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RESEARCH

The current status and global trends of clinical trials related to robotic surgery: a bibliometric and visualized study

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Abstract

Conducting clinical trials can evaluate the effectiveness and safety of surgical robots. To promote the advancement of academic robotic programs in surgery, this study captures the development trend and research hotspots of clinical trials related to surgical robots by bibliometric analysis. Bibliometrix package in R software was used to analyze the publication year, authors, countries, institutes, and journals. The visualization maps of keywords were formed using VOSviewer. The keywords with the strongest citation bursts and the institutional collaboration map were created by CiteSpace. Urology dominates with 31.3% of publications and the controlled clinical trials in urology and orthopedic accounted for the highest proportion, reaching 73%. North America, the USA, and Seoul National University lead in productivity. The most productive country, region and institution are North America, USA and Seoul National University, respectively. The trend of collaboration is regional instead of international. Keyword and burst keyword analysis revealed a primary focus in clinical research on robotic surgery: evaluating process improvements, comparing robotic and traditional surgery, and assessing feasibility. Long-term clinical trials assess surgical robots not only intraoperative performance but also postoperative complications and overall surgical outcomes. The development in the field is unbalanced between regions and countries. To promote multi-center clinical trials, governments can streamline review procedures and establish international consensus review standards, while academic institutions can form academic alliances. Also, the study offers recommendations for the development of academic robotic programs and regional collaboration units in robotic surgery, which may provide researchers with a strong reference for future research.

Keywords Robotic surgery · Bibliometric study · Clinical trial · Robot

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Introduction

The application of surgical robots in the medical field is becoming more and more mature. In 2020, worldwide surgeries with the Da Vinci system reached 1.243 million [1], and the global market share of surgical robots was $9.6 billion in 2021 [2]. Urology stands as the most mature field [3]. Meanwhile, Robotic surgery is also expanding into other departments like orthopedics, thoracic surgery and otolaryngology, allowing for more precise placement of implants [4, 5]. Although robotic surgery can alleviate iatrogenic injuries [6, 7], there is still a debate over whether it can replace traditional surgery, given the issues of prolonged surgical duration and high maintenance costs [6–9]. Therefore, conducting clinical trials can help identify shortcomings, improve surgical techniques, and expand the application of surgical robots across different specialties and procedures.

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Additionally, high-quality clinical trials are crucial for obtaining regulatory approval for newly developed robotic systems.

In order to help researchers gain a deeper understanding of robotic surgery, it is necessary to discover its development status and research hotspots. Bibliometric analysis is a method used to evaluate the characteristics and development of a certain field, presenting the results of research in a visual way [10–14]. At present, studies related to robotic surgery are common, but studies focusing clinical trials related to surgical robots are relatively few. Therefore, we hope to capture the research hotspots and explore the development trend in this field from the aspects of document types and publication outputs, regional analysis, author analysis, journal and co-cited journal analysis, keyword and burst keyword analysis.

Material and methods

Search strategy and criteria

Documents concerning clinical trials related to surgical robots from inception to July 31, 2023 were retrieved in Web of Science Core Collection database. "robotic surgery" and "clinical trial" were two main terms included in the search query. The searching strategy is illustrated in Supplementary Table S1.

The language of articles included in this study was limited to English. There were no restrictions on data category and publication year in the study. Afterwards, 722 documents were screened out based on document type, followed by a preliminary selection by the title, keywords, and the abstract of the document. Five hundred and thirty seven documents were retained after four kinds of articles excluded: (1) articles that are unrelated to robotic surgery or clinical applications; (2) articles that only include animal or cadaver trials; (3) articles that only include simulation tests (in vitro); (4) and articles focusing on the surgical robot technology. Ultimately, 208 articles that met the inclusion criteria were retrieved, getting rid of observational studies, case reports and retrospective studies by reading the content of identified articles. A complete selection process is depicted in Fig. 1.

Analysis method

In this study, Bibliometrix package (version 3.2.1) in R software (version 4.1.3) was used to analyze the documents. The networks of co-authorship of countries were displayed

