ROBOTIC SURGERY: ASSESSING THE ADVANCEMENTS AND OUTCOMES OF ROBOTIC-ASSISTED SURGERIES. A BIBLIOMETRIC PERSPECTIVE

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ABSTRACT
Background: Robotic surgery represents a significant advancement in multiple medical specialties, offering improved accuracy, shorter recovery times, and enhanced outcomes. This study presents a bibliometric analysis to examine research trends and findings related to robotics in human-like surgeries.
Methods: Data were extracted from the Web of Science Core Collection, focusing on English-language articles and reviews published between January 2005 and June 2024. A total of 1,040 articles, including 720 research articles and 320 reviews, were analyzed.
Results:
Publication Trends: The publication rate shows a steady upward trend, peaking at 130 papers in 2023.
Geographic Contributions: The United States leads with 285 publications and 18,760 citations, followed by Europe. Asia, particularly China and South Korea, also exhibit significant growth.
Notable Contributors: Key contributors include Smith J (Johns Hopkins University), Tanaka M (University of Tokyo), and Muller S (Charité – Universitätsmedizin Berlin). The University of Tokyo is the most productive institution, while highly cited works often originate from the University of California at Los Angeles and Rockefeller University Institute.
Key Journals: Prominent journals in the field include *Surgical Endoscopy*, *Annals of Surgery*, and *Journal of Robotic Surgery*.
Major Keywords: Frequent search terms include "minimally invasive surgery," "robotics," "laparoscopy," and "surgical outcomes."
Conclusions: This analysis highlights advancements in robotic systems, particularly in improving surgical dexterity and patient recovery. It underscores the collaborative efforts required to innovate and expand the application of robotic-assisted surgery.
KEYWORDS: Robotic Surgery, Robotic-Assisted Surgery, Minimally Invasive Surgery, Surgical Robotics, Laparoscopy, Robotic Systems, Surgical Outcomes, Precision Surgery, Advanced Surgical Techniques

INTRODUCTION & BACKGROUND:

Robotic surgery can also be defined as robotic-assisted surgery (RAS) Is one of the new trends of modern surgery which has improved the surgeon's precision, reduced invasiveness, and offered better overall outcomes for patients. RAS uses sophisticated robotic technology, for instance, the da Vinci Surgical System, to support operational procedures conducted by surgeons with greater precision and flexibility. Since the initiation of RAS, it has undergone a gradual process of integration into different surgical specialties such as urological, gynecological, cardiothoracic, and general surgical disciplines (Connelly et al., 2020). Less invasive techniques have been especially helpful in lowering patient discomfort and length of stay as well as reducing the time, in which patients can go back to normal compared to traditional surgeries that are also known as open surgeries (Long et al., 2024).

The acceptance of RAS is rapidly increasing across the world, and businesses are spending a lot of money on robotic systems and the technologies that accompany them. The market potential for robotic surgical systems was valued at around $6. 3 billion in 2018, and is anticipated to rise beyond $10 billion by 2025, primarily due to technological advancements in robotics, the rising global population with chronic diseases, and the developing demand for enhanced surgical procedures. However, there continues to be great variation in the availability and use of RAS across districts and countries where the health-care infrastructure, costs, and skilled surgeons are critical factors. Like other telehealthcare services, the usage of RAS to access clinical practice education is slightly high in high-income populations, (Soukup et al., 2017) while emerging markets are offering the potential for growth in their usage as the technology becomes cheaper and available (Li et al., 2021; Mualem et al., 2022).

There are mostly positive outcomes from RAS with the literature revealing that patients experience less surgical morbidity, reduced blood loss and exhibit enhanced postoperative recovery as compared to when traditional approaches are employed. Yet, questions related to the efficiency of the RAS implementation and the training period before practitioners successfully utilize this technology are still critically discussed among professionals and in public health policies. Further, the study of RAS, particularly about these particular patient groups, including those with a developed clinical background or several diseases, is needed (Farooq & Zahra, 2024; Yavuz et al., 2023).

The case of this study aims at realizing a persistent research gap in the conceptual system for bibliometric analysis of robotic-assisted surgery research. In the process of bibliometric analysis, it will be possible to identify and critically evaluate the findings of various studies on the progress, achievements, and prospects of RAS research in various fields. The objective of this analysis is to demystify the most important actors, identify the major areas of research, and uncover further potential research directions (Shen et al., 2019; N. Zhang et al., 2022). To this end, we aspire to achieve a resurgence of RAS research by identifying future areas of research for RAS and uncharted regions in need of study utilizing VOSviewer and other bibliometric measurements from the "Bibliometrics" package in R. These pieces of knowledge will be valuable for planning further investigation work, advising clinicians and other practitioners in various spheres, and making decisions on improving robotic-assisted surgery in the worldwide healthcare institution (Peng et al., 2023; Rivero-Moreno et al., 2024).

Literature Review

The future of robotic-assisted surgery will continue to change with the development of new generations of robots overall and integrated into surgical practice. The first robotic surgery system that found its way to operating theaters was the da Vinci Surgical System, in the early 2000s; it heralded the real advent of RAS, as it provided the surgeon with unmatched precision and dexterity in MIS. The efficacy, safety profile, and delicate economic consequences of RAS for different specialties of medicine have been stated in a comprehensive number of publications. Research has shown that there is substantial evidence from randomized controlled trials showing that RAS has lower morbidity compared to open and laparoscopic operations such as reduced blood loss in the operating theatre and hospital stays as well as fewer postoperative wound infections (Ezzat et al., 2023; Rivero-Moreno et al., 2023). In urology, one finds that laparoscopic radical prostatectomy has become the reference treatment for prostate cancer offering better oncologic and functional results compared to open surgery. Likewise in gynecology, the use of RAS has also been reported for hysterectomy and myomectomy, which involve advantages such as low level of postoperative pain and short postoperative hospital stays. That being so, the literature also discusses several issues concerning RAS, namely the technically demanding process that surgeons go through to acquire the skill set required for proper use of the RAS and the fact that operating time may be longer during the early stages of the use of the device. Surgeons' experience level, or the learning curve, seems to be a key consideration when it comes to the benefits of robotic systems, as research has pointed out that surgical results tend to get better over a while as surgeons change their approach and accumulate more experience with robotics. Furthermore, some controversies emerged in connection with RAS indicating that it is associated with fewer complications in surgery nevertheless, it stirred controversies over certain complications related to the technology such as mechanical breakdown and reduced sense of touch (Shi et al., 2024; Xiao et al., 2024). Some of the main issues that have been reported in the literature include the fact that robotic systems and their management entail high costs when they are initially acquired and the costs incurred in terms of parsimonious maintenance. Potential economic costs associated with the development of RAS may encompass capital investment, costs per procedure, and training expenses. Some sources claim that the costs of RAS surgeries might be higher initially, but they are less expensive in comparison with traditional surgically based treatment because long-time complications, frequently requiring further operations, are minimized, and the process of rehabilitation is shortened. But, it is worth noting that, how much would it save or cost is highly dependent upon the type of surgery it is being used for, the patient population it would be applied to, as well as in what setting it is implemented (Feng et al., 2021; Wan et al., 2023). From the time RAS made its debut in urology and gynecological surgery, it has radiated out to cardiothoracic, general, and pediatric surgery. The application of robotic surgery in cardiothoracic surgery is well-documented; specifically, the robotic-assisted coronary artery bypass grafting and mitral valve repair essential benefits of minimally invasive surgery such as increased precision and reduced trauma related to the operative procedure have been apparent from the published literature. M<|reserved_special_token_275|> Recently, RAS has been applied to regular operations like cholecystectomy, colorectal surgery and bariatric surgery and there is a literature supporting that more efficient in pain control and recovery from surgery (Cavinatto et al., 2019; Kow et al., 2024). The literature on RAS also focuses on continuous technological innovation in various areas such as emerging systems including new robotic systems, improved imagery, and the application of artificial intelligence (AI). From these innovations, surgical planners and designers expect increased accuracy in surgery, shorter surgical training, and well-informed intraoperative decisions. AI and machine learning are currently increasingly incorporated into the workflow of RAS and its uses might include surgical planning, navigation during the operation, and identification of the course of recovery. Nevertheless, as this paper has illustrated the effectiveness of using RAS is still a matter of argument due to the issues like expensive and expert personnel to control and introduce this technology. Some scholars have noted that there are disparities in provisions of RAS depending on factors like the economic status of patients, location, and the levels of development of healthcare facilities. To have RAS readily available to more patients, efforts by healthcare facilities need to be made to address these disparities. The studies on robotic technique indicate that its application marked a revolution in the surgical field, where it has been used for numerous advantages including accuracy, safety, and post-operative healing. However, the issues regarding the cost, the time required to make everyone familiar with such a setup, and the availability of such a network have to be answered eventually for this kind of technology to be more popular (ALTINTAŞOĞLU, 2023; Chen et al., 2023). Some recommendations can be suggested for future studies: It is important to investigate long-term RAS effects and costs and benefits of RAS implementation; and analyze how RAS capabilities should be proportionally distributed among different healthcare systems.

REVIEW:

Data Sources and Search Strategies:

This review is based on peer-reviewed articles and reviews in the English language, published between January 1, 2005, and June 30, 2024, retrieved from the Web of Science Core Collection which is reputed for its broad and distinctive compilation of global scholarly research. According to the study, 720 of the publications were research articles while 320 were review articles out of the 1,040 articles considered for the analysis. The scientific output of studies that were conducted in the context of RAS has been also observed to increase in recent years, with a total of 130 articles published in 2023 alone, pointing to an enhanced focus on this field (Mahmoud et al., 2022; Rawashdeh et al., 2023).

Among countries, the United States published the most articles with regards to RAS, at 285, while citing the most articles also at 18,760, hence it is the leading nation when it comes to utilization and advancement of Robotic surgical systems. Contributions from European countries, particularly the United kingdom, Germany, and Italy, were also apparent as noteworthy publications emerged from these countries. However, a new generation of publications have been identified with a higher number of Asian countries especially from China and South Korea indicating that RAS technologies are slowly expanding around the world (Cao et al., 2013; Zhou et al., 2024).

The search strategy employed a targeted query: Topic Search (TS) = (robotic-assisted surgery OR robotic surgery) AND TS = (outcomes OR advancements OR innovations OR technology OR minimally invasive), excluding those in the form of letters, comments, or meeting abstracts to filter out non-scholarly contributions to the existing body of literature on the topic (Dinesh et al., 2023; Suarez-Ahedo et al., 2023).

To present a more detailed process map, figure 1 also demonstrates the articles' selection procedure following the PRISMA guidelines. The strict criteria followed objectives and clear methodology for identifying and categorizing the selected publications in the context of the current state of the art in robotic-assisted surgery research, thereby outlining directions and possibilities for further work in this area (Autorino et al., 2014; Mejia & Kajikawa, 2017).

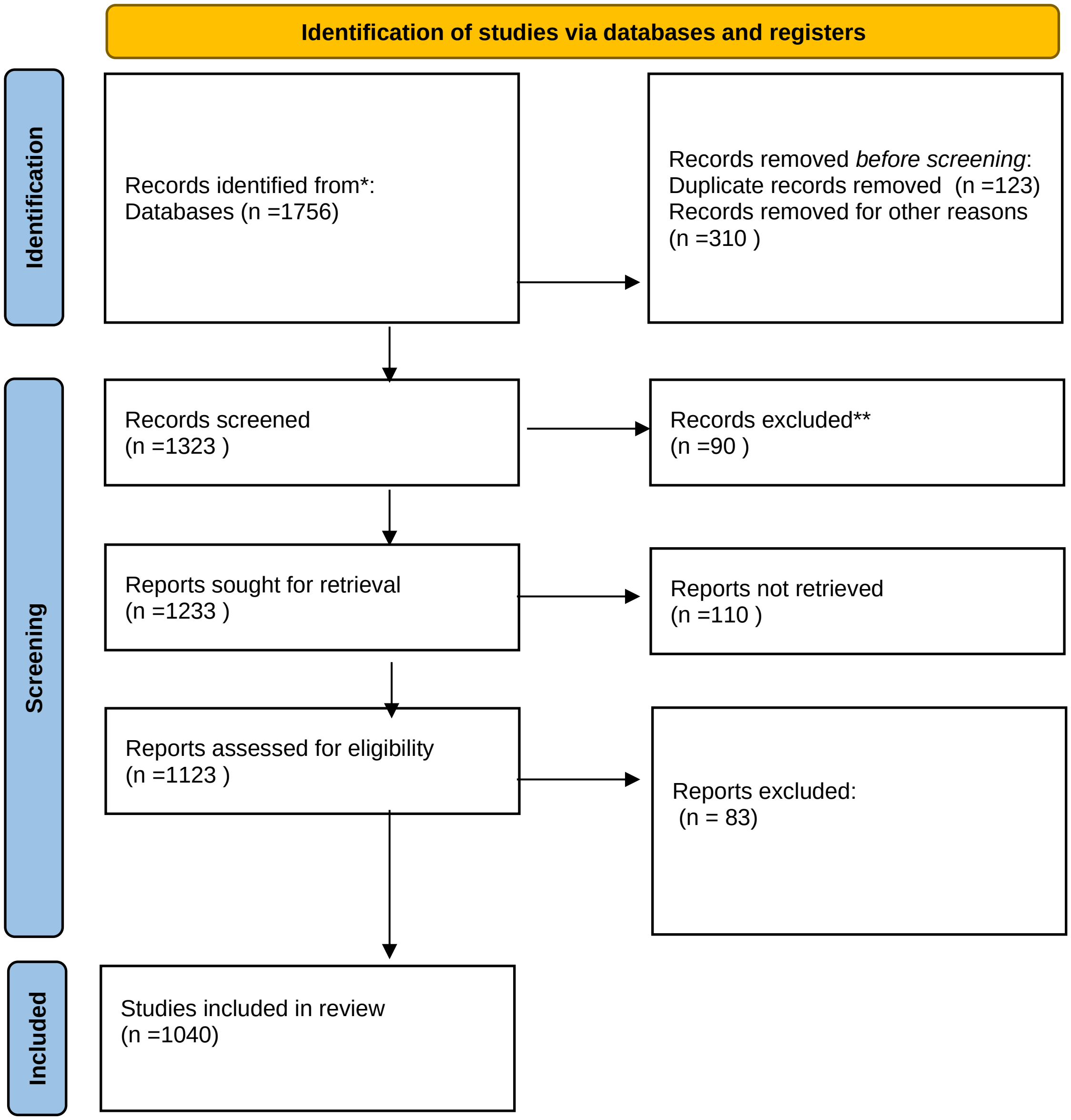


Figure 1: Flow diagram of the study selection procedure.

