Robotic Surgery in the United States: A Comprehensive Analysis of Scientific Production and Trends

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Abstract

The aim of this study was to determine the characteristics and trends of articles published regarding Robotic Surgery by American authors. Research using Web of Science database was conducted in June 2023, considering only original articles published between 2018 and 2022. Robotic surgery is a rapidly growing field, with a consistent and steady increase in research output from American institutions during the last 5 years. The previous analysis was helpful to provide an overview of the scientific production in the leading country in the field, especially regarding the institutions with the highest contributions.

Keywords: Bibliometrics, Robotic-Assisted Surgery, United States.

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Introduction

Robotic surgery (RS) has transformed minimally invasive surgery and overcome the technological constraints of laparoscopy. RS is rapidly gaining ground across a range of disciplines, with an average yearly growth rate of about 15%. Furthermore, there are over 900 new robotic platforms installed globally each year (1).

With 1.24 million robotic units sold worldwide in 2020, the United States accounted for 70.6% of the total sales. The use of enhanced high definition (HD) and three-dimensional (3D) visualization, along with greater dexterity, tremor filtration, and extremely precise movement, has expanded the applications of robotic assistance in minimally invasive surgery. This advancement has particularly benefited more delicate and complex procedures, allowing for increased precision and improved outcomes (2).

The idea of telepresence and the development of surgical robots both evolved from necessity. The demand for surgical treatments for soldiers stationed in remote locations was one of the driving forces behind these advancements (3).

The Bradley 557A was created by the American military's Defense Advanced Research Projects Agency (DARPA). In 1994, it utilized a microwave connection to perform the first ex vivo organ anastomosis telepresence surgery. Furthermore, with the advancement of space exploration, astronauts on extended missions required the ability to perform long-distance tasks. As a result, a telemanipulator from the Stanford Research Institute was integrated with a head-mounted display and data glove from NASA Ames Research Center (4).

The U.S. Food and Drug Administration (FDA) granted its initial human use approval for the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA, USA) in 2000 (5).

The benefits that come from the application of RS are numerous. Among the most relevant: better visualization since the operating surgeon obtains a three-dimensional image that improves depth perception; camera motion is stable and easily controlled by voice-activated or manual master controls; manipulation of robotic arm instruments enhances range of motion, allowing the surgeon to conduct more complicated surgical operations (6); reduced the chance of readmission by half (52%); and revealed a 77% reduction in the prevalence of blood clots (deep vein thrombosis and pulmonary emboli) (7).

Robotic surgery has revolutionized the field of urology, enabling surgeons to perform complex procedures with greater precision and accuracy. One of the primary uses of RS in this specialty is the robotic-assisted laparoscopic radical and partial prostatectomy for the treatment of prostate cancer (8). It has been widely adopted in various other fields of medicine beyond urology, such as neurosurgery. Its usage in neurosurgery dates back to 1985, initially primarily used for biopsies (9).

In the early 1990s, the first robotic orthopedic surgery application was total hip arthroplasty, followed by knee arthroplasty (10). Since the 2000s, gynecology has also adopted this technique for common benign disorders, with hysterectomy and myomectomy being the most popular procedures (11).

Since the 2000s, there has been an increase in robotic cardiac surgery, with the majority of cases involving endoscopic coronary artery bypass grafting (CABG) and mitral valve repair (MVP). However, relatively few cases involve aortic valve repair (12).

Robotics will continue to change modern surgery over the next few years as haptic feedback, machine learning/artificial intelligence (AI), and training technologies progress.

By the end of 2017, the Institute company shipped 5,770 robot systems. After accounting for trade-ins and returns, a total of 4,409 platforms were installed globally, including 2,862 (65%) in the United States. The estimated annual procedure volume increased from 136,000 in 2008 to 877,000 in 2017. In 2017, 644,000 procedures (73%) were performed in the United States (13). This indicates that the United States is the leading country in robotic surgical procedures worldwide. Therefore, understanding its scientific production will provide us with a good overview of the progress and evolution of RS.

Bibliometric studies are ideal for providing an overview of scientific production in a specific field. They offer valuable information on the results of the research process, including volume, evolution, visibility, and structure. These studies enable the assessment of scientific activity and the impact of research and sources within the field (14).

