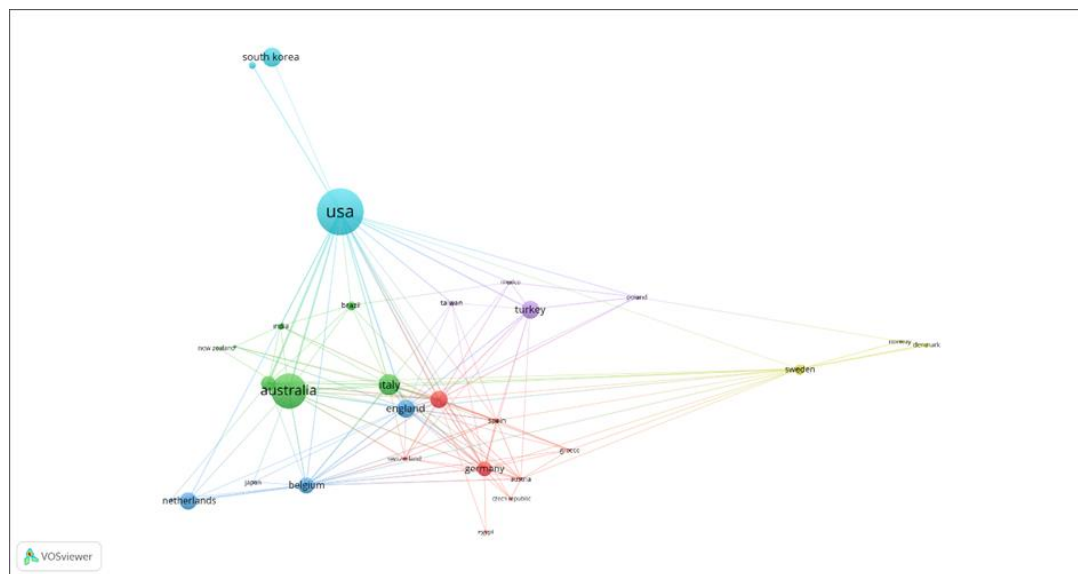


Figure 3. International collaboration network generated by VOSviewer. Node size is proportional to the number of publications from each country, while link thickness represents the intensity of collaboration between countries. Colors indicate clusters of countries with strong collaborative relationships.

c. Institute

This article identifies a total of 1,164 institutions based on author affiliations from publications between 2005 and 2024. Table 2 presents the ten most active institutions and their countries of origin, ranked by the number of publications related to BoNT-A research in CP. Katholieke Universiteit (KU Leuven) in Belgium ranks first with 68

publications, followed by leading research institutions from Australia, South Korea, the Netherlands, Taiwan, and the USA. The table emphasizes the global scope of research in this field, particularly noting that Australia boasts several prominent institutions.

Table 2. Top 10 Institutions by Number of Publications

Ranking	Institute	P	Country
1	Katholieke Universiteit Leuven	68	Belgium
2	Royal Childrens Hospital	57	Australia
3	Radboud University Nijmegen	51	Holland
4	Yonsei Univ	50	South Korea
5	University Hospitals Leuven	38	Belgium
6	National Cheng Kung University	30	Taiwan
7	University Western Australia	27	Australia
8	University Queensland	26	Australia
9	Shriners Hospital Children	25	The USA
10	University Melbourne	25	Australia

d. Funding Sources

Of the articles reviewed, 360 received funding from various agencies. The most common funding sources were AbbVie (27 publications), Allergan (26 publications), and IPSEN (21 publications). Details of the top 10 funding sources are presented in Table 3.