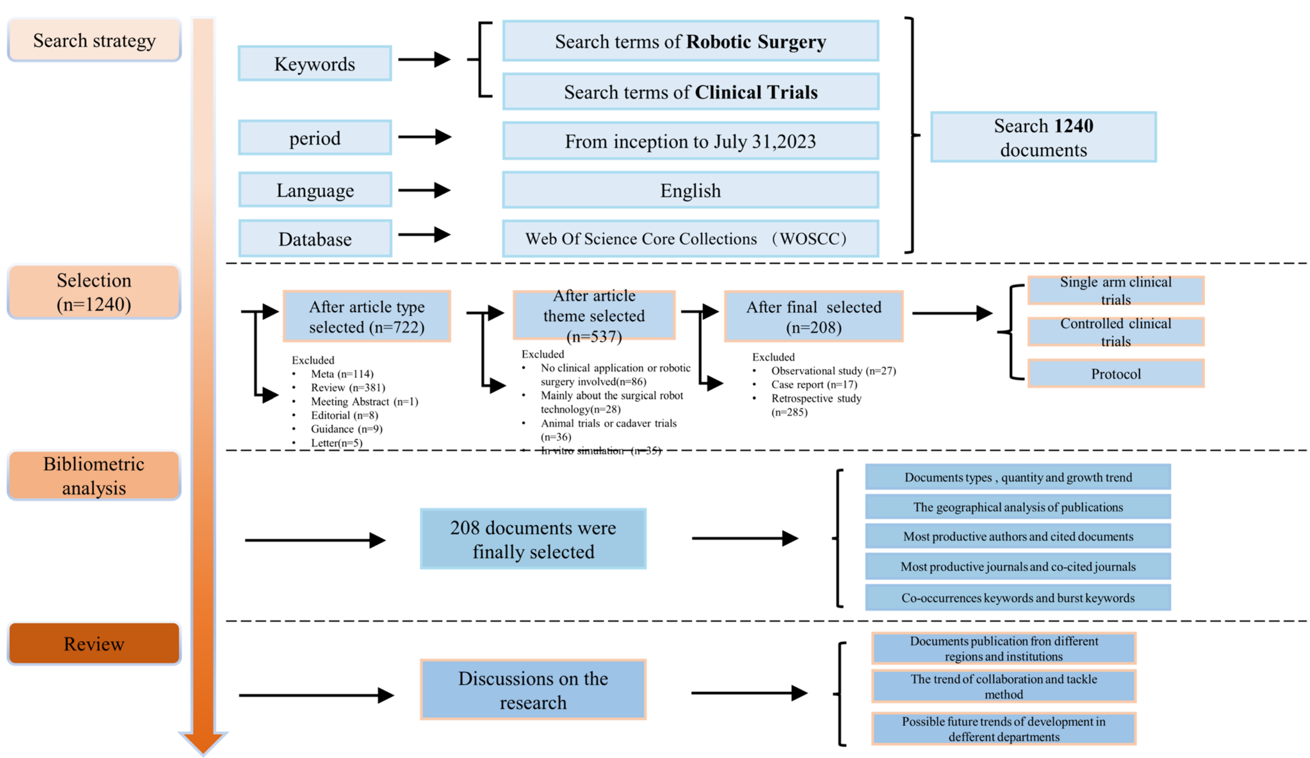


Fig. 1 Document selection and flow chart of the research framework

using SCImago Graphica Beta (version 1.0.23). The visualization maps of keywords were formed using VOSviewer (version 1.6.19.0). The keywords with the strongest citation bursts and the institutional collaboration map were created by CiteSpace (version 6.2.4.0). The data aggregation and analysis were conducted using WPS Office software (version 11.1.0.13703), and the pie chart of document types, bar chart of annual accumulative number of publications and percentage chart of the document types in different medical departments were generated using OriginPro software (version 2022). The remaining graphics plotted were formed by the Ggplot2 package (version 3.3.5) in R software (version 4.1.3).

Results

Document types and publication outputs

Figure 2a depicts a rising trend in publication outputs from 1999 to 2023. The number of publications on robotic surgery and clinical trials per year surpassed 10 after 2016, constituting approximately 73% of the total publications from 2016 to 2023. In 2021, the annual publications reached a peak at 30. Figure 2b illustrates departmental contributions, with urology representing the largest proportion at 31.3%, followed by gastrointestinal surgery and orthopedics, each contributing more than 30 publications and accounting for

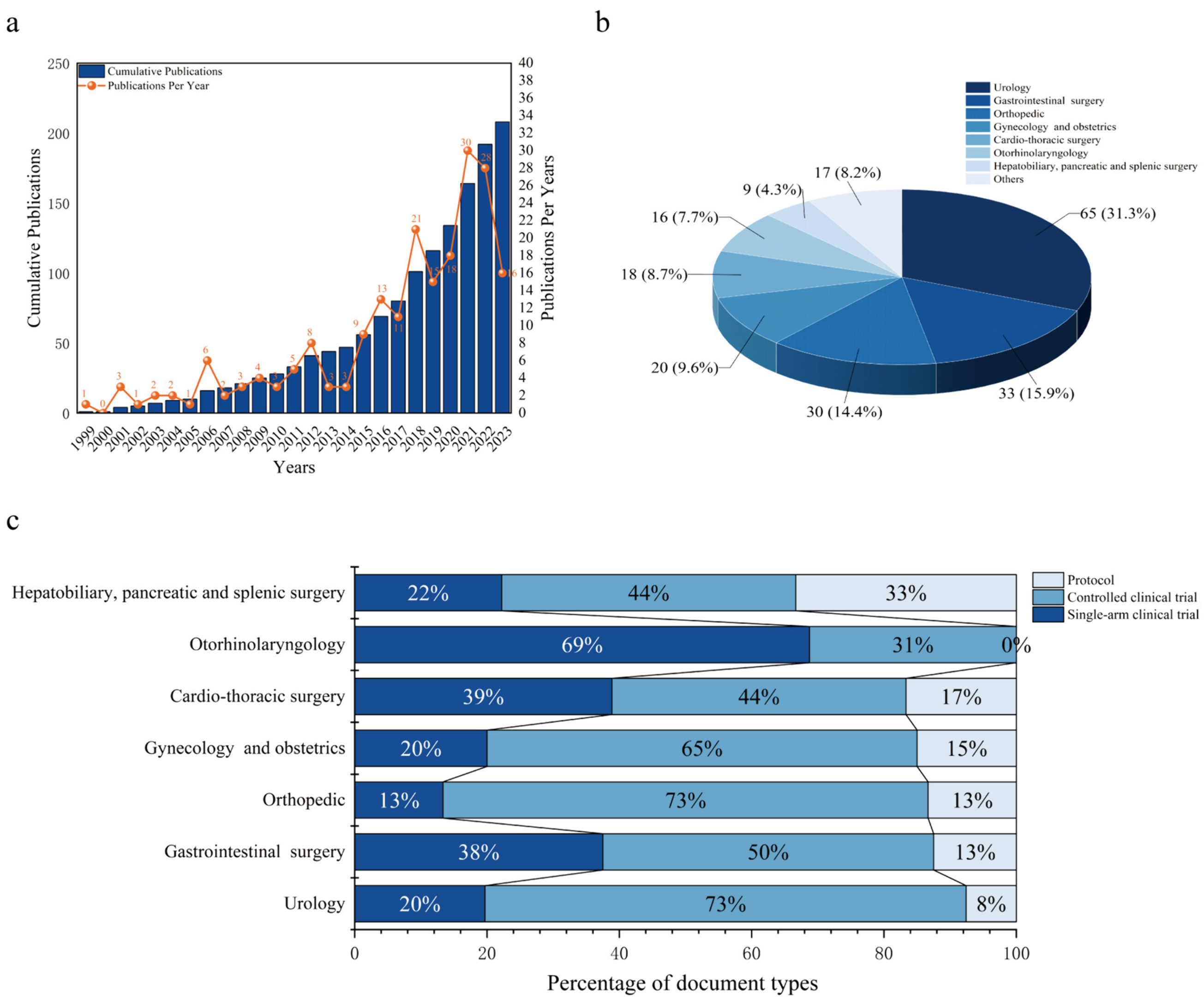


Fig. 2 Document types and publication outputs. **a** Publications number per year and annual accumulative number. **b** Percentage of each category of document. **c** Percentage of trial types in different medical departments. Protocol refers to a clinical trial that has a registered clinical trial number but is still in progress

15.9% and 14.4%, respectively. Other departments with publication rates exceeding 5% include Gynecology and obstetrics, cardio-thoracic surgery, and otolaryngology. Figure 2c shows trial types in various departments, with controlled clinical trials in urology and orthopedics comprising the highest proportion at 73%.

