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REVIEW

Global trends and hotspots in robotic surgery over the past decade: a bibliometric and visualized analysis

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Abstract
Since its introduction, robotic surgery has experienced rapid development and has been extensively implemented across various medical disciplines. It is crucial to comprehend the advancements in research and the evolutionary trajectory of its thematic priorities. This research conducted a bibliometric analysis on the literature pertaining to robotic surgery, spanning the period from 2014 to 2023, sourced from the Web of Science database. The objective was to delineate the publication trends and trace the development of research topics within the domain of robotic surgery. From 2014 to 2023, there has been a consistent upward trend in the annual volume of publications concerning robotic surgery. The United States emerges as the leading country in terms of both the number of publications (n=3402) and citations (n=57731). The Journal of Robotic Surgery has the highest number of publications (n=506), while IEEE Transactions on Robotics has the highest number of citations (n=53). Yonsei University is the institution with the greatest number of publications (n=196), and the University of Washington has the highest average citation count (n=30). Alexandre Mottrie is the author with the most publications and citations (n=70 publications, n=1816 citations). Keyword analysis revealed seven distinct clusters: (1) applications and techniques of robotic surgery; (2) urological surgery and associated complications; (3) gastrointestinal diseases and surgical interventions; (4) robotic thyroid surgery and related complications; (5) gynecological diseases and corresponding surgical procedures; (6) Da Vinci robot and its training; (7) pulmonary diseases and associated surgeries. Artificial intelligence (AI) has been identified as a newly emerging keyword in the field. The corpus of literature on robotic surgery has seen a steady rise over the past decade, marked by extensive collaboration among various countries, institutions, and researchers. This study has delineated the global trends, identified research hotspots, highlighted emerging topics, and outlined the foundational knowledge within the field of robotic surgery. Looking forward, the integration of AI with robotic surgery is poised to offer substantial benefits and is anticipated to become a pivotal trend and area of focus in the field's future advancement.

Keywords Robot · Robotic surgery · Bibliometrics · Visual analysis

Introduction

With the progression of technological innovation, there has been a growing demand for enhanced surgical precision and safety, which has catalyzed the development of robotic surgery. Since its inception approximately 4 decades ago, robotic surgery has garnered significant interest from the medical community. The inaugural surgical robot, introduced in 1985, was designed to conduct selective brain biopsies. The incorporation of a mechanical arm in this pioneering device endowed it with a futuristic esthetic, while its high level of accuracy and surgical precision highlighted the vast potential of robotic surgery [1]. Following the approval of the Da Vinci robotic system by the United States Food and Drug Administration, the domain of robotic-assisted

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surgery has experienced rapid expansion across multiple disciplines [2]. The advent of AI has propelled robotic surgery to new frontiers, offering unparalleled precision and safety, which in turn allows for the delivery of higher-quality patient care [3].

Bibliometric analysis, by examining published literature, enables the assessment of trends in the development of a specific topic over a designated timeframe. The analysis of research hotspots within the field is particularly effective in delineating the most recent research directions, acting as a significant guide for researchers. It is becoming increasingly evident that bibliometrics has evolved into a vital tool for the evaluation of research endeavors [4].

To date, a significant volume of bibliometric studies focusing on robotic surgery has been documented in the literature [5–7]. Nevertheless, the field of robotic surgery has witnessed rapid progression, leading to an especially notable increase in the literature output over the past decade. Analyzing the literature from this period can provide a clearer understanding of the evolutionary trajectory of robotic surgery in the last 10 years, thereby offering guidance to scientists in making informed decisions. Consequently, conducting a bibliometric analysis of the robotic surgery literature from the past decade is of paramount importance.

This study has conducted an analysis of publications in the realm of robotic surgery from the past decade, uncovering the prevailing publishing trends within this research domain. It has identified the most impactful journals, countries, institutions, and authors, and has delved into the international collaboration network, research hotspots, and emerging themes. Such insights assist researchers in recognizing shifts in research focal points and facilitate the selection of areas of interest and significance for their scholarly inquiries.

Method

Data retrieval

This study employed the Web of Science database, a widely recognized and frequently used resource for literature search and retrieval. The Web of Science Core Collection is subject to a stringent evaluation process, ensuring the provision of information that is both credible and influential. Consequently, it is an ideal choice for the purposes of this research [8].

Retrieval method

The search was performed on March 18, 2024, within the Science Citation Index Expanded database of the Web of Science Core Collection. The search parameters were as follows:

Title=(Robot* Surgery or Robot* Surgical) or Author Keywords=(Robot* Surgery or Robot* Surgical) or Keyword Plus=(Robot* Surgery or Robot* Surgical)

The search criteria specified a publication timeframe from January 1, 2014, through December 31, 2023. The literature was restricted to the English language and the article type, with non-article publications excluded (Fig. 1). To ensure data consistency and to circumvent the effects of database updates, the bibliometric data were downloaded in full on March 18, 2024. The downloaded information includes: titles, authors, affiliations, countries, keywords, journal, publication year, funding agencies.

Analysis tools and methods

VOSviewer, a freely available computer program introduced in 2010, is designed to construct and visually represent bibliometric networks. Since its launch, it has gained widespread popularity for its application in research visualization [9].

For this study, VOSviewer version 1.6.20 was utilized to perform citation analysis of journals, co-authorship analysis of institutions and individual authors, co-citation analysis of references, and co-occurrence analysis of keywords. Furthermore, the research included descriptive analysis encompassing publication years, countries, journals, institutions, and authors to provide a comprehensive overview of the dataset. The publication year is directly extracted from the Web of Science, while the quantity and citation counts are extracted using VOS. The average citations and average publication year are calculated by VOS, and the impact factor is retrieved from the Web of Science Core Collection.

Results

Trend analysis of annual publication volume

A total of 9432 publications pertinent to robotic surgery were identified, and the trend in annual publication volumes from 2014 to 2023 is depicted in Fig. 2. In 2014, the publication count stood at 500, and by 2020, the number of publications surpassed the 1000 mark for the first time, culminating in a peak of 1460 publications in 2023. The publication count in 2023 was 2.92 times that of 2014.

Over the period from 2014 to 2023, there was a consistent upward trajectory in the number of publications annually. The cumulative number of publications from 2019 to 2023 was 6319, which represented a 2.03-fold increase over the number of publications from 2014 to 2018 (3113).

