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Article

A bibliometric and visual analysis of lean manufacturing in medicine from 2009 to 2023

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Abstract: Lean (also referred to as the Toyota Production System, TPS) is considered to be a radical alternative to the traditional method of mass production and batching principles for maximising operational efficiency, quality, speed and cost. Many hospitals inspired from lean manufacturing to develop their process. They had many improvements in their process. Hospitals reduced their patient waiting times, defects, wastes related to inventory, staff movement and patient transportation by implementing. This study utilizes scientometric and bibliometric tools to analyze visually the literature published in the field of medical lean manufacturing from 2009 to 2023. The relevant articles published from 2009 to 2023 were retrieved from the Web of Science Core Collection, VOSviewer and R software were used for bibliometric analysis and visualization. The number of publications related to the research has been increasing year by year before 2021, and then showed a downward trend, including 418 articles from 64 countries and regions, 743 institutions, 198 journals, and 1766 authors. The United States, Italy, and England are the main publishing countries in this research field. The journal "International Journal of Lean Six Sigma" published the most papers (n = 21) about lean manufacturing in medicine, the author with the most publications is Teeling SP, and the most influential author is Improta G. The top three keywords are "Healthcare", "Quality improvement" and "Management". This study provides a comprehensive bibliometric analysis of lean manufacturing in medicine, which can help researchers understand the current research hotspots in this field, explore potential research directions, and identify future development trends.

Keywords: bibliometric analysis; Web of Science; lean; medicine; Toyota production system

1. Introduction

Lean, also known as "Lean Production", "Lean Enterprise", or "Lean Thinking", is a management philosophy designed to eliminate redundant and unnecessary activities (Robinson et al., 2016). It involves a range of principles, practices, and methods used for designing, improving, and managing processes (Carter et al., 2012). Lean stems from automaker Toyota's production philosophy. Liker defines Toyota's Production System (TPS) as "an organization-wide management system that focuses on overall customer satisfaction in an evolutionary environment of teamwork and improvement" (Antierens et al., 2018). Lean management helps achieve better performance and improve efficiency and quality of service while reducing bottlenecks, defects and delivery cycles. The system relies on two pillars: creating value and eliminating waste. "Lean production" was first used to describe Toyota production

systems in “The World-Changing Machine” by Womack et al. (Poksinska, 2010). Lean production was initially applied in manufacturing with the aim of reducing any type of waste and inconsistencies in the production system (D’Andreamatteo et al., 2015). Gradually, the concept of lean production has been continuously optimized and developed, and it is gradually applied in many fields, such as architecture, software development, financial services, medical and health services, and laboratory science (Mason et al., 2015).

Lean in health care is defined as “the cultural commitment of an organization’s ability to apply scientific approaches to design, execute, and continuously improve the work delivered by the team, thereby bringing measurable better value to patients and other stakeholders” (Toussaint and Berry, 2013). Unlike Taylorism, the center of lean production is to respect the core principle. However, medical lean production is not set by the “benefit expert” standards, but by the working employees using scientific methods and their own ideas to improve. When deep understanding is really adopted, lean can improve the quality and safety of patients and employees, and achieve sustainable work (Surgery for Severe Ischemic Mitral Regurgitation, 2016). While some scholars have questioned its applicability in health care, 53% of US hospitals have also adopted lean management. In the public sector in the UK, 51% of business improvement methods are based on TPS, with 35% occurring in the medical and health sector (Antierens et al., 2018). The Royal Bolton Hospital reduced the mortality rate of patients by one third after implementing the Bolton Improved Care System (Lean). In addition, the time required for hospitals to handle important blood types has been reduced from 2 days to 2 hours, and the average turnaround time of pathology has been shortened from more than 24 hours to 2–3 hours (Fillingham, 2007). After redesigning the lean principle of aseptic processing center and clinical laboratory working area, Nebraska Medical Center reduced staff walking by 167 miles a year, shortened the turnaround time of specimen processing by 20%, and reduced the average hospitalization time from 6.29 days to 5.72 days (Radnor et al., 2012).

Generally, the healthcare system faces increasing medical expenditure and an aging population, which enables the healthcare system to improve and develop continuously to seek more efficient ways of care. Many healthcare organizations adopt lean production as a performance improvement approach, which provides them with an alternative method of improvement that can be achieved without high investment (Bahensky et al., 2005; Holden, 2011). In addition, many hospitals during the COVID-19 pandemic have improved their internal operational framework and adopted a structured Lean Six Sigma quality improvement approach that has effectively helped departments reduce waste and improve patient flow. Ailish Daly et al employed a pre-/post-intervention design using Lean methodology and utilised a rapid improvement event approach underpinned by person-centred principles (Daly et al., 2022). Francesca Pellini et al noted that lean may help optimize pre-and postoperative time during the current pandemic, minimizing healthcare and patient exposure to SARS-CoV-2, and facilitating rational use of limited resources (Pellini et al., 2021).