Analysis of authors

1554 authors are involved in the study. The detailed information of top 10 most productive authors (Including tie ranking, N=12) is in Table 1. KIM HJ leads in document count with 6 publications and 422 total citations. Following closely are CARLSSON S, HAGLIND E, HUGOSSON J, STEINECK G, STRANNE J, WIKLUND P and RUURDA JP, each with five documents. The last four authors all published four documents.

Table 2 concludes detailed information of articles with the top 10 citations. The article titled 'Effect of Robotic-Assisted vs Conventional Laparoscopic Surgery on Risk of Conversion to Open Laparotomy Among Patients Undergoing Resection for Rectal Cancer: The ROLARR Randomized Clinical Trial,' published in JAMA-J AM MED ASSOC, holds the top spot with 650 citations and an annual citation rate of 92.86. Following is an article by O'MALLEY BW published in LARYNGOSCOPE with 484 citations but a lower average annual citation of 26.89. Two articles by PAREKH DJ in 2018 and YAXLEY JW in Lancet in 2016 have total citations of 420 and 413, respectively, with high average annual citations of 70 and 51.63. Other articles on the list have total citations below 400.

Publication distribution of countries, institutes, and regions

Corresponding authors of 208 publications represent 26 countries, with the USA leading in publications (n=34), followed by China (n=32) and Korea (n=25), while other countries have less than 20 publications. In terms of total citations, the USA leads with 3010, averaging 88.5 citations per article (Figure 3a and Table 3). Further details on the top 12 most productive countries can be found in Table 3. Figure 3c illustrates filled maps of cluster results and the total link strength between countries. Overall, the level of cooperation among countries is not strong.

A total of 408 institutions contributed to the publications in the study. In Figure 3b, the top 20 most productive institutes are highlighted, with their respective publication numbers. The top five institutions in the output of articles are Seoul National University (Korea, n=33), Yonsei University (Korea, n=22), Shanghai Jiao Tong University (China, n=20), Yonsei University Health System (Korea, n=19), Karolinska Institutet (Sweden, n=15). Notably, four of the top 20 institutions are from Korea, with Seoul National University leading in rank. Additionally, five institutions from the UK are also among the top 20.

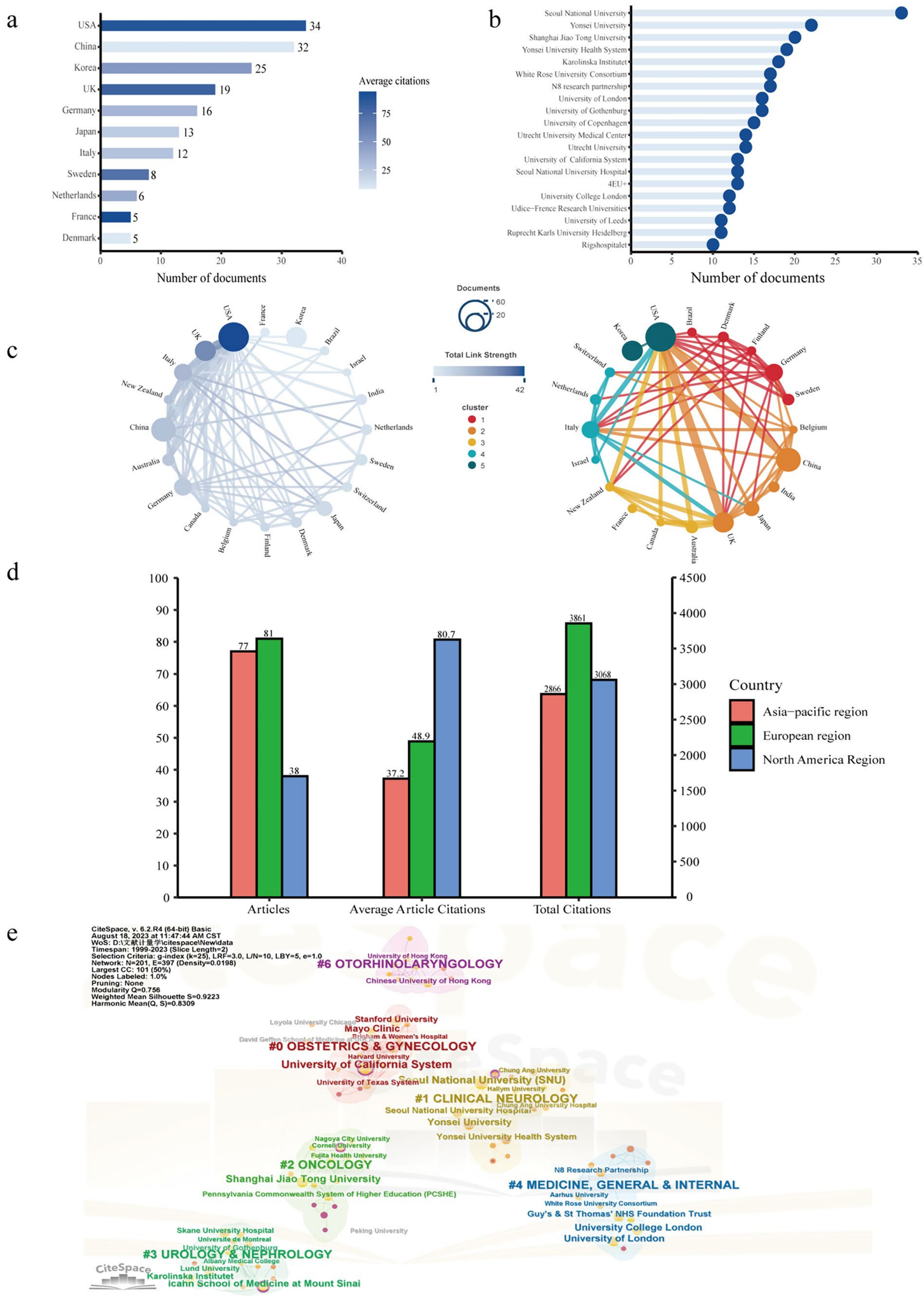
The Asian-Pacific, European, and North American regions are pivotal markets for surgical robots, as reflected in Fig. 3d, indicating their total number of articles, total citations, and average article citations. The North America region (3068 times), although it was inferior to both the Asian-Pacific region and the European region in total number of articles, was superior to the Asian-Pacific region (2866 times) and had not much difference with the European