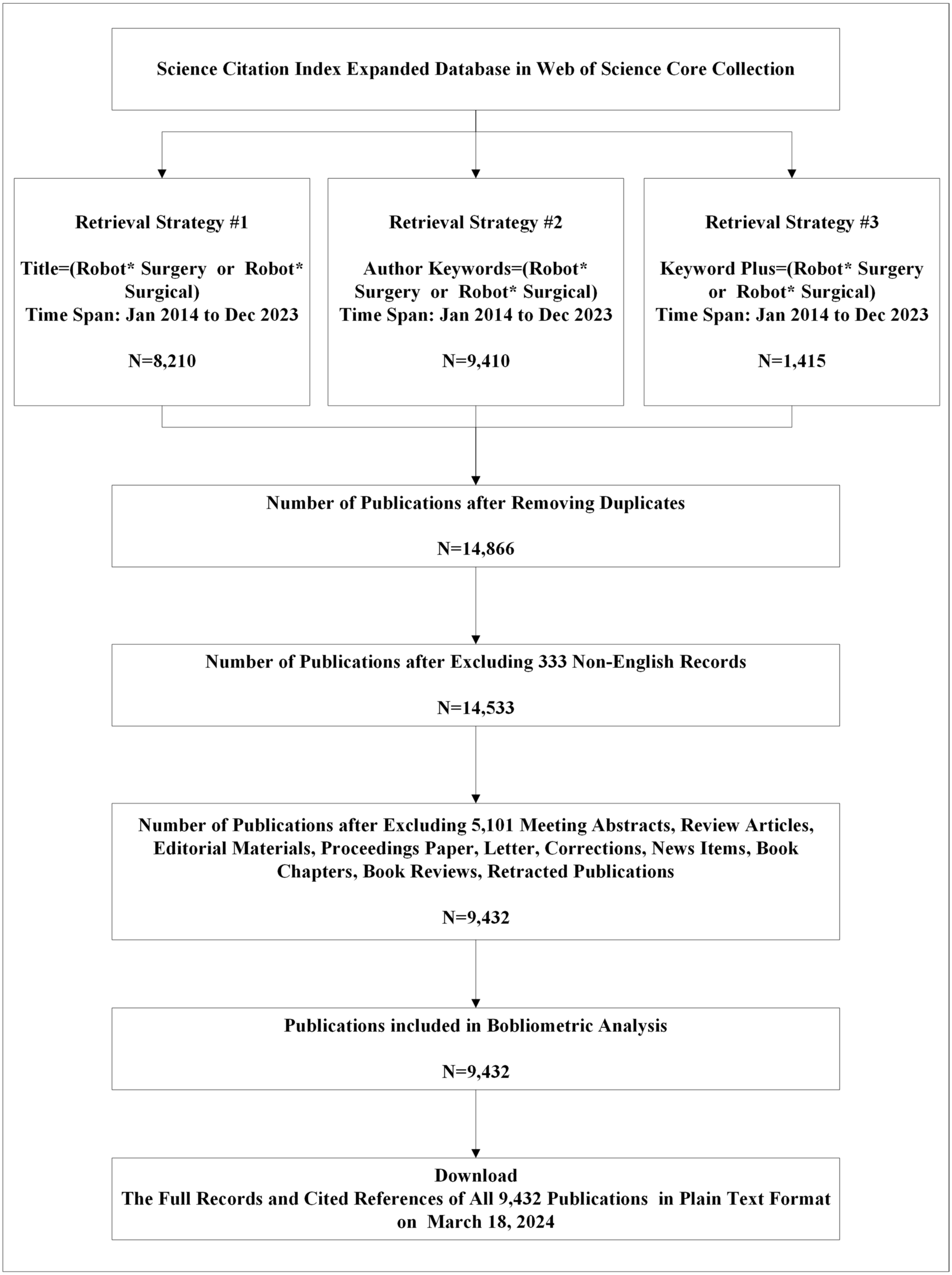

Fig. 1 The data including and excluding strategy

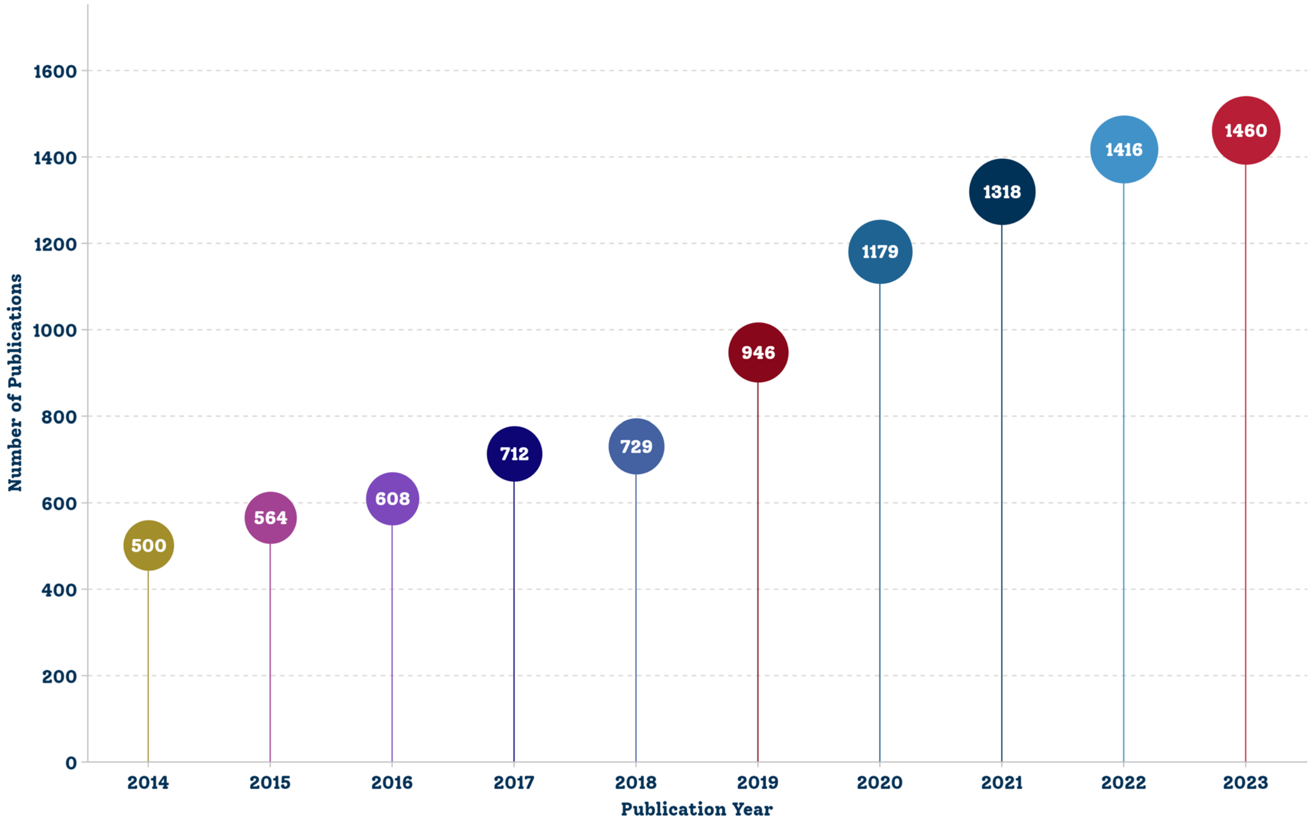

Fig. 2 Annual publication volume and trends of robotic surgery papers from 2014 to 2023

Publication analysis among countries/regions

Ninety-one countries and regions across the globe have contributed to research in the field of robotic surgery, as illustrated in Fig. 3. Among these, 19 countries and regions have published more than 100 articles, and 3—North America, Asia, and Europe—have contributed over 1,000 publications each.

The top ten countries in terms of the number of publications are identified in Table 1. The United States of America (3402 counts, 57731 citations) ranks first in both the number of publications and citations, followed by China and Italy. Among the top ten countries, the United Kingdom and the Netherlands demonstrate the highest average citation frequencies. In addition, four of these countries—China, Japan, the Netherlands, and Belgium—have an average publication year that exceeds 2020.

Analysis of journal publication patterns

A comprehensive analysis of the literature on robotic surgery reveals that a total of 948 journals have contributed to this field. By setting a cutoff of 20 publications per journal, we identified 102 high-output journals. These 102 journals account for 6273 publications, which constitutes 66.51% of the total publications in the domain. A citation analysis was performed on these high-output journals, and an overlay visualization map was generated to illustrate the findings (Fig. 4). The size of the circles within the map represents the number of publications, while the color gradient, ranging from blue to red, signifies the average citation frequency, with blue indicating lower and red higher frequencies. *Journal of Robotic Surgery* stands out with the highest number of publications (n=506), followed by *Surgical Endoscopy and Other Interventional Techniques* (n=481), and *International Journal of Medical Robotics and Computer Assisted Surgery* (n=444). Seventeen journals, highlighted in red on the map, have an average citation frequency exceeding 20. The journal with the highest average citations is *IEEE Transactions on Robotics* (n=53), with *Annals of Surgery* (n=51) and *European Urology* (n=49) in close pursuit.

Analysis of institutional publication volume and co-authorship

A total of 6865 institutions have contributed to the publication of research papers in the field of robotic surgery. The top ten institutions, ranked according to the number of publications, are listed in Table 2. Yonsei University emerged as the leader with 196 publications, followed by Johns Hopkins