However, comprehensive, quantitative statistics and analysis specifically targeting medical lean research are lacking. Our work in this study provided a comprehensive and in-depth interpretation of the current status and evolution of medical lean research, and predicted future trends in the field. We analyzed 418

publications on the Web of Science Database (WOS) platform from 2009 to the end of 2023. By analyzing the bibliometric metrics implemented on the WOS, we illustrated the distribution of publications, the most influential journals, the most cited publications, the most important authors, the most prominent institutions, and countries. Furthermore, through visual analysis using VOSviewer and the incited software, we presented the co-citation of the cited references, the cited authors, and the cited Citespace journals. We also explored the evolution of medical lean research using R-bibliometrix package, and based here we have predicted the research hotspots and future trends in the field of medical lean research.

2. Methods and data sources

2.1. Data sources

In this study, Web of Science Core Collection (WoSCC) is selected for analysis. WoSCC is a significant academic information database, with its core collection from 1985. This includes the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts and Humanities Citation Index (A&HCI), among others. The two main advantages of the WoSCC are reference tracking and citation reporting. In addition to supporting the retrieval of leading academic journals, books, and citation networks, it also employs a rigorous selection mechanism based on bibliometrics' Bradford' s law, only including critical academic journals and major international academic conferences across all subject areas (Brookes, 1969).

The search strategy is as follows. TS= ((“lean thinking” OR “lean adoption” OR “lean implement” OR “lean design” OR “lean production” OR “lean management” OR “six sigma”) AND (hospitals)). The time span begins from January 2009 to December 2023. Literature types were selected as Article and Review, with language selected as English. Finally, 418 valid papers were used for subsequent bibliometric analysis. The flow chart is shown in **Figure 1**.

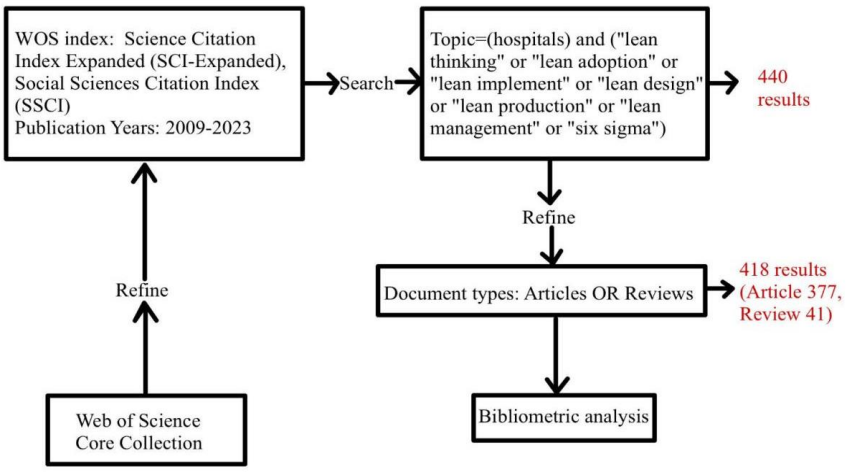

Figure 1. Flowchart of the screening process.

2.2. Date analysis

Using the analysis search results and citation report module in WOS,we

preliminarily analyze the general information of the literature, including title, author, journal, country, institution, year of publication, etc. Applying VOSviewer and R-bibliometrix package for bibliometric and visual analysis, bibliometrics scholars indicate that visual co-citation analysis can facilitate data interpretation and make results more comprehensive while mining the intrinsic connections of this information (Merigó et al., 2015). This paper used VOSviewer software as a tool for co-citation analysis, and provides a variety of visual views in keywords, co-organization, co-author and other fields, including network view (Network Visualization), superposition view (Overlay Visualization) and density view (Density Visualization), and then realized the visual analysis of the knowledge structure, with the characteristics of convenient drawing and beautiful image (van Eck and Waltman, 2010). On the basis of understanding the platform research structure, we also conducted an evolutionary analysis through R-bibliometrix package to explore the evolution of the field. Bibliometrix is an open-source tool for executing a comprehensive science mapping analysis of scientific literature. It was programmed in R to be flexible and facilitate integration with other statistical and graphical packages (Aria and Cuccurullo, 2017). In Scientometrics, this tool is explicitly used for quantitative and qualitative evaluation of research performance using a comprehensive range of indicators (Malik et al., 2021).