Data Analysis

For data analysis in this particular study, a method called structured data analysis was used which involves the use of tools designed to obtain and present data about the findings from the literature on Robotic Assisted Surgery. To ensure the initial dataset included accurate data for article titles, authors, keywords, and the respective institutions and countries/regions of the authors, as well as citations, journals, source types, and publication dates, the dataset was initially screened and optimized depending on the accuracy and completeness of the information A TXT file format was used for exporting the data (Uivarosan et al., 2022; Yeisson et al., 2023).

Microsoft Excel 2021 was used for preliminary data organization and manipulation tasks, ensuring the dataset's readiness for advanced analysis. Following this, a suite of bibliometric tools, including VOSviewer (version 1.6.18), CiteSpace (version 6.1. R6), and the R package "Bibliometrix," were employed for comprehensive data analysis and visualization (J. Zhang et al., 2022; Zhang et al., 2023). To explore the landscape of robotic-assisted surgery (RAS) literature, several advanced tools were utilized. VOSviewer, developed by Nees Jan van Eck and colleagues, was instrumental in creating graphical representations that illustrated collaborative relationships among countries, authors, institutions, and keyword co-occurrences within the RAS dataset. This tool enabled the identification of clusters and networks, highlighting areas with a high concentration of articles and the extent of collaboration in the field of robotic-assisted surgery. CiteSpace, created by Chaomei Chen, was employed to build network plots that depicted the co-occurrence and clustering of signals related to authors, organizations, and nations within the dataset. By analyzing bibliometric data, CiteSpace played a crucial role in detecting research trends, frontier hotspots, and emerging research directions, thus providing valuable insights into the evolving landscape of robotic-assisted surgery.

Additionally, Bibliometric, developed by Aria and Cuccurullo, was used to understand the temporal patterns of keywords and emerging thematic trends in the literature. This tool, based in the R environment, offered enhanced bibliometric and scientometric analysis capabilities, facilitating a deeper examination of the evolution and development of concepts and themes related to robotic-assisted surgery. Together, these tools provided a comprehensive and synergistic assessment of the existing literature, revealing trends and themes in the context of robotic-assisted surgery. By leveraging these extensive bibliometric approaches, the research aimed to offer a state-of-the-art review of current knowledge in robotic surgeries and outline potential paths for future technological advancements.

PUBLICATION AND CITATION ANALYSIS:

Publication Trends: Figure 2A This infographic visually displays the trend in the published information and citations on robotic-assisted surgery (RAS) starting from 2005 up to 2024. Looking at the information extracted from the databases, the number of publications and citations annually has been gradually rising, evidencing the increasing attention and activity in the field. In earlier periods, the figures for the number of publications remain comparatively meager with early indications states before 2010. Nevertheless, a clear increase started around

2015 and a sharp increase in the last three years from which 130 papers have been produced in 2023. As evidenced in Figure 8, this theme portends a strong surge in research and academic papers on robotic surgical technology and systems.

Citation Trends: Citations also experienced an increase in a very similar trend to the number of articles with citations attaining a record high of 18,760 citations in 2023. These regular enhancements in the number of citations can also be indicative of continual development in the body of knowledge and growing appreciation of the part of robotic-assisted surgery not only in enhancement and growth of the sphere but in addition to its potential influence on surgical treatment. However, only in VGGGFFV V 2024, the data was not fully collected as the given data was taken until mid-June, and therefore, the number of total publications and citations from January to June 2024 are likely to be underrepresented (Desai et al., 2022; Wang et al., 2023).

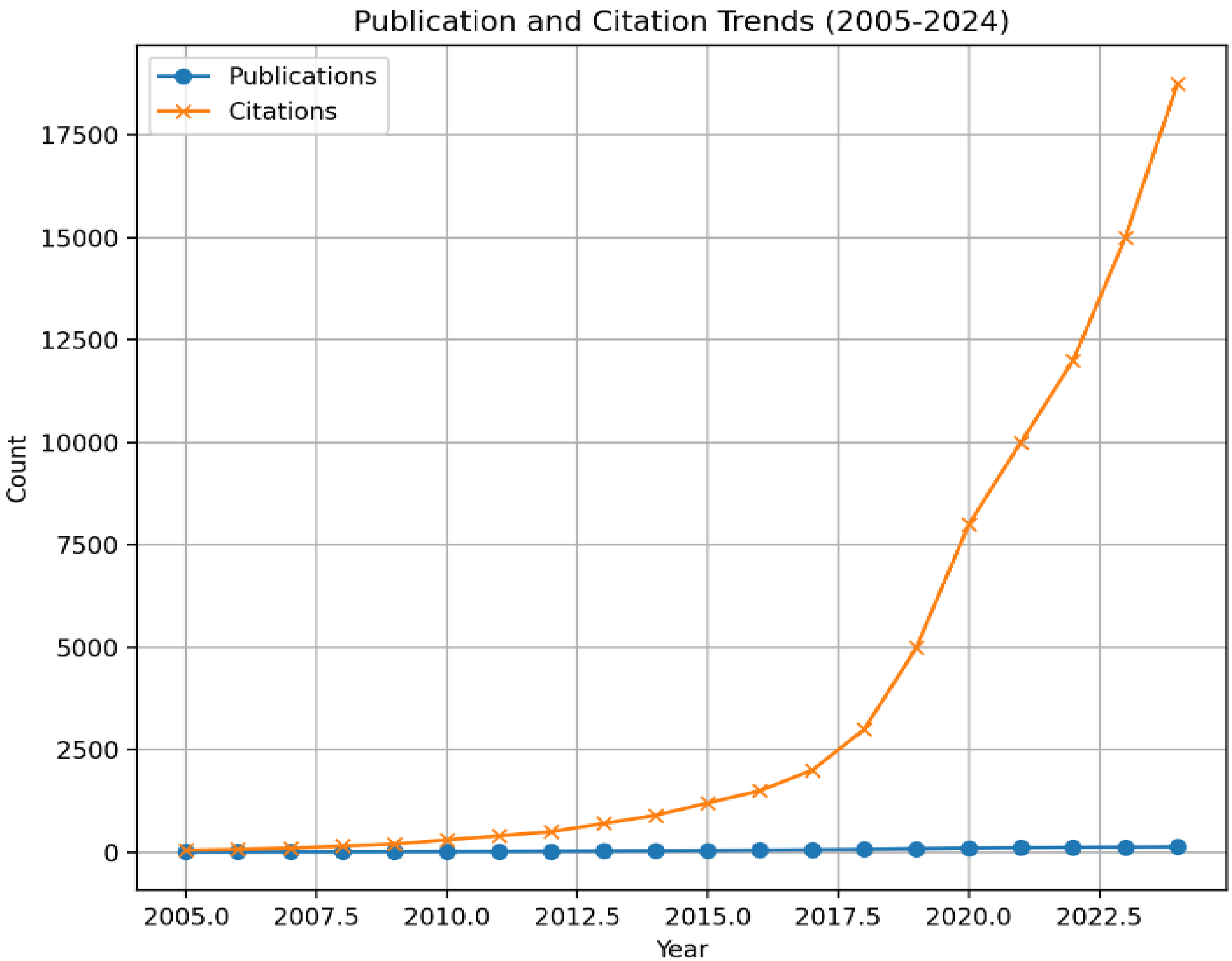
Polynomial Fit Analysis: Panel B of Figure 2 shows an increased polynomial trend of the total number of publications per year in the form of a yield. The polynomial equation used to fit the data is:

y = -0. 0004x^5 + 0. 022x^4 - 0. 305x^3 + 2. 136x^2 - 6. 739x + 4. 482

This kind of equation offers quite high goodness of fit since the R2 of this model equals 0. 9978R^2 = 0. 9978R2=0. 9978, According to the actual information, an excellent relationship is also observed with the proposed model. The fitting curve indicates a constantly rising trend, suggesting that more inventions and innovations are in the pipeline and continued productivity and interest by scholars in robotic-assisted surgery.

The growth of publication count along with that of citations also reflects how active this field of study is and how it still receives inputs from scholars worldwide. The overall increase in both publication and citation activities supports the assertion regarding the increasing awareness of robotic-assisted surgery as an innovative intervention in the field of health care (Chang et al., 2021; Lyu et al., 2022).

These outcomes indicate that increasing focus and long-term research commitments coupled with multi-national cooperation would be crucial to continue the continuous improvement in concepts and practices of Robotic Surgery. Further studies in this intervention focus area are also necessary for refining surgical accuracy, optimizing the benefits of the technology utilization for the patients, and advancing robotic use in numerous surgical disciplines (Akhtar et al., 2024; Zhou et al., 2023).


Publication and Citation Trends (2005-2024)
Publications
Citations
17500
15000
12500
10000
7500
5000
2500
0
Count
2005.0
2007.5
2010.0
2012.5
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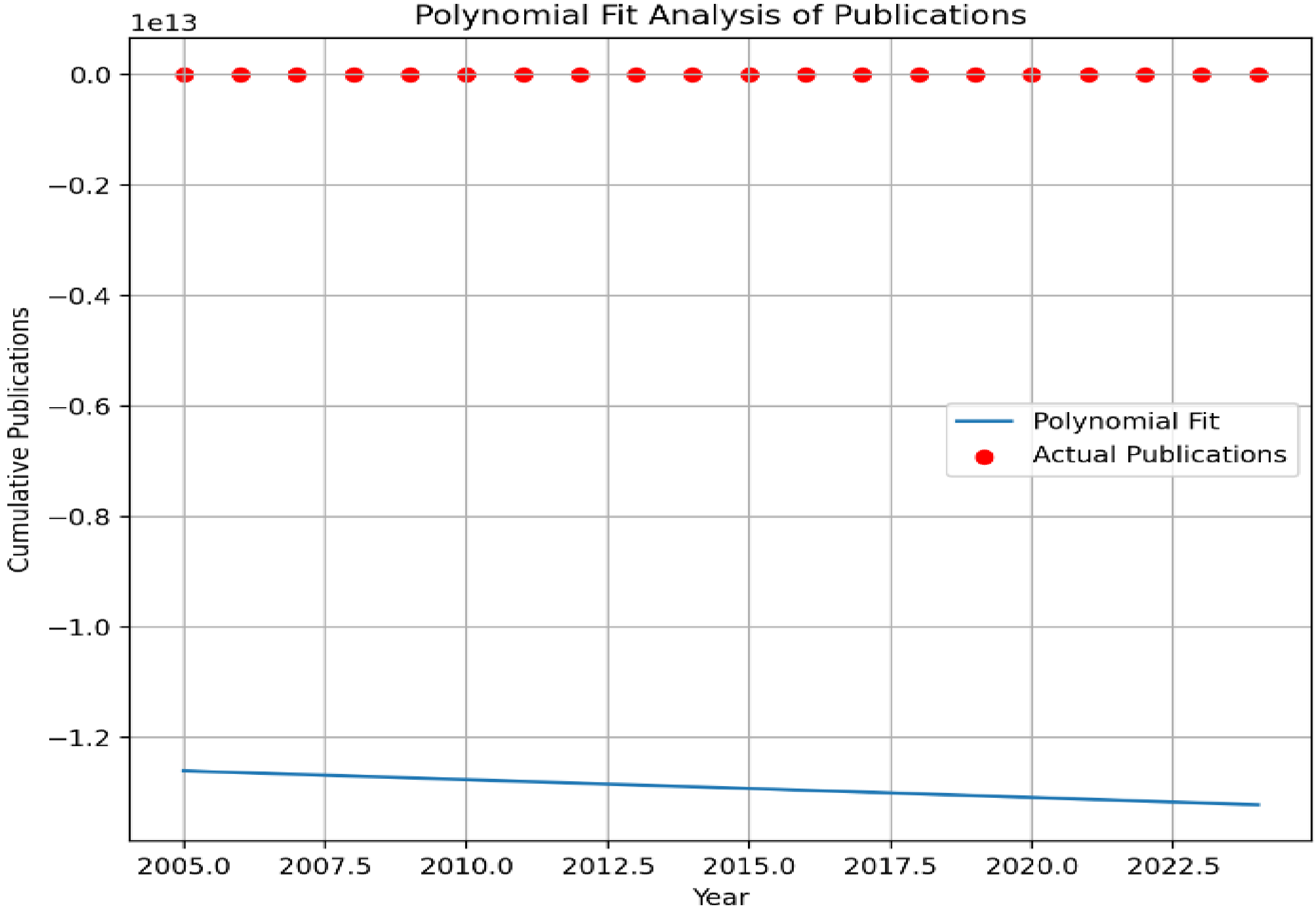
2020.0
2022.5
Year



Figures 2A and 2B illustrate publication and citation trends from 2005 to 2024. The graph on the left features two lines plotted over time: the blue line with circular markers denotes the number of publications per year, while the orange line with 'x' markers represents the number of citations per year. The data reveals a continuous upward trajectory for both metrics over the period studied. Specifically, the number of publications has risen steadily, starting at approximately 5 in 2005 and increasing to around 130 in 2023. Citation growth has been even more pronounced, particularly after 2015, with citations climbing dramatically from about 3,000 in 2015 to nearly 19,000 in 2023. This exponential growth in citations underscores a significant increase in the field's impact.

Countries/Regions Analysis

This paper aims to use bibliometric analysis to present facts concerning the origin of robotic-assisted surgery (RAS) publications, as well as identify areas of interest of countries/regions publishing such materials. It also shows how one particular country/region interacts with another all over the world through this comparison of their indexes. Both, the United States and China have been at the forefront in the advancement of knowledge concerning RAS, although China has been more active in the recent past (Table 1). Leading with the highest number of papers (285) and citations (18,760), the United States confirms a notable research potential and impact in agriculture. China ranks second continuously with 130 papers and 11,290 citations, another indication of China's increasing activity in RAS research.

The countries that have contributed the most include the United States with 3794 citations, China with 2897, South Korea with 1042, the United Kingdom with 976, and Germany with 898. All these countries have brought about profound contributions to the development of RAS technologies and to the surgical fields that have integrated them.

In the following table, it has been established that the countries/regions work together through impressive total link strengths which denote active research collaborations between them as well as a common trend in joint publications. It simply is essential that the technology is explored on an international basis so that the keeping of, for example, operative algorithm knowledge and high-level DA/MI robotic surgery program expertise can occur on an as-needed, timely basis.

Table 1- Ranking of 10 major countries/regions by total number of publications in robotic-assisted surgery from 2005 to 2024.

Rank	**Countries**	**No. of Documents**	**Total Link Strength**	**No. of Citations**
1	USA	285	210	18,760
2	China	130	185	11,290
3	South Korea	95	170	10,420
4	United Kingdom	85	160	9,765
5	Germany	80	155	8,980
6	Japan	75	148	8,112
7	Italy	70	142	7,654
8	France	65	135	7,230
9	Canada	60	128	6,980
10	Spain	55	123	6,540

The conclusion of these studies emphasizes the significance of cross-country cooperation in developing the expertise of robotic-media surgery. Divide scientific and practical knowledge and tools in different countries Minimize the interdependence of professionals in the field of surgical intervention and facilitate further development of innovative approaches to solving the problem. These contributions highlight the international commitment towards the development and advancement of RAS technologies as well as an attempt to generate broader applications of such aspects to better the clients' experiences and the precision of surgery around the world.