There is a limited number of bibliometric analyses available on the scientific production of RS specifically in the United States, despite the country's leadership in this field. Consequently, the objective of this study was to investigate the characteristics and trends of articles published by American authors on RS and examine how they have evolved over the years.

Methodology

A bibliometric analysis of original articles published by authors with American affiliation in journals indexed in Web of Science (WOS) was carried out.

Search strategy

The search strategy involved using the terms "United States," "Robotic," "robot," "Surgery," and "Surgical Procedures" in all fields of the Web of Science (WOS) database. This strategy aimed to retrieve studies where the patients, institution, or main author were American, rather than just studies where the American author was a collaborator. The search was conducted on June 10, 2022.

Selection of articles

The metadata of the identified records from the search were downloaded as a .ciw file. Subsequently, they were imported into the Rayyan web application, where a review process took place. During the review, the titles, abstracts, and authors of each record were examined to determine if they met the inclusion criteria: original articles with at least one author affiliated with an American institution and published between 2018 and 2022, as the year 2023 was still ongoing at the time.

Any records that did not meet these criteria were excluded. The WOS "Accession Number" was extracted from each excluded record to exclude them from the initial search and obtain the final set of complete records for the bibliometric analysis.

Bibliometric Analysis

Bibliometric indices were obtained using the Bibliometrix package in the R programming language. (15) Similarly, the VOS viewer software version 1.6.17 from Leiden University in the Netherlands (16) was utilized to develop bibliometric networks based on co-authorship. This analysis involved considering information such as author names, institutional affiliations, and keywords from the retrieved records. Prior to the network analysis, a manual standardization of the data was conducted for the author, institutional affiliation, and keywords fields. The aim was to eliminate redundancies and inconsistencies by creating thesauruses in .txt format, following the two-column format (label and replace by) as specified in the VOSviewer version 1.6.17 software manual. Additionally, Microsoft Excel was employed to create tables and graphs for data presentation (17).

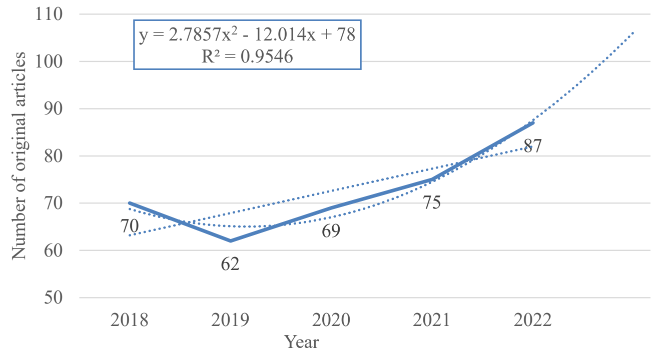
Results

The search strategy resulted in 561 articles, out of which 363 were included after the screening process from a total of 158 different journals.

There was a 5.59% annual increase in the scientific production of RS in the United States during the period studied, with an average of 72.6 original articles published per year. The highest production year was 2022, with 87 original articles.

Furthermore, a second-degree polynomial trend was observed in the publications between 2018 and 2022, with an R-squared value of 0.9546, as showed in Figure 1. This indicates a strong correlation between the year and the number of publications in the field of RS during that time period.

Figure 1. Scientific production in robotic surgery in United States 2018–2022.



The average number of citations per document was 13.3. The most cited article was a clinical trial conducted by Parekh et al., published in the journal Lancet in 2018. The article, titled "Robot-assisted radical cystectomy versus open radical cystectomy in patients with bladder cancer (RAZOR): an open-label, randomized, phase 3, non-inferiority trial," received a total of 413 citations. A detailed list of the top 10 most cited authors can be found in Table 1.

Table 1. Most Cited Articles in Robotic Surgery by North American Authors in 2018–2022.