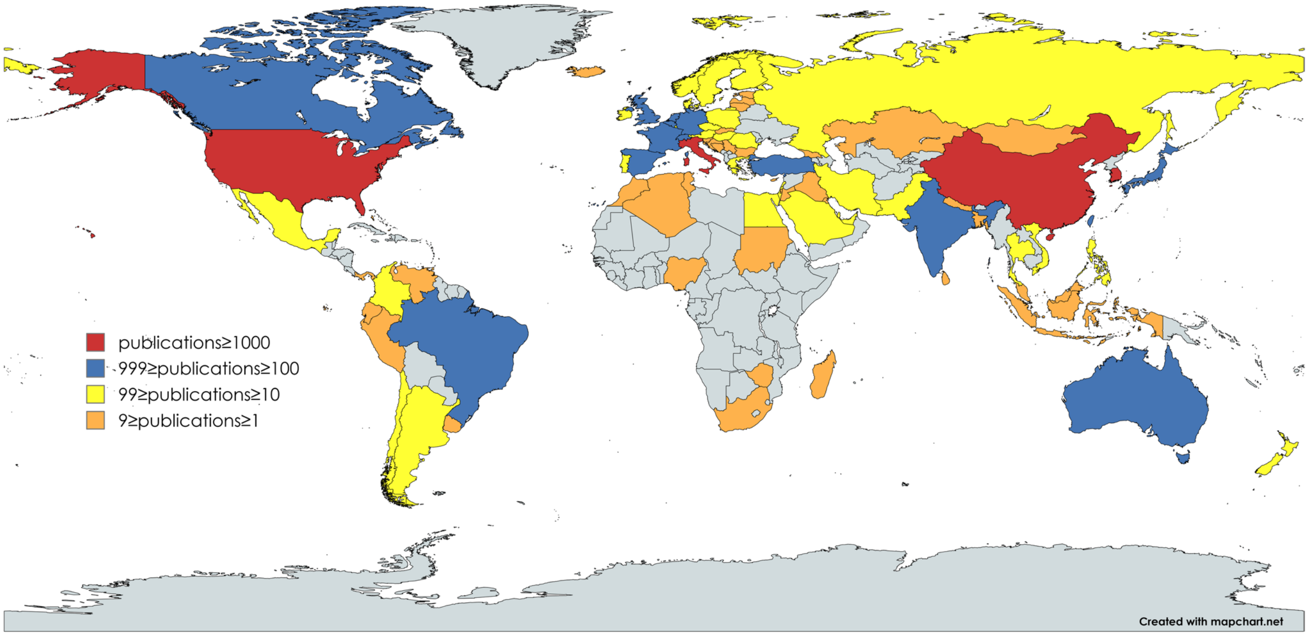

Fig. 3 Countries and regions worldwide participating in research on robotic surgery (2014–2023)

Table 1 Top ten countries by number of publications in the field of robotic surgery research (2014–2023)

Rank	Country	Counts	Citations	Avg. Citations	Avg. Pub. Year
1	United States of America	3402	57731	17	2019.28
2	China	1571	17107	11	2020.43
3	Italy	1053	17749	17	2019.81
4	South Korea	706	9475	13	2019.26
5	United Kingdom	639	13179	21	2019.59
6	Japan	618	6023	10	2020.20
7	Germany	531	9269	17	2019.71
8	France	505	8099	16	2019.67
9	Netherlands	286	5922	21	2020.27
10	Belgium	283	5376	19	2020.16

University with 177, and Shanghai Jiao Tong University with 158. In terms of citations, Johns Hopkins University stands out with the highest total of 4660 citations, with the Cleveland Clinic in second place with 3800 citations, and Yonsei University in third with 3635 citations. Among the top ten institutions, the University of Washington boasts the highest average citation count. In addition, Shanghai Jiao Tong University and The Chinese University of Hong Kong have the most recent average publication year.

A threshold of 20 publications per institution was established, leading to the identification of 247 high-output institutions from a total of 6865. Co-authorship analysis of these 247 institutions was conducted using VOSviewer, revealing that all institutions are represented within a co-authorship network comprising 6 distinct clusters. The largest cluster, colored red, includes 77 institutions (Fig. 5). Johns Hopkins University demonstrates the most extensive collaboration network, partnering with 114 high-output institutions. Yonsei University follows closely with collaborations with 113 high-output institutions, while both Mayo Clinic and Stanford University have established collaborations with 100 high-output institutions.

Analysis of author publication quantity and co-authorship

A comprehensive review of the authorship in the field of robotic surgery reveals that a total of 38,105 authors have contributed to publications. The top 12 authors, ranked according to the number of publications, are presented in Table 3. Alexandre Mottrie emerges as the author with the highest number of publications, totaling 70, with Francesco

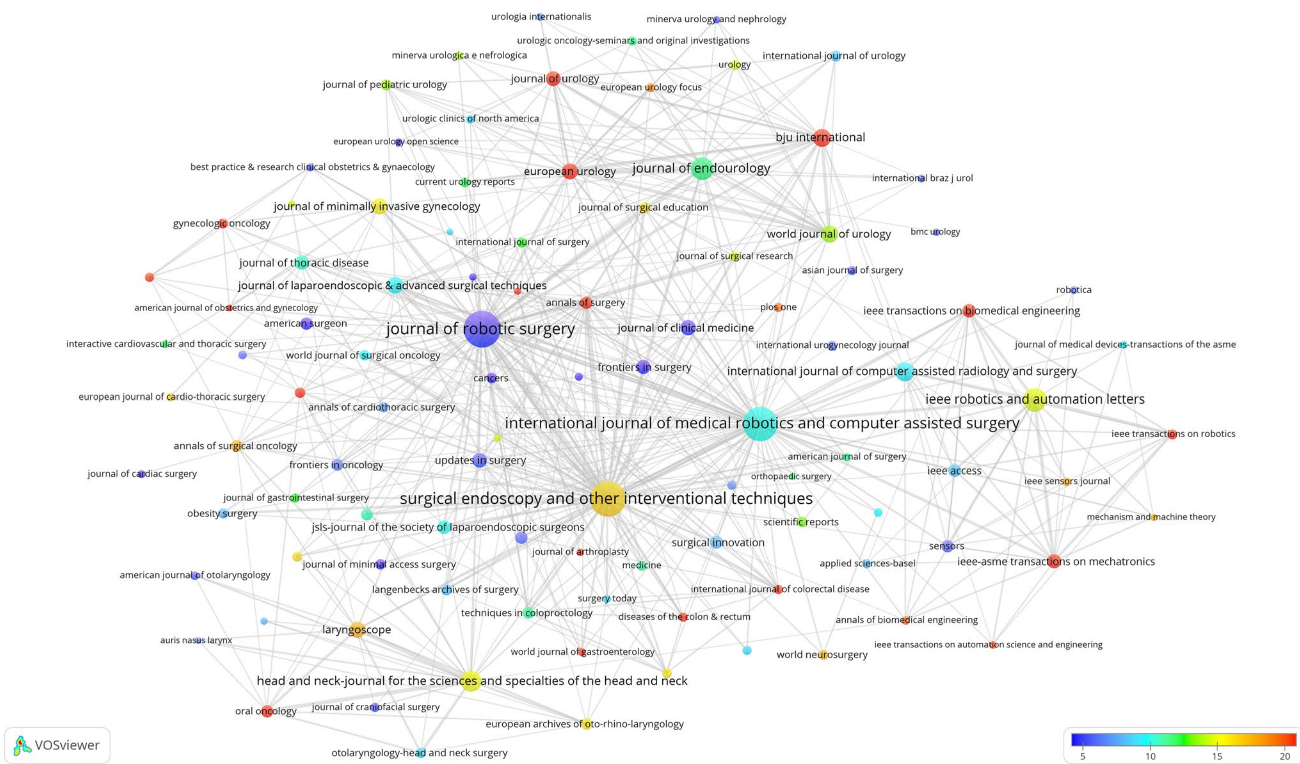

Fig. 4 Overlay visualization map of publication volume and citation count for journals with more than 20 publications in the field of robotic surgery (2014–2023)

Table 2 Top ten institutions by number of publications in the field of robotic surgery research (2014–2023)

Rank	Institution	Counts	Citations	Avg. Citations	Avg. Pub. Year
1	Yonsei University	196	3635	19	2019.19
2	Johns Hopkins University	177	4660	26	2019.37
3	Shanghai Jiao Tong University	158	2002	13	2020.36
4	Cleveland Clinic	150	3800	25	2018.43
5	Mayo clinic	143	2717	19	2019.55
6	The Chinese University of Hong Kong	133	2973	22	2020.23
7	Harvard University	131	2541	19	2019.17
8	Stanford University	120	2715	23	2018.85
9	University of Washington	115	3480	30	2018.91
10	Seoul National University	113	1927	17	2019.22

Porpiglia in second place with 52 publications, and Rong Liu in third with 45. In terms of citations, Alexandre Mottrie also leads with 1816 citations, followed by Prokar Dasgupta with 1784 citations, and Arianna Menciassi with 1435 citations. Prokar Dasgupta has the highest average citation count at 41, with Arianna Menciassi and Khurshid A. Guru following with 38 and 30, respectively. Among the top 12 authors, Andrea Minervini has the most recent average publication year, suggesting a rapid development and increasing presence in the field in recent years.