Table 3. The top 10 funding sources

Ranking	Funding Sources	Countries	Frequency
1	ABBVIE	USA	27
2	ALLERGAN	USA	26
3	IPSEN	France	21
4	National Institutes of Health (NIH)	USA	15
5	United States Department of Health Human Services	USA	15
6	National Health Medical Research Council (NHMRC)	Australia	12
7	FWO	Belgium	9
8	Medytox INC.	South Korea	6
9	National Institutes Of Health Research (NIHR)	UK	6
10	Netherlands Government	Holland	6

e. Journals

The journals with the highest number of publications were Developmental Medicine and Child Neurology, which had 83 articles, and Toxins, which had 32 articles. In terms of impact factor (IF), Toxins had the highest value at 3.9, followed closely by Developmental Medicine and Child Neurology, which had an IF of 3.8 (**Table 4**). In the citation analysis, Developmental Medicine and Child

Neurology was the most cited journal, with 616 co-citations. It was followed by the European Journal of Neurology, which had 100 co-citations, and the Journal of Pediatric Orthopedics, with 92 co-citations. Among the top 10 co-cited journals, Pediatrics had the highest impact factor at 8 (Table 4).

Table 4. The top 10 journals by number of publications and co-citations from 2005 to 2024.

Journals	P	IF	Co-cited Journals	Cit	IF
Developmental Medicine and Child Neurology	83	3.8	Developmental Medicine and Child Neurology	616	3.8
Toxins	32	3.9	European Journal of Neurology	100	4.5
American Journal of Physical Medicine & Rehabilitation	23	2.2	Journal of Pediatric Orthopedics	92	1.4

Journal of Child Neurology	21	2.0	European Journal of Paediatric Neurology	68	2.3
European Journal of Paediatric Neurology	20	2.3	Archives Physical Medicine and Rehabilitation	66	3.6
Archives of Physical Medicine and Rehabilitation	14	3.6	Journal Child Neurology	52	2.0
European Journal of Physical and Rehabilitation Medicine	11	3.3	Clinical Rehabilitation	35	2.6
Frontiers in Neurology	11	2.7	Pediatrics	46	8.0
Gait & Posture	11	2.2	Physical Therapy	40	3.5
BMC Pediatrics	10	2.0	Disability Rehabilitation	34	2.1

f. Citations

When examining the average annual citation counts, an increase was noted during the periods of 2009–2011 and 2012–2014. The most significant growth occurred between 2017 and 2020. However, after 2020, there was a noticeable decline in citation rates (Figure 1). Table 5 lists the ten most cited articles on CP and the applications of BoNT-A, all of which have significantly contributed to the literature. The studies by Novak I, published in 2013 and 2020, focused on evidence-based treatment approaches in CP and ranked at the top of the list with 878 and 541 total citations, respectively (16,17). Similarly, the

studies by Simpson DM and Sadowska M have established a significant presence in the literature by outlining the efficacy and safety profile of BoNT-A in treating spasticity (18,19). Heinen F and Delgado MR provided an in-depth discussion of the clinical applications of botulinum toxin in pediatric neurology (21,22). These studies stand out with their high annual citation rates and emphasise the importance of BoNT-A in the treatment of CP. The fact that most of these articles were published after 2010 indicates a growing research interest in BoNT-A during this period.

Table 5. Top 10 Most Cited Articles (2005-2024)

Title	First Author	Source Title	Total Citations	Average Citations
A systematic review of interventions for children with cerebral palsy: state of the evidence (16)	Novak I	Developmental Medicine and Child Neurology	878	64.5
State of the Evidence Traffic Lights 2019: Systematic Review of Interventions for Preventing and Treating Children with Cerebral Palsy (17)	Novak I	Current Neurology and Neuroscience Reports	541	90.17
Assessment: Botulinum neurotoxin for the treatment of spasticity (an evidence-based review): report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology (18)	Simpson DM	Neurology	270	15
Cerebral Palsy: Current Opinions on Definition, Epidemiology, Risk Factors, Classification and Treatment Options (19)	Sadowska, M	Neuropsychiatric Disease and Treatment	248	41.33
Efficacy of upper limb therapies for unilateral cerebral palsy: a meta-analysis (20)	Sakzewski, L	Pediatrics	213	17.75
The updated European Consensus 2009 on the use of Botulinum toxin for children with cerebral palsy (21)	Heinen F	European Journal of Paediatric Neurology	193	12.06