Paper	**Total Citations**
Robot-assisted radical cystectomy versus open radical cystectomy in patients with bladder cancer (RAZOR): an open-label, randomised, phase 3, non-inferiority trial. 10.1016/S0140-6736(18)30996-6	413
Trends in the Adoption of Robotic Surgery for Common Surgical Procedures. 10.1001/jamanetworkopen.2019.18911	222
The Learning Curve Associated with Robotic Total Knee Arthroplasty. 10.1055/s-0037-1608809	90
Ultrarestrictive Opioid Prescription Protocol for Pain Management After Gynecologic and Abdominal Surgery. 10.1001/jamanetworkopen.2018.5452	86
Phase II Randomized Trial of Transoral Surgery and Low-Dose Intensity Modulated Radiation Therapy in Resectable p16+ Locally Advanced Oropharynx Cancer: An ECOG-ACRIN Cancer Research Group Trial (E3311). 10.1200/JCO.21.01752	84
The long-term survival of robotic lobectomy for non-small cell lung cancer: A multi-institutional study. 10.1016/j.jtcvs.2017.09.016	84
Minimally Invasive Versus Open Pancreaticoduodenectomy: A Propensity-matched Study From a National Cohort of Patients. 10.1097/SLA.0000000000002259	73
Proving the Effectiveness of the Fundamentals of Robotic Surgery (FRS) Skills Curriculum: A Single-blinded, Multispecialty, Multi-institutional Randomized Control Trial. 10.1097/SLA.0000000000003220	68
A deep-learning model using automated performance metrics and clinical features to predict urinary continence recovery after robot-assisted radical prostatectomy. 10.1111/bju.14735	61
Incidence of adverse events in minimally invasive vs open radical hysterectomy in early cervical cancer: results of a randomized controlled trial. 10.1016/j.ajog.2019.09.036	59

The most relevant topics were related with general surgery (46%), urology and nephrology (14.9%), oncology (11%), Obstetrics and Gynecology (8.3%), and Otorhinolaryngology (8%).

The journal Surgical Endoscopy and Other Interventional Techniques had the highest number of articles published by American authors in the last five years, with a total of 20 publications. It is worth noting that all of the 10 most productive journals in this field, as shown in Table 2, fall within Zone 1 as per Bradford's Law, indicating their high productivity (18)

Table 2. Journals with the highest number of articles in in Robotic Surgery by American authors.

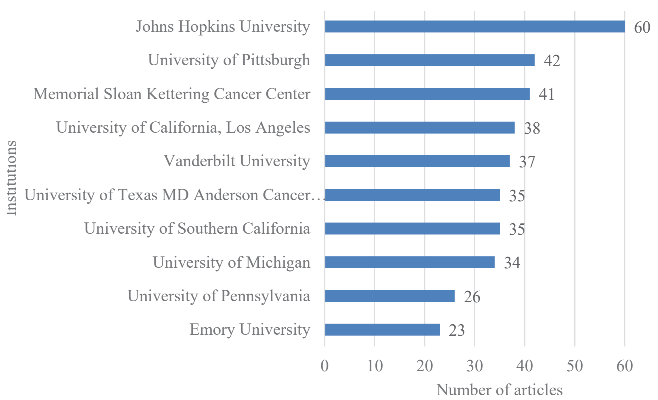
Sources	Q	Articles
Surgical endoscopy and other interventional techniques[1]	1	20
Journal of endourology[1]	1	14
International journal of medical robotics and computer assisted surgery[2]	2	11
Journal of robotic surgery[2]	2	11
Surgery for obesity and related diseases1	1	10
IEEE transactions on biomedical engineering[1]	1	9
Journal of urology[1]	1	9
Journal of surgical education[1]	1	8
Head and neck[1]	1	7
American journal of obstetrics and gynecology[1]	1	6

[1]From United States [2]From United Kingdom

The selected studies had an average of 15.4 authors per article, indicating a high level of collaboration. International cooperation in co-authorship was observed in 18.73% of the cases. The author with the highest scientific production was Hung AJ, who contributed 11 original articles. Hung AJ was affiliated with the University of Southern California Institute of Urology.

There were 528 affiliations, of which Johns Hopkins University was the most frequently reported in the articles, followed by the University of Pittsburgh, as shown in Figure 2. The University of Michigan and the Mayo Clinic were the institutions with the highest number of citations from their articles.