A threshold of 10 publications per author was set, resulting in the identification of 492 high-output authors from a pool of 38,105. Co-authorship analysis was performed on these 492 authors using VOSviewer, revealing that 429 authors formed the largest co-authorship network, which consisted of 17 clusters (Fig. 6). Approximately 90% of the high-output authors were represented within this network. Among the most collaborative authors, Francesco Montorsi stands out, having collaborated with 104 high-output authors. Alexandre Mottrie follows with collaborations with 100 high-output authors, and Francesco Porpiglia with 89. Notably, within the network, two groups have established particularly close collaborative relationships. Francesco Porpiglia, Cristian Fiori, Daniele Aparore, and Enrico

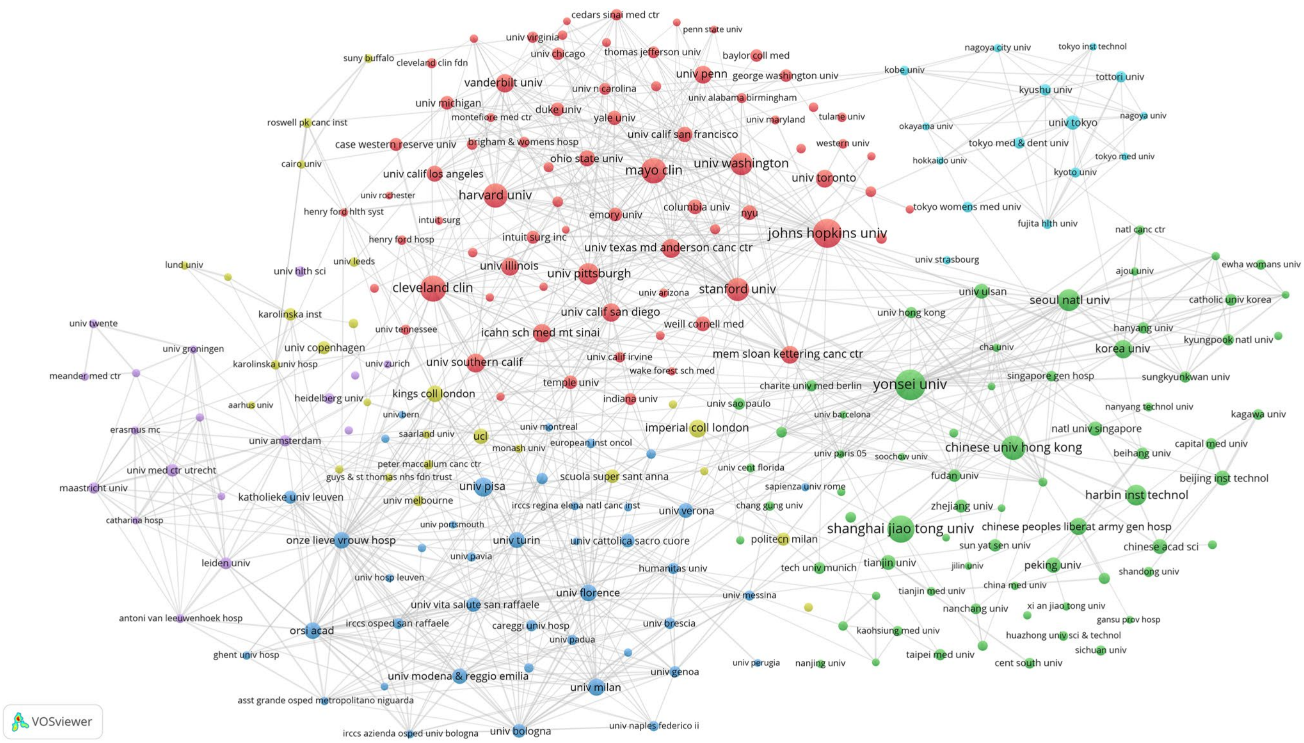

Fig. 5 Co-authorship network diagram of institutions with more than 20 publications in the field of robotic surgery (2014–2023)

Table 3 Top twelve authors by number of publications in the field of robotic surgery research (2014–2023)

Rank	Author	Counts	Citations	Avg. Citations	Avg. Pub. Year
1	Mottrie, Alexandre	70	1816	26	2020.16
2	Porpiglia, Francesco	52	1296	25	2020.12
3	Liu, Rong	45	614	14	2020.62
4	Dasgupta, Prokar	43	1784	41	2018.30
5	Kaouk, Jihad	43	1193	28	2019.98
6	Montorsi, Francesco	43	1048	24	2019.93
7	De Momi, Elena	39	960	25	2019.59
8	Menciassi, Arianna	38	1435	38	2018.08
9	Guru, Khurshid A.	35	1041	30	2017.86
10	Yang, Guang-Zhong	35	945	27	2017.57
11	Abaza, Ronney	35	631	18	2019.26
12	Minervini, Andrea	35	515	15	2021.06

Checcucci form one tight-knit collaborative group (green cluster), while Alexandre Mottrie, Geert De Naeyer, and Ruben De Groote constitute another (light blue cluster).

Analysis of co-citation in references

All scientific research is built upon the foundation of previous studies. Analyzing references can help us understand the foundational knowledge in a particular field of research. The 9,432 publications on robotic surgery have cited a total of 127,758 references. We set the threshold for the number of citations for references at 60 times, and from the 127,758 references, we selected 110 highly cited references. We used VOSviewer to conduct a co-citation analysis of these 110 highly cited references and constructed a density map (Fig. 7), which is similar to a heatmap. In the map, red represents the highest number of citations, followed by yellow. The most cited article is by Dindo, published in Ann Surg in 2004, which has been cited 872 times. The article criticizes the accuracy and acceptability of the current classification of postoperative complications and proposes a new objective and

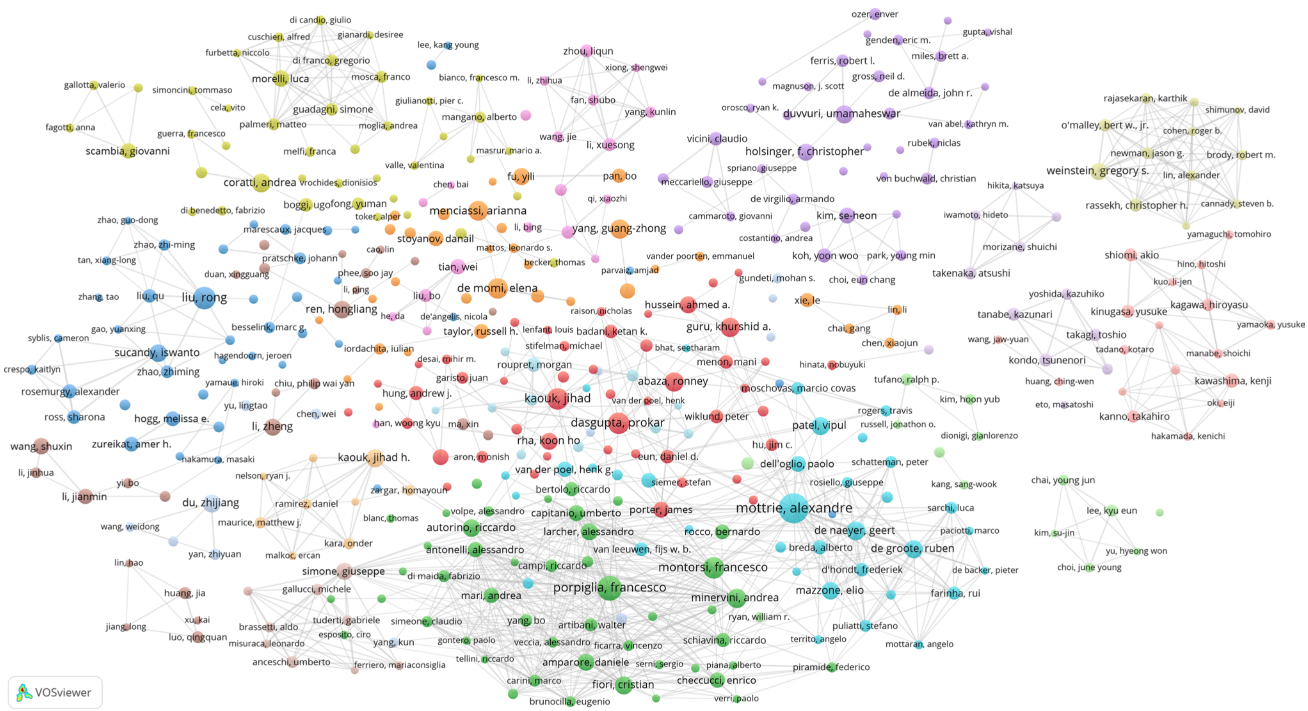

Fig. 6 Co-authorship network diagram among authors with more than 10 publications in the field of robotic surgery research (2014–2023)

