

Polymer-based drug delivery systems: A bibliometric analysis

Les systèmes polymériques pour l'administration des médicaments: Analyse bibliométrique

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ABSTRACT

Objective: The aim of this study was to provide researchers in the medical field with information about leaders, collaborations, and trends in the field of polymer-based drug delivery systems (DDS) using bibliometric analysis.

Methods: a three-step process were followed: (1) data identification using PubMed. English papers published during the last five years (2018-2022) were included. (2) Data extraction and cleansing. (3) Data analysis based on publication-related metrics and science mapping using VOSviewer.

Results: A total of 1532 papers related to polymers in DDS were included. With 476 papers, China was the greatest contributor to this field as a source country. Kannan RM, by working on DDS in ocular and neurodegenerative diseases, was the most influential author in this field. Surprisingly, collaboration among organizations and countries were limited. Regarding key concepts, cancer and antineoplastic drugs have been extensively studied using various types of polymeric systems.

Conclusion: By uncovering key concepts related to polymer-based DDS, our results can provide researchers with ideas for investigation and help them position their contributions to the field.

Keywords: Polymers, Drug Delivery, Bibliometric, Science mapping

RÉSUMÉ

Objectif : Le but de cette étude était de fournir aux chercheurs du domaine médical des informations sur les leaders, les collaborations et les tendances dans le domaine des systèmes d'administration de médicaments (SAM) à base de polymères à l'aide d'une analyse bibliométrique.

Méthodes : un processus en trois étapes a été suivi : (1) identification des données à l'aide de PubMed. Les articles en anglais publiés au cours des cinq dernières années (2018-2022) ont été inclus. (2) Extraction et nettoyage des données. (3) Analyse des données basée sur des mesures liées à la publication et une cartographie scientifique à l'aide du logiciel VOSviewer.

Résultats : Un total de 1 532 articles liés aux polymères dans les SAM ont été inclus. Avec 476 articles, la Chine a été le plus grand contributeur dans ce domaine en tant que pays source. Kannan RM, en travaillant sur les SAM dans les maladies oculaires et neurodégénératives, a été l'auteur le plus influent dans ce domaine. Étonnamment, la collaboration entre les organisations et les pays était limitée. Concernant les concepts clés, le cancer et les médicaments antinéoplasiques ont été étudiés de manière approfondie en utilisant divers types de systèmes polymériques.

Conclusion : En découvrant des concepts clés liés aux SAM à base de polymères, nos résultats peuvent fournir aux chercheurs des idées d'investigation et les aider à positionner leurs contributions dans ce domaine.

Mots clés : Polymères, médicaments, bibliométrie, cartographie scientifique

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INTRODUCTION

Polymers are playing an essential role in pharmaceuticals thanks to their ability to satisfy the challenges of drug storage and release (1,2). They have been used as excipients in drug formulations in which they can be (3) binding agents, disintegrates (3), viscosity enhancers (2), surface coating agents (2), release modifiers (4), stabilizers (2), emulsifiers and suspending agents (3). In particular, they have been employed in diffusion-controlled systems (monolithic devices), solvent-activated systems (swellable or osmotically-controlled devices), biodegradable systems (chemically controlled) and environmentally-responsive systems (smart polymers) to control drug delivery (5).

A Drug Delivery System (DDS) can be described as any platform or carrier that loads active compounds and releases them in the target tissue (6,7). By controlling time, place, and speed of drug release, it enhances safety and efficacy of the drug (6,7). Liposomes, micelles, and nanoparticles are among the most famous DDSs (7).

During the last decade, the use of polymers in drug delivery has known an expanding interest. A growing number of polymeric materials, forms, and techniques have been introduced (8,9). Moreover, hundreds of papers related to polymer-based DDSs were published each year. Since this important volume of scientific data is too large for manual review, we had the idea to conduct a bibliometric analysis.

Bibliometric analysis is a scientific computer-assisted review methodology appropriate to large volumes of scientific data (10). It is used to uncover emerging trends, collaboration patterns and research constituents (11). Moreover, it enables and empowers scholars to gain a one-stop overview and identify knowledge gaps (11). Recently, bibliometric analysis has gained immense popularity in biomedical research (12). For instance, several bibliometric analyses have been published on the subject of chitosan and PVC polymers in biomedical applications (13), dental polymers (14), Magnetite Nanoparticles (15), Aluminium Oxide Nanoparticles (16) and Nanocrystalline Cellulose Research as Medical Implant (17). However, none has been done on polymer-based DDSs. To our knowledge, this is the first bibliometric analysis related to this topic.