3. Results

Statistical analysis of the data obtained in the WOS found that the sample in this study consisted of 418 publications published by 1766 authors in 743 institutions in 64 countries, published in 198 journals, citing 12,197 references.

3.1. Distribution of publications by year

The output distribution of annual publications reflects the research level and development degree of a certain subject field. From 2009 to 2023, WOSCC included 418 documents related to “medical lean production”. **Figure 2** shows the yearly publications in the medical lean production research field in the 15 years (2009–2023). Compared with other years, 66 articles were published in 2021, which is the year with the most articles published. In general, the field of medical lean manufacturing has seen a low number of annual publications over the past 15 years. As an emerging field, research in this area is still in its infancy. Utilizing Lean methods to optimize operational care delivery in synergy with improved medical education has the potential to increase long-term sustainable results as well as ultimately to improve care and patient outcomes. This type of implementation of operations principles may ultimately be as critical to the future of developing health systems as the transfer of basic medical knowledge.

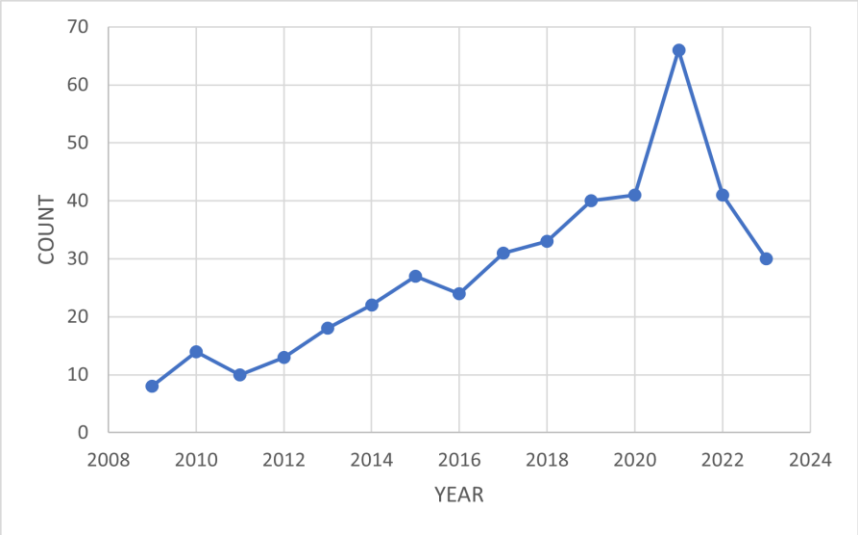

Figure 2. Trends in the number of publications and analysis of countries/regions in Medical lean production per year since 2009.

3.2. Countries/regions and institutions

The 418 articles published in the past 15 years are from 64 countries and 743 institutions. The top 10 countries in terms of the number of articles published each year are as shown in the **Figure 3**. The United States (139), the Italy (54) and Australia (39) are the top three countries/regions. It was found in the national data analysis of the top 10 published literature that the early research in the field of medical lean production mainly focused on the United States, Netherlands and England. The overall trend of publication output has shown an increase before 2021, and then it shows a downward trend. The United States ranks first in the steady growth of annual publication output. **Table 1** presents the top 5 institutions ranked by publication count. As for the leading research institutions, University of California System ranks first in productivity, with 20 publications cited 201 times. However, University of Naples Federico II has the most citations (319) and the highest average citations (23).