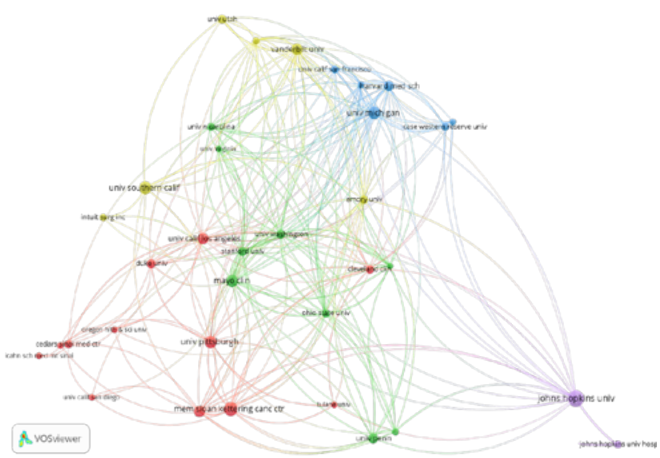
Figure 2. Scientific production in Robotic surgery by institution, 2018–2022.



When considering the different campuses (Los Angeles, San Diego, Irvine, Davis, Berkeley, etc.) of the University of California as one institution, it resulted in having the highest production.

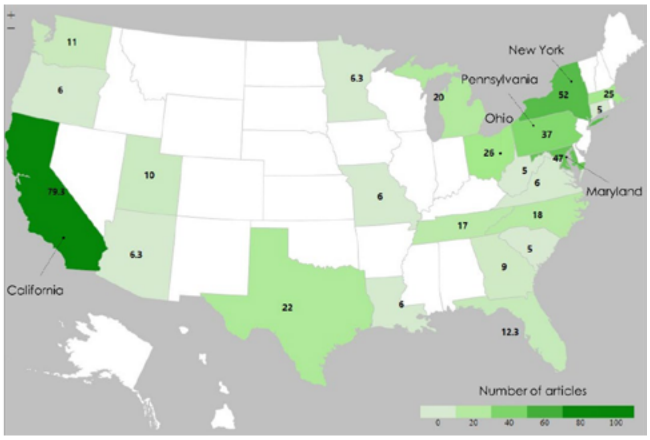
The density of the main affiliations and the collaboration networks between them can be observed in Figure 3.

Figure 3. Collaborative Network Map: Robotic Surgery Research among institutions in the United States in 2018-2022.



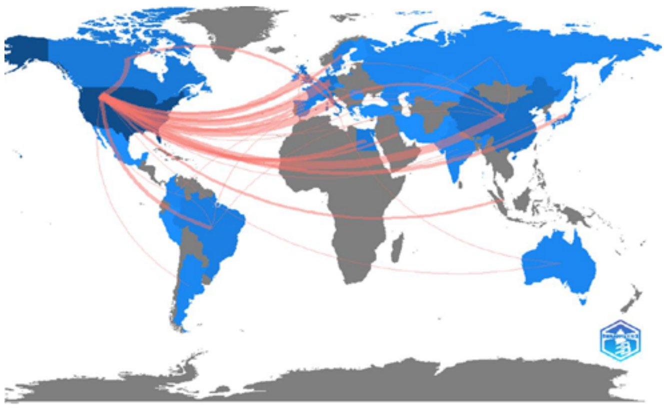
The distribution of scientific production by state was also analyzed, as shown in Figure 4.

Figure 4. Number of articles published on robotic surgery by state, 2018-2022.



The countries with which there was more collaboration were China, Italy, United Kingdom, Germany, and Canada. The network of collaborations by countries is seen in Figure 5.

Figure 5. Collaborative Network Map: Robotic Surgery Research in the United States and International Collaborations.



Regarding the keywords, a total of 1,618 terms were identified. After arranging them using thesauri and establishing a minimum occurrence of 4. As observed, the predominant keywords during the study period were "robotic-assisted surgery," "minimally invasive surgery," "laparoscopy," "cancer," and "complication."

Discussion

The present study aimed to determine the American scientific production in RS over the last five years, as this country holds the highest scientific output in this field. (19) The study also aimed to explore the different specialties related to RS. No previous analysis had specifically focused on the original scientific production in the United States.