Herein, a bibliometric analysis was performed to provide information about leaders, collaborations, and trends in the field of polymer-based drug delivery systems during the last five years (2018-2022). This research would give scholars and researchers new ideas for investigation and help them position their contributions to the field.

METHODS

We conducted a bibliometric, cross-sectional, and exhaustive analysis of the literature to identify the leading authors, countries, journals, and institutions, and to explore collaborations and areas of interest on the topic of "Polymer-based drug delivery systems" from 2018 to 2022. Thus, a three-step process was followed:

data identification, data extraction and data analysis.

Data identification

As a digital database, we chose PubMed to perform our analysis. The research on PubMed website was conducted on May 29, 2023. Using Boolean operator and Mesh terms, we searched PubMed for (("Drug Delivery Systems"[Mesh]) AND "Polymers/therapeutic use"[Mesh])). We expanded our research to all types of articles published during the last 5 years. Papers should be published from 1 January 2018 to 31 December 2022. No specific non-inclusion criteria were applied apart from the language. Non-English papers were not included. No exclusion criteria were applied. Search filters were also used to find the most publishing countries. For example, to search for country publications from China we searched PubMed for (("Drug Delivery Systems"[Mesh]) AND "Polymers/therapeutic use"[Mesh]) AND "China"[affiliation].

Data extraction

Data including authors, title, abstract, publication year, keywords and journal's title were extracted and exported as Comma-Separated Values (.csv) and text (.txt) files. The CSV file was saved in Microsoft Excel (.xlsx) format. Then, we checked data to ensure that no essential information was missing or incorrect.

Data analysis

Our data analysis was based on Performance analysis and science mapping. As performance analysis variables we focused on publication-related metrics which are number of total publications, number of publications per year, countries, Journals, type of articles and contributing authors. For Science mapping we analyzed relationships among authors (authors co-authorship), their affiliations (organizations co-authorship), and relationships among keywords in our research field (keywords co-occurrence). For keywords analysis, a thesaurus file (.csv) was created in to merge different variants of one word.

Microsoft excel was used to provide descriptive statistics including frequency and percentage and to produce tables and graphs. Information about journals (Publisher name, quartile) were provided by Scimago Journal and country Rank (SJR). VOSviewer, a free software available at www.vosviewer.com, was used for science mapping. When interpreting the network maps generated by this software, the following points were considered (18,19):

- Items (nodes) are the objects of interest. Items are in our case authors, organizations, or keywords. Node's size indicates the occurrence of an entity. Items may be grouped into clusters (communities) to indicate a close relationship between items.
- A link (edge) is a connection between two items. Total link Strength (TLS) of an item indicated the cumulative "Link strength" of all of its "Links" (20).

RESULTS

Characteristics of the included papers

A total of 1532 English papers related to polymer-based DDS were published from 01/01/2018 to 31/12/2022 and included in our study. The greatest number of these papers were published in 2018 (n=457, 29.8%). Then, the number of publications were decreasing to attend its lowest level in 2022 (n=120, 7.8%) (figure 1).

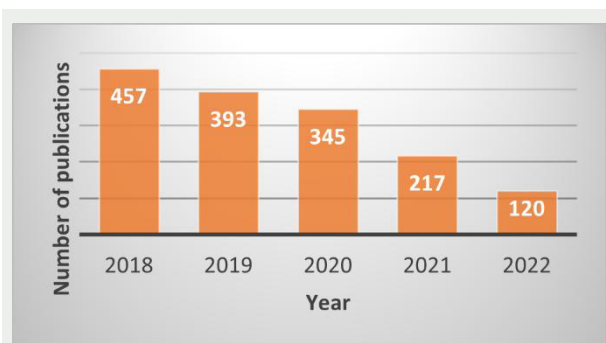


Figure 1. evolution of the number of publications (2018-2022)

Our database consisted of original research articles (n=1239, 81%) and reviews (n=293, 19%). The analysis identified that International Journal of Pharmaceutics (n=177, 11.6%) was the leading publishing journal, followed by Journal of Controlled Release (n=96, 6.3%), and International Journal of Biological Macromolecules (n=73, 4.8%) (table I). Six journals from Elsevier, two from Springer, and one from MDPI and Ivyspring International Publisher were on our top 10 list. None of our top ten most prolific journals was a nonimpact factor journal. All of them, except AAPS PharmSciTech (n=61, 4.0%, Q2), were ranked Q1 by SJR.