Practice parameter: pharmacologic treatment of spasticity in children and adolescents with cerebral palsy (an evidence-based review): report of the Quality Standards Subcommittee of the American Academy of Neurology and the Practice Committee of the Child Neurology Society (22)	Delgado, MR	Neurology	175	10.94
Botulinum toxin A as an adjunct to treatment in the management of the upper limb in children with spastic cerebral palsy (23)	Hoare, BJ	Cochrane Database of Systematic Reviews	140	8.75
Botulinum toxin assessment, intervention and after-care for lower limb spasticity in children with cerebral palsy: international consensus statement (24)	Love, SC	The European Journal of Neurology	132	8.25
Medial gastrocnemius muscle volume and fascicle length in children aged 2 to 5 years with cerebral palsy (25)	Barber, L	Developmental Medicine & Child Neurology	130	8.67

g. Authors

The authors with the most publications include Desloovere K with 29 publications, and both Molenaers G and Van Campenhout A, each with 23 publications (**Table 6**). Among these ten authors, Graham HK and Molenaers G are notable for having the highest citation impact. When considering the H-index, which reflects influence in academia, Graham HK and Desloovere K stand out as the most influential authors (**Table 6**). **Figure 4** examines the types of collaborations in academic publications based on the countries of the corresponding authors.

The USA is prominent in academic leadership, having the highest number of corresponding authors. However, the majority of its work falls into the category of Single Country Publications (SCP), indicating that much of the research output is produced at the national level. In contrast, European countries show a comparatively more balanced distribution between Multiple Country Publications (MCP) and SCP, highlighting their greater involvement in international collaborations.

Table 6. Top 10 Authors by Number of Publications

Authors	P	Institution	Countries	Citations	Average citation	h-index
DESLOOVERE, K	29	KU Leuven	Belgium	1050	36.2	45
MOLENAERS, G	23	KU Leuven	Belgium	1149	49.9	41
VAN CAMPENHOUT, TA	21	KU Leuven	Belgium	717	34.1	28
GRAHAM, HK	20	Royal Children's Hospital Melbourne	Australia	1133	56.6	63
VAN HULST, K	14	Radboud University Nijmegen Medical Center	Netherlands	358	25.5	19
PARK, ES	13	Yonsei University	South Korea	256	19.6	26
BAR-ON, L	11	Amsterdam UMC location Vrije Universiteit	Netherlands	259	23.5	21
VAN DEN HOOGEN, FJA	12	Radboud University Nijmegen Medical Center	Netherlands	216	18.0	32
JONGERIJUS, PH	11	Sint Maartens Clinicdept Rehabilnijmegen, Netherlands	Netherlands	515	46.8	21
RHA, DW	11	Yonsei University	South Korea	224	20.3	23

P: Number of publications

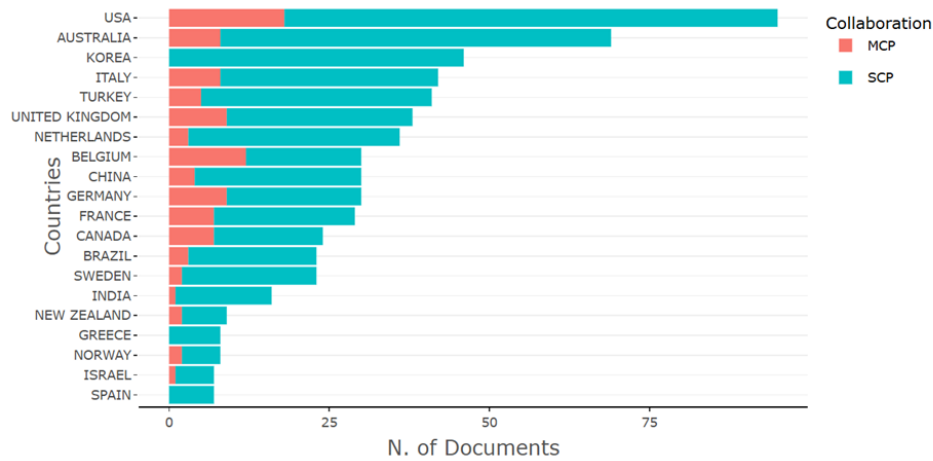


Figure 4. Corresponding author's countries. MCP: Multiple Country Publications, SCP: Single Country Publications.

h. Analysis of Keywords

Keyword analysis provides valuable insights into research trends and areas of focus. Terms like "cerebral palsy," "botulinum toxin," and "spasticity" highlight central themes in this field. Additionally, the frequent use of words such as "rehabilitation,"

"gait analysis," and "quality of life" indicates a thorough examination of treatment strategies. In recent years, there has also been an increase in the use of technological innovations, including "ultrasound" and "electromyography" (Figure 5).