An increase in the number of original articles from authors with American institutional affiliation was observed, with the highest production occurring in 2022. The study identified the leading authors and institutions, along with their respective collaborative networks. Additionally, the main scientific journals where the articles were published, and the most studied keywords in recent years were determined. Unlike other studies that covered longer time periods, (20) this analysis followed a screening process to specifically include original articles as a measure of new and substantial contributions to scientific production. Moreover, unlike other analyses that only considered the most relevant articles, this study aimed to provide a more comprehensive interpretation of the findings. (21)

Robotic surgery is undergoing rapid growth, with exponential expansion evident in the rising scientific production. This trend has been consistently observed in previous bibliometric analyses, including those with longer periods of analysis. (19,22) The present study served to reinforce and confirm this ongoing trend.

Urology remains the predominant specialty within RS research, (22) although others such as Gynecology & Obstetrics have been noted as one of the most common in other analyses encompassing all fields. (23) However, several bibliographic analyses have been conducted focusing on specific fields, such as spinal surgery, (24) robot-assisted arthroplasty, (25) urology, (26) or pediatrics. (27)

In this bibliometric analysis, the proportion of journals falling within Zone 1, as per Bradford's Law, was higher compared to other studies on the same topic (8% vs 2%, respectively). (22) This discrepancy may be attributed to the inclusion criteria, which focused exclusively on original articles from American institutions.

The analysis conducted highlights the leadership of John Hopkins University and the University of California in scientific research output in the field of RS. Similar findings were reported in a study by Mualen et al., where John Hopkins University emerged as the primary affiliation among the 100 most influential articles pertaining to spine surgery. (24) However, the distribution may vary as other studies focused on the same specialty identified Northwestern University and Harvard University as leading institutions in terms of research output and citations. (19) Institutions such as Cleveland Clinic, Mayo Clinic, and the University of Pittsburgh also exhibited substantial research productivity according to the analyses conducted by Shen et al. covering more than 20 years of RS research on a global scale. (20)

Due to the University of California's distinct campuses (Davis, Irvine, Los Angeles, San Diego, San Francisco) and the typical evaluation of affiliations on an individual campus basis rather than as a collective university, there is a potential for underestimating its genuine scientific impact and leadership in RS research. As a result, it was not recognized between the most productive institutions in previous analyses. (20)

China was found as the first country with scientific collaboration with the United States in RS. According to data from the Web of Science, the number of articles published by at least one Chinese author in the combined subjects of biomedical engineering and robotics climbed from 142 to 4,507 between 1999 and 2019, with two spikes during that time. There are two prominent peaks in this rapid expansion of RS in China, one in 2008, which was two years after the first deployment of the da Vinci robotic system for minimally invasive procedures in Chinese hospitals. The other one was in 2017, a year after the first Chinese-designed robot being made available for minimally invasive spinal surgery. (28)

Apart from the United States' leadership in scientific production of RS, Italy has positioned itself as one of the prominent countries conducting research in this field, as indicated by the analysis from Musbahi et al. on 20 years of literature. (22) Furthermore, this analysis reveals that Italy ranked second in terms of scientific collaboration. Germany, ranking fourth, is also a leading contributor to scientific production, particularly in the field of spine surgery. (24) These countries follow the United States in terms of global scientific production in RS. (20) Additionally, it is worth noting that England stands out as a leader in robotic-assisted arthroplasty, according to reference. (29)

Within the limitations of the study, the bibliometric analysis relies on the availability of data from articles obtained through the search strategy. Additionally, it should be noted that the search was conducted in a single database (WOS), therefore excluding American production on RS from other bibliographic databases such as Scopus or Medline. Despite these limitations, WOS is one of the most prominent bibliographic databases, enabling us to demonstrate the advancements in knowledge within these research areas and objectively highlight the leading role of academic institutions.

Robotic surgery is a rapidly expanding field, as evidenced by the consistent growth in the number of original publications affiliated with American institutions over the past five years. The preceding analysis has provided an overview of the scientific production of RS in the United States, although it should be acknowledged that the main institutions associated with this production may vary depending on the analytical approach. The screening process allowed to draw conclusions based on robust evidence. To enhance the accuracy of the analysis and its results, it is recommended to expand this research to include other databases. Such comprehensive investigation would facilitate scientific and academic comparisons and foster competitiveness among leading authors and institutions in the field.

CONFLICTS OF INTEREST: The authors of this study do not report any conflict of interest.

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