Findings also revealed that China was the greatest contributor in this field during the last five years (n=476, 31.1%), followed by USA (n=188, 12.3%) and India (n=167, 10.9%). Egypt (n=62, 4.0%) was the only African country figuring in the top 10 list (Table I). Moreover, 4790 organizations and departments worked on the published papers during the last five years. School of pharmacy in Shenyang pharmaceutical university was the most productive organization (n=7, 0.5%), followed by Biotechnology research center (n=6, 0.4%) and Nanotechnology research center (n=5, 0.3%) in Mashhad university of medical sciences (Table 1).

Our results showed also that 9002 authors contributed to the published papers during this period. Kannan RM was the only author who published more than 10 papers (n=11, 0.8%) (Table II). Four authors from Johns Hopkins School of Medicine in Baltimore, two authors from School of pharmacy in Shenyang pharmaceutical university in China, and one from Donghua University in China, Nanchang University in China, University of Porto in Portugal, and FDA White Oak Campus in Maryland were able to get their names on this list (Table 2).

Table 1. Leading journals, countries, and organizations /departments

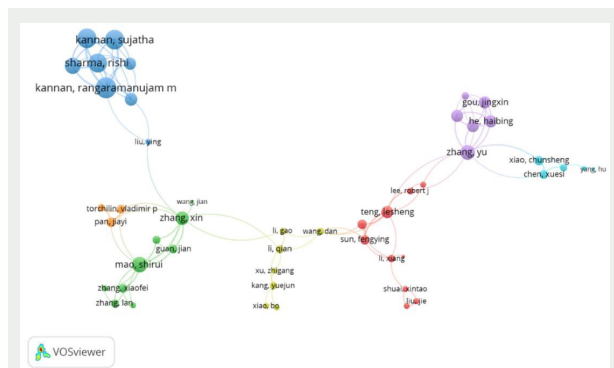
	Characteristic	Publications	Percentage (%)
Top 10 Journals	International Journal of Pharmaceutics	177	11.6
	Journal of Controlled Release	96	6.3
	International Journal of Biological Macromolecules	73	4.8
	AAPS PharmSciTech	61	4.0
	Carbohydrate Polymers	52	3.4
	Drug Delivery and Translational Research	49	3.2
	European Journal of Pharmaceutical Sciences	49	3.2
	Molecules	34	2.2
	European Journal of Pharmaceutics and Biopharmaceutics	32	2.1
	Theranostics	28	1.8
Top 10 countries	China	476	31.1
	USA	188	12.3
	India	167	10.9
	Iran	95	6.2
	Korea	69	4.5
	Egypt	62	4.0
	UK	61	4.0
	Spain	60	3.9
	Germany	59	3.9
	Brazil	55	3.6
Top 9 organizations / departments	School of pharmacy, Shenyang pharmaceutical university, Shenyang.	7	0.5
	Biotechnology research center, pharmaceutical technology institute, Mashhad university of medical sciences, Mashhad.	6	0.4
	Nanotechnology research center, pharmaceutical technology institute, Mashhad university of medical sciences, Mashhad.	5	0.3
	Center for nanomedicine, department of ophthalmology, Wilmer eye institute, Johns Hopkins university school of medicine, Baltimore.	4	0.3
	Department of anesthesiology and critical care medicine, Johns Hopkins university school of medicine, Baltimore.	4	0.3
	Department of pharmaceutics, faculty of pharmacy, Alexandria university, Alexandria.	4	0.3
	Department of pharmaceutics, school of pharmaceutical education and research, Jamia Hamdard, new Delhi.	4	0.3
	Drug applied research center, Tabriz university of medical sciences, Tabriz.	4	0.3
	key laboratory of polymer Ecomaterials, Changchun institute of applied chemistry, Chinese academy of sciences, Changchun.	4	0.3

Table 2. Top 10 authors of Polymers in DDS

Authors	Affiliation	Publication	Percentage
Kannan RM	Department of Ophthalmology, Center for Nanomedicine, Johns Hopkins School of Medicine, Baltimore, USA.	11	0.7
Zhang X	School of Pharmacy, Shenyang Pharmaceutical University, China.	10	0.7
Kannan S	Department of Anesthesiology and Critical Care Medicine, Johns Hopkins University School of Medicine, Baltimore, USA.	9	0.6
Mao S	School of Pharmacy, Shenyang Pharmaceutical University, China.	9	0.6
Shi X	Key Laboratory of Science & Technology of Eco-Textile, Donghua University, Shanghai, China.	9	0.6
Sharma A	Department of Ophthalmology, Center for Nanomedicine, Wilmer Eye Institute Johns Hopkins University School of Medicine, Baltimore, USA.	8	0.5
Zhong Z	Department of Vascular Surgery, the Second Affiliated Hospital of Nanchang University, Nanchang University, Nanchang, China.	8	0.5
Sharma R	Department of Ophthalmology, Center for Nanomedicine, Wilmer Eye Institute Johns Hopkins University School of Medicine, Baltimore, USA.	7	0.5
Sarmiento B	INEB - Instituto Nacional de Engenharia Biomédica, Universidade do Porto, Portugal. i3S - Instituto de Investigação e Inovação em Saúde, Universidade do Porto, Portugal. CESPU, Instituto de Investigação e Formação Avançada em Ciências e Tecnologias da Saúde, Portugal.	7	0.5
Wang Y	Food and Drug Administration, White Oak Campus, Silver Spring, Maryland, USA.	7	0.5