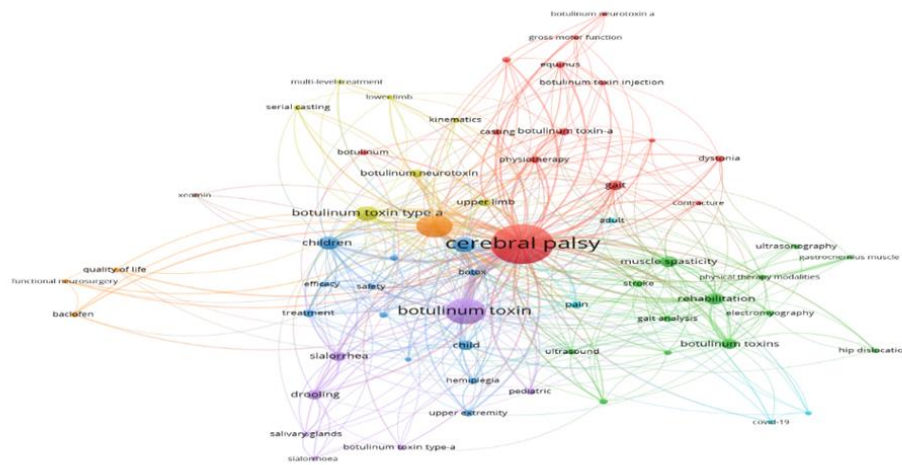


Figure 5. Keywords analysis. The co-occurrence network of keywords was generated using VOSviewer. In this network, the size of each node reflects the frequency of keyword occurrence, while the thickness of the links represents the strength of co-occurrence between keywords. Different colors indicate clusters of keywords that frequently appear together.

i. References

Table 7 lists the most frequently cited references in the literature regarding CP and the use of botulinum toxin. The study by Palisano et al. from 1997 ranks first, having received 121 citations for its significant contribution to classifying the motor functions of individuals with CP (26). Following closely are Bohannon's 1987 study on assessing spasticity with

110 citations, and Graham's 2000 research on the effects of botulinum toxin on gait and posture, which has garnered 100 citations (27,28). The majority of these studies address key issues related to motor skills and spasticity management in CP, and they have been published in prestigious journals such as *Developmental Medicine and Child Neurology*.

Table 7. The Top 10 Most Local Cited References

Cited References	Citations	First Author	Journal	Publication year
Development and reliability of a system to classify gross motor function in children with cerebral palsy (26)	121	Palisano, R	Developmental Medicine and Child Neurology	1997
Interrater reliability of a modified Ashworth scale of muscle spasticity (27)	110	Bohannon, RW	Physical Therapy & Rehabilitation Journal	1897
Recommendations for the use of botulinum toxin type A in the management of cerebral palsy (28)	100	Graham, HK	Gait & Posture	2000
A report: the definition and classification of cerebral palsy April 2006 (29)	93	Rosenbaum, P	Developmental Medicine and Child Neurology	2007
Botulinum toxin type A neuromuscular blockade in the treatment of lower extremity spasticity in cerebral palsy: a randomized, double-blind, placebo-controlled trial. BOTOX Study Group (30)	88	Koman, LA	Journal of Pediatric Orthopaedics	2000
The updated European Consensus 2009 on the use of Botulinum toxin for children with cerebral palsy (31)	84	Heinen, F	European Journal of Paediatric Neurology	2010
Randomised double blind placebo controlled trial of the effect of botulinum toxin on walking in cerebral palsy (32)	76	Ubhi, T	Archives of Disease in Childhood	200
Botulinum toxin assessment, intervention and after-care for lower limb spasticity in children with cerebral palsy: international consensus statement (33)	74	Love, SC	European Journal of Neurology	2010
Management of cerebral palsy with botulinum-A toxin: preliminary investigation (34)	69	Koman, LA	Journal of Pediatric Orthopaedics	1993
Botulinum toxin in the management of the lower limb in cerebral palsy (35)	67	Cosgrove, AP	Developmental Medicine and Child Neurology	1994