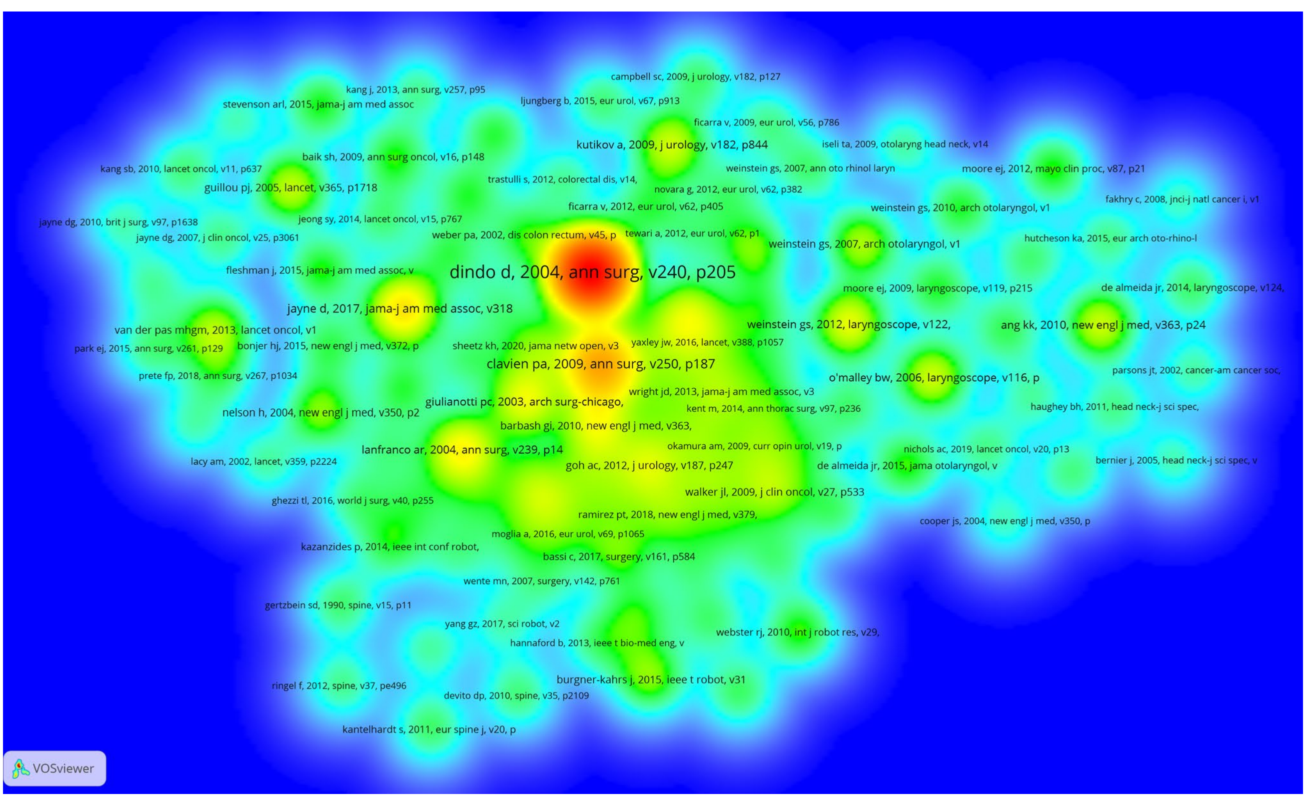

Fig. 7 Density map of references cited more than 60 times in the field of robotic surgery (2014–2023)

reproducible grading system for postoperative complications [10].

Clustering and co-occurrence analysis of keywords

Subsequently, we analyzed the keywords across all publications, totaling 18,785 keywords within the 9432 articles. A threshold of 30 occurrences was set to define high-frequency keywords, leading to the identification of 278 keywords that met this criterion. A co-occurrence analysis was performed on these 278 high-frequency keywords, and a co-occurrence network map was generated (Fig. 8). This network map comprises seven clusters, each denoted by a distinct color. The red cluster, which includes 54 keywords, is the largest. Cluster 1 (red), Cluster 2 (green), Cluster 3 (blue), Cluster 4 (yellow), Cluster 5 (purple), Cluster 6 (light blue), and Cluster 7 (orange) are focused on the following research topics, respectively: (1) application and related technologies of surgical robots, (2) urological surgeries and complications, (3) digestive system diseases and surgeries, (4) robot-assisted thyroid surgery and complications, (5) gynecological diseases and related surgeries, (6) da Vinci robot and related training, (7) lung diseases and related surgeries. This clustering provides a visual representation of the key research topics within the field of robotic surgery based on keyword co-occurrence.

Following this, we utilized VOSviewer to construct an overlay map for the 278 high-frequency keywords (Fig. 9). The color of each node represents the average publication year of that keyword, with the transition from blue to red indicating more recent publication years.

Discussion

With the progression of technological advancements, the precision of surgical procedures has notably improved. In this regard, minimally invasive surgery has gained popularity among patients, largely due to its benefits of decreased trauma and abbreviated hospital stays, making it the method of choice for many clinical scenarios. Robotic surgery, a cutting-edge technology within the realm of minimally invasive surgery, has undergone five generations of development since its inception, continually evolving to meet the needs of patients. It presents a range of advantages, including abbreviated recovery periods and enhanced surgical safety. Nonetheless, challenges such as extended operation times and significant variations in hospital costs persist. Analyzing the literature from the past decade can provide insights into future trends, guiding the development of surgical robots to better align with patient needs and thereby more effectively serve humanity.

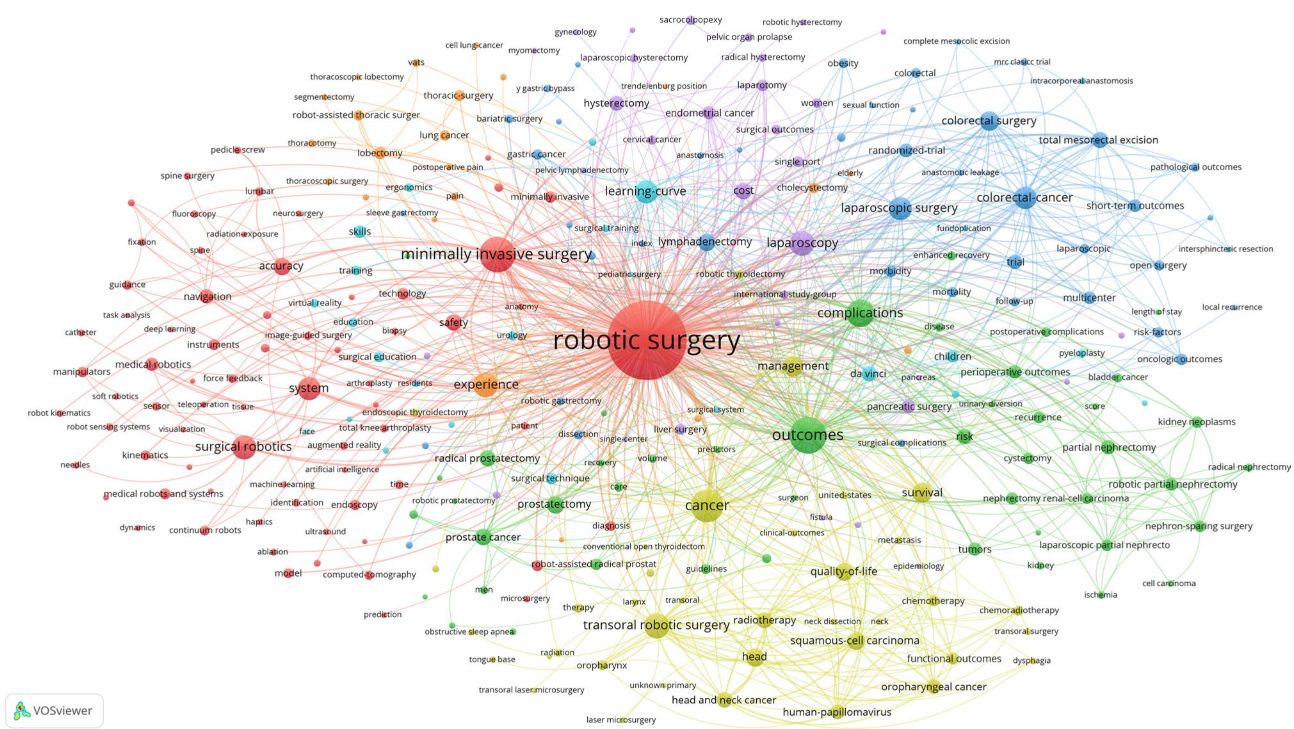

Fig. 8 Co-occurrence network map of keywords appearing more than 30 times in the literature of robotic surgery (2014–2023)