Authors Co-authorship

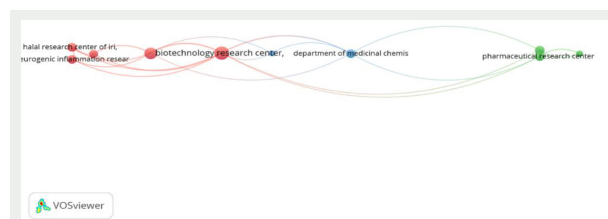
Collaboration between authors was depicted in figure 2. Minimum number of documents of an author was set at three and full counting was applied. Of the 9002 authors, 209 met the threshold. The largest set of connected items consisted of 48 authors organized by VOSviewer into seven main clusters (Figure 2). Nodes represent authors and their size was correlated to the TLS of each author. Authors in clusters one to seven were 10, 9, 8, 7, 6, 5, and 3, respectively. Six of the ten most prolific authors appeared in this network. Based on TLS, authors with the highest collaboration intensity in the field were: Kannan RM (documents= 11, TLS=37), Kannan S (documents=9, TLS=31), Sharma A (documents=8, TLS=31), Sharma R (documents=7, TLS=29), and Liaw k (documents=5, TLS=21). All of them are from the US and belonged to cluster 3. Mao S (documents=9, TLS=20) was the most collaborative author from China in this network (Figure 2).

**Figure 2.** Authors co-authorship network (weight: TLS)

Organizations co-authorship

A minimum of two documents per organization and a full counting were applied. Of 4790 organizations, 175 met the threshold. The largest set of collaborative organizations consisted of ten Iranian organizations

grouped by VOSviewer into three clusters (Figure 3). Based on TLS, Biotechnology research center, pharmaceutical technology institute, Mashhad university of medical sciences was the most collaborative organization in the field during the last five years (documents=6, links = 8, TLS= 16).

**Figure 3.** Organizations co-authorship network (weight: TLS)

Co-occurrence of all Keywords

The network visualization of keyword co-occurrences is depicted in Figure 4. Minimum number of occurrences of a keyword was set at five and full counting was applied. Nodes's size was correlated to the occurrence of each keyword. Of the 5671 keywords, 75 met the threshold. "Humans" was the most used keyword (occurrences = 1117, TLS= 5518), followed by "animals" (occurrences= 981, TLS= 4871), and "drug delivery system" (occurrences= 836, TLS= 3983). Keywords were organized by VOSviewer into six clusters according to their closeness to a specific theme. Cluster 1 (red) described innovative "drug delivery systems" supported by in-vivo experiments on "animals" while cluster 2 (green) focused on antitumor therapeutics supported by in-vitro experiments on cancer "cell lines" (n=357, TLS= 2173). Cluster 3 (dark blue) highlighted the use of polymeric "micelles" (n=122, TLS= 763) as "drug carriers" (n=598, TLS= 3125) for "antineoplastic agents" (n= 275, TLS= 1792). Cluster 4 (yellow) revealed the use of Poly (Lactic co-Glycolic Acid), "PLGA" (n=126, TLS= 612) in DDS whilst cluster 5 (purple) focused on the applications of "nanoparticles" (n=574, TLS= 3157). Finally, cluster 6 (light blue) represented the uses of "dendrimers" (n=156,

TLS= 642) in this field (Figure 4).