Table 1 Details about the top 10 most productive authors for the research

Author	H index	G index	M index	Total citations	Document	Year of initial publication
KIM HJ	6	6	0.429	422	6	2010
CARLSSON S	4	5	0.308	361	5	2011
HAGLIND E	4	5	0.308	361	5	2011
HUGOSSON J	4	5	0.308	361	5	2011
STEINECK G	4	5	0.308	361	5	2011
STRANNE J	4	5	0.308	361	5	2011
WIKLUND P	4	5	0.308	361	5	2011
RUURDA JP	5	5	0.278	257	5	2006
THORSTEINSDOTTIR T	4	4	0.308	358	4	2011
BJARTELL A	3	4	0.333	303	4	2015
GILLING P	4	4	0.5	262	4	2016
MULLER-STICH BP	4	4	0.235	147	4	2007

Table 2 Details about the top 20 most cited documents for the research

Paper	DOI	Total Citations	Citations per year	Title
JAYNE D, 2017, JAMA-J AM MED ASSOC	https://doi.org/10.1001/jama.2017.7219	650	92.86	Effect of Robotic-Assisted vs Conventional Laparoscopic Surgery on Risk of Conversion to Open Laparotomy Among Patients Undergoing Resection for Rectal Cancer The ROLARR Randomized Clinical Trial
O'MALLEY BW, 2006, LARYNGOSCOPE	https://doi.org/10.1097/01.mlg.0000227184.90514.1a	484	26.89	Transoral Robotic Surgery (TORS) for Base of Tongue Neoplasms
PAREKH DJ, 2018, LANCET	https://doi.org/10.1016/S0140-6736(18)30996-6	420	70	Robot-assisted radical cystectomy versus open radical cystectomy in patients with bladder cancer (RAZOR): an open-label, randomised, phase 3, non-inferiority trial
YAXLEY JW, 2016, LANCET	https://doi.org/10.1016/S0140-6736(16)30592-X	413	51.63	Robot-assisted laparoscopic prostatectomy versus open radical retropubic prostatectomy: early outcomes from a randomised controlled phase 3 study
NIX J, 2010, EUR UROL	https://doi.org/10.1016/j.eururo.2009.10.024	399	28.5	Prospective Randomized Controlled Trial of Robotic versus Open Radical Cystectomy for Bladder Cancer: Perioperative and Pathologic Results
BOCHNER BH, 2015, EUR UROL	https://doi.org/10.1016/j.eururo.2014.11.043	394	43.78	Comparing Open Radical Cystectomy and Robot-assisted Laparoscopic Radical Cystectomy: A Randomized Clinical Trial
LOULMET D, 1999, J THORAC CARDIOV SUR	https://doi.org/10.1016/S0022-5223(99)70133-9	303	12.12	Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments
PARAISO MFR, 2011, OBSTET GYNECOL	https://doi.org/10.1097/AOG.0b013e318231537c	295	22.69	Laparoscopic Compared With Robotic Sacrocolpopexy for Vaginal Prolapse A Randomized Controlled Trial
HAGLIND E, 2015, EUR UROL	https://doi.org/10.1016/j.eururo.2015.02.029	275	30.56	Urinary Incontinence and Erectile Dysfunction After Robotic Versus Open Radical Prostatectomy: A Prospective, Controlled, Nonrandomised Trial
PARK JS, 2012, BRIT J SURG	https://doi.org/10.1002/bjs.8841	243	20.25	Randomized clinical trial of robot-assisted versus standard laparoscopic right colectomy


a
USA 34
China 32
Korea 25
UK 19
Germany 16
Japan 13
Italy 12
Sweden 8
Netherlands 6
France 5
Denmark 5
Number of documents
Average citations
75
50
25
b
Seoul National University
Yonsei University
Shanghai Jiao Tong University
Yonsei University Health System
Karolinska Institutet
White Rose University Consortium
N8 research partnership
University of London
University of Gothenburg
University of Copenhagen
Utrecht University Medical Center
Utrecht University
University of California System
Seoul National University Hospital
4EU+
University College London
Udice−Frence Research Universities
University of Leeds
Ruprecht Karls University Heidelberg
Rigshospitalet
Number of documents
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Documents
60
20
Total Link Strength
1
42
cluster
1
2
3
4
5
d
Articles
Average Article Citations
Total Citations
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81
38
37.2
48.9
80.7
2866
3861
3068
Country
Asia−pacific region
European region
North America Region
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Timespan: 1999-2023 (Slice Length=2)
Selection Criteria: g-index (k=25), LRF=3.0, L/N=10, LBY=5, e=1.0
Network: N=201, E=397 (Density=0.0198)
Largest CC: 101 (50%)
Nodes Labeled: 1.0%
Pruning: None
Modularity Q=0.756
Weighted Mean Silhouette S=0.9223
Harmonic Mean(Q, S)=0.8309
#6 OTORHINOLARYNGOLOGY
University of Hong Kong
Chinese University of Hong Kong
Stanford University
Mayo Clinic
#0 OBSTETRICS & GYNECOLOGY
University of California System
Seoul National University (SNU)
#1 CLINICAL NEUROLOGY
Seoul National University Hospital
Yonsei University
Yonsei University Health System
#2 ONCOLOGY
Shanghai Jiao Tong University
Pennsylvania Commonwealth System of Higher Education (PCSHE)
#4 MEDICINE, GENERAL & INTERNAL
N8 Research Partnership
Guy's & St Thomas' NHS Foundation Trust
University College London
University of London
#3 UROLOGY & NEPHROLOGY
Karolinska Institutet
Icahn School of Medicine at Mount Sinai
CiteSpace