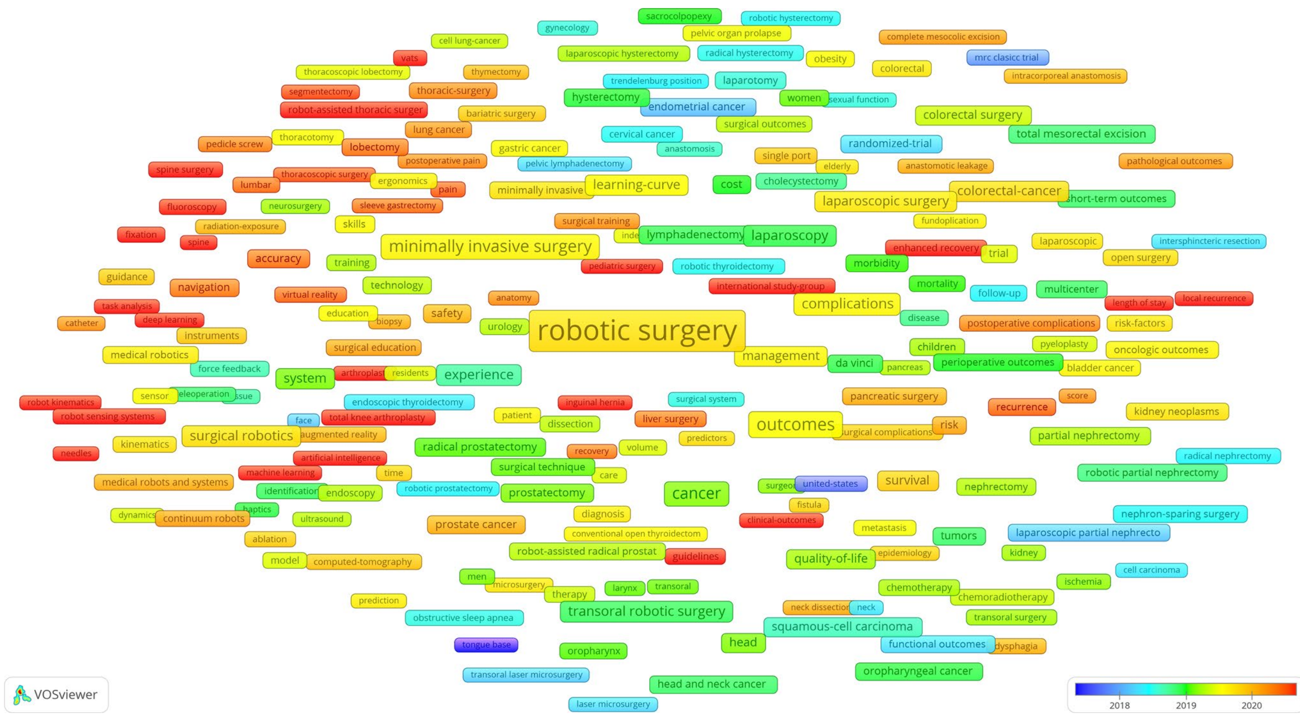

Fig. 9 Co-occurrence overlay map of keywords appearing more than 30 times in the literature on robotic surgery (2014–2023).

Publication trends

Our bibliometric analysis has revealed a consistent upward trajectory in the number of articles published over the past decade, from 2014 to 2023, reflecting the rapid growth and high level of interest among researchers in the field of robotic surgery. The United States stands out as the leading nation in both the volume of publications and the number of citations, maintaining its dominance in this domain. A total of 948 journals have contributed to the research on robotic surgery, with 102 of these journals publishing more than 20 articles, which constitutes 66.51% of the total publications. The *Journal of Robotic Surgery* holds the distinction of having the highest number of publications, while *IEEE Transactions on Robotics* is the journal with the most citations.

International collaboration

A comprehensive review of the research landscape in robotic surgery reveals that a total of 6865 institutions and 38,105 authors have been actively involved. Within the top ten institutions in terms of publication output, Yonsei University and Johns Hopkins University take the lead, not only in terms of the number of publications but also in citations. These institutions are also known for their extensive collaborations, acting as pivotal global research centers. Shanghai Jiao Tong University and The Chinese University of Hong Kong demonstrate the most current average publication years, suggesting a significant increase in their research activity in recent times. Among the top 12 authors by publication volume, Alexandre Mottrie stands out with the highest number of publications and citations, and he has an extensive network of collaborations with 100 high-output authors. Prokar Dasgupta boasts the highest average citation count, while Andrea Minervini has the most recent publication year, indicating a surge in his research contributions.

Research clustering and hotspots

Among the 18,785 keywords extracted from 9432 publications, a threshold of 30 occurrences was established to identify 278 high-frequency keywords. Subsequent co-occurrence analysis revealed that these keywords were organized into seven distinct clusters, each reflecting a specific research focus within the domain of robotic surgery.

Red: application and related technologies of robotic surgery

Robot-assisted surgery (RAS) has been an integral part of surgical practice for several decades since its inception, gaining widespread acceptance due to its enhanced flexibility, high-resolution visualization, and the expanded field of view it offers for surgical procedures. Despite initial challenges, such as high costs and a learning curve for operators, RAS has demonstrated advantages over traditional open surgery, including reduced blood loss, shorter hospital stays, and expedited patient recovery. The annual volume of robotic surgeries has seen a substantial increase over the years. However, it is noteworthy that in certain surgical specialties, RAS has not yet been definitively shown to be significantly superior to conventional surgical techniques [11–14]. The potential reasons for the lack of significant superiority in some surgical fields may include the initial lack of experience among surgeons, which hindered their ability to fully master the necessary skills, as well as the limited body of research available. However, there is no need for undue concern, as the benefits of RAS are anticipated to become more evident with the accumulation of experience and the expansion of data. Notably, Bravi and colleagues' research revealed that there was no significant difference in the incidence of complications between less experienced and experienced surgeons when performing robot-assisted radical prostatectomy [15]. This finding suggests that robotic surgery can be readily adopted by surgeons, enabling them to perform surgeries with a level of proficiency comparable to that of experienced practitioners, even in the early stages of their careers. In terms of operation time, seasoned robotic surgeons have demonstrated the ability to significantly decrease the duration of surgical procedures, achieving efficiency on par with traditional laparoscopic surgeons [16, 17]. Therefore, intensifying training in robotic surgery and enhancing coordination within surgical teams can markedly reduce operation times. Studies have indicated that in rectal cancer surgery, the operation time significantly decreases once the entire robotic team has completed more than 30 procedures. It is anticipated that this trend will be observed in other surgical specialties as well, and greater proficiency in utilizing the technology would significantly benefit patients [18]. Most significantly, research has demonstrated that surgeons can transition directly from open surgery to robotic surgery without the need for extensive prior experience in laparoscopic procedures. This transition can be successfully implemented before the adoption of robotic surgery, indicating the potential for rapid integration of this technology into surgical practice [19]. In the future, robotic surgery is poised to become the preferred method for many surgeons. The primary concern is to mitigate risks to patients when adopting new surgical techniques. Consequently, early educational courses are crucial to ensure that the learning curve for new technologies is as brief and efficient as possible, thereby enhancing the safety of surgical procedures. By integrating robotic surgery training into their early education, surgeons can become proficient in these techniques more rapidly, enabling them to provide optimal patient care.

Green: urological surgeries and complications

The standard surgical approach for auto-transplantation typically involves performing open surgery following a laparoscopic nephrectomy [20]. However, robot-assisted kidney transplantation has notably enhanced the safety of the procedure, not only by reducing the incidence of surgical complications but also by eliminating the need for conversion to open surgery [21]. In addition, Vigués and colleagues have demonstrated that for patients who are not candidates for heterotopic kidney transplantation, in situ robot-assisted kidney transplantation is a feasible and safe option [22]. Moreover, robot-assisted retroperitoneal lymph node dissection has produced outcomes that are comparable to those of open surgery [23]. Furthermore, Calpin and colleagues have shown that in the context of partial nephrectomy, robotic surgery significantly outperforms open surgery and traditional laparoscopic surgery in terms of postoperative complications, hospital stay, and blood loss, while also being equivalent in other respects [24]. In bladder surgery, Khetrapal and colleagues conducted an analysis of the effectiveness of robotic surgery for cystectomy. Although the operation time was longer and the incidence of complications was comparable to that of open surgery, patients who underwent robotic surgery experienced significantly shorter hospital stays and significantly reduced blood loss, which often obviated the need for blood transfusions [25]. Furthermore, in a study by Martini and colleagues, it was found that patients who underwent robot-assisted cystectomy had a lower incidence of incontinence at 12 months following neobladder reconstruction, and their erectile function was generally well-preserved [26]. Similarly, in prostate surgery, Haney's systematic review revealed that patients who underwent robot-assisted radical prostatectomy had a significantly lower incidence of incontinence at 3 and 6 months postoperatively compared to those who underwent traditional laparoscopic surgery, although there was no significant difference in incidence at 12 months. In addition, for patients with nerve preservation, robotic surgery was more effective, and the positive surgical margin rate was equivalent to that of traditional laparoscopic surgery [27]. Beyond its application in surgical procedures, robotics also plays a role in urological diagnostics. Petov and colleagues conducted a meta-analysis on the diagnostic efficacy and safety of robot-assisted prostate biopsy, which found that it not only has high monitoring accuracy but also comparable detection rates of prostate cancer and overall detection rates to systematic prostate biopsy, with a lower risk of complications [28]. This is significant for the early diagnosis of prostate cancer. Lastly, studies have indicated that patients with a history of previous prostate surgery are at a higher risk of adverse outcomes following robot-assisted radical cystectomy [29]. This suggests that previous surgeries can influence the incidence of surgical complications.