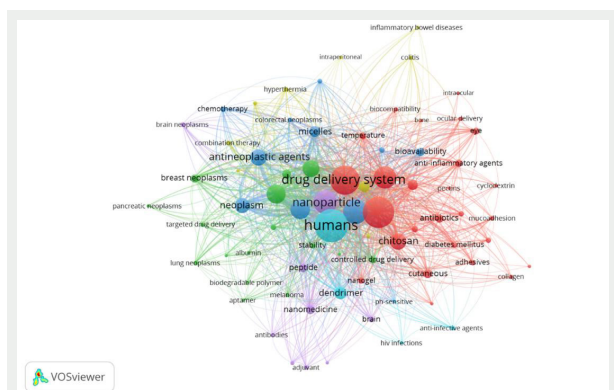


Figure 4. Co-occurrence of keywords (weight: occurrences)

DISCUSSION

In this study, we conducted a bibliometric analysis to identify leaders, collaborations and trends related to polymer-based DDSs during the last five years (2018–2022). Although complex, this approach provides more objective and reliable analyses than other literature review techniques (21). In our case, it revealed that scientific publication in this field was gradually decreasing during the last five years and that China had a leading position. It showed also that collaborations were intense among authors, especially those from China and USA, but limited among organizations.

Scientific production related to polymer-based DDSs decreased from 457 papers in 2018 to 120 in 2022. On the contrary, the overall scientific production has grown exponentially without restrictions (22). Reasons behind this decrease should be determined but may in part be explained by a change in research priorities. COVID-19 has arguably been the main focus of medical and scientific institutions since its appearance (23). Actually, the number of articles in LitCovid, an open database for covid-19 literature, has increased from 55000 to about 300 000 over the past 2.5 years, with a consistent growth rate of 10000 articles per month (24,25).

Geographically, more than half of the produced papers came from three countries: China (31.1%), USA (12.3%) and India (10.9%). The other countries in the top 10 list didn't even reach the 10% mark. Similarly, a bibliometric analysis conducted lately on "Trend of Polymer Research Related to COVID-19 Pandemic" and a systemic review related to Polymer-based DDSs for anticancer drugs showed that China, USA, and India were the three most productive countries (7,26). According to data from the US National Science Foundation, China, USA and India are the largest producers in science and engineering fields in terms of papers number (27). China ranked first holding the most prolific institution in the field, School of pharmacy in Shenyang pharmaceutical university, and numerous highly publishing authors. The leading position of China came from a sustained investment by the nation for more than 20 years, a focused national system building, and a targeted deployment of international connections and resources (28). This may be also true for the US. In fact,

increased financial resources, funding acquisition, and finest research facilities were fuels for authors from the US to produce high-quality scientific papers (14). The US ranked second and had five of our top ten leading authors in the field. India ranked third in publishing the highest number of papers. additionally, the leading journal was, by far, International Journal of Pharmaceutics (11.6%).

According to our analysis, Kannan RM was the most influential author in this field during the last five years. He is a professor of ophthalmology in Johns Hopkins School of Medicine and author of four patents and more than 80 peer-reviewed publications (29). He focused, during the last years, on dendrimer-based DDSs for ocular and neurodegenerative diseases.

Collaboration is a key factor to improve the quality and the frequency of scientific publication (30). In this study, collaboration among authors and organizations was evaluated. At author-level, our results showed that collaboration was massive among authors from the same country or organization. Collaboration between Chinese and US-based scientists was also noticeable. This was similarly found in many other studies in different fields (31). In 2020, NSB data showed that China-US collaboration exceeded the co-authorship between China and all countries in Europe taken together (27,28). This may be explained by the fact that China is the largest foreign country of origin for international US students (27). At organization-level, our study showed that few organizations were engaged in collaborations. Surprisingly, only Iranian organizations showed a tendency towards co-authorship. Equally, another study showed that Iranian researchers tend to collaborate more with researchers from other Iranian institutions (32). In other words, scientific collaboration of Iranian institutions and researchers is mainly with domestic institutions and researchers (33).

The most repeated keywords were "humans", "animals", and "drug delivery system". In addition, 81% of publications related to polymer-based DDSs were original research articles. Taken together, these findings suggest the predominance of the experimental work in this field. Regarding key concepts, the use of polymer-based DDSs in cancer diagnosis and treatment have been extensively studied during the last five years. Various types of cancer were investigated such as breast cancer (34,35), brain cancer (36), pancreatic cancer (37), and lung cancer (38). In addition, many antineoplastic drugs were used as loaded agents such as Docetaxel (35), Doxorubicin (39), Methotrexate (40), and Vincristine (41). Studies demonstrated that, by loading these agents into a polymer system, we can obtain higher tumor specificity, lower systemic toxicity, and better drug dissolution (7,42). Other chronic diseases such as diabetes, Alzheimer, eye diseases, obesity, and poorly responsive chronic wounds took interest during the last five years (43–46).