◂**Fig. 3** Publication distribution of countries, institutes, and regions. **a** The number of articles and average citations among the top 10 most productive countries. **b** The number of articles among the top 20 most productive institutes. **c** Two maps of the cooperation between various countries. Left one reflects the total link strengths of different countries and right one shows the cluster result of the countries. The arrow demonstrates cooperation between the corresponding two countries. **d** The total number of articles, total citations and average article citations of Asia–Pacific region, European region and North America region. **e** Visualized map of co-authorship of the institutes

region (3861 times) in total citations. Additionally, the North America region exceeds the latter two far in average article citations, reaching 80.7 times per article, with the European region (48.9 times) and the Asian-Pacific region (37.2 times).

What's more, collaboration among diverse institutions is depicted in Fig. 3e with several clusters labeled by subjects. Obviously, institutions from the same country tend to concentrate on the same subject. For instance, both Seoul National University, Yonsei University, Yonsei University Health System, and Seoul National University Hospital in Korea are clustered in Clinical Neurology. Similarly, Lund University, Skane University Hospital, University of Gothenburg and Karolinska Institute, located in Sweden, are in the same cluster Urology & Nephrology. Also, Five institutions from the UK, including the White Rose University Consortium, N8 Research Partnership, University of London, University College London, and University of Leeds, engaged in academic collaboration obviously. Moreover, the first two mentioned are academic alliances composed of multiple universities in the UK.

Analysis of journals, co-cited journals, and co-cited references

All the articles involved originate from 114 journals totally. The journal that published the most articles was SURGICAL ENDOSCOPY AND OTHER INTERVENTIONAL TECHNIQUES from the USA, which had published 12 articles and had 756 citations in all. TRIALS and BJU INTERNATIONAL, which are both from the UK, had published 11 and 8 documents separately. Their total citations were not high, however, only 244 and 271. In terms of citations, the journal EUROPEAN UROLOGY from Switzerland ranked first among the top 10 productive journals, by virtue of 1266 citations. More than half of the top 10 journals (Including tie ranking, N=12) were from the USA, with four of the remaining ones from the UK and one from Switzerland. In point of subject, SURGERY (4 journals) and UROLOGY & NEPHROLOGY (3 journals) were two hot spots (Table 4). The cumulative publications of the top 10 productive journals can be seen in Fig. 4a, 4b shows corresponding H index, G index, M-index of the 12 journals.

Figure 4c is a co-citation map of journals with more than 10 citations. EUROPEAN UROLOGY (316 citations) held the first place, followed by SURGICAL ENDOSCOPY (250 citations), ANNALS OF SURGERY (177 citations). Figure 4d, however, is a co-citation map of cited references with more than four citations, and Table 4 concludes the top 10 cited references, based on their total citations which are an especially vivid reflection of how much attention is fixed on the reference.

Analysis of keywords and burst keywords

Figure 5a is the clustering result of 75 keywords that occurred for at least five times. These keywords referred to the main indications of surgical robots, including gastric cancer, prostate cancer and so on, and the main surgical methods cholecystectomy, hysterectomy, etc. Indicators for intraoperative and postoperative evaluation included accuracy, mortality rate, survival rate, complications, recovery, etc. Additionally, research methods had randomised clinical trial and randomised controlled trial, among which surgery, complication, outcomes, cancer, robotic surgery, quality of life and clinical trial were all highly linked with other words. This suggests a focus on these keywords in the majority of the documents.

Figure 5b shows the emergence frequency of keywords over time. Some keywords, such as robot, da vici, bladder cancer and cystectomy occurred relatively early, concretely, around 2015, indicating the initial study direction. Additionally, some keywords like robot-assisted surgery, replacement, pancreatic surgery and accuracy, occurred late, and they show the study trend recently.

Figure 5c illustrates the density map, highlighting keywords like surgery, robotic surgery, outcomes, complications, and cancer with the highest frequency and importance. Burst analysis in Fig. 5d reveals early clinical studies focused on Da Vinci's application, particularly in bladder and gastric cancer surgery. Recent clinical trials shift towards assessing both intraoperative performance and long-term outcomes, as well as postoperative complications.

Discussion

As we know, this study is the first bibliometric study based on clinical trials related to surgical robots(Supplementary Table S2), which can provide researchers with better understanding of the status and trend of clinical trials related to robotic surgery and facilitate the advancement of academic robotic programs and regional collaboration units in robotic surgery. There was a substantial increase of publications in 2015 and cumulative publications from 2016 to 2023

Table 3 Details about top 10 most productive countries for the research

Country	Documents	Citations	Average citations
USA	34	3010	88.5
CHINA	32	305	9.5
KOREA	25	1232	49.3
UNITED KINGDOM	19	1528	80.4
GERMANY	16	552	34.5
JAPAN	13	296	22.8
ITALY	12	336	28
SWEDEN	8	568	71
NETHERLANDS	6	240	40
DENMARK	5	42	8.40
FRANCE	5	470	94

accounted for 73% of all publications(Fig. 2a). The phenomenon is closely related to the development history of surgical robot [15, 16].

Nowadays, most studies on robotic surgery are retrospective due to the challenging conditions associated with conducting clinical trials for surgical robots, which also explains the lack of highly productive authors. Clinical trials demand substantial human resources and medical facilities, necessitating that implementing institutions possess and maintain costly robotic equipment [17]. Furthermore, cultivating seasoned surgeons, who completed an average of 150 to 250 operations to achieve proficiency with rich experience is crucial for such experiments [17]. Also, there should be comprehensive regulatory framework in place to minimize participant risks and ensure informed consent of participants [18].