Therefore, future research should further investigate which patient populations stand to gain the most from robotic surgery and develop personalized treatment plans tailored to these patients.

Blue: digestive system diseases and surgeries

Since the advent of minimally invasive surgery, this technology has significantly enhanced the cosmetic outcomes for patients with colorectal cancer, while concurrently reducing complications, substantially shortening hospital stays, decreasing the need for analgesics, and expediting the recovery of intestinal function. Consequently, the surgical approach for these patients has progressively shifted from open surgery to minimally invasive surgery [30]. However, laparoscopic surgery presents certain limitations, such as limited flexibility in managing complex situations and inadequate exposure to the surgical field. The introduction of robotic surgery addresses some of these limitations but also introduces new challenges. Despite this, the benefits of robot-assisted colon surgery over laparoscopic colon surgery have not been definitively established in prospective experiments. Weber and colleagues were among the first to report on robot-assisted colon surgery [31]. Following over a decade of development, robotic technology has advanced significantly. For colon cancer surgery, robotic surgery has been shown to reduce the surgical stress response compared to laparoscopic surgery [32]. Cuk and colleagues conducted a comparison of the long-term survival outcomes between robotic surgery and laparoscopic surgery for patients with colon cancer, ultimately finding that robotic surgery could significantly improve recurrence-free survival, although there was no significant improvement in overall mortality and cause-specific mortality [33]. In a statistical analysis of patients with middle and low rectal cancer, robotic surgery did not significantly enhance the quality of total mesorectal excision [34]. Khajeh and colleagues compared the advantages and disadvantages of robotic surgery, open surgery, and laparoscopic surgery in rectal cancer surgery, and the results indicated that, aside from longer operation times and higher costs, robotic surgery was superior to both laparoscopic surgery and open surgery in all other aspects [35]. Importantly, operation times were observed to decrease with increasing experience in robotic surgery, and if the surgeon's proficiency with robotic and laparoscopic techniques was equivalent, the time required for robotic surgery was shorter than that for laparoscopic surgery [36]. In addition, studies have found that the amount of bleeding during robotic surgery was significantly less than that during open surgery and laparoscopic surgery, which may be attributed to the flexibility of surgical maneuvers, the precision of resection, and advanced visualization technology [37]. However, there are also studies that present contrasting findings, and due to the challenges in assessing blood loss during surgery, this conclusion should be interpreted with caution. Currently, numerous articles have evaluated the incidence of postoperative adverse reactions following robotic surgery, but the conclusions drawn are not entirely consistent. Establishing multi-center, large-sample, prospective randomized controlled studies to investigate the long-term effects of robotic surgery remains a priority.

Yellow: robot-assisted thyroid surgery and complications

Traditional thyroid surgery typically involves an open direct approach, which is a safe and effective treatment method. However, it leaves a noticeable surgical incision on the neck, which is particularly undesirable for female patients, who constitute the majority of thyroid cancer patients. The advent of endoscopic technology has effectively addressed this issue, offering better control over complications compared to traditional open surgery, and making it more popular among young women [38, 39]. However, endoscopic surgery also has limitations, such as reduced flexibility and the absence of stereoscopic imaging. The introduction of robotics has successfully overcome these limitations, and in addition, robots can exert more powerful and continuous control over the gland, reducing unnecessary manipulations during surgery, and allowing for safer and more precise operations, which has led to the gradual acceptance of this emerging technology [40, 41]. However, Lee and colleagues compared the outcomes of robotic surgery to laparoscopic surgery in patients with papillary thyroid microcarcinoma and found that patients undergoing robotic surgery experienced transient hypocalcemia more frequently after surgery, while other complications, including recurrence during iodine treatment, were not abnormal [42]. The possible reason for this is that robotic surgery may remove thyroid tissue more thoroughly, potentially leading to temporary damage or ischemia of the parathyroid glands due to the proximity of the operation. On the other hand, studies have demonstrated that the number of lymph nodes dissected during robotic surgery is greater than that during laparoscopic surgery, indicating that under the same length of incision, robotic surgery can perform a wider range of surgical operations and more thorough resections [42]. Furthermore, Paek and colleagues compared the efficacy of bilateral axillary breast approach robotic surgery to traditional open surgery for neck lymph node dissection, and the results revealed that the two surgical methods were comparable in terms of surgical integrity and the incidence of complications [43]. In addition, single-port axillary thyroidectomy is a novel technique that has emerged following the development of the new version of the da Vinci robotic system. This approach offers several benefits to patients, including less visible scarring and milder postoperative reactions, while also enhancing surgeon comfort by shortening the time required for instrument docking and increasing the portability of the surgery [44]. Lastly, transoral robotic thyroidectomy represents the latest advancement in this field. By utilizing the vestibular approach, patients can avoid skin incisions, and the exposure of the recurrent laryngeal nerve is improved, making it particularly suitable for individuals with a higher body mass index. This technique has already been widely adopted in clinical practice [45]. In summary, as technology continues to advance, the application of robot-assisted thyroid surgery is expected to expand further, bringing benefits to a greater number of patients. Robot-assisted thyroid surgery has seen significant advancements in recent years, offering patients more diverse treatment options.

Purple: gynecological diseases and related surgeries

In the past few decades, minimally invasive surgery has gained increasing prominence in the treatment of gynecological malignant tumors and has become a standard surgical approach. Robotic surgery, with its enhanced flexibility, precision, and significant benefits during the perioperative period, has been widely integrated into clinical practice. However, the long-term oncological outcomes following surgery remain a critical consideration. A meta-analysis conducted by Csirzó and colleagues compared the perioperative outcomes of robot-assisted laparoscopy (RAL) and conventional laparoscopy (CL) in the treatment of endometriosis, revealing that RAL did not demonstrate significant differences from CL in most aspects, although CL exhibited advantages in terms of operation time and efficiency [46]. Nonetheless, in clinical practice, RAL offers certain advantages over CL, and further research is necessary to fully elucidate the respective merits and limitations of both techniques in medicine. In the treatment of uterine fibroids, since the first report of robot-assisted laparoscopic myomectomy (RALM) in 2004, it has been widely recognized as a safe and effective procedure [16]. However, a meta-analysis by Kayani and colleagues comparing the surgical outcomes of RALM, laparoscopic myomectomy (LM), and abdominal myomectomy (AM) found that RALM significantly reduced blood loss, the need for blood transfusions, and hospital stay when compared to AM, while operation time and costs increased. When compared to LM, RALM showed a higher risk of blood transfusion and increased costs, with no significant differences in other aspects [47]. Therefore, overall, RALM demonstrated short-term benefits, but further investigation is required to assess its long-term efficacy and cost-effectiveness. Regarding postoperative fertility and pregnancy, multiple studies have demonstrated that the postoperative fertility rate following RALM exceeds 70%, indicating favorable efficacy [48, 49]. In addition, Baeten and colleagues conducted a study on the learning curve of RAL in patients with early-stage cervical cancer. They found that after 61 surgeries, the operator's experience significantly increased, and there was a trend toward reduced complications and recurrence rates [50]. Therefore, for patients, skilled operation enhances surgical safety, and for the operator, ensuring patient safety is paramount when performing robotic surgery. In summary, as the complexity of gynecological surgeries increases, robotic surgery has become an indispensable surgical tool.