Both synthetic and natural polymers have been used. Based on our keywords co-occurrence analysis, the most common drug carriers were chitosan, alginate, cellulose, collagen, hyaluronic acid, Poly (ethylene glycol), Poly (Lactic co-Glycolic Acid), and cyclodextrin. These findings witness of an increasing trend, during the last years, to

substitute synthetic polymers by natural materials. In fact, The latter have key properties such as sustainability, biocompatibility, biodegradability, and affordability (47). Furthermore, various morphologies and sizes of polymeric systems have been studied. Dendrimers, polymeric micelles, nanogels, hydrogels, nanoparticles, and liposomes were investigated.

The present analysis presents some limitations. In this paper, we searched PubMed database for Mesh indexed terms. This method may lead to underestimation of the total number of published articles because of the delay between citation in PubMed database and the Mesh indexation. In addition, our research was based on two specific Mesh terms, which may have excluded studies indexed under other related terms. Also, citation-related metrics were not analyzed since data exported from PubMed cannot be used for identifying citation, and co-citation links between items (19). Also, non-English papers may have been missed.

CONCLUSION

In this paper, we analyzed 1532 papers to uncover trends and key concepts related to Polymer-based Drug Delivery Systems during the last five years (2018-2022). To our knowledge, this is the first bibliometric analysis related to this topic.

Our analysis showed that the number of publications was decreasing during this period concomitantly with the emergence of covid-19 and the change in research priorities. The leading journal in the field was International Journal of Pharmaceutics. Additionally, with 476 papers, China was the greatest contributor to this field as a source country. Kannan RM, by working on DDS in ocular and neurodegenerative diseases, was the most influential author in this field during the last five years. Surprisingly, collaboration among organizations and countries were limited and needs to be strengthened to improve the quality of scientific publications. Regarding key concepts, cancer and antineoplastic drugs have been extensively investigated using various types of polymeric systems. Among polymers, natural materials have gained a special attention during the last years.

Our study's results identified leading journals, organizations, and authors to be considered when looking for research or collaboration in this field. It also identified the ongoing research trends to help medical researchers and scholars interested in Polymer-based Drug Delivery Systems find inspirations and find knowledge gaps for their future studies.