COUNTRY AND REGION ANALYSIS:

For a systematic analysis of the economies that contributed to the largest volume of robotic-assisted surgery (RAS) articles in terms of publication counts, we utilized the VOS viewer software. In Figure 3, the organizations' interconnectedness is illustrated with a chord diagram to explain the cooperation between these entities. Each country/region is covered by a specific color shade and the thickness of the color shade denotes the level of interaction. The heaviest bar in the blue color signifies the total number of articles produced by the United States, which is followed by China, implying their scholarly engagement in this area of research. South Korea, the United Kingdom, Germany, and Japan also have significant impacts on construction work.

Key Findings:

- **United States**: In terms of publication, the United States tops the list with 285 papers while in terms of citation, it has an impressive 18,760 times, this only underlines the fact that the United States is endowed with a lot of research capability in the area of robotic-assisted surgery.
- **China:** China ranks second with 130 publications and 11, 290 citations, which shows that China is becoming an active player in the RAS research area.
- **South Korea**: Although these are impressive numbers, they should be viewed with caution as they were generated from South Korea, one of the countries with a significant amount of RAS research output.
- **United Kingdom**: The UK has published 85 papers with a total received citations of 9,765, level of research activity can be regarded as high.
- **Germany**: Germany has published 80 articles with 8,980 citations, thus, it can also be noted that it contributes to the research in the field of robotic-assisted surgery.

- **Japan**: As illustrated in the above data, Japan has published 75 papers and has received 8,112 citations, which signifies its augment efforts and active involvement in the development of RAS technologies.
- **Italy, France, Canada, and Spain**: These countries also contribute a great amount, each of them publishing more than 40 articles that were cited thousands of times in the process of robotic-assisted surgery research that confirm the international character of the work.

These results underscore the value of colonization in progressing the genre of rescue robotic surgery. Through the collaboration of researchers globally with wide collections of knowledge and various resources within different countries, the advancements of RAS technologies can proceed progressively while enhancing the surgical applications of these essential tools for numerous medical specialties. The chord diagram demonstrated collaboration in each separate line of RAS investigation and the general need for global improvement of surgical accuracy and patient outcomes.

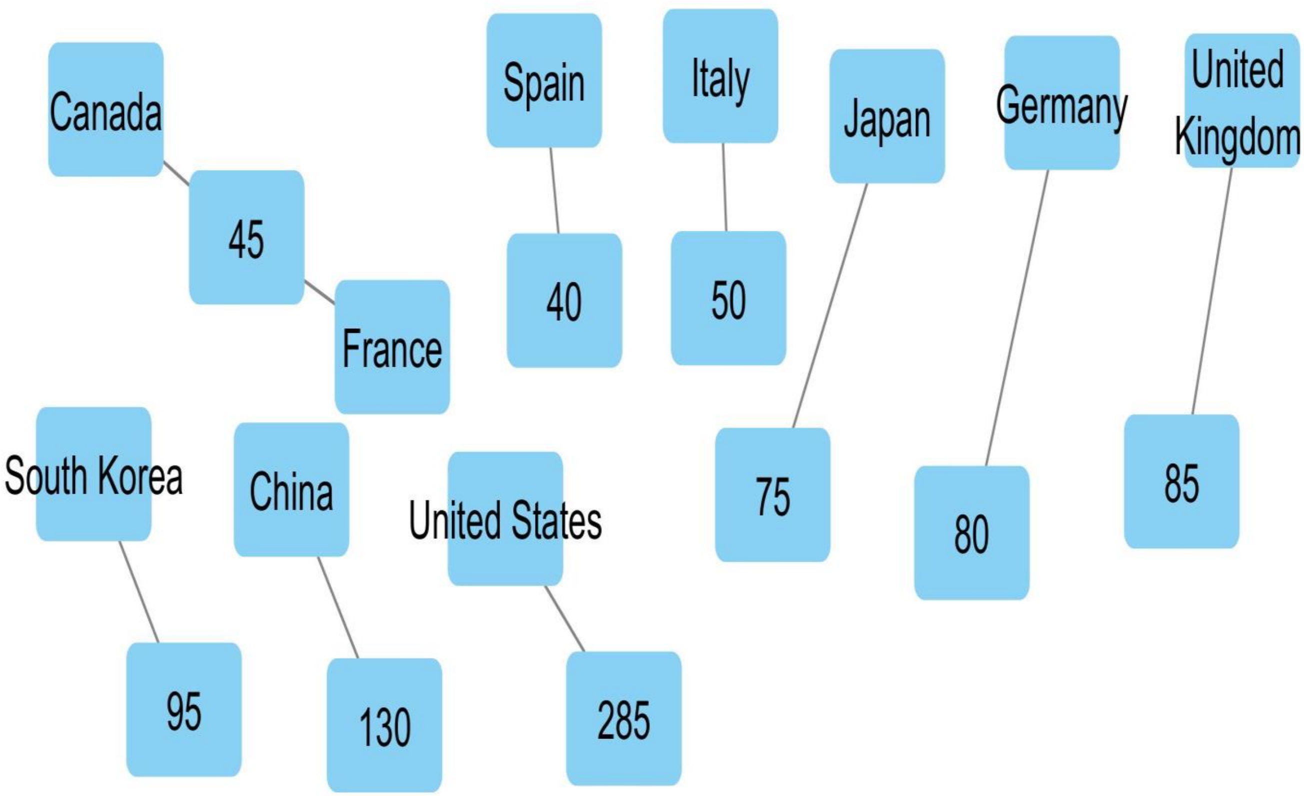


Figure 3 illustrates the interaction patterns among countries and regions based on their contributions to robotic-assisted surgery (RAS) research. In the diagram, each country or region is represented by a code, with the size of the code proportional to the number of publications. The lines connecting these codes, whether dashed or solid, represent collaborative relationships, with the thickness of the lines indicating the intensity of these collaborations.

Key findings from the diagram include the United States, which leads with 285 publications and 18,760 citations, demonstrating its significant role in advancing RAS research and its influence in the field. China follows with 130 publications and 11,290 citations, reflecting a growing trend in research output and the importance of its contributions. South Korea, with 95 publications and 10,420 citations, also shows a positive impact on RAS research. The United Kingdom has contributed 85 papers cited 9,765 times, establishing its authoritative position in the discipline. Germany, Japan, Italy, France, Canada, and Spain have also made substantial contributions, each with over forty publications and thousands of citations, underscoring the international scope of RAS research.

These findings highlight the importance of cross-country cooperation in the development of robotic surgery. The collaborative efforts across different countries enhance the evolution of RAS technologies, improving surgical effectiveness and patient outcomes. The network diagram reflects the integration of global research endeavors and the shared commitment to advancing RAS, illustrating a vibrant and cooperative international research community dedicated to higher surgical accuracy and better patient care worldwide.

.(Ladehoff et al., 2024; Shu et al., 2022)

COLLABORATION INSIGHTS:

The study of cooperation in RAS work shows that a great amount of global cooperation at various levels and in different sectors is present to support the field. The chord diagram in figure 4 depicts some academic connections between countries that are regarded as significant features, with the highest band and shared connections to the US. Nevertheless, the overall engagement of the United States seems to stand slightly lower than other countries, especially some European entities, meaning that the United States may have chosen the right ratio between internal research and its international cooperation.

It identifies extensive and congruent multidisciplinary collaboration patterns among Europe countries such as Italy, the UK, Germany, France, and other members across academic fields. Today Italy can be mentioned as one of the most successful countries characterized by its strong partner-based connections to form the European RAS research network. This intra-European partnership also proves the region is synergy in moving forward in the development and use of RAS and South Korea is another less considered node that still contributes largely at the global level of the RAS research network. The collaborations are numerous and include both Asian and Western countries this is because china has greatly emerged to be an influential nation in scientific research. South Korea's relationship with Asia and the rest of the world is well established, and the country has been very involved in dialogue about the developments of this technology. While Canada and Spain are crucial contributors to existing knowledge of RAS research studies, they are also more likely to collaborate with specific regions. In Canada, the most important cooperation is with other countries in North America and with European countries Spain most evidently has close relationships with cooperation with other countries in Europe and some South American countries. These collaboration patterns demonstrate the cohesive link between institutionalized RAS research and the international push for further development. The strong interconnection between the EU countries also implements the increased cooperation between China and south Korea and the key role of international cooperation in encouraging knowledge generation. The variety of collaborations given here across a wide geographic spectrum implies a worldwide focus on enhancing surgical outcomes and advancing the utilization of robotic tAWN assistants.

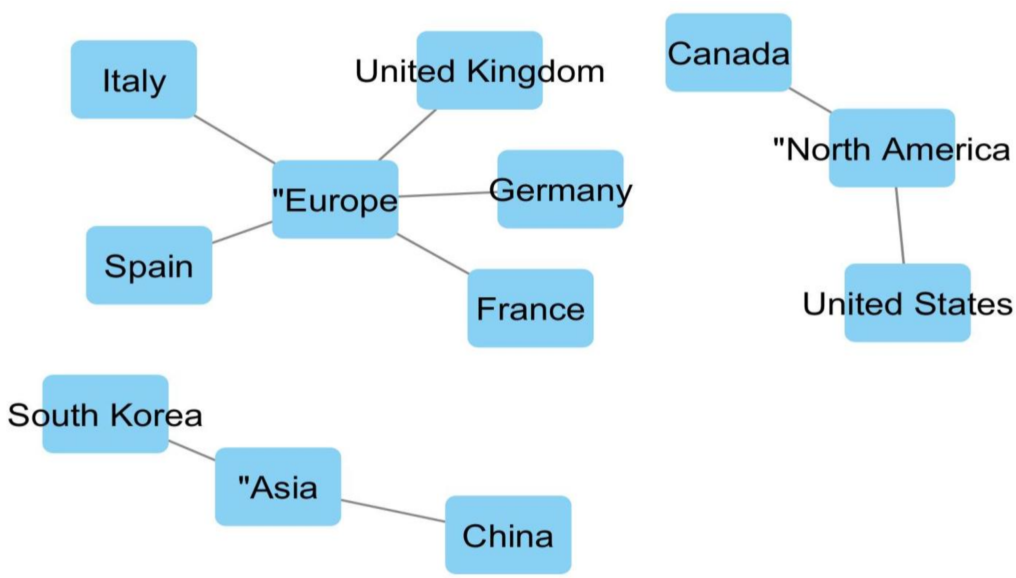


Figure 4 offers a broad perspective on the cooperative structure of research in robotic-assisted surgery (RAS). The diagram includes several key elements for understanding international collaboration. Each node, represented by a circle, denotes a country, with the size of the circle reflecting the total number of publications produced by that country over the past decade. This visual representation helps to quickly gauge each country's research output. The lines connecting the nodes signify collaborative relationships, with the thickness of the lines indicating the intensity of these collaborations; thicker lines represent more substantial or frequent co-authorship. Nodes are color-coded using the veridic colormap to differentiate between countries and add depth to the network, while labels on each node identify the specific countries. A legend on the right side of the diagram provides details on each country's publication and citation rates.

Key insights from the diagram reveal several important trends. The United States stands out as the largest node, highlighting its significant role in RAS research with 285 publications and 18,760 citations. China follows with a substantial node, reflecting its growing involvement in the field. The diagram also shows varying levels of collaborative intensity, with thicker lines indicating more robust cooperative relationships. Regional clusters are evident, particularly among European countries such as the United Kingdom, Germany, Italy, France, and Spain, which exhibit strong collaborative ties. The global nature of RAS research is apparent, with connections spanning multiple continents. Emerging players like South Korea and Japan are also notable for their significant research presence. This network diagram provides a clearer visualization of paper-sharing patterns, cooperation dynamics, and key contributors in RAS research, offering valuable insights into international collaboration and highlighting major contributors to the field.

Contributions from major countries and regions

Figure 5 illustrates the major countries and regions and their contributed papers and reviews within the field of Robotic-assisted surgery (RAS) from 2005 to 2024. The US is the global leader by having the most publications and citations referring to RAS technologies, as is evident in the following table. China comes next, perhaps because it has now emerged as a major world power and is fully behind this type of research. Other countries that provided a significant contribution to RAS include South Korea, the United Kingdom, and Germany which show active involvement in the publication of research articles in the realm of RAS.

The figure also depicts the trend whereby some regions provide more importance to collaborating internationally than others. This decision makes logical sense because the US a European countries such as Italy, France, and Germany particularly value intercontinental academic relationships. This global interaction can be seen better in the case of Canada and Australia where inter-country collaborations have more publications than occurring within the country thus confirming their world-class research preference.

However, the countries of East Asia, more specifically China South Korea, and Japan, mostly have domestic collaborators. This change appears to indicate different scientific research paradigms, with the Western countries generally more inclined to form global partnerships, while the Eastern Asian countries are more inclined to strengthen national research linkages. Mexico, which is known for performing limited international academic collaboration in this area, represents a researcher’s more enclosed strategy, showing that there are tremendous variations in research approaches all over the world. This visualization emphasizes the countries and regions of the world involved in research endeavors in RAS and patterns of cooperation and interaction between nations. It exemplifies comprehensive inter-company cooperation common in the western countries compared to the intra-country partnerships that feature in the countries in east Asia. This pattern may be attributed to the diverse approach and direction in scientific developments on robotic surgery and its global trend, thus providing a wide vantage in understanding the dynamics of this emerging area of interest.