Clinical trials for surgical robots show imbalances between countries and regions. In Table 3, the United States, with the highest publication and citation rates, also boasts a remarkably high average citation rate. This is closely associated with its status as the birthplace of the da Vinci surgical robot, affording it a technological advantage. Following the United States is China with a lower average citation rate, which may be attributed to the majority of articles being published after 2016 and primarily consisting of non-randomized clinical trials. Ranking third is South Korea, boasting a relatively high average citation rate. It is likely due to the majority of articles being designed as randomized controlled trials, thereby possessing significant research value. As shown in Figure 3d, North American papers notably higher than Asia-Pacific and Europe. The Asia-Pacific region is likely hindered by the high equipment costs and insufficient medical infrastructure, especially developing countries in the region, which limits clinical research and impeding market growth.

Research in this field shows a trend of regional collaboration rather than international cooperation in Figure 3c and 3e. Research institutions within the same country or region

Table 4 Top 10 most cited references and citations

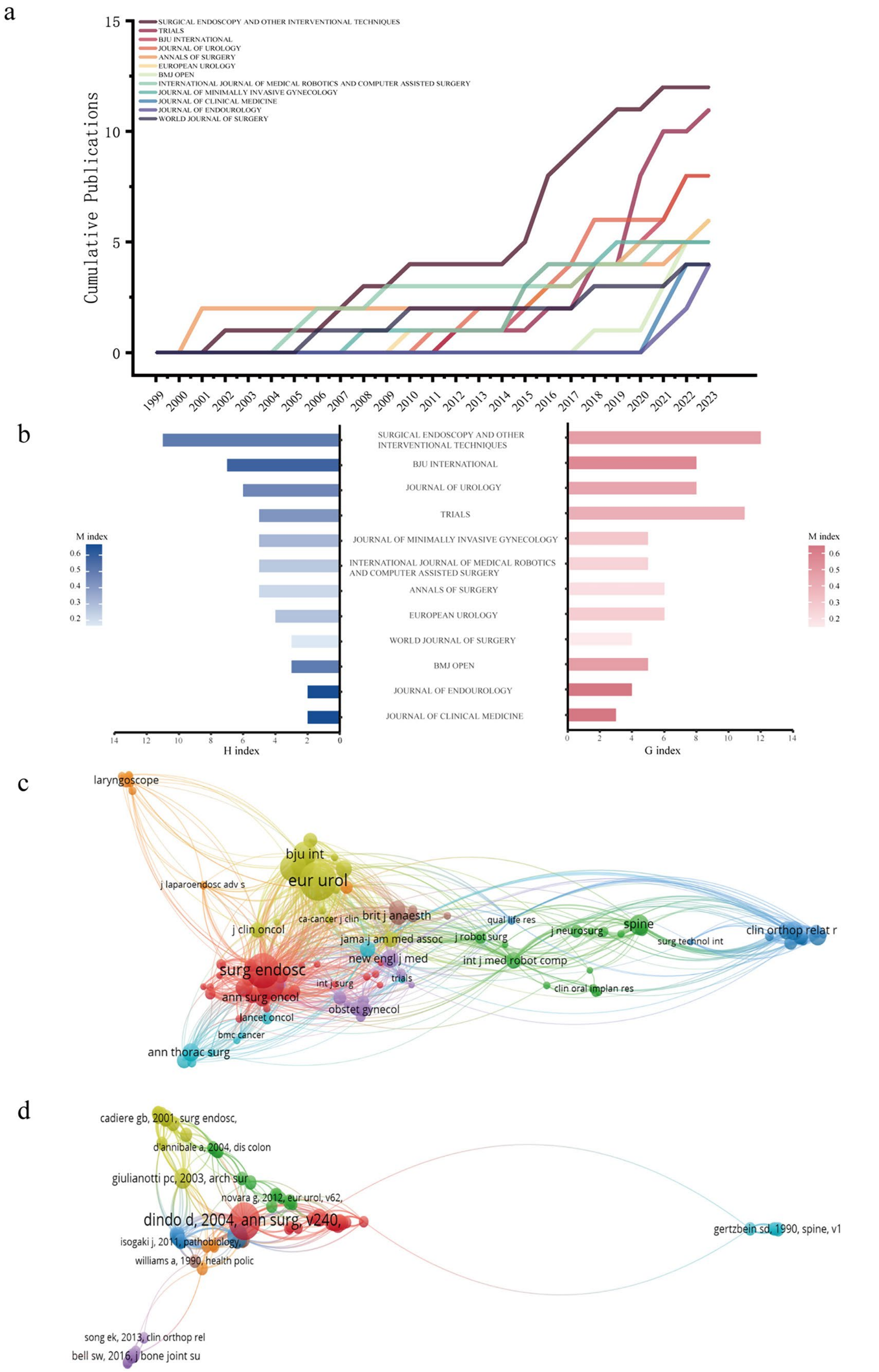
Rank	Cited References	Citations
1	DINDO D, 2004, ANN SURG, V240, P205, https://doi.org/10.1097/01.SLA.0000133083.54934.AE	40
2	CLAVIEN PA, 2009, ANN SURG, V250, P187, https://doi.org/10.1097/SLA.0B013E3181B13CA2	17
3	GIULIANOTTI PC, 2003, ARCH SURG-CHICAGO, V138, P777, https://doi.org/10.1001/ARCHSURG.138.7.777	12
4	NIX J, 2010, EUR UROL, V57, P196, https://doi.org/10.1016/J.EURURO.2009.10.024	9
5	YAXLEY JW, 2016, LANCET, V388, P1057, https://doi.org/10.1016/S0140-6736(16)30,592-X	9
6	CADIERE GB, 2001, SURG ENDOSC, V15, P918, https://doi.org/10.1007/S004640000217	8
7	BELL SW, 2016, J BONE JOINT SURG AM, V98, P627, https://doi.org/10.2106/JBJS.15.00664	7
8	BOCHNER BH, 2015, EUR UROL, V67, P1042, https://doi.org/10.1016/J.EURURO.2014.11.043	7
9	HAGLIND E, 2015, EUR UROL, V68, P216, https://doi.org/10.1016/J.EURURO.2015.02.029	7
10	MELVIN WS, 2002, J GASTROINTEST SURG, V6, P11, https://doi.org/10.1016/S1091-255X(01)00032-4	7
11	MORINO M, 2006, BRIT J SURG, V93, P553, https://doi.org/10.1002/BJS.5325	7
12	PARK JY, 2012, BRIT J SURG, V99, P1554, https://doi.org/10.1002/BJS.8887	7
13	SHABSIGH A, 2009, EUR UROL, V55, P164, https://doi.org/10.1016/J.EURURO.2008.07.031	7
14	SONG J, 2009, ANN SURG, V249, P927, https://doi.org/10.1097/01.SLA.0000351688.64999.73	7
15	WEBER PA, 2002, DIS COLON RECTUM, V45, P1689, https://doi.org/10.1007/S10350-004-7261-2	7
16	WOO Y, 2011, ARCH SURG-CHICAGO, V146, P1086, https://doi.org/10.1001/ARCHSURG.2011.114	7