REFERENCES

- Englert C, Brendel JC, Majdanski TC, Yildirim T, Schubert S, Gottschaldt M, et al. Pharmapolymers in the 21st century: Synthetic polymers in drug delivery applications. *Prog Polym Sci*. déc 2018;87:107-64.
- Srivastava A, Yadav T, Sharma S, Nayak A, Kumari AA, Mishra N. Polymers in Drug Delivery. *J Biosci Med*. 25 déc 2015;4(1):69-84.
- Ogaji IJ, Nep EI, Audu-Peter JD. Advances in Natural Polymers as Pharmaceutical Excipients. *Pharm Anal Acta* [Internet]. 2012 [cité 20 mai 2023];03(01). Disponible sur: <https://www.omicsonline.org/advances-in-natural-polymers-as-pharmaceutical-excipients-2153-2435.1000146.php?aid=3778>
- Raizada A, Bandari A, Kumar B. POLYMERS IN DRUG DELIVERY: A REVIEW. (8).
- Liechty WB, Kryscio DR, Slaughter BV, Peppas NA. Polymers for Drug Delivery Systems. *Annu Rev Chem Biomol Eng*. 2010;1:149-73.
- Calori IR, Braga G, de Jesus P da CC, Bi H, Tedesco AC. Polymer scaffolds as drug delivery systems. *Eur Polym J*. 15 avr 2020;129:109621.
- Salari N, Faraji F, Torghabeh FM, Faraji F, Mansouri K, Abam F, et al. Polymer-based drug delivery systems for anticancer drugs: A systematic review. *Cancer Treat Res Commun*. 2022;32:100605.
- Pires PC, Mascarenhas-Melo F, Pedrosa K, Lopes D, Lopes J, Macário-Soares A, et al. Polymer-based biomaterials for pharmaceutical and biomedical applications: A focus on topical drug administration. *Eur Polym J*. 3 avr 2023;187:111868.
- Molavi F, Barzegar-Jalali M, Hamishehkar H. Polyester based polymeric nano and microparticles for pharmaceutical purposes: A review on formulation approaches. *J Controlled Release*. 10 avr 2020;320:265-82.
- Han J, Kang HJ, Kim M, Kwon GH. Mapping the intellectual structure of research on surgery with mixed reality: Bibliometric network analysis (2000–2019). *J Biomed Inform*. 1 sept 2020;109:103516.
- Donthu N, Kumar S, Mukherjee D, Pandey N, Lim WM. How to conduct a bibliometric analysis: An overview and guidelines. *J Bus Res*. 1 sept 2021;133:285-96.
- Fu Y, Mao Y, Jiang S, Luo S, Chen X, Xiao W. A bibliometric analysis of systematic reviews and meta-analyses in ophthalmology. *Front Med* [Internet]. 2023 [cité 25 mai 2023];10. Disponible sur: <https://www.frontiersin.org/articles/10.3389/fmed.2023.1135592>
- Ranjan N. Chitosan with PVC polymer for biomedical applications: A bibliometric analysis. *Mater Today Proc*. 1 janv 2023;81:894-8.
- Ali S, Fatima Alam B, Ur Rehman S, Ahmad S, Iqbal K, Farooq I. Global research on dental polymers and their application: A bibliometric analysis and knowledge mapping. *Saudi Dent J*. 1 févr 2023;35(2):197-205.
- Fleming CL, Golzan M, Gunawan C, McGrath KC. Systematic and Bibliometric Analysis of Magnetite Nanoparticles and Their Applications in (Biomedical) Research. *Glob Chall*. 2023;7(1):2200009.
- Rufaida Z, Nandiyanto ABD. Bibliometric Analysis of Aluminium Oxide Nanoparticle in Biomedical Applications. *Adv Sustain Sci Eng Technol*. 6 nov 2022;4(2):0220203.
- Hafilah D, Nandiyanto ABD. A Bibliometric Analysis of Nanocrystalline Cellulose Research as Medical Implant Using VOSviewer. *J Kedokt Diponegoro Diponegoro Med J*. 30 nov 2022;11(6):285-92.
- Moosa V, Shareefa M. Science mapping the most-cited publications on workplace learning. *J Workplace Learn*. 1 janv 2020;32(4):259-72.
- van Eck NJ, Waltman L. VOSviewer Manual. :51.
- Viktoria Paschalidou. Bibliometric Analysis on Business Processes. School of Engineering, Department of Production and Management Engineering, Democritus University of Thrace; 2022.
- Aria M, Cuccurullo C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J Informetr*. 1 nov 2017;11(4):959-75.
- Bornmann L, Haunschild R, Mutz R. Growth rates of modern science: a latent piecewise growth curve approach to model publication numbers from established and new literature databases. *Humanit Soc Sci Commun*. 7 oct 2021;8(1):1-15.
- Chahrour M, Assi S, Bejjani M, Nasrallah AA, Salhab H, Fares MY, et al. A Bibliometric Analysis of COVID-19 Research Activity: A Call for Increased Output. *Cureus* [Internet]. 21 mars 2020 [cité 6 juin 2023]; Disponible sur: <https://www.cureus.com/articles/29507-a-bibliometric-analysis-of-covid-19-research-activity-a-call-for-increased-output>
- Chen Q, Allot A, Leaman R, Wei CH, Aghaarabi E, Guerrero JJ, et al. LitCovid in 2022: an information resource for the COVID-19 literature. *Nucleic Acids Res*. 6 janv 2023;51(D1):D1512-8.
- Chen Q, Allot A, Lu Z. LitCovid: an open database of COVID-19