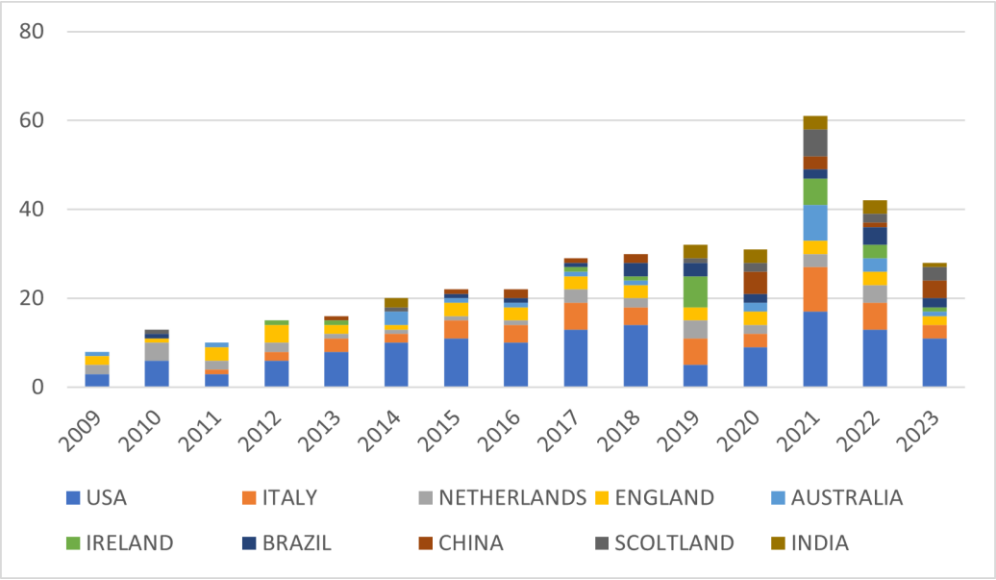

Figure 3. The yearly worldwide publication output.

Table 1. Top 5 productive institutions.

Rank	Institutions	Articles (N)	Citations	Average citations	H-Index
1	University of California System	20	201	10	8
2	University of Naples Federico II	14	319	23	8
3	University of California Berkeley	13	79	6	5
4	University College Dublin	12	143	12	8
5	Trinity College Dublin	11	116	11	7

3.3. Journal analysis

From 2009 to 2023, a total of 198 journals published relevant articles, and 5355 journals were co-cited. The details of the top 5 journals by publication count and the top 5 co-citation journals by citation count are listed in **Table 2**. Impact Factor (IF) is a quantitative indicator used to evaluate the importance of a journal, representing the total citation frequency. Journal Citation Reports (JCR) is the most commonly used international standard for journal ranking. It is published by Clarivate Analytics and classifies journals into different subject categories based on their impact factor, which is used to divide them into four quartiles. Among the top 5 productive journals, *International Journal of Lean Six Sigma* has published the most publications (n = 21), followed by *International Journal of Environmental Research* (n = 20) and *BMC Health Services Research* (n = 17). The IF of these journals ranges from 1.3 to 4.614, with the highest IF belonging to *International Journal of Environmental Research and Public Health* (IF = 4.614). Among the top 5 co-cited journals, three journals were cited over 200 times, with *International Journal of Health Care Quality Assurance* having far more citations (233) than the other journals. Among them, the journal with the highest IF is *International Journal of Lean Six Sigma* (IF = 4). Among the top 5 journals by publication count and the top 5 co-citation journals, journals are mainly located in the Q2 and JCR area.

Table 2. Top 5 productive journals and co-cited journals related to lean production.

Rank	Journal	Count (N)	IF (2022)	Quartile in category	Co-cited Journal	Count (N)	IF (2022)	Quartile in category
1	International Journal of Lean Six Sigma	21	4	Q2	International Journal of Health Care Quality Assurance	233	1.5	Q4
2	International Journal of Environmental Research and Public Health	20	4.614	Q2	International Journal of Lean Six Sigma	205	4	Q2
3	BMC Health Services Research	17	2.8	Q3	International Journal for Quality in Health Care	202	2.6	Q3
4	International Journal for Quality in Health Care	15	2.6	Q3	Leadership in Health Services	196	1.7	Q3
5	Quality Management in Health Care	13	1.3	Q4	Joint Commission Journal on Quality and Patient Safety	161	2.3	Q2

3.4. Author analysis

According to the cooperative analysis of VOSviewer authors, from 2009 to 2023,

a total of 1,766 authors published relevant documents. **Table 3** presents detailed information on the top 5 most productive authors and co-cited authors in terms of citation rankings, including primary authors, number of publications, citation counts, total link strength. The top three authors with the most published papers are Teeling SP (*n* = 12), Improta G (*n* = 11), and Triassi M (*n* = 10). Usually, the author's influence in the scientific field is evaluated by the number of citations (de Bree, 2015). The most frequently cited author is Improta G (311), followed by Triassi M (232) and Teeling SP (104). The co-cited authors refer to two or more authors who are simultaneously cited by another article, forming a co-citation relationship. The analysis shows that Improta G the highest citation frequency with95 total citations, followed by Mazzocato P (90) and Antony J (85). The total link strength reflects the degree of association with other researchers. Among the top 5 most productive authors, the author with the highest total link strength is Improta G (48), while among the top 5 authors with the most co-citations, the author with the highest total link strength is Brandao de Souza L (128). It can be indicated that Improta G, Triassi M and their group play a significant role in medical lean production. In summary, analyzing the relationships between authors and co-cited authors can help to identify the core authors and key collaborations in the field.

Table 3. Top 5 productive authors and co-cited authors related to lean production.