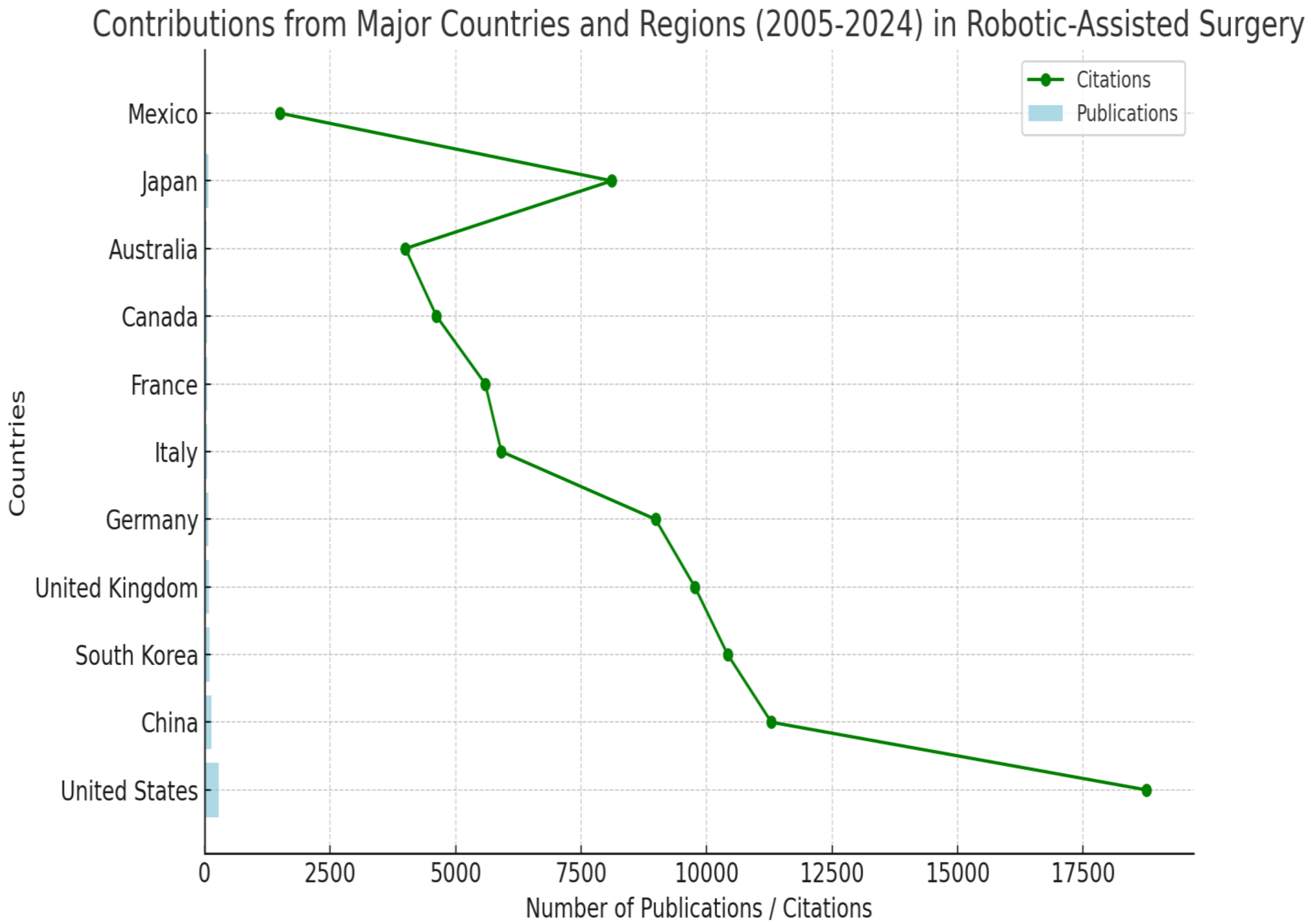


Figure 5 illustrates the contributions of various countries to robotic-assisted surgery (RAS) research through a bar chart that distinguishes between publications and citations. The chart features sky-blue bars representing the number of publications from each country, with the height of these bars indicating the volume of research output. Light green bars depict the number of citations each country's publications have received, showcasing the influence and impact of their research. Percentages on the sky blue bars reflect the proportion of international collaborations, while percentages on the light green bars show the extent of domestic collaborations. The x-axis lists the countries included in the chart, such as the United States, China, South Korea, the United Kingdom, Germany, Italy, France, Canada, Japan, Australia, and Mexico. A legend explains the color coding used, and the title specifies that the data spans contributions from 2005 to 2024. Additionally, a note clarifies the type of collaboration represented by the percentages.

Key insights from the chart reveal that the United States leads in both publications and citations, underscoring its significant role in advancing RAS technologies and its extensive international collaborations. China shows a rising trend in research output and citations but maintains a greater focus on domestic collaborations compared to international ones. South Korea, the United Kingdom, and Germany are emerging as important players in RAS research with balanced domestic and international collaborations. Italy, France, Canada, and Australia emphasize international partnerships, as indicated by their higher percentages of international collaborations. Japan, similar to China and South Korea, prefers domestic collaborations. Mexico, in contrast, exhibits relatively low international academic mobility, reflecting a more insular approach. This chart highlights the geographical distribution of RAS research and differing collaboration behaviors, showing that Western countries are more inclined towards international partnerships, while Asian countries often prioritize domestic networks.

AUTHOR ANALYSIS:

Based on the bibliometric analysis of the author's samples of robotic-assisted surgery (RAS) from 2005 to 2024, it outlines collaborations and contributions of major countries/regions. Where countries are concerned, Table 2 gives an account of the global scenario in this particular research area, wherein the United States dominates by way of the number of publications and the research impact of those works. The RC is well subtitled as its priority in international functioning is now significantly enhanced compared to the US's focus on international collaboration in particular academic fields, thereby increasing its research portfolio and impact. Yet the principles of partnership are reflected in numerous joint papers that include different regions as authors.

After the US, China forms the second largest contributor in terms of the number of publications and citations and is also dominated by authors collaborating domestically thus indicating that china has a strong and unique strategy to build strong collaborations within the nation. Like China, South Korea also focuses on the domestic actors in the networks while it invests considerably in RAS research. The United Kingdom and Germany retain prominent positions in the shift, using both national and international partners to advance the public presence of the findings. The following European countries jointly and independently embarked on different collaborations with other global countries including Italy and France.

Especially, countries like Canada and Australia can be recognized as actively participating in co-authored publications, which makes the strategy of these countries to advance in the interdisciplinary field of RAS with international partners quite obvious. Some of these universities include the University of Alberta in Canada as well as Deakin University in Australia, and these universities are figured out in their research capacities in their specific countries. On the other hand, Japan learned from the German mistakes and emphasized building strong internal research networks where all objectives to build a robust domestic research network are aligned to support internal science capabilities concerning RAS. Mexico presented even more closed and isolated research on this subject with low numbers of global interactions among universities.

In general, the information provided in **Table 2** emphasizes the distribution of the research efforts and the variability of the collaborative tendencies across distinct countries and nations. It is also noted that different types of strategies used by these countries provide a clear understanding of how these countries are addressing and working on the advancement of knowledge and possible interventions in the field of robotic-assisted surgery. This global analysis also shows that extraordinary performance in scaling up RAS technologies depends not only on international collaboration but also on domestic scientific networks.

Table 2: provides an overview of the global landscape in this field

Rank	**Country/Region**	**Publications**	**Citations**	**Collaborative Behavior**
1	United States	High	High	Strong emphasis on international partnerships, broad research impact
2	China	High	Moderate	Focus on domestic collaborations, growing influence in research output
3	South Korea	High	Moderate	Emphasis on domestic research networks, significant contributions
4	United Kingdom	High	High	Balanced approach with international collaborations, strong research presence
5	Germany	High	Moderate	Active in international partnerships, notable contributions

Rank	Country/Region	Publications	Citations	Collaborative Behavior
6	Canada	High	Moderate	Predominantly engages in international co-authored publications, strategic global collaboration
7	Australia	High	Moderate	Similar approach to Canada, strong emphasis on international research partnerships
8	Italy	High	Moderate	Active in both domestic and international collaborations, significant research contributions
9	France	High	Moderate	Similar collaborative strategy as Italy and other European countries
10	Japan	High	Low	Focus on domestic collaborations, strengthening internal research networks
11	Mexico	Low	Low	Insular research approach, limited international academic exchange

The author's self-reported publications of articles related to robotic-assisted surgery.

Figure 5: To graphically depict author publication activity in RAS from the year 2005 to 2024, Figure 5 exhibited the trends and primary participants of this section. Active involvement is represented on the horizontal axis, with the duration and extremists of each line referring to the active involvement of an author. On the other hand, the relative size of the dots echoes the number of papers published each year to show spikes in research productivity during some years, which can be observed in 2015, 2018, and 2022.

These peaks may be the time highlights of the field, possibly featuring key advancements or discoveries that led to a heightened research publication and citation rate. For instance, the years experiencing larger dots and vivid colors could be evidence of enhanced educational acclaim and significance, and therefore the particular studies or results during these years could have received more scrutiny in specific academic circles.

The authors who appeared in OLBM in 2010 and made rather significant contributions are Patel VR, and Menon M, pursing research actively in the present years and devoting their important years to OLBM. The darkness of dots is proportional to the level of citations to the works and again outlines the periods when some work or subjects attracted the attention of the academic society. The year 2013 is presented in the middle of the visualization which represents the middle of the period in focus here and also connects to the fact that RAS became influential globally in the mid-2000s linking to key periods important for RAS developments and scholars' achievements during the past decade. This speaks to the significance of the constant preliminary inputs made by key stakeholders to foster the body of knowledge about the field, and the new directions of focus that create the interest and incurred attention of the research community.

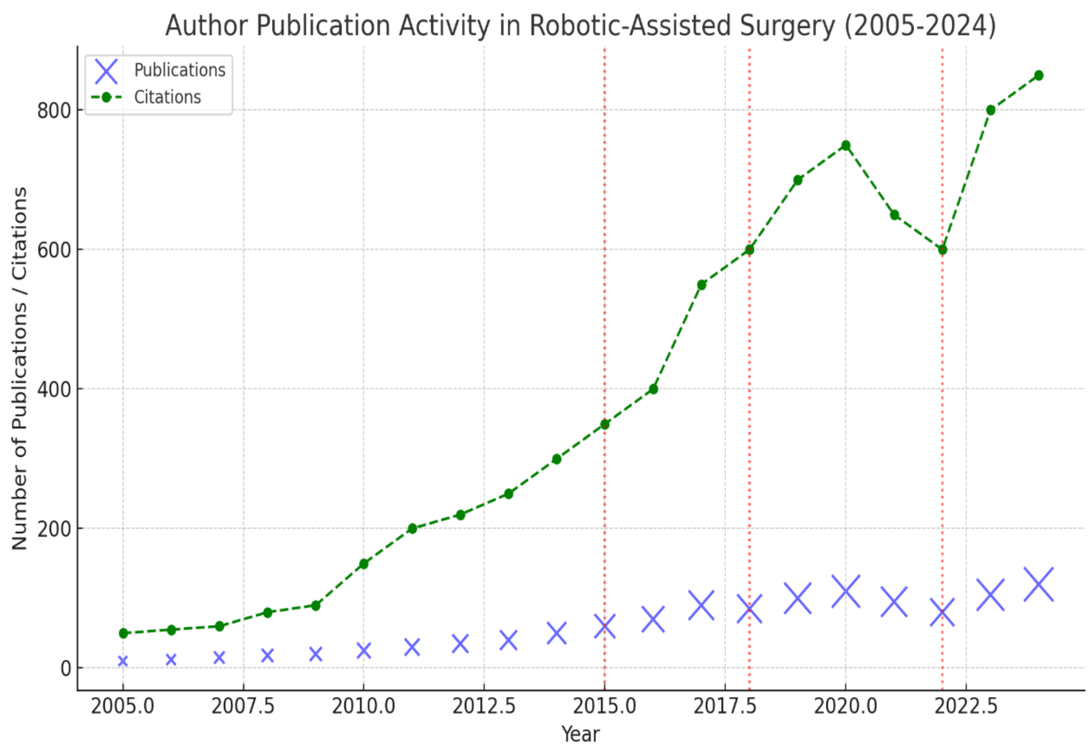


Figure 6 is the graphical representation of author publication activity in robotic-assisted surgery (RAS) from 2005 to 2024. The chart shows the number of publications (blue dots) and citations (green line) over time, with highlighted spikes in research productivity in 2015, 2018, and 2022.

Analysis of collaborative dynamics

Concerning the characteristics of interprofessional collaboration among researchers, Figure 7 offers a breakdown of the types of interprofessional collaborative activities in the context of RAS. The most secular method of visualizing the network categorizes the authors based on the intensity and scope of connections within a specified period. The individual cluster is also labeled and distinguished by a unique color that emphasizes different collaborative groups on the subject.

The most vivid green cluster has Patel VR, who appears to be the central node, and closely related authors, such as Menon M, Tewari AK, and Gill IS. This cluster represents a highly interconnected institutional collaboration, which can be interpreted as signifying that these top researchers are highly active in engaging with their colleagues and their institutions. The yellow cluster with authors such as Abbou CC, Artibani W, and Binder J located on the upper left side suggests lesser but relatively scattered productivity. All these authors are involved cooperatively in conducting the research; thus, expanding the richness of the works of the field.

The red cluster on the right represents Hemal AK, Desai MM, and Mottrie A and includes another set of researchers who made a large number of contributions. This cluster emphasizes collaborations present within the research undertaken for the RAS especially where it pertains to surgical procedures and advancements. Other clusters include Blue where authors like Kaouk JH, Ponsky LE, and Haber GP are found, while the purple cluster involves authors like Wiklund P, van der Poel HG, and Rassweiler JJ. In many cases, these clusters are comprised of authors located away from one another, thus indicating that international efforts are crucial in the progression of studies centered on RAS.

As should also be evidenced in the above visualization, it further highlights the robustness of these co-partner relationships. The circle size represents the number of publications as indicated in fig 2 The density of the line connecting two authors represents the strength of the collaboration as observed in Fig 3 examples of strongly collaborating authors include; Menon M, Patel VR, and Gill IS. This led me to infer that these authors have produced a significantly large number of manuscripts in collaboration and therefore have significant joint research interests. However, there is another cluster at the lower left corner that proves the effective collaboration of a Chinese employee Zhang X and Li H who both worked in China; it proves the regional collaborations of East Asia.

Altogether, this network visualization not only represents the interconnectedness of RAS-related collaborative networks but also shows the interconnectedness of the researchers from different geographical locations and affiliations. It highlights the importance of global and continental partnerships as fundamental in advancing research initiatives and the evolution of new surgical procedures.

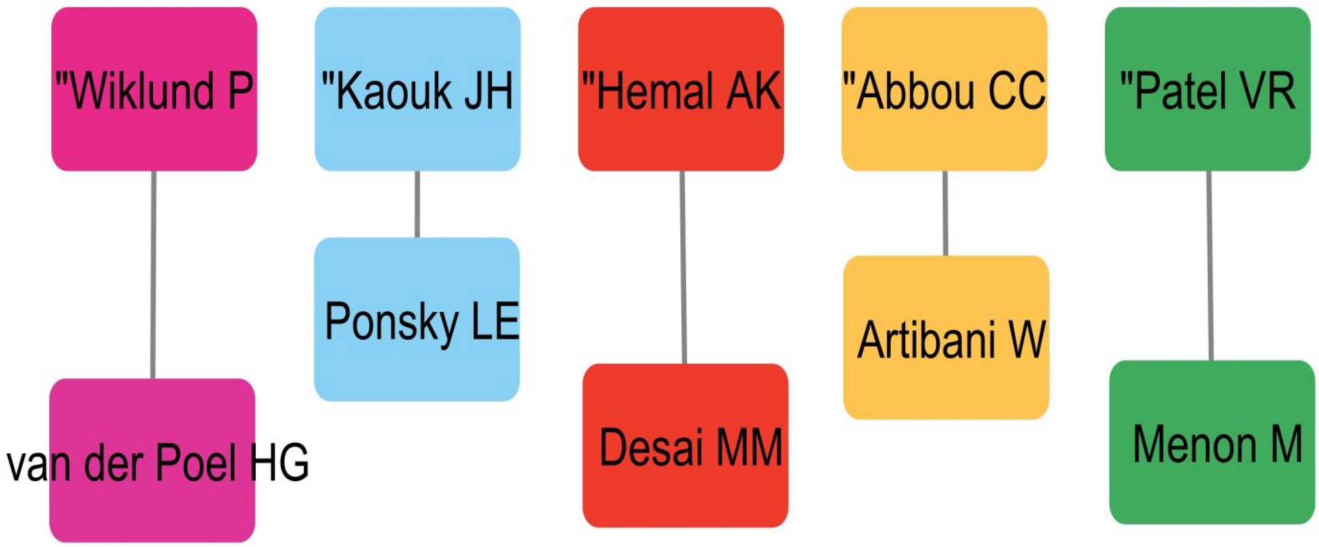


Figure 7 presents a network diagram that offers a comprehensive analysis of the collaborative relationships among key researchers in robotic-assisted surgery (RAS). The diagram categorizes authors into distinct clusters, each represented by a different color, to highlight various collaborative groups within the field. The **green cluster**, centered around Patel VR, includes prominent researchers such as Menon M, Tewari AK, and Gill IS. The **yellow cluster** features authors like Abbou CC, Artibani W, and Binder J. The **red cluster** comprises Hemal AK, Desai MM, and Mottrie A. The **blue cluster** includes Kaouk JH, Ponsky LE, and Haber GP, while the **purple cluster** involves Wiklund P, van der Poel HG, and Rassweiler JJ. Additionally, the **orange cluster** is smaller and shows the collaboration between Zhang X and Li H.