are more likely to cluster around similar research subjects mainly due to the cooperation. This trend aligns with the characteristic that high-quality clinical trials often require multi-center participation [19, 20].However, multi-center clinical trials, especially those conducted by international cooperation, usually face challenges including complex review processes and high costs. Therefore, Researchers are more inclined to choose cooperation with domestic research institutions, especially those of the same affiliation. The U.S. addresses this through joint reviews, allowing a core institutional review board to replace others, streamlining the process [21]. The European Union employs the Clinical Trials Information System (CTIS) to facilitate the submission and review of multinational clinical trial materials [22]. Notably, some universities have formed academic alliances to conduct research easily, such as the White Rose University Consortium, N8 Research Partnership, Udice-French research universities and 4EU+. The last one comprises six universities from six European countries.

Urology, gastrointestinal surgery, and orthopedics are among the most extensively studied specialties for clinical trials involving surgical robots (Fig. 2b). Especially in urology, not only does it hold the highest proportion of literature among all departments, but its randomized controlled trials also constitute high percentage within the department (Fig. 2c),which can be attributed to the deep location of organs within the pelvic cavity [23] and potential complications such as erectile dysfunction and urinary incontinence [17], leading to the early development of robotic surgery and surpass other departments. As shown in Fig. 5a, 'erectile dysfunction', 'urinary incontinence', 'quality of life' and 'prostatectomy' are clustered together, which reflects that researchers focus on postoperative complications and the quality of life of patients as the mainstream directions. Despite the relatively mature development of robotic surgery in urology, there are still insufficient prospective randomized controlled trials comparing laparoscopic surgery with robotic surgery, thereby providing clear guidance for the treatment choices of more patients. Most studies focus on refining robotic procedures rather than directly comparing outcomes due to several challenges: surgeons, proficiency in both laparoscopy and robotics, are reluctant to randomize patients [24], and the institution must have necessary resources for long-term follow-up to assess distant outcomes. Additionally, researchers may encounter a misalignment between the invested time and effort and the expected returns.

The red cluster in Fig. 5a represents the research hotspots in orthopedics, which contains 'replacement', 'spine surgery', 'accuracy' and 'placement'. Figure 5b indicates that these keywords emerged relatively late. Burst keyword analysis also highlights the expanding functions of surgical robots, emphasizing 'navigation' and 'replacement' (Fig. 5d). This can be explained as robotic surgery's development in orthopedics being relatively later than in general surgery, but progressing rapidly. In orthopedics, surgical robots excel in procedures requiring precise implantation, such as assisted pedicle screw insertion and joint replacements. Unlike their role in radical organ resection, where they address potential tissue damage, the focus in orthopedics is on surgical path planning and accurate implantation. Surgical robots reduce errors from hand tremors, minimize radiation exposure, and shorten hospital stays compared to traditional methods, signifying an expanded role in orthopedic functions.

Articles in this field show a rising trend, emphasizing the need for enhanced collaboration and streamlined approval processes to facilitate clinical trials. Strengthening both local and international partnerships is crucial, particularly in the Asia-Pacific region, which lags behind Europe and North America. Establishing academic alliances can boost collaboration. For future research, focusing on comparing short-term surgical outcomes and long-term benefits of traditional laparoscopic and robotic surgeries in general surgery is recommended as they are relatively mature compared to other specialties. In orthopedic surgery, beyond the da Vinci system, current studies explore new navigation systems and the integration of technologies like augmented reality and artificial intelligence to enhance clinical outcomes. As for robotic systems in orthopedic, otolaryngology and so on, which emphasize precision implantation in surgical procedures, it is especially worth exploring the integration of other technologies with robotic surgery, such as augmented reality and artificial intelligence. This exploration can lead to innovations in navigation systems and enhance the benefits in clinical outcomes. In specialties like cardiothoracic surgery, otolaryngology, and neurosurgery, robotic systems are still in the developmental stages, with most clinical trials being prospective single-arm trials aimed at validating the feasibility of robotic surgery. It may due to the complexity and risks associated with surgeries, such as cardiothoracic and neurosurgical procedures. However, the suitability of surgical robots for performing precise procedures in these fields still suggests their value in application. Tailoring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Cumulative Publications
SURGICAL ENDOSCOPY AND OTHER INTERVENTIONAL TECHNIQUES
TRIALS
BJU INTERNATIONAL
JOURNAL OF UROLOGY
ANNALS OF SURGERY
EUROPEAN UROLOGY
BMJ OPEN
INTERNATIONAL JOURNAL OF MEDICAL ROBOTICS AND COMPUTER ASSISTED SURGERY
JOURNAL OF MINIMALLY INVASIVE GYNECOLOGY
JOURNAL OF CLINICAL MEDICINE
JOURNAL OF ENDOUROLOGY
WORLD JOURNAL OF SURGERY
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M index
H index
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laryngoscope
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j laparoendosc adv s
brit j anaesth
j clin oncol
qual life res
spine
clin orthop relat r
jama-j am med assoc
j robot surg
j neurosurg
surg technol int
new engl j med
int j med robot comp
surg endosc
trials
ann surg oncol
obstet gynecol
clin oral implan res
lancet oncol
bmc cancer
ann thorac surg
d
cadiere gb, 2001, surg endosc,
d annibale a, 2004, dis colon
giulianotti pc, 2003, arch sur
novara g, 2012, eur urol, v62,
dindo d, 2004, ann surg, v240,
isogaki j, 2011, pathobiology,
williams a, 1990, health polic
gertzbein sd, 1990, spine, v1
song ek, 2013, clin orthop rel
bell sw, 2016, j bone joint su