Rank	Author	Count	Citations	Total link strength	H-Index	Co-cited author	Citation	Total link strength
1	Teeling SP	12	104	9	7	Improta G	95	91
2	Improta G	11	311	48	8	Mazzocato P	90	127
3	Triassi M	10	232	45	6	Antony J	85	104
4	Shortell SM	10	58	15	4	De Souza LB	71	128
5	Rundall TG	9	57	15	4	Womack JP	70	96

3.5. Citation analysis

To fully recognize the full view of co-cited references in medical lean production, the top 10 highly co-citation of cited references on "lean production" are shown in **Table 4**. Citation analysis is considered an important method for assessing the impact of publications. According to **Table 4**, The most frequently cited article is by Zoe J Radnor et al., published in Social science & medicine, which has been cited 53 times. This article demonstrated that the application of specific Lean "tools", such as "kaizen blitz" and "rapid improvement events", tends to produce small-scale and localised productivity gains. However, when moving to a more system-wide approach, there are significant contextual differences between healthcare and manufacturing, which may severely constrain Lean' s impact on healthcare productivity at the systems level if it is not solved.

Table 4. Top 10 co-citation of cited references on "medical lean production".

Rank	Title	Total Citations	Year	First Author	Source
1	Lean in healthcare: the unfilled promise?	53	2012	Zoe J Radnor	Social science & medicine
2	Lean thinking in healthcare: a realist review of the literature	50	2010	Pamela Mazzocato	Quality & safety in health care.
3	Trends and approaches in lean healthcare	46	2009	Luciano Brandao de Souza	Leadership in Health Services
4	Lean Thinking in emergency departments: a critical review	45	2010	Richard J Holden	Annals of emergency medicine
5	Lean in healthcare: A comprehensive review	44	2015	Antonio D'Andreamatteo	Health Policy
6	The use of Lean and Six Sigma methodologies in surgery: a systematic review	38	2014	SE Mason	The surgeon: journal of the Royal Colleges of Surgeons of Edinburgh and Ireland.
7	Lean Six Sigma in Healthcare	35	2006	Henk de Koning	Journal for Healthcare Quality
8	The Machine That Changed the World	37	1992	JP Womack	Business Horizons
9	Assessing the evidence of Six Sigma and Lean in the health care industry	37	2010	Jami L DelliFraine	Quality management in health care
10	Lean healthcare: rhetoric, ritual and resistance	32	2010	Justin J Waring	Social science & medicine

3.6. Keyword analysis

Keywords condense the core and essence of the paper, and the use of keyword co-occurrence analysis is helpful for find the research hotspot in a certain subject field. The keyword co-occurrence network view of 418 documents was drawn along with VOSviewer, and 50 keywords with frequencies greater than or equal to 10 were selected for visualization, the results of which are shown in the figure below. The larger the circle node, the more frequently the keyword appears, indicating the more representative of the domain hotspot. The nodes' connecting lines represent the association strength, and the thicker the connecting lines indicate that the two appear together in the same literature more often. The color of the nodes denotes different clusters, i.e., research topics. In order to better understand the specific situation of the keywords, the keywords with a frequency of more than 10 are exhibited in the **Figure 4**. It can be seen from the figure that the high-frequency keywords such as quality improvement, health-care and management constitute the representative terms in this field. Through the co-occurrence analysis of the keywords, we obtained a network consisting of four clusters (**Figure 4**). For the sake of getting the characteristics of different keywords appearing in the year, we overlay the view of the keywords appearing more than 10 times by VOSviewer (**Figure 5**). The latest keyword is "efficiency". In addition, "quality improvement" and "health-care" are the main themes in the field.