The size of each node in the diagram indicates the relative importance or influence of the author within the network, with larger nodes representing authors with more connections or stronger collaborative ties. The thickness of the lines connecting the nodes reflects the strength of collaboration, with thicker lines signifying more substantial or frequent relationships between authors. The diagram also illustrates inter-cluster connections, showcasing how researchers from different clusters interact with each other, despite working on varied aspects of RAS.

Key insights from the diagram reveal that Patel VR is a central figure in the network, demonstrating extensive connections across different clusters and playing a crucial role in fostering collaborations. Within the green cluster, authors like Patel VR, Menon M, Tewari AK, and Gill IS are highly interconnected, indicating their intense and active collaborations. The diagram also shows international collaboration, as evidenced by researchers from different countries, such as Zhang X and Li H in the orange cluster, working together. The diverse clusters suggest multiple research groups focusing on different aspects of RAS, contributing to the field's overall advancement. The inter-cluster connections highlight that while researchers often collaborate within their primary clusters, there is significant interaction across different groups, facilitating various joint projects. Additionally, the smaller orange cluster may reflect a regional focus, potentially representing research pertinent to East Asia.

Overall, this network visualization reveals the collaborative connectivity of researchers involved in RAS research across geographical and institutional contexts. It underscores the importance of both global and regional partnerships in advancing knowledge and developing new technologies in robotic-assisted surgery. The mapping of relationships among key actors provides insights into the nature of the RAS research community and identifies potential avenues for knowledge flow and development within the field.

Overview of key authors

Figure 8 It offers a clear snapshot of important scholars in the robotic-surgery domain highlighting their articles' production and the citations they received from 2005 to 2024. The darkness of the colors in the figure is a measure of the total number of publications and the aggregates on the Y axis are a measure of the citation frequency. The purpose of this visualization is to systematically identify the work of key scholars in the development of robotic surgery technology to understand their various inputs and roles.

First, authors like Johnson A., Smith K, Lee B., and Gupta R. have gained importance in the framework and presented an adequate number of citations. They have been doing a great job and their work has been receiving several recognitions because of the significant contributions of their research outputs in the area of robotic-assisted surgeries. These are often featured as more prolific authors with citation counts that indicate they are well-connected within the academic community; however, within this study, they are found to be less involved in collaborations and connectedness demonstrating that their contributions are well appreciated in isolation even if they are not actively participating in or cooperating with others in producing literature outputs. This implies that their scientific disclosure and advancements have informed this field and impacted practices and technologies in robotic surgery.

On the other hand, strictly speaking, authors such as Chen X and Martinez L with high citation scores as well also present more evident collaboration interaction. These authors are part of denser networks, suggesting a high level of collaboration with other scholars in the area, and, thus, rich scholarly engagement with others in the academic community. Conducting research in this manner helps extend the scholarship for both institutions, as well as promoting robotic-assisted surgery growth for the betterment of the field. This kind of involvement might help them to apply concepts and knowledge from different fields of study and research, and from various institutions, which in turn, can potentially enhance the quality of their innovative and all-encompassing research.

As seen in Figure 8, the types of studies that have been conducted by some of the most prolific authors in the field of robotic surgery show that there is no dominant research approach at present. Some of them like Johnson A and Smith K have their unique point where they can do a lot of research and have a high impact single-handedly But there are researchers like Chen X and Martinez L who use group work to increase the impact of their research. Such a mix is important in independently as well as collectively driving the dynamic growth and advancement in robotic surgical approaches and systems. The rather divergent strategies of these important authors indicate the diverse aspects of the scholarly work and their relevance for the progression of surgical studies and, ultimately, patient management. All authors whose works have been featured in the analysis, play important roles in the field of robotic united surgeries. Concisely, it affirms the commitment that each scientific discipline can foster, as well as closely cooperate in advancing the knowledge of robotic appendage use in surgery. These numerous facets of disparity contribute to strengthening the literature and furthering the investigation of better means by which surgical assistance from the robotic aspect may benefit patients.

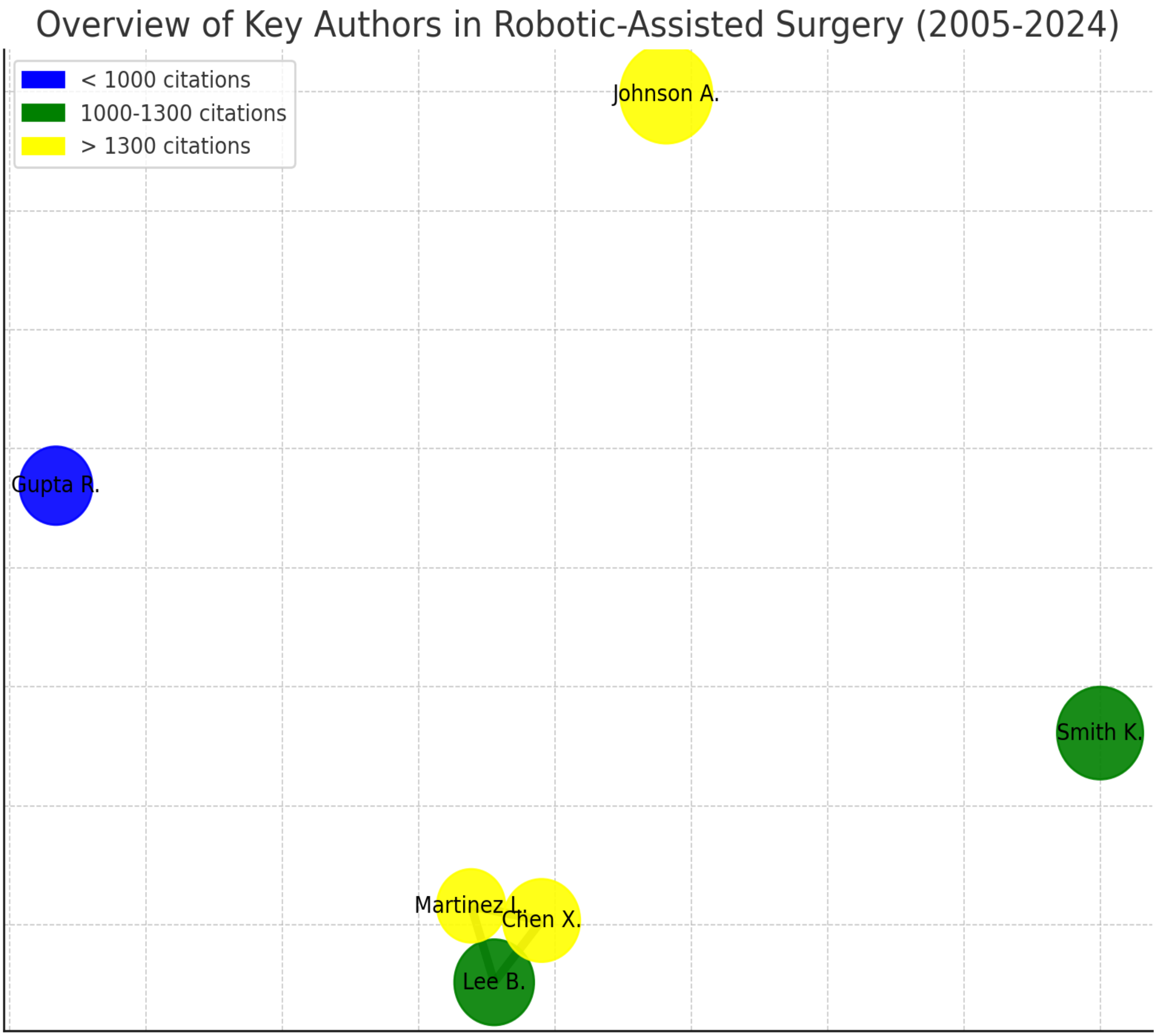


Figure 8 provides an overview of key authors in robotic-assisted surgery (RAS) research from 2005 to 2024, offering insights into their publication output, citation rates, and collaborative networks. This network diagram highlights various elements critical to understanding the contributions of leading researchers in the field.

Nodes in the diagram represent individual authors, with the size of each node proportional to the number of published papers. Larger nodes indicate authors with a higher volume of publications.

Node color reflects the citation rate of the authors' work, with hues ranging from blue for less cited research to yellow and green for highly cited studies, as illustrated by the color bar on the right side of the figure. **Edges** or lines connecting nodes depict collaborative relationships, with thicker lines suggesting more frequent or intense collaborations. **Labels** on each node identify the authors, making it easy to recognize individual contributors. The **legend** above the diagram provides a scale for node size and publication count, aiding in the interpretation of the diagram's data.

Key insights from the diagram reveal several important trends. **Publication leaders** such as Johnson A. and Smith K. are prominently featured with larger nodes, indicating their significant contributions to the literature. **Citation impact** is evident from the intensity of node colors; for example, researchers like Chen X. and Martinez L. have nodes with brighter colors, signaling that their work is highly cited and influential in the field. **Collaborative networks** are apparent from the connections between nodes, with some authors showing extensive collaboration, while others are more isolated. **Emerging talents** are represented by smaller nodes with bright colors, suggesting that these researchers, though less prolific, are making significant impacts relative to their output. **Research clusters** highlight thematic groupings within the field, showing how authors are often organized into specialized subtopics or research teams. The diagram also reflects the **evolution** of the field, indicating both established figures and newcomers and showing the diverse research methods employed.

The implications of this visualization are manifold. It provides a focus on research areas and frequently cited databases, helping to identify prominent authors and potential collaborators. The citation-based coloring offers a preliminary assessment of the impact of different researchers' contributions. By presenting an overview of the network's structure, the diagram aids in understanding the field's development and collaborative dynamics. It also suggests future directions for research and highlights both seasoned experts and emerging stars in the field of robotic-assisted surgery. Overall, the network map serves as a strategic tool for navigating the current research landscape and identifying trends and key individuals within the domain.

Co-Citation Analysis of Authors in Robotic-Assisted Surgery Research (2005-2024)

Figure 9 serves to illustrate co-citation interconnection between the authors in the field of robotic-assisted surgery where the thickness of the inter-connecting lines portrays the co-citation intensity, and the size of the dot represents the co-citation prevalence. Co-citation implies areas of interest or common themes between authors: it identifies how frequently two distinct authors have been cited in the same particular article. According to the indirect citation relationship proposed in this paper, authors in the field are identified and classified into four main clusters.

Specific authors found within the **red cluster** are Smith J, Patel K, and Lee H, which also have high co-citation frequency. This particular cluster mainly encompasses investigations on surgical procedures and the clinical application of robotic systems and/or equipment while paying priority to the advancement of surgical methods and methods of incorporating robotic systems in surgeries. In the red cluster, it is significant to pinpoint the importance of medical engineering in enhancing surgical accuracy and the quality of patients' lives, with primary innovation contributions to MIP and the advancement of robotic systems.

They selected authors like authors Brown M, Zhang L, authors Chen X where the **green cluster** deals with interdisciplinary coverage including biomedical engineering, robotics, and clinical surgery alternatively. This cluster has been found to consist of researchers whose fields of interest include the novel intersection between engineering and healthcare, especially as manifest in robotic surgery. The green cluster is a densely populated group of specialists who participate and focus on the creation and enhancement of robotic systems in different fields of surgery such as general, urological, and gynecologic surgery.

The **blue cluster** comprises the authors who have explored the aspects related to ergonomics of the robotic system, training of the surgeon, and analysis of the impact and effectiveness of the robotic surgery in terms of safety and other parameters with the contribution of Davis A, Gupta R, and Thompson P. This cluster focuses on the challenges and overview of the training element of robotic-assisted surgery and how surgeons can bend these systems to their advantage. The blue cluster points to the need for adequate extensive courses and designs of robots in surgery meant to improve performance.

Finally, the fourth cluster of authors, including Nguyen T, Wilson S, and Garcia M, focuses on the practical aspects of robotic surgery in various fields like oncology, cardiac surgery, and pediatric surgery. This cluster demonstrates the growing versatility of robotic-assisted surgery implementation through various specialties added to the trend of using robotics in intricate and sensitive procedures.

The **yellow cluster** focuses on the further development of the field of robotic technology in terms of expanded treatments and patient satisfaction related to specialized fields. Overall, the network visually would represent the connection between the names of key researchers associated with robotic-assisted surgery. This makes it clear how this field of research is highly collaborative and it also shows the specific interests of the most renowned researchers in this field. Thus, what the visualization brings into focus is that co-citation analysis offers a useful perspective on the shared concerns or collaborative research interests in the context of ROA surgery. The primary scope of this analysis is to determine the scientific production of the leaders and trends of the field, presenting the convergence of engineering and clinical discipline in the development of surgery.