◂**Fig. 4** The analysis of journal, co-cited journal, co-cited reference. **a** The cumulative publications of the top 12 productive journals. **b** G-index, H-index, and M-index of the top 12 productive journals. **c** Network map of co-cited journals. **d** Network map of co-cited references

improvements in surgical robots to specific surgical site characteristics is crucial. In otolaryngology, the use of flexible robotic systems for procedures within natural lumens like the nasopharynx and oropharynx demonstrates feasibility and safety [25–27].

The study has its limitations. Our analysis is based on the WOS database, which may have missed some publications available in commonly used databases like Scopus, PubMed [28, 29], among others. Additionally, our focus was on clinical trials of surgical robots, so we did not include experiments conducted on models, animals, or cadavers.

Conclusion

In summary, this bibliometric study on surgical robot clinical trials reveals a significant surge in publications since 2015, with North America leading the research landscape. Urology, gastrointestinal surgery, and orthopedics emerge as primary focuses. The debate between laparoscopic and robot-assisted surgeries underscores the need for comprehensive research. The study recommends strengthened collaboration, streamlined processes, and increased data sharing for future multi-center research. As surgical robots expand into various specialties, exploring technologies like augmented reality and artificial intelligence are highlighted as crucial. Despite limitations, these findings offer valuable insights for the future trajectory of surgical robot research.

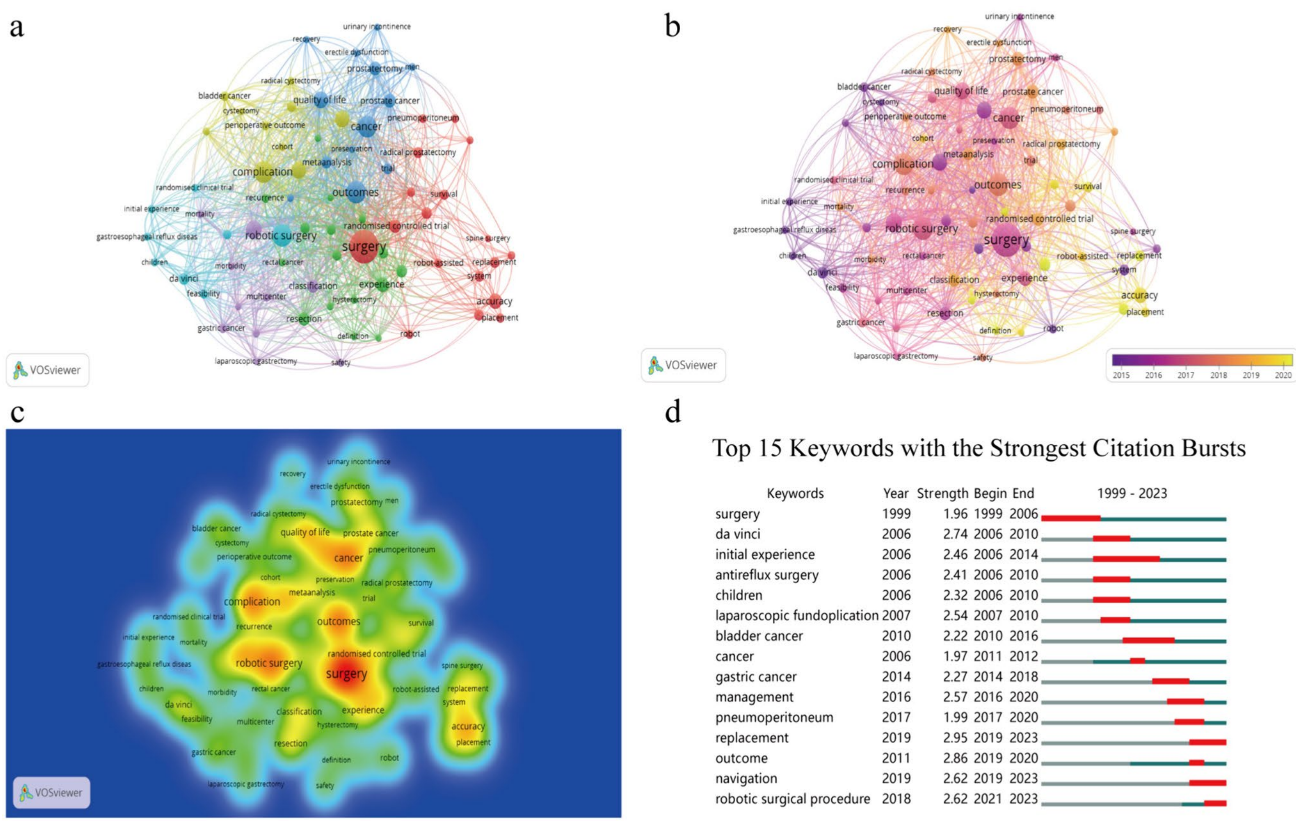

Fig. 5 Analysis of keywords. **a** Clusters network visualization map of keywords. **b** Overlay visualization map of keywords. **c** Density visualization map of keywords. **d** The top 15 keywords with strongest citation bursts

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Declarations

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