4. Discussion

In this study, we conducted a bibliometric analysis of publications on CP and BoNT applications at WOSCC between 2005 and 2024. We used R, Bibliometrix, and VOSviewer for this analysis. This study makes a significant contribution by comprehensively examining general CP bibliometric data and, in particular, the usage trends of BoNT-A applications within CP.

According to our findings, although the number of publications fluctuated over the years, there was an overall upward trend. Similar increases in research articles have also been reported in other bibliometric studies on CP (36). As highlighted in the literature, since the 1980s intramuscular BoNT-A injections have been increasingly used to modulate spasticity in CP, particularly contributing to improved

functional outcomes in the pediatric population (22, 37). Although 2020 was the year in which the FDA approved BoNT-A for the treatment of spasticity in pediatric CP, the graph shows a decrease in publications in 2020 and 2021 (Figure 2). This is most likely related to the COVID-19 pandemic. The slowdown in research activities and interruptions in clinical studies during the pandemic may explain this decline. With the easing of pandemic effects, publication numbers gained momentum again in 2023 and 2024.

Studies on BoNT-A applications in CP were distributed across 247 journals and books, reflecting the interest of multiple medical disciplines. Developmental Medicine and Child Neurology was the journal with the highest number of publications

in this specific field, with 83 articles. Graham HK was the most cited author with 1,133 citations, while Desloovere K was the most productive author with 29 publications. When countries' research productivity is evaluated, as shown in Table 1, the USA leads with 115 publications. This leadership can be attributed to its robust academic infrastructure, substantial research funding, large population, and interest in innovative treatments. The USA also leads in publications on BoNT-A applications for spasticity across all conditions, not only in CP (38). Australia ranks second in the total number of publications but leads in average citation count (AAC) with 53.9, suggesting that studies from Australia have a significant impact. Turkey ranks fourth with 41 publications; however, its AAC of 8.90 is considerably lower than that of other countries. Turkey's international cooperation level (MCP: 5) shows the need for further development to enhance its impact in this area. Examination of the international collaboration network also highlights the contributions of European countries, particularly in terms of multi-country publications and global cooperation.

The analyses showed that the terms “cerebral palsy,” “botulinum toxin,” and “spasticity” occupy a central position in the literature, while concepts such as “rehabilitation,” “gait analysis,” and “quality of life” were also among the most frequently used keywords. This indicates that research in this field is not limited to improving motor functions but also focuses on enhancing quality of life and supporting functional gains. Terms specific to BoNT-A applications, such as “dysport,” “xeomin,” “efficacy,” and “safety,” were noted, reflecting a strong emphasis on drug efficacy and safety. Keywords such as “gait analysis,” “rehabilitation,” and “muscle spasticity” remain classical themes consistently present in the literature, indicating their long-term status as key research focuses. Since 2016, there has been a significant increase in the use of keywords such as “ultrasound” and “electromyography,” highlighting the ongoing advancements in this field due to technological innovations. The important role of ultrasound guidance in BoNT-A applications has been emphasized (39,40). Ultrasound accurately identifies the target muscle during injection, enhancing procedural precision. Additionally, it offers valuable insights for predicting treatment responses and monitoring structural changes in the muscle (41–43).

In recent years, “sialorrhea” has emerged as a significant theme. The literature emphasizes that sialorrhea is common in children with CP and

greatly impacts their quality of life (44). Intraglandular BoNT-A injections have been reported to significantly reduce saliva production, typically administered at an average dose of 2 U/kg/gland into the parotid and submandibular glands under ultrasound guidance (44,45). Suskind et al. reported doses of 10–30 U per gland (45).