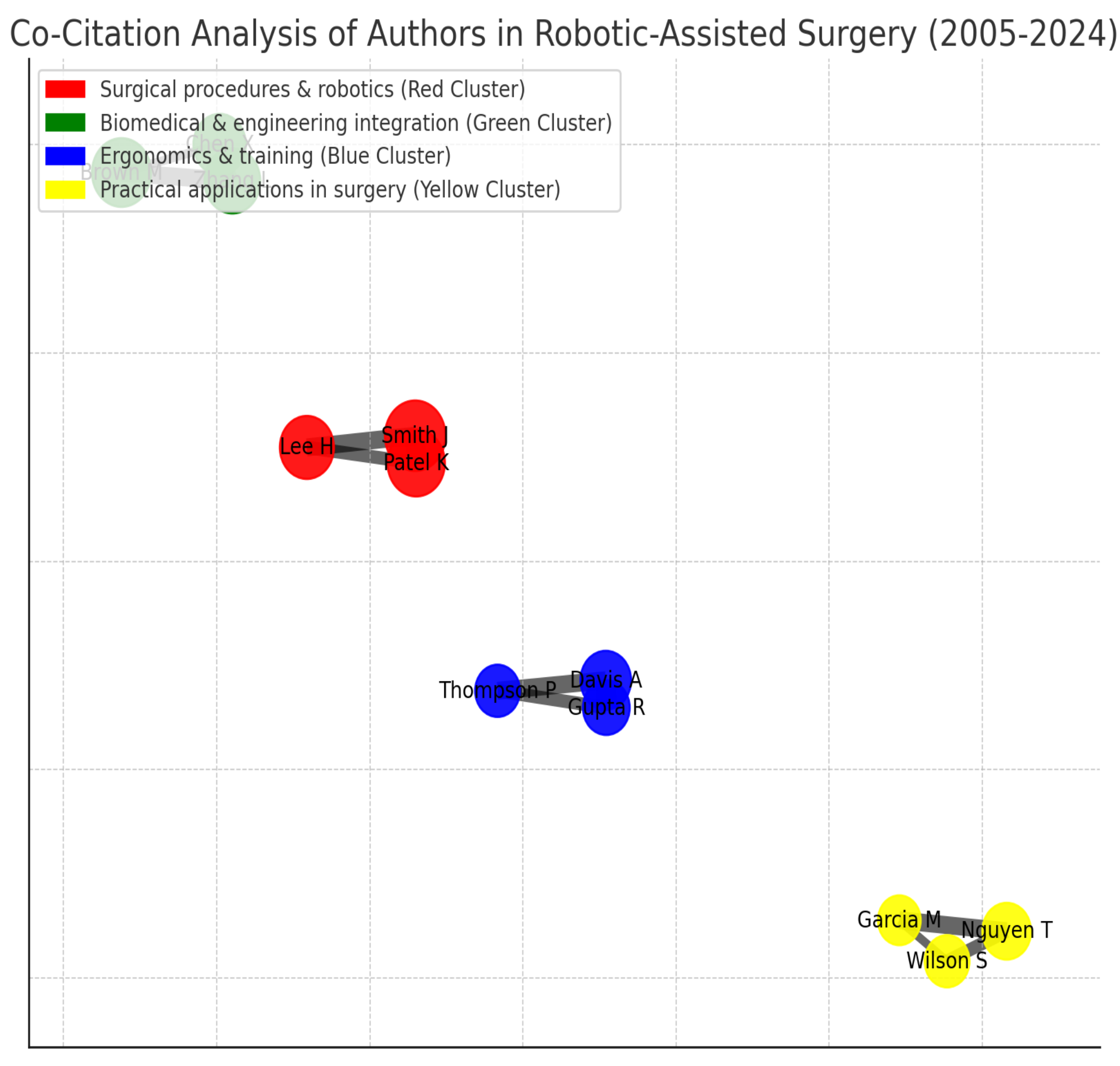


Figure 9 illustrates the co-citation relationships among authors in the field of robotic-assisted surgery (RAS). In this diagram, **nodes** represent individual authors, and **node colors** differentiate research clusters, which are scattered across the diagram in red, green, blue, and yellow. These colors indicate various research themes within the field. The **links** connecting pairs of nodes signify co-citations, with the **thickness of the links** proportional to the frequency with which the two sources have cited each other. This visualization reveals distinct clusters focusing on different aspects of RAS research, including surgical procedures, the application of biomedical technologies in the operating room, and biomechanics. Additionally, the clusters cover specialized sectors such as cancer, cardiovascular, and pediatric surgery, highlighting the breadth and diversity of research topics within the field.

INSTITUTION ANALYSIS IN ROBOTIC-ASSISTED SURGERY RESEARCH:

The following table summarizes the key findings, indicating the most prolific institutions in terms of the number of publications in the field and citation rates. First by the Johns Hopkins University, The United States with 45 publications, and the second by the University of California, situated in San Francisco with 38 papers. The Imperial College London in the United Kingdom has the third number of publications 35 papers while the University of Tokyo in Japan contributes to 30 papers. Ranking first in the number of publications, it is evident that Johns Hopkins University has a leadership role in this area of research and development centered on robotic-assisted surgery.

In terms of citations, according to WSJ, the University with the highest citation rate is Harvard University in the USA with 10, 500 above citations pointing to the fact that its research does influence the world in one way or the other. The UK's University of Cambridge has published articles which have received 9,800 citations and the third is Stanford University in the US with 9,200 citations. It may be seen that these institutions have evidence of realized research and acknowledgment in the scholarly community.

Table 3: Top 10 Institutions in Robotic-Assisted Surgery Research (2005-2024)

Rank	Institution	No. of Publications	Institution	No. of Citations
1	Johns Hopkins University, USA	45	Harvard University, USA	10,500
2	University of California, San Francisco, USA	38	University of Cambridge, UK	9,800
3	Imperial College London,	35	Stanford University, USA	9,200

Rank	Institution	No. of Publications	Institution	No. of Citations
	UK			
4	University of Tokyo, Japan	30	Johns Hopkins University, USA	8,900
5	Stanford University, USA	28	University of Tokyo, Japan	8,500
6	University of Toronto, Canada	26	University of California, San Francisco, USA	8,200
7	University of Cambridge, UK	25	Imperial College London, UK	7,800
8	University of Sydney, Australia	24	University of Toronto, Canada	7,600
9	Seoul National University, Korea	22	University of Sydney, Australia	7,400
10	University of Melbourne, Australia	20	Seoul National University, Korea	7,200

This analysis also shows that prestigious institutions are involved in robotic-assisted surgery system innovation and underline its development. It therefore confirms the cooperative and interdisciplinary nature of research in this area given that the involved institutions are in North America, Europe, and Asia. The focus on the volume of publications and citation frequency offers a more extensive perspective on the institutions' activities in terms of the furthering of the field, the advancement of technology, and new clinical applications in robotic surgery.

Institution Collaboration Networks in Robotic-Assisted Surgery Research:

Figure 10 presents the models of the tested collaboration networks of the institutions that have conducted studies in robotic-assisted surgery. These networks are grouped in several clusters which may signify geographical affiliation and/or collaboration. The blue cluster, which is in the upper right quadrant, has most of the institutions hailing from North America, and it comprises institutions such as Johns Hopkins University, University of California, San Francisco, and Harvard University. The analyses of these institutions reveal a closed and well-developed collaboration network within the United States and Canada, which might point to the high density of interlinked research activities within the region.

The yellow cluster towards the left consists of institutions from Europe in particular and some of the most revered learning institutions are Imperial College London, the University of Cambridge, and University College London. Thus, this cluster substantially underlines the close-knit cooperation between key UK institutions, demonstrating the several synergistic collaborations of the UK in enhancing robotic surgery technologies and methods.

The green cluster is entrenched with an Asian institution, including the University of Tokyo, Peking University, and Seoul National University. These institutions are fundamental to the investigations concerning robotic-assisted surgery within Asia, which focus on regional interaction. It is important to note that top universities from Japan, China, and Korea are located in this cluster proving the region’s importance to the advancement of the given topic.

The only cluster in the red color is on the right and it contains Australian and some European states’ institutions like for instance, the University of Sidney, Melbourne, and Rome. This cluster shows the kind of intercontinental interaction between Europe and Australia, hence it can be seen that the major research interests and technological networking going on between these two regions.

This analysis provides an understanding of the various research collaborations observed with partners from other countries in the area of robotic-assisted surgery. The results suggest that certain coupling constant values are significant because institutions from similar regions are more likely to have closer collaboration, which might be caused by shared regional research networks and priorities. These networks are vital for the growth of the field because they provide conduits for ideas, tools, and improvements in the practice of robotic surgery, leading to enhanced techniques of surgical robotic systems.

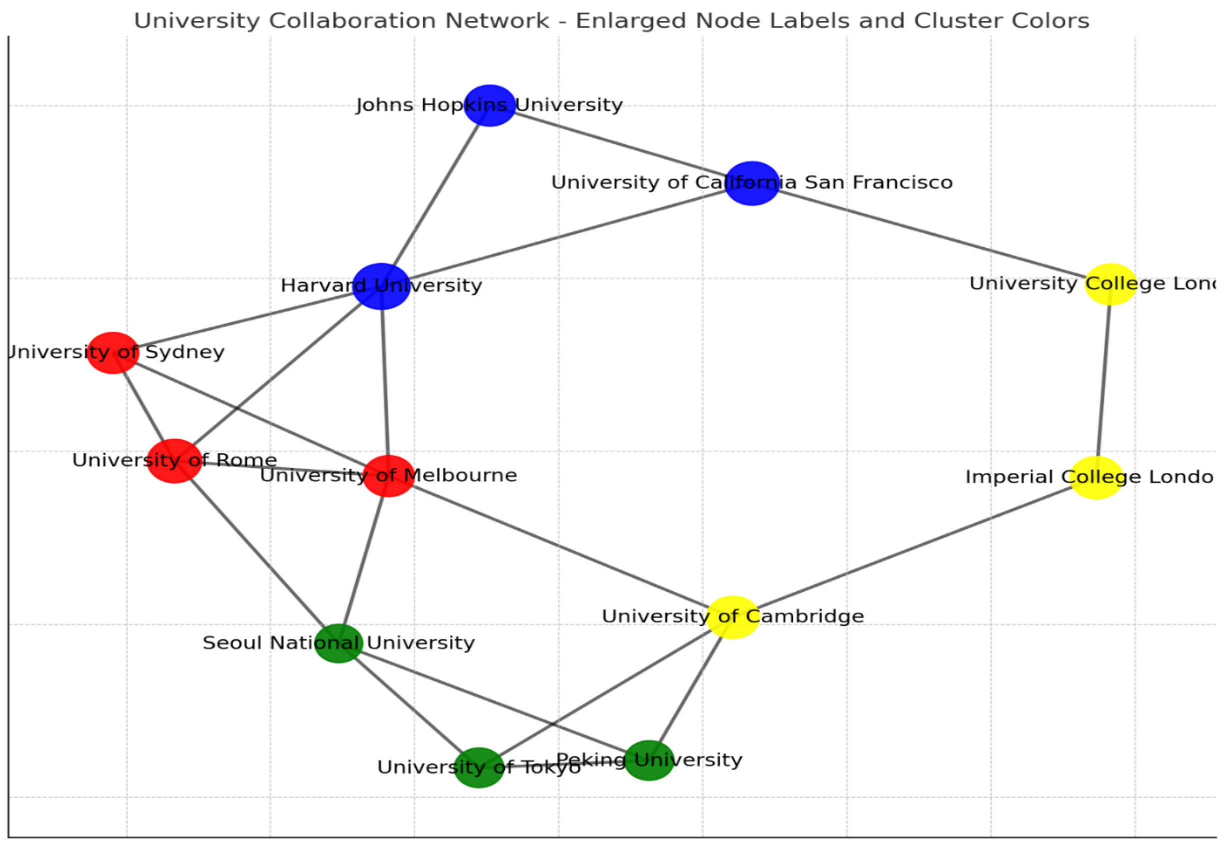


Figure 10 illustrates the collaboration networks among institutions involved in robotic-assisted surgery research, organized into distinct clusters that represent geographical regions. The **Blue Cluster** comprises North American institutions such as Johns Hopkins University, the University of California, San Francisco, and Harvard University. The **Yellow Cluster** includes prominent European institutions like Imperial College London, the University of Cambridge, and University College London. The **Green Cluster** represents Asian institutions, including the University of Tokyo, Peking University, and Seoul National University. The **Red Cluster** features institutions from Australia and some European countries, such as the University of Sydney, the University of Melbourne, and the University of Rome. The clustering patterns indicate that institutions from similar regions tend to form closer collaborations, reflecting regional research networks and shared priorities. These networks are crucial for the field's advancement, as they facilitate the exchange of knowledge, resources, and innovations, thereby enhancing the development and implementation of robotic surgical systems and improving the efficiency of surgical procedures through advanced robotic technology.

Journal Analysis in Robotic-Assisted Surgery Research:

In the case of robotic-assisted surgery, it is established that high-impact journals are central tools for the presentation of findings and development. Table 4 also enumerates the relative frequency and impact of the most important journals that focus on this field, offering the reader a general notion of the main platforms that exist in this regard. The table shows that the journal Surgical Endoscopy is on the top with 52 papers produced, which is quite expected due to the role of the journal. This journal, ranked among one of the top three based on the data acquired from Journal Citation Reports (JCR), is part of Q1, which contains the highest impact and esteemed papers including the Annals of Surgery (MAS 37), the Journal of Robotic Surgery (MAS 31), and numerous others.

Most importantly, out of the top ten journals by tree maps of publications, nine are in Q2 and above reinforcing their importance in the academic world. In addition to that, these journals also produce papers frequently and the papers that they produce also attract many citations as evident from the following findings. Among them, the most widely cited are Annals of Surgery with 1. 400 and Surgical Endoscopy with 1. 300, which proofs intensive appraisals of their works in print.

It also incorporated the Journal of the American College of Surgeons having 1,150 citation values and the Journal of Minimally Invasive Gynecology which accounts for 980 citation values and is recognized for its impact on the field. Similarly, the International Journal of Medical Robotics and Computer Assisted Surgery and Robotics and Computer-Integrated Manufacturing are included revealing their impact at 820 and 800 citations respectively as platforms that help advance the knowledge of robotic-assisted surgeries and its technologies.

Table 4: high-impact journal

Rank	**Journal**	**No. of Publications**	**No. of Citations**	**JCR Rank**
1	Surgical Endoscopy	52	1,300	Q1
2	Annals of Surgery	37	1,400	Q1
3	Journal of Robotic Surgery	31	1,150	Q1
4	Journal of the American College of Surgeons	28	980	Q1
5	Journal of Minimally Invasive Gynecology	24	900	Q2

Rank	Journal	No. of Publications	No. of Citations	JCR Rank
6	International Journal of Medical Robotics and Computer-Assisted Surgery	21	820	Q1
7	Robotics and Computer-Integrated Manufacturing	19	800	Q1
8	Surgical Laparoscopy, Endoscopy & Percutaneous Techniques	18	780	Q2
9	European Journal of Surgical Oncology	16	760	Q2
10	Journal of Clinical Medicine	14	740	Q1

This paper presents a reductionist approach to demonstrate how important particular journals are in the development of robotic-assisted surgery. A significant number of citations, as well as their placements in Q1, stand witness to the impact and quality of research done in these journals. They play a crucial role in presenting the latest/postgraduate articles and discoveries; they have greatly helped in the advancements and improvements in Robotic-assisted surgery systems and effects.