- literature. *Nucleic Acids Res.* 8 janv 2021;49(D1):D1534-40.
26. Chiari W, Damayanti R, Harapan H, Puspita K, Saiful S, Rahmi R, et al. Trend of Polymer Research Related to COVID-19 Pandemic: Bibliometric Analysis. *Polymers.* janv 2022;14(16):3297.
 27. Publications Output: U.S. Trends and International Comparisons | NSF - National Science Foundation [Internet]. [cité 6 juin 2023]. Disponible sur: <https://ncses.nsf.gov/pubs/nsb20206/publication-output-by-region-country-or-economy>
 28. Marginson S. 'All things are in flux': China in global science. *High Educ.* 2022;83(4):881-910.
 29. Johns Hopkins Medicine [Internet]. [cité 13 juin 2023]. Kannan Rangaramanujam, Ph.D., M.S., Professor of Ophthalmology. Disponible sur: <https://www.hopkinsmedicine.org/profiles/details/kannan-rangaramanujam>
 30. Schäfermeier B, Hirth J, Hanika T. Research topic flows in co-authorship networks. *Scientometrics* [Internet]. 2022 [cité 14 juin 2023]; Disponible sur: <https://doi.org/10.1007/s11192-022-04529-w>
 31. Fry CV, Cai X, Zhang Y, Wagner CS. Consolidation in a crisis: Patterns of international collaboration in early COVID-19 research. *PLOS ONE.* 21 juill 2020;15(7):e0236307.
 32. Erfanmanesh M, Arshadi H. Co-authorship Network of Institutions in Iranian Knowledge and Information Science Papers. *Acad Librariansh Inf Res.* 21 mars 2015;49(1):79-99.
 33. Dastani M, Mardaneh J, Moshari J. Mapping the Scientific Structure of Iranian Brucellosis Researches Using the Co-authorship and Co-occurrence Network Analysis. *Iran J Med Microbiol.* 10 juill 2022;16(4):336-9.
 34. Trombino S, Curcio F, Poerio T, Pellegrino M, Russo R, Cassano R. Chitosan Membranes Filled with Cyclosporine A as Possible Devices for Local Administration of Drugs in the Treatment of Breast Cancer. *Mol Basel Switz.* 26 mars 2021;26(7):1889.
 35. Andisheh F, Oroojalian F, Shakour N, Ramezani M, Shamsara J, Khodaverdi E, et al. Docetaxel encapsulation in nanoscale assembly micelles of folate-PEG-docetaxel conjugates for targeted fighting against metastatic breast cancer in vitro and in vivo. *Int J Pharm.* 10 août 2021;605:120822.
 36. Madani F, Esnaashari SS, Webster TJ, Khosravani M, Adabi M. Polymeric nanoparticles for drug delivery in glioblastoma: State of the art and future perspectives. *J Control Release Off J Control Release Soc.* sept 2022;349:649-61.
 37. Shabana AM, Kambhampati SP, Hsia RC, Kannan RM, Kokkoli E. Thermosensitive and biodegradable hydrogel encapsulating targeted nanoparticles for the sustained co-delivery of gemcitabine and paclitaxel to pancreatic cancer cells. *Int J Pharm.* 25 janv 2021;593:120139.
 38. Yee Kuen C, Masarudin MJ. Chitosan Nanoparticle-Based System: A New Insight into the Promising Controlled Release System for Lung Cancer Treatment. *Mol Basel Switz.* 12 janv 2022;27(2):473.
 39. Hsu MY, Huang YT, Weng CJ, Chen CM, Su YF, Chu SY, et al. Preparation and in vitro/in vivo evaluation of doxorubicin-loaded poly[lactic-co-glycol acid] microspheres using electrospray method for sustained drug delivery and potential intratumoral injection. *Colloids Surf B Biointerfaces.* juin 2020;190:110937.
 40. Wang MY, Qu Y, Hu DR, Chen LJ, Shi K, Jia YP, et al. Methotrexate-loaded biodegradable polymeric micelles for lymphoma therapy. *Int J Pharm.* 25 févr 2019;557:74-85.
 41. Ghosh S, Lalani R, Maiti K, Banerjee S, Bhatt H, Bobde YS, et al. Synergistic co-loading of vincristine improved chemotherapeutic potential of pegylated liposomal doxorubicin against triple negative breast cancer and non-small cell lung cancer. *Nanomedicine Nanotechnol Biol Med.* janv 2021;31:102320.
 42. Alalaiwe A. Bioconjugated nanometals and cancer therapy: a pharmaceutical perspective. *Nanomed.* août 2021;16(20):1791-811.
 43. Abdelkader H, Fathalla Z, Seyfoddin A, Farahani M, Thrimawithana T, Allahham A, et al. Polymeric long-acting drug delivery systems (LADDs) for treatment of chronic diseases: Inserts, patches, wafers, and implants. *Adv Drug Deliv Rev.* oct 2021;177:113957.
 44. Alshaikh RA, Waeber C, Ryan KB. Polymer based sustained drug delivery to the ocular posterior segment: barriers and future opportunities for the treatment of neovascular pathologies. *Adv Drug Deliv Rev.* août 2022;187:114342.
 45. Abdelkader DH, Osman MA, El-Gizawy SA, Hawthorne SJ, Faheem AM, McCarron PA. Effect of poly(ethylene glycol) on insulin stability and cutaneous cell proliferation in vitro following cytoplasmic delivery of insulin-loaded nanoparticulate carriers - A potential topical wound management approach. *Eur J Pharm Sci Off J Eur Fed Pharm Sci.* 1 mars 2018;114:372-84.
 46. Chen TC, Ho YY, Tang RC, Ke YC, Lin JN, Yang IH, et al. Thiolated Chitosan as an Intestinal Absorption Carrier with Hesperidin Encapsulation for Obesity Treatment. *Nutrients.* 9 déc 2021;13(12):4405.
 47. Mallakpour S, Azadi E, Hussain CM. Chitosan, alginate, hyaluronic acid, gums, and β -glucan as potent adjuvants and vaccine delivery systems for viral threats including SARS-CoV-2: A review. *Int J Biol Macromol.* 1 juill 2021;182:1931-40.