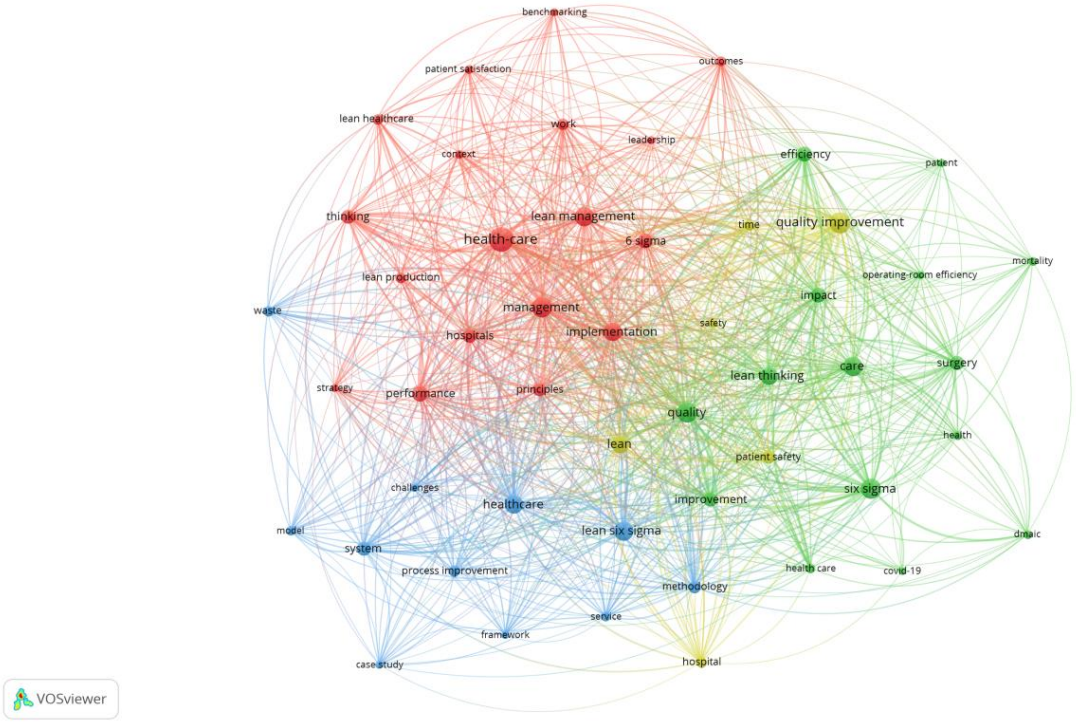

Figure 4. Co-occurrence analysis of keywords (Network Visualization). The network visualization of the keywords (50 items) was conducted.

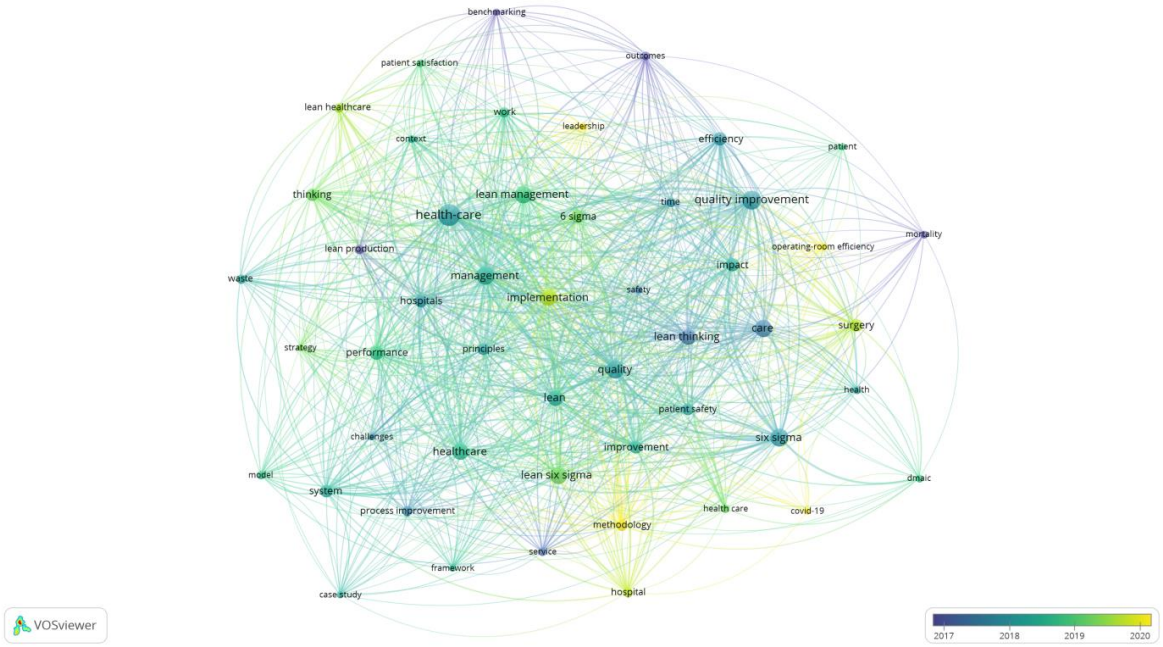

Figure 5. Co-occurrence analysis of keywords (Overlay Visualization). The network visualization of the keywords (21 items) was conducted.