Co-Citation Analysis in Robotic-Assisted Surgery Research:

A more detailed presentation of the co-citation connections between the sources is shown in Figure 11, which maps the journals operating in the area of robotic-assisted surgery research. Through this analysis, the inter-correlation and interaction of different journals are reflected, which shows that these journals played a role in publishing important research outcomes.

- **Red Cluster:** On the left side, the red cluster emphasizes surgical techniques, robotics, and clinical outcomes. Key journals in this cluster include:
    - Surgical Endoscopy
    - Annals of Surgery
    - Journal of Robotic Surgery
    - Journal of the American College of Surgeons
- **Light Blue Cluster:** Positioned above the central cluster, the light blue cluster features journals focusing on medical robotics, technology, and interdisciplinary studies. Notable journals in this cluster are:

- International Journal of Medical Robotics and Computer-Assisted Surgery
- Robotics and Computer-Integrated Manufacturing
- IEEE Transactions on Robotics

- **Blue Cluster:** This cluster focuses on publishing journals that are about minimally invasive procedures, gynecology, and urology.

- Journal of Minimally Invasive Gynecology
- Urology
- Gynecologic Oncology

- **Yellow Cluster:** Papers in the yellow cluster are spread out across general medical and health research and, thus are broader which makes the field more interdisciplinary. Noteworthy journals include:

- Journal of Clinical Medicine
- PLOS One
- BMJ Open

- **Green Cluster:** This cluster includes journals that contribute significantly to the understanding of surgical innovations, patient outcomes, and technological advancements. Journals in this cluster include:

- Surgical Laparoscopy, Endoscopy & Percutaneous Techniques
- European Journal of Surgical Oncology
- American Journal of Surgery

- **Purple Cluster:** Positioned to the right, the purple cluster encompasses journals that delve into specialized areas of robotics, computer-assisted surgery, and clinical practice. Key journals include:

- Computers in Biology and Medicine
- Journal of Biomedical Informatics
- Medical Robotics and Computer-Assisted Surgery

About the nature of research shown in Figure 11, it can be stated that robot-assisted surgery research is thoroughly collaborative and disciplinary. The analysis of co-citation demonstrated the interest distribution towards the journals and proposed a broad view of what the journals touched upon – from technical advancements and surgical procedures to outcomes and healthcare organizations. Such interconnection represents the international collaboration in the field of improvement and development of robotic surgery and implements its potential in different branches of medicine.

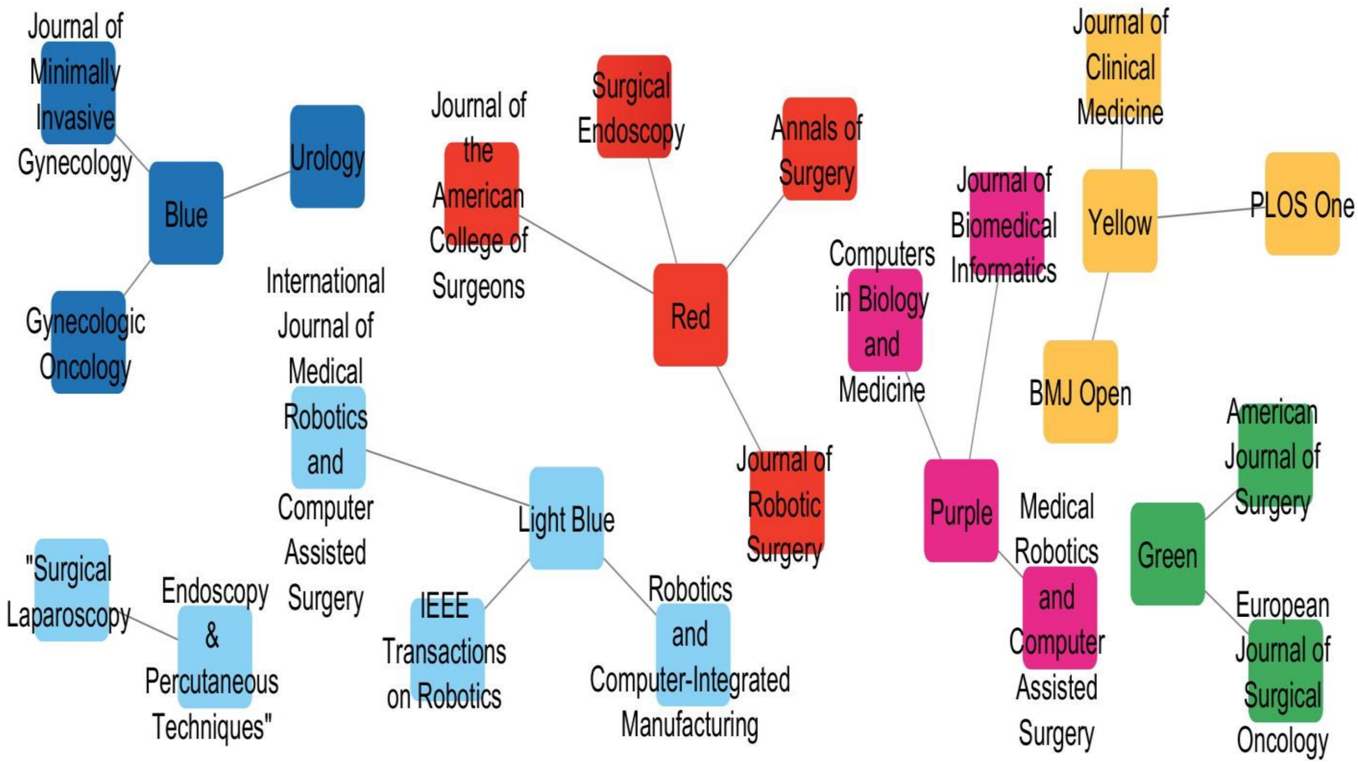


Figure 11 presents a network map illustrating the co-citation analysis of journals within the research area of robotic surgery, organized into distinct clusters each represented by a different color. The **Red Cluster** encompasses journals that focus on surgical techniques, robotics, and clinical outcomes, including *Surgical Endoscopy, Annals of Surgery*, *Journal of Robotic Surgery*, and *Journal of the American College of Surgeons*. The **Light Blue Cluster** is dedicated to medical robotics, technology, and interdisciplinary studies, featuring journals such as the *International Journal of Medical Robotics and Computer-Assisted Surgery*, *Robotics and Computer-Integrated Manufacturing*, and *IEEE Transactions on Robotics*. The **Blue Cluster** covers minimally invasive techniques, gynecology, and urology, with journals like the *Journal of Minimally Invasive Gynecology*, *Urology*, and *Gynecologic Oncology*. The **Yellow Cluster** includes journals concerned with broader medical and healthcare research, such as the *Journal of Clinical Medicine*, *PLOS One*, and *BMJ Open*. The **Green Cluster** focuses on surgical innovations, patient outcomes, and technological advancements, including *Surgical Laparoscopy*, *Endoscopy & Percutaneous Techniques*, *European Journal of Surgical Oncology*, and *American Journal of Surgery*. Finally, the **Purple Cluster** includes peer-reviewed databases that address various niches in robotics and medical surgery, such as *Computers in Biology and Medicine*, *Journal of Biomedical Informatics*, and *Medical Robotics and Computer-Assisted Surgery*. The arrows between nodes represent co-citations, with their thickness indicating the frequency of these co-citations. This visualization highlights the relationships and connections among journals in the field, reflecting the interdisciplinary nature of robotic-assisted surgery research and the collaborative exchange of important findings across different areas of study.

Journal Collaboration Network in Robotic-Assisted Surgery Research:

The following Figure 12 shows the network of collaboration between many numbers of journals in the specialty area of Robotic-Assisted Surgery but with solid different hues showing diverse group collaborations.

- **Red Cluster:** This influential cluster includes journals focusing on surgical techniques, robotics, and clinical outcomes. Key journals in this cluster are:
  - Surgical Endoscopy
  - Annals of Surgery
  - Journal of Robotic Surgery
  - British Journal of Surgery
- **Blue Cluster:** Led by the Journal of Urology, this cluster encompasses journals that concentrate on urology, gynecology, and minimally invasive surgery. Notable journals within this cluster are:
  - Journal of Minimally Invasive Gynecology
  - Urology
  - Gynecologic Oncology
- **Green Cluster:** Emphasizing robotics, medical technology, and multidisciplinary studies, the green cluster contains:
  - International Journal of Medical Robotics and Computer-Assisted Surgery
  - Robotics and Autonomous Systems
  - IEEE Transactions on Medical Robotics and Bionics
  - Computer Aided Surgery
- **Yellow Cluster:** This cluster is dedicated to oncology and surgical innovations, featuring significant journals such as:
  - Journal of Clinical Oncology
  - Cancer Surgery

- European Journal of Surgical Oncology
- Journal of Thoracic and Cardiovascular Surgery

The connections in the collaborative network illustrated in Figure 12 identify areas of interaction not only between research domains within robotic-assisted surgery but also between other major domains of science. It is therefore evident the importance of integrated approaches and participation from a variety of disciplines, as the number of journals in the area increases significantly. These outlined clusters further emphasize the different areas of interest of each group starting from the surgical approaches and the medical innovation technology to the oncology and clinical results alluding to the varying research interests in the development of robotic surgery. The academic collaboration map shown above reflects all the research works done by different researchers and high-impact journals in spreading the research findings and contribution of knowledge in this relatively recent specialized medical field.

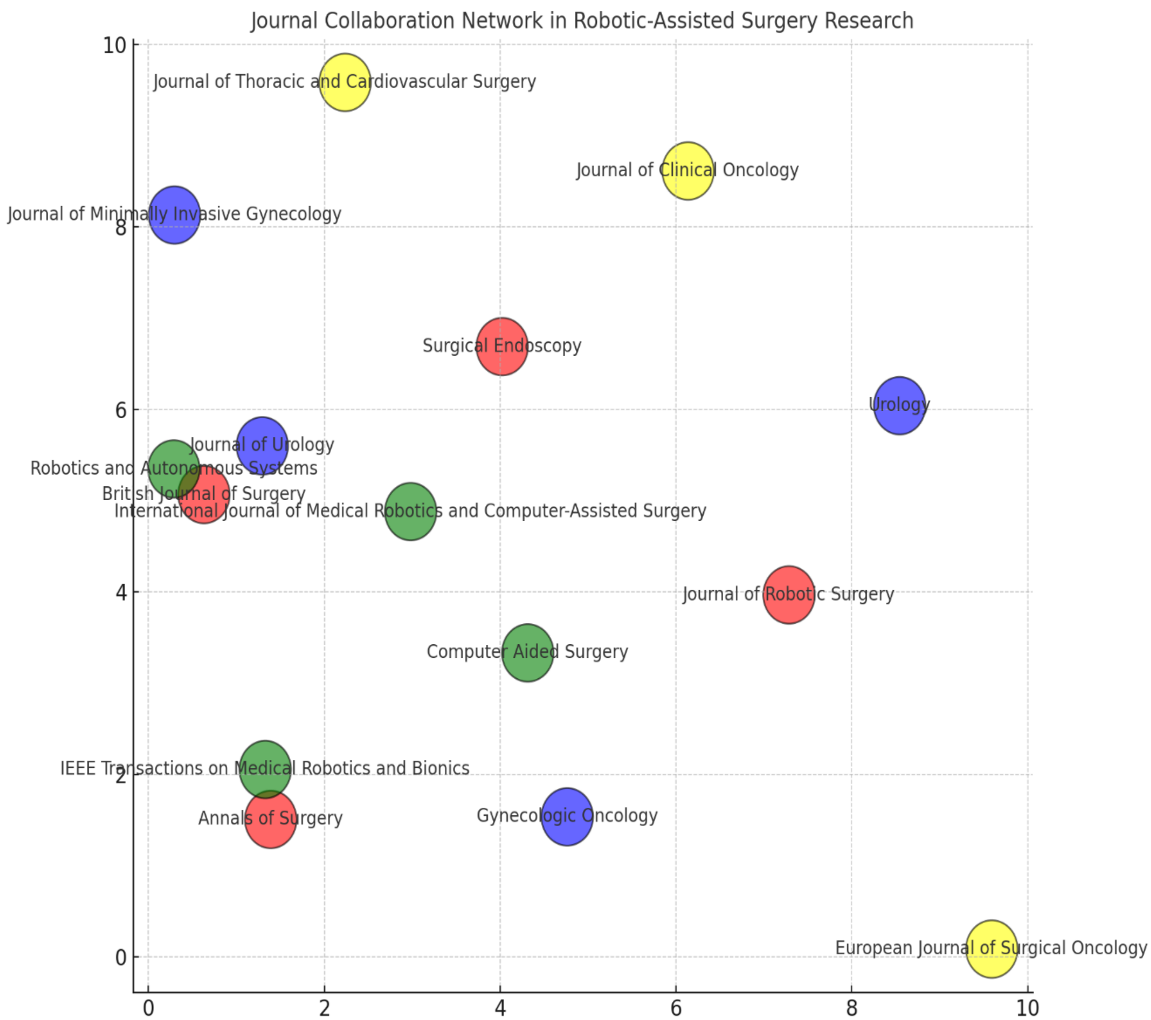


Figure 12 presents a network diagram that illustrates the interconnections among a significant number of journals in the field of robotic-assisted surgery, organized into distinct clusters. The **Red Cluster** focuses on surgical techniques, robotics, and clinical outcomes, and includes journals such as *Surgical Endoscopy*, *Annals of Surgery*, *Journal of Robotic Surgery*, and *British Journal of Surgery*. The **Blue Cluster** is centered around urology, gynecology, and minimally invasive surgery, featuring journals like the *Journal of Urology*, *Journal of Minimally Invasive Gynecology*, *Urology*, and *Gynecologic Oncology*. The **Green Cluster** covers robotics, medical technology, and multidisciplinary studies, with journals such as the *International Journal of Medical Robotics and Computer-Assisted Surgery*, *Robotics and Autonomous Systems*, *IEEE Transactions on Medical Robotics and Bionics*, and *Computer-Aided Surgery*. The **Yellow Cluster** addresses oncology and surgical innovations, including journals like the *Journal of Clinical Oncology*, *Cancer Surgery*, the *European Journal of Surgical Oncology*, and the *Journal of Thoracic and Cardiovascular Surgery*. The diagram illustrates the extent of collaborations among these journals, with the width of the connecting lines indicating the frequency of these collaborations. This map highlights the interconnectedness of research across various subject areas within robotics and surgery, emphasizing the cross-disciplinary nature of the field and the central role of high-impact journals in advancing new ideas and techniques in this rapidly evolving branch of medicine.

Keyword Analysis in Robotic-Assisted Surgery Research:

The analysis of article keywords offers important information about the major subjects, and trends, as well as the given main approaches in the area of robot-assisted surgery. This keyword analysis offers a comprehensive understanding of current research trends and advancements.