We found that 52% of the total publications received external funding. As shown in Table 3, the list of top funding organizations reveals that U.S.-based institutions (ABBVIE, ALLERGAN, NIH, HHS) supported a total of 83 studies. This suggests that the geographical distribution of research may be unbalanced, with global funding sources concentrated in certain regions.

European (21) and international (24) consensus statements emphasise that BoNT-A is safe and effective, particularly for lower-limb spasticity, but should always be implemented within a multidisciplinary approach. These guidelines recommend setting treatment goals collaboratively with the family and the care team, taking GMFCS levels into account, and evaluating effectiveness using multidimensional measures. The trends identified in our bibliometric analysis are consistent with the framework outlined in these guidelines. In the study by Novak et al., in 2013, BoNT-A was listed among the strongly recommended interventions for managing spasticity in children with CP (16). The study highlighted that BoNT-A not only reduces hypertonia but also contributes to functional improvement. It was further noted that targeted rehabilitation approaches, such as physiotherapy and occupational therapy, applied after BoNT-A administration significantly enhance treatment effectiveness. These findings support the importance of multidisciplinary approaches in integrating BoNT-A into clinical practice. Novak et al.'s updated systematic review, published in 2019, changed the status of using serial casting after BoNT-A injection for contracture management at week four from “emerging” to “recommended” (17). Additionally, there is low-level evidence suggesting some benefits of incorporating electrical stimulation with BoNT-A. However, a previous evidence-based review from 2008 indicated that combining serial casting with BoNT-A did not offer any additional advantage for treating equinus deformity (18). BoNT-A is effective for pain management in children with CP, particularly for equinus gait, adductor spasticity, and after adductor lengthening surgery. However, evidence regarding its effects on hamstring spasticity remains limited (18).

Research indicates that injecting BoNT-A into the upper limbs of individuals with spasticity can aid in facilitating passive movements. When these injections are paired with task-oriented and goal-directed rehabilitation approaches, as shown in a 2014 meta-analysis, they may offer modest but meaningful additional functional benefits (20). However, further research is necessary to better understand their effects on active functional improvements (18, 20). Nevertheless, there are also opposing findings in the literature. For example, the systematic review by Farag et al. reported that BoNT-A reduces upper-limb spasticity in the short term but found no evidence of long-term improvements in function or quality of life (46). Similarly, another study demonstrated that adding BoNT-A injections did not provide any additional benefit compared with rehabilitation alone (47). A 2010 Cochrane review also emphasised that BoNT-A alone has limited effectiveness in the upper limb, but when combined with goal-oriented occupational therapy, it provides meaningful additional benefits in reducing spasticity and achieving functional goals (23). Future studies should investigate the effects of repeated injections at various doses and frequencies on upper limb spasticity (23).

Considering the current evidence, there is a need for more comprehensive and prospective studies evaluating the long-term efficacy and safety outcomes of BoNT-A treatments. Furthermore, increasing the number of studies on upper limb function, which is less represented in the literature, would strengthen the evidence base for clinical practice. Finally, enhancing multicenter and

interdisciplinary collaborations between countries and institutions would contribute to improving the quality and global impact of scientific output in this field.

This study has certain limitations. First, the analysis was based solely on the WOSCC database and English-language publications; therefore, studies indexed in other databases or published in other languages were excluded. Furthermore, the data analyzed were limited to the period from 2005 to 2024, and studies outside this timeframe were not considered. Since the bibliometric methods used rely on quantitative indicators, they do not directly assess the methodological quality or clinical impact of the publications. Moreover, country, institution, and author information was recorded based on the first author, which may not fully reflect the contributions of co-authors. On the other hand, this study also has strengths. We comprehensively examined research trends and collaborations in BoNT-A applications for CP using a large and up-to-date dataset. The combined use of powerful analytical and visualization tools such as Bibliometrix and VOSviewer enabled a detailed representation of both the quantitative and network structures of the literature. In this respect, the study provides a comprehensive overview that may guide future research in this field.

In conclusion, this bibliometric analysis highlights the growing global importance of BoNT-A applications in CP and demonstrates the need for research to become more multidisciplinary, internationally collaborative, and technology-integrated.

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