3.7. Historiography and thematic evolution

Bibliometrix also performs in the historiographic analysis, the histplot function plots a chronological citation network (called a historiograph) that represents a

chronological map of the most relevant citations resulting from a bibliographic collection (Hao et al., 2019; Garfield, 2004). In order to trace the dynamic changes in medical lean, we constructed the historiography of the 418 selected documents. The results are shown in the figure below. It can be concluded from the **Figure 6** that the development of medical lean is still in its infancy during the period of 2009–2023, which is a difficult and necessary process for medical lean to experience, and that it is a process in which researchers continuously contribute to the theoretical basis.

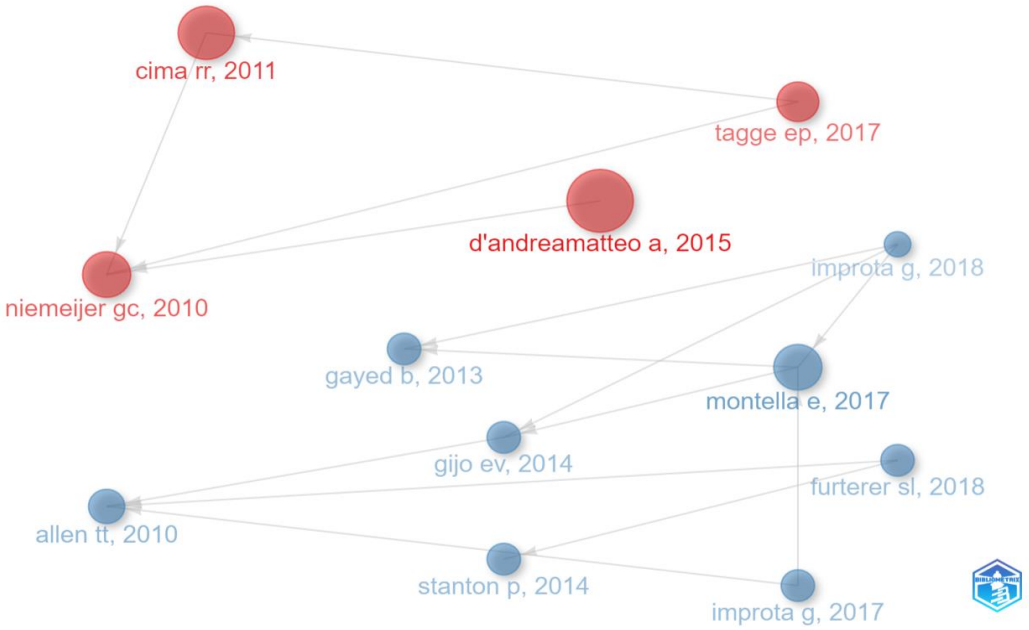

Figure 6. Historiography of medical lean production research. Each circle represents an article, with adjusted number of node to 15 and node label to short id (1st Author, Year).

4. Discussion

4.1. General information

Bibliometric analysis is a quantitative analytical method that can be used to evaluate the impact of research institutions, research fields, journals, authors, and articles. As time goes by, bibliometrics is increasingly being used to obtain scientific achievements of specific academic fields during a certain period of time and to evaluate the trends and advances in various research areas (Ninkov and Maggio, 2022). Lean originates from Toyota production system, which includes 14 management principles (Liker, 2004). The successful implementation of Lean requires managers to fully understand the internal logic of TPS. Currently, there are few studies on the long-term effectiveness assessment of lean in medical and health systems, and there is no authoritative guidance on the implementation of medical lean. Here, we employed bibliometric analysis to examine the literature related to lean in the field of medicine, providing valuable insights into the current development and research frontiers of this field.

During the 15-year period covered by this study, the statistical analysis of related

publications published every year shows that the number of lean publications in the medical field is generally on the rise. This trend peaked in 2021, and then declined slightly. In recent years, lean has been increasingly applied to health systems (Tsai et al., 2021; DelliFraine et al., 2010). However, there are not abundant research articles on medical lean, and the lack of cooperation among different countries, organizations and authors still exists on medical lean, which may partly limit the development of lean in the medical field. In general, although more and more hospitals begin to adopt lean operation mode, its effect is not so significant in improving hospital and patient management (Waring and Bishop, 2010).

The analysis of the top five institutions shows that the institution with the highest publication volume is University of California System. University of Naples Federico II is the most frequently cited institution and has substantial authority in the research field. Frequently occurring keywords can reveal research hotspots, focal points of attention, and potential developments in a field. The most frequently occurring terms are "healthcare," followed by "quality improvement," "management," "lean six sigma," and "implementation." Further analysis of relevant publications and references in conjunction with keyword analysis reflects that lean is mainly used for "healthcare" and "hospital." This is consistent with the research reflected in the "Top 10 Highly Cited Papers." Analyzing and mining high frequency keywords can assist researchers in better understanding the research dynamics and trends, as well as the core concepts and research hotspots in a field, providing valuable references and guidance for further studies.