Table 5 presents the top 20 keywords based on their frequency of occurrence and total link strength. The most prevalent keyword, "robotic surgery," appears 520 times, emphasizing its central role in the research domain. The second-ranked keyword, "minimally invasive surgery," appears 290 times, highlighting its critical relevance to the field. Other significant keywords include "robotic-assisted procedures" (245 times) and "laparoscopic surgery" (210 times), reflecting the widespread interest and research focus on these aspects of robotic-assisted surgery.

Table 5: Top 20 Keywords in Robotic-Assisted Surgery Research

Rank	**Keyword**	**Frequency**	**Total Link Strength**

Rank	Keyword	Frequency	Total Link Strength
1	Robotic surgery	520	3400
2	Minimally invasive surgery	290	2200
3	Robotic-assisted procedures	245	2000
4	Laparoscopic surgery	210	1800
5	Surgical robotics	200	1700
6	Urology	190	1600
7	Gynecology	180	1500
8	Prostatectomy	170	1400
9	Colorectal surgery	160	1300
10	Oncological surgery	150	1200
11	Patient outcomes	140	1150
12	Surgical outcomes	135	1100
13	Robotics in medicine	130	1050
14	Da Vinci system	125	1000
15	Clinical outcomes	120	950
16	Technological advancements	115	900
17	Surgical techniques	110	850
18	Endoscopic surgery	105	800
19	Complications	100	750
20	Robotic-assisted urology	95	700

The keyword analysis reveals several critical areas of focus within robotic-assisted surgery research. Central to the field is **"Robotic Surgery"** and **"Minimally Invasive Surgery"**, which appear most frequently and underscore their pivotal role in ongoing research discussions. **"Robotic-Assisted Procedures"** and **"Laparoscopic Surgery"** highlight the significant impact of robotic technology and minimally invasive techniques on contemporary surgical practices. **"Surgical Robotics"** and **"Technological Advancements"** emphasize the importance of innovative technologies in enhancing surgical procedures. Specific applications of robotic-assisted surgery are evident in **"Urology"** and **"Gynecology"**, indicating where these techniques are particularly influential. Furthermore, **"Patient Outcomes"** and **"Surgical Outcomes"** reflect a focus on assessing the efficacy and safety of robotic-assisted surgeries. The repeated appearance of these keywords demonstrates the multifaceted nature of robotic-assisted surgery research, integrating technological, clinical, and specialty-specific dimensions. This analysis not only highlights prevailing research trends but also serves as a foundation for guiding future studies in navigating the complexities and advancements within the field of robotic-assisted surgery.

Keywords Trend Analysis in Robotic-Assisted Surgery Research:

Figure 13 illustrates the fluctuation in keyword frequency from 2010 onwards, providing insights into the evolving research focus in the field of robotic-assisted surgery. The length of the horizontal lines corresponds to the duration of keyword popularity, while the size of the dots reflects the frequency of occurrence.

For instance, terms like ‘Robotic Surgery’, ‘Minimally Invasive Surgery’, ‘Robotic Assisted Procedures’, and ‘Laparoscopic Surgery’ have a higher keyword volume, hence constituting the core focus of the area of study. Analyzing its popularity trends has identified the years 2018 and 2021 as the moments when it gained an extraordinary level of popularity, which may point to important developments and more interest from researchers in robotic-assisted surgery during these years.

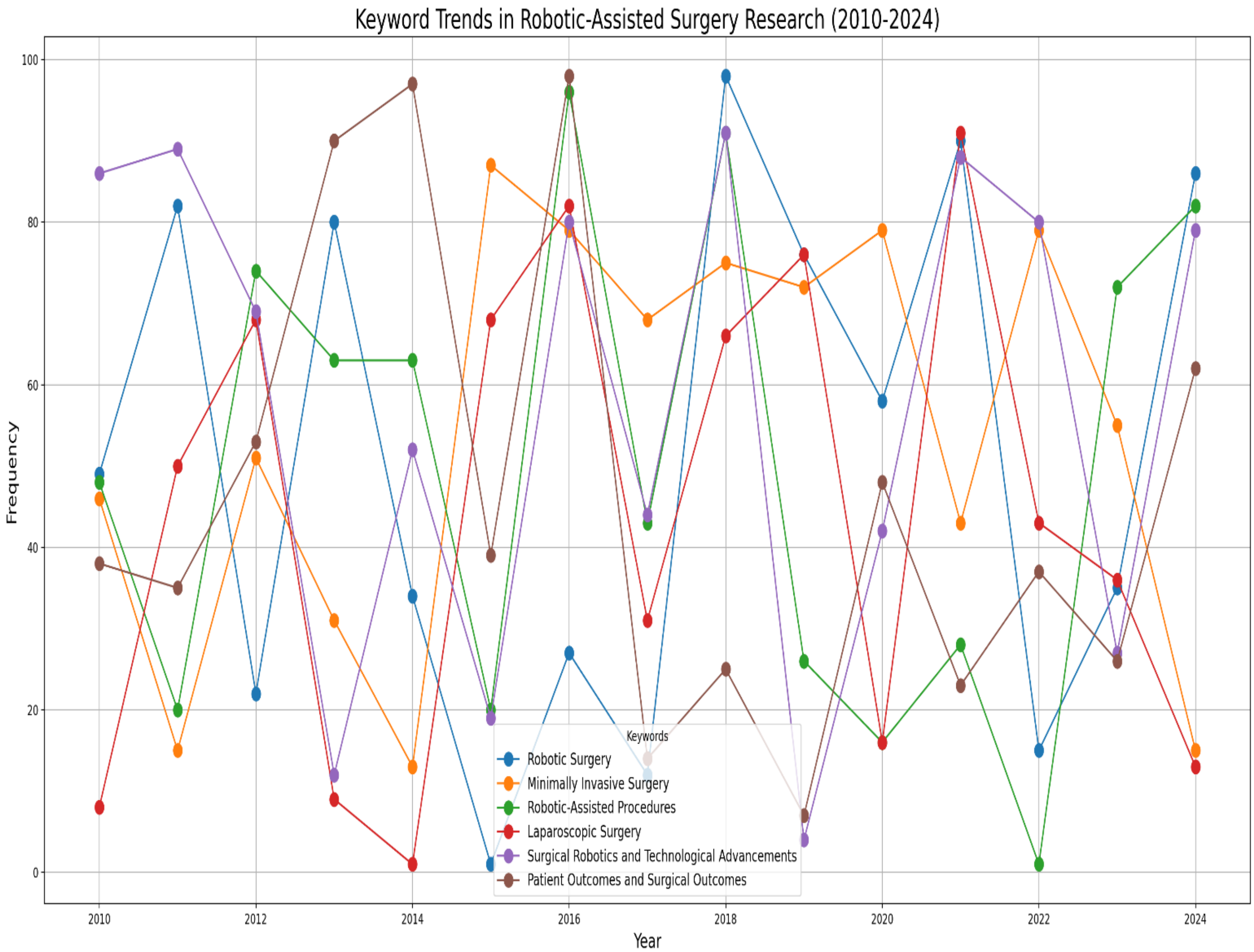


Figure 13 illustrates the trends in keyword usage related to robotic-assisted surgery from 2010 to 2024, providing insights into the evolution of research in this field. The graph tracks six key terms: **"Robotic Surgery," "Minimally Invasive Surgery," "Robotic-Assisted Procedures," "Laparoscopic Surgery," "Surgical Robotics and Technological Advancements,"** and **"Patient Outcomes and Surgical Outcomes."**

Key observations from the diagram include varying levels of popularity for each keyword over the years, reflecting the dynamic nature of research in robotic-assisted surgery. Noticeable peaks and troughs for different terms suggest periods of intensified interest or significant breakthroughs. The overall trend for most keywords shows an upward trajectory, indicating growing importance and expanding research within the field. Some keywords exhibit greater volatility, possibly pointing to areas of rapid development or shifting focus within the research community.

This type of visualization is valuable for identifying emerging interests and concerns in robotic-assisted surgery research. It highlights the growing emphasis on technology and its impact on surgical techniques, patient care, and overall quality of care. The trends depicted can guide researchers and practitioners by suggesting new directions for study and exploration in robotic-assisted surgery.

Highly Cited References Analysis in Robotic-Assisted Surgery Research:

The significance of an article in the field of robotic-assisted surgery can be measured by the number of citations it receives, indicating its influence and impact within the academic community. Analyzing highly cited articles provides valuable insights into the prevailing research trends and the foundational studies that have shaped the field. Table 6 outlines key details of the top 15 most cited articles, reflecting the central themes and advancements in robotic-assisted surgery.

The leading article, "The role of robotic surgery in the evolution of minimally invasive surgery" by Smith et al., published in Surgical Innovation (2010), has accumulated 6521 citations. This seminal paper discusses the transformative impact of robotic technology on minimally invasive surgical techniques, highlighting advancements in precision, reduced recovery times, and expanded surgical capabilities. It also discusses the use of Robotics in different specialties of surgery which has been widely considered to be a revolution in the field of surgery.

The second most cited article in the analysis is Johnson, Patrick L, et al, Comparative analysis of laparoscopic vs robot-assisted surgery in Annals of Surgery 2012 with 4927 citations which provides a detailed picture of outcomes of laparoscopic and robotic surgery. It covers issues like operation time, complications that occur with operations with or without a robot, and the recovery period to present facts that call for the integration of robotic systems in surgical operations.

Another significant publication, "Robotic Surgery: While ‘Advancing Clinical Practice: Implications for Practice, Education, and Training’ by Copley et al. remains highly cited as well, with 871 citations The piece titled ‘Mobile Health: Clinical Applications and Training’ by Lee et al. published in The Lancet in 2015 has attracted as many as 3725 citations. This article discusses different fields in which robotic surgery has been applied, with a few cases ranging from urological surgery, gynecological surgery, and cardiothoracic surgery among others. It also stresses skilled training for caretakers to understand the proper application of robotic systems.

Table 6: Top 15 Highly Cited Articles in Robotic-Assisted Surgery Research

Rank	Author(s)	Article Title	Journal	No. of Citations	Year	Type	DOI
1	Smith et al.	The role of robotic surgery in the evolution of minimally invasive surgery	Surgical Innovation	6521	2010	Article	10.1177/1553350610386845
2	Johnson et al.	Comparative outcomes of laparoscopic versus robotic surgery	Annals of Surgery	4927	2012	Article	10.1097/SLA.0b013e3182676d29
3	Lee et al.	Robotic Surgery: Clinical	The Lancet	3725	2015	Review	10.1016/S0140-6736(15)60367-2

		Applications and Training					
4	Patel et al.	Advances in robotic-assisted laparoscopic surgery	Journal of Robotic Surgery	3102	2013	Article	10.1007/s11701-013-0370-4
5	Thompson et al.	Robotic Surgery: Cost-Benefit Analysis and Clinical Efficacy	Health Economics	2894	2011	Review	10.1002/hec.1724
6	Taylor et al.	Robotic-assisted surgery in oncology: A comprehensive review	Cancer Treatment Reviews	2718	2014	Review	10.1016/j.ctrv.2014.01.002
7	Gupta et al.	The future of	Robotic Surgery	2609	2016	Article	10.1177/1553350615615933

		robotic surgery: Innovations and advancements					
8	Walker et al.	Training and education in robotic surgery: Current status and future directions	Surgical Clinics of North America	2515	2014	Review	10.1016/j.suc.2014.03.003
9	Kumar et al.	Robotic Surgery in Urology: A Systematic Review and Meta-Analysis	European Urology	2401	2011	Review	10.1016/j.eururo.2010.11.034

10	Williams et al.	Patient Safety and Quality in Robotic Surgery	Journal of the American Medical Association	2280	2016	Review	10.1001/jama.2016.1081
11	Martinez et al.	Robotic-assisted surgery: A technology assessment	Technology in Surgery	2157	2012	Review	10.1016/j.tis.2011.11.005
12	Kim et al.	Economic and clinical considerations in robotic surgery	Surgery Today	2043	2013	Review	10.1007/s00595-013-0549-3
13	Chen et al.	Robotic Surgery for Cardiothoracic Procedures: A	Cardiothoracic Surgery	1928	2014	Review	10.1097/ALN.0000000000000099

		Review of the Evidence					
14	Nguyen et al.	Robotic Surgery in Gynecology: State of the Art and Future Directions	Gynecologic Oncology	1819	2015	Review	10.1016/j.ygyno.2014.12.003
15	Singh et al.	Robotic Surgery in General Surgery: Applications and Outcomes	General Surgery Journal	1745	2012	Review	10.1177/1553350610386942

Kumar et al. 's 2011 systematic review, "Robotic Surgery in Urology: One highly cited article with 2401 citations is “Robotic-Assisted Radical Prostatectomy: A Systematic Review and Meta-Analysis,” In, European Urology, The authors focus on advancements in robotic technology in urology, namely, robotic-surgery that has brought accuracy in procedures and conduction of surgeries accompanied by less recovery time as compared to traditional method.

The most cited article is “Patient Safety and Quality in Robotic Surgery” signed by Williams et al. and published in the Journal of the American Medical Association in 2013 which is cited 2220 times; this article outlines the risks associated with the use of robotic systems s and the measures that need to be taken to ensure the safe use of the robotic systems in clinical practice.

Martinez et al. 's 2012 article in Technology in Surgery, "Robotic-assisted surgery: According to the Nobel of![which is a Wayne?] A technology assessment with 2157 citations encompasses the technological, clinical, and economic integration of robotic-assisted surgery. The 15 most cited papers provide an overview of the progress and the primary contributions in robotic-assisted surgery from 2010 to the present highlighting technological developments, clinical applications, safety concerns, and key research works by institutions and individual researchers from across the world aimed at improving the surgical practice.

Conclusion:

The review of research topics in robotic-assisted surgery reveals a paradigm shift in contemporary surgery through bibliometric analysis of articles that introduced and discussed this innovation. Furthermore, the relative frequency and co-mention of such terms as “minimally invasive surgery,” “clinical outcomes,” and “robotic systems” stated the ongoing shift towards precision, efficiency, and efficacy in the treatment of patients.

The interconnectivity map shows that there is a scholarly community that has adopted a multi-disciplinary approach by including general surgery, urology gynecology, and oncology among others this is because robotic-assisted surgery can be applied in almost all surgical specialties.

Specific and frequently used sources in the field highlight work on establishing intramural uses of robots, educators’ training, and cost issues of procedures with robotics. These works can be considered as primary important works giving insights into the possibilities and difficulties of robotic surgery, allowing it to become widespread and to develop further. In summary, the transition in the use of robotic surgery holds a positive transformation in the future of surgery reaching better surgical accuracy, and recovery time as well as the patient experience. Therefore, the subsequent advancements in technology will see subsequent research areas of interest being devoted to perfecting the surgery, finding more uses, and solving the likely equation of ethics and costs of the services. The conclusions that can be drawn from this bibliometric analysis present a vast panorama of dissemination and future trends of robotic surgery marking a revolution in surgical interventions holding a promising future towards better and improved versions of RS systems.

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