Light blue: da Vinci robot and related training

Although laparoscopic surgery yields favorable outcomes, operators often experience neck, forearm, or finger pain and fatigue due to the suboptimal design of laparoscopic instruments and improper body posture. Robotic surgery has effectively addressed these issues [51]. Since the da Vinci robotic surgery system received approval from the U.S. Food and Drug Administration for general surgery in 2000, it has initiated a revolution in minimally invasive surgery. As defined by the International Organization for Standardization, the da Vinci surgery system is a master-slave system or telemanipulator that requires human intervention to perform tasks. Initially used for cardiac surgery, it was subsequently approved for use in various surgical specialties, including urology and gynecology, and has since become the most widely used robotic platform [52]. Several versions of the system have been released, and with the introduction of the da Vinci single-port robotic platform, the benefits of robotic surgery have been further amplified. In some developed countries, the use of the da Vinci system for robotic surgeries has reached millions of cases. However, despite the potential advantages of robotic surgery, it has not been widely adopted in middle- and low-income countries. GlobalSurg Collaborative Studies have shown that surgical infection rates are higher in these countries, and robotic surgery can significantly reduce surgical-site infections, making its introduction in these settings a clear benefit [53]. As robotic technology is used more frequently, training for operators new to the technology becomes particularly crucial, as early-stage operators with less experience may have poorer outcomes in terms of operation time and results compared to experienced operators. Therefore, adequate initial training helps operators overcome the initial lack of experience, benefiting patients more. In addition, standardized training programs are necessary to ensure that residents in training programs have similar levels of knowledge and skills, allowing residents to be trained early and to perform surgeries with better techniques. Various training methods are already available [54, 55]. The da Vinci robotic surgery system represents an important milestone in the development of medical technology, as it not only improves surgical precision and safety but also reduces patient trauma and recovery time. As technology continues to advance and its applications expand, corresponding training and education will also continue to develop to meet clinical needs and technological progress. In summary, early training on the da Vinci robot is significant for doctors' personal skill enhancement, patient safety, hospital service quality, and the development of medical technology. With the continuous advancement of technology, early training will become an indispensable part of a doctor's career.

Orange: lung diseases and related surgeries

Robot-assisted thoracoscopic surgery (RATS) was first reported in 2002 [56]. Although minimally invasive surgery has largely replaced open surgery for chest tumors, the advantages of RATS over video-assisted thoracoscopic surgery (VATS) remain controversial, with no definitive conclusions reached to date and various studies presenting conflicting findings. However, it is generally believed that RATS offers several clear advantages over VATS, including more stable instruments, better maneuverability, improved precision, and continuous innovation and improvement of the robot, which addresses past limitations. Numerous studies have explored the benefits of both approaches. A prospective single-center randomized trial by Jin and colleagues demonstrated that in lobectomy, traditional VATS and RATS have equivalent efficacy in the treatment of early-stage non-small cell lung cancer, with no significant differences in early outcomes and complication rates. However, RATS was found to have a higher lymph node detection rate and significantly lower bleeding compared to VATS [57]. Kent and colleagues analyzed the outcomes of patients with clinical stage IA-IIIA lung cancer and compared the outcomes of open surgery, VATS, and RATS. They found that VATS and RATS had lower complication rates, shorter hospital stays, and lower transfusion rates compared to open surgery. Importantly, RATS showed more advantages in these aspects compared to VATS [58]. In addition, Yang and colleagues also compared the efficacy of RATS and VATS in Segmentectomy and found that RATS had advantages in terms of hospital stay and blood loss, although the cost was higher [59]. As most conclusions are based on short-term observations, the evidence base is growing, and there will be a greater need for skilled robotic surgeons in the future. Since RATS is still in the early stages of development, the issue of high costs is a significant consideration. However, it is important to note that VATS typically requires at least three operators to complete the surgery, while RATS only requires two. It can be anticipated that with technological advancements and increased competition among various brands, the cost of RATS will decrease to a more acceptable level in the future. Despite the challenges, robotic lung surgery remains a rapidly evolving field, providing patients with more treatment options and showing great potential for improving surgical precision and patient recovery. With the progression of technology and the accumulation of experience, the advantages of robotic lung surgery are expected to become more pronounced.

Emerging topics

In recent years, the development of AI has surpassed expectations, and the widespread adoption of AI technologies, such as ChatGPT, signals a future deeply intertwined with AI assistance. Currently, AI has been integrated into various fields, particularly in medicine, where it has been enthusiastically embraced and can even rival the expertise of experienced medical professionals [60, 61]. The advent of AI may disrupt the current landscape of surgical robotics, potentially challenging the dominance of a few approved devices [62]. The fusion of AI and robotics has brought about revolutionary changes in the medical field. AI can interface with robots, providing real-time sensory data, and enabling doctors and robots to respond collaboratively to various surgical situations and intervene as necessary. The integration of AI empowers robots to learn from surgeons' demonstrations, gaining the ability to perform tasks autonomously with satisfactory speed and precision, which helps alleviate surgeon fatigue during procedures. Presently, robots are capable of performing operations such as suturing and knot-tying under the guidance of AI. With the development of more sophisticated algorithms, the capabilities of robots in executing complex actions continue to advance. This synergy not only enhances the precision and efficiency of surgical procedures but also provides crucial support to surgeons, making the surgical process safer and more dependable. Human–computer interaction is a pivotal application area of AI technology, especially within the domain of medical-surgical robotics. With sophisticated sensors and algorithms, robots can recognize and interpret non-contact commands from surgeons, such as eye gaze, speech, and gestures. This form of interaction not only enhances the precision and efficiency of surgical procedures but also minimizes the risk of infection that can occur during surgery [63, 64]. As technology progresses, the application of human–computer interaction in medicine will become more extensive and profound, offering greater convenience and benefits to both healthcare providers and patients. The advent of 5G technology has significantly accelerated the integration of robotic surgery. Li and colleagues reported on a case where a radical nephrectomy was performed remotely via 5G technology, with a median distance of 187 kilometers between the surgeon and the primary hospital and a median round-trip delay of just 26 milliseconds. The synergy of 5G technology and robotic surgery ensures surgical quality while substantially reducing patient costs, enabling patients to access a higher standard of medical care [65]. It is evident that the application of robotic surgery in developed countries or regions far outpaces that in other areas. To bridge this gap, it is crucial to research and develop equipment suitable for primary hospitals. For instance, Zhang and colleagues demonstrated an AI-driven bronchoscope robot, which empowers inexperienced physicians to safely and adeptly perform lung examinations, thereby helping to mitigate disparities in medical care in underserved areas [66]. In the future, we should strive to develop more affordable and versatile robots to meet the needs of the general public. With technological advancements and cost reductions, robotic surgery is anticipated to be applied more widely, thereby enhancing the quality and accessibility of global medical services. Although we are currently in the early stages of integrating AI with robotic surgery, AI has already made significant contributions across various domains. It is undeniable that the widespread application of AI will pose challenges to existing laws, ethics, and even morality. Therefore, it is crucial for us to establish comprehensive policies and guidelines to address these issues. In addition, most of the current research on the application of AI in robotic surgery is retrospective, and it often has limitations such as small datasets and lack of external validation. In the future, we need to conduct more prospective studies to thoroughly explore the weaknesses and limitations of AI, ensuring its safe, effective, and reliable application in the medical field. With the continuous advancement of technology and the deepening of research, we can anticipate AI playing an even greater role in robotic surgery, ultimately leading to better treatment outcomes for patients. Finally, as Yang and colleagues have highlighted, the increasing prevalence of robots and AI in the medical field is accompanied by an improvement in the autonomy of robots, which may shift the role of doctors toward decision-making for diseases. This raises a new question: whether the introduction of new technology will lead to a decline in doctors' surgical skills and other abilities, and what impact this will have on the future of medical practice. This is clearly an issue that we cannot ignore [67]. In summary, the integration of AI and robotic surgery presents both significant opportunities and challenges to the medical field. We must consider its impact on doctors' skills and training while promoting technological development and formulate corresponding policies and measures to ensure the quality and safety of medical services. With the continuous advancement of technology and the refinement of regulations, we can anticipate that the combination of AI and robotic surgery will bring about further innovation and breakthroughs in the medical field.

Conclusion

This study conducted a bibliometric and visualization analysis of robotic surgery-related literature over the past decade. The findings indicate that the field of robotic surgery has experienced remarkable growth, with the number of publications showing a steady increase, suggesting a high level of interest and engagement from the research community. The United States emerges as a dominant force in this domain, and there is extensive collaboration among institutions and authors worldwide. Furthermore, the analysis of keywords revealed seven predominant research themes, with AI emerging as a current focal point and anticipated to be a significant trend in the future.

Limitation

As with other bibliometric analyses, this study has certain limitations:

The selection of English publications may lead to language bias.

Inaccurate or inconsistent spelling of author and institutional names may lead to biases in the statistical results.

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Declarations

Conflict of interest The authors declare no competing interests.

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