4.2. Lean model of the Flinders Medical Centre

The Flinders Medical Centre launched a clinical process re-engineering programme in 2003 to apply Lean methods to healthcare, which was the first systematic integration of lean with healthcare. Unlike in manufacturing industry, medical lean production serves patients, which requires managers to process improve lean production methods depending on the health system situation (Ciulla et al., 2018). It is roughly divided into three stages, the first phase analyzed the hospital's deficiencies and contradictions and selected appropriate lean methods to reform the hospital's operational and management framework and to acquire professional Lean knowledge and processes. The second phase was to improve safety, reduce congestion and restore the integrity of the surgical program by improving some of the higher volume patient services such as emergency, adult medical and surgical inpatient care. The third phase is to establish sustainable and standardized processes through diagnostics and front-line engagement to negotiate and develop the best and most efficient way to implement processes that are developed by those involved in the work and are continuously improved and refined during the engagement process (Ben-Tovim et al., 2007).

4.3. Application prospect of lean in medical field in developing China countries

In spite of the fact that many countries around the world have applied lean processes in their healthcare systems (Brandao de Souza, 2009; Mazzocato et al.,

2010), however, few studies have revealed how lean principles have been implemented in healthcare in developing countries. A case study analysis of two hospitals in Brazil demonstrates the key features as well as the specificities of the lean implementation process in developing countries by analyzing and comparing these case studies with the literature. The case studies show that reducing patient lead times and costs and improving financial aspects were the main factors driving the implementation of lean in the hospitals studied, while barriers to the implementation of lean principles were mainly related to human factors such as mistrust among staff, incomplete understanding of lean principles, and lack of participation (Costa et al., 2017).

4.4. Lean in medical education

Furthermore, lean can also be applied to medical education. Adopting lean thinking and lean production mode, the medical undergraduate gain creative management and graduate education and improvement, which makes students receive more standardized and scientific medical training, and promotes the connection between different disciplines. It can do good interaction between basic science and clinical science and it is a long-term development for medical and health system (Kaylan et al., 2022). The University of Kentucky College of Medicine undertook a medical education reform in 2003. Based on the lean production model, separating institutional accountability (management) of quality courses from decision-making processes (production) required to ensure quality courses aims to gradually optimize the curriculum management culture. Stratton et al. propose a hybrid QA governance structure based on the University of Kentucky College of Medicine reform model that embeds individual, locally owned curricular quality programs into a larger, centrally managed quality program. There is a continuous, interdependent cycle of communication between various departments and components. Lessons are learned from manufacturing and production and carefully explored to move toward a model with better quality through innovative, responsive curriculum governance (Stratton et al., 2007).

Three production eras are described in the world-changing machines, by (Womack et al.,1991). In the artisan era, generalists work independently and produce custom products; in the mass age, special personnel work to create standardized products under centralized control; and finally, in the lean era, generalist teams of cross-trained experts use standard procedures under decentralized control to produce customer-specific products. At present, lean production in the medical field, including medical education, medical equipment and other aspects, is in between the mass era and lean era. In general, the successful implementation of medical lean production is affected by many factors, and medical lean production still needs a long time to explore. In this paper, we used sociometry and bibliometrics to visually analyze the indicators such as hotspots, topics and publishing institutions of lean production research in the medical field, aiming to help scholars better grasp the dynamic changes and development trends in the field of medical lean production research.

5. Conclusion

This study combines bibliometrics with scientific knowledge mapping to comprehensively and objectively analyze research on lean in the field of medicine. Overall, the application of lean in medical field started late, and has not become a stable core author group and high-yield research institution in the field. The United States is the leading country in this field, with the highest number of publications. The study identified "healthcare", "quality improvement" and "management" as hot topics in the field. Therefore, the future research should focus on the application and development of quality improvement and lean management in health care system, so as to reduce a series of existing problems, such as waiting time of patients, waste related to inventory, staff turnover and patient transportation, reluctance of staff, difficulty in seeing doctors, and shortage of senior managers. The comprehensive bibliometric analysis and visualization maps presented in this study provide valuable insights and serve as a useful reference for further research in this domain.

Author contributions: Conceptualization, YZ, XY, MZ and QH; methodology, YZ, CS and BC; software, YZ, CS and BC; writing—original draft preparation, YZ and CS; writing—review and editing, YZ, CS, BC, XY, MZ and QH; project administration, YZ, XY, MZ and QH; funding acquisition, XY, MZ and QH. All authors have read and agreed to the published version of the manuscript.

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