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Original research

Global scientific production of robotic surgery in medicine: A 20-year survey of research activities

Guoxin Fan [1], Zhi Zhou [1], Hailong Zhang, Xin Gu, Guangfei Gu, Xiaofei Guan, Yunshan Fan, Shisheng He*

Orthopedic Department, Shanghai Tenth People's Hostipal, Tongji University School of Medicine, China

HIGHLIGHTS

- This was the first bibliometric analysis to demonstrate the macroscopic view of robotic surgery.
- There is a skyrocket trend of robotic surgery over the last two decades.
- Countries with high GDP tend to make more contributions.

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ABSTRACT

Introduction: Robot-assisted surgery operations are being performed more frequently in the world these years. In order to have a macroscopic view of publication activities about robotic surgery, the first bibliometric analysis was conducted to investigate the publication distributions of robotic surgery.

Methods: The original articles about robotic surgery were extracted from the Science Citation Index Expanded (SCI-E) on Web of Science and analyzed concerning their distributions. We also explored the potential correlations between publications of different countries and their Gross Domestic Product (GDP).

Results: The total number of original articles retrieved from SCI-E was 3362 from 1994 to 2015. The number of original articles published in the last decade has a burgeoning increase of 572.87% compared with that published in the former decade. The leading country was USA who have published 1402 pieces of articles (41.701%), followed by Germany with 342 (10.173%). The journal published the highest number of original articles was Journal of Endourology with 237 (7.049%), followed by Surgical Endoscopy and Other Interventional Techniques (188, 5.592%). There was strong correlations between publication numbers and GDP of different countries ($r^2 = 0.889$, $p < 0.001$). In the different medical fields, urology has the highest number of articles (n = 878, 26.007%).

Discussions: The macroscopic view of research activities has the potential to guide future trend in the field of robotic surgery.

Conclusions: There is a skyrocket trend of robotic surgery in medical research over the last two decades, and countries with high GDP tend to make more contributions to the medical field of robotic surgery.

1. Introduction

For decades, surgical robots have gained more and more attentions all over the world, and it began playing an important role in current clinical practice [1,2]. Surgical robots provide surgeons with advanced hand and create a new surgical fields which are less-invasive with virtual reality, micro observation, and remote operation [3]. It has been validated that the application of robotic technology for surgery was technically feasible and safe with the help of improved dexterity, better visualization, and high level of precision [4]. To provide a macroscopic view about the distributions of robotic surgery and evaluate the value of the articles about robot surgery might be an interesting topic to witness its development. However, to the best of our knowledge, there was no available literature of bibliometric analysis focusing on robotic surgery.

* Corresponding author. 301 Yanchang Road, Shanghai, 200072, China.
E-mail address: tjhss7418@foxmail.com (S. He).
[1] These two authors equally contribute to the study.

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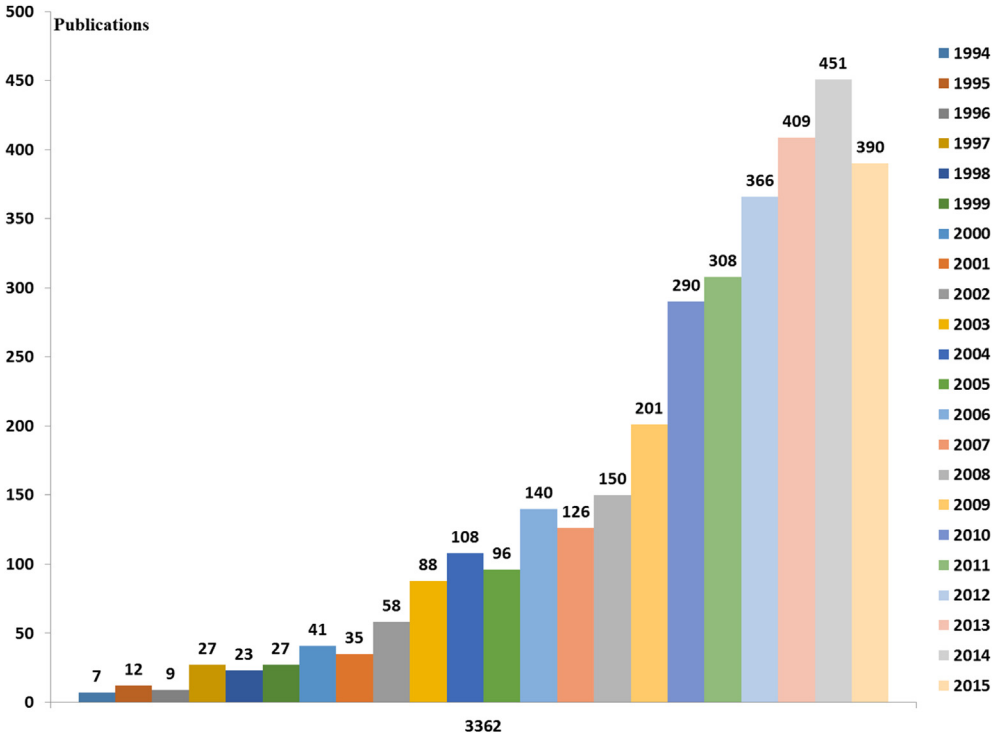

Fig. 1. Publications about robot surgery from SCI-E distributing in each year (by Nov. 2015).

Nowadays, the quantity and quality of scientific literature are well-validated measurements of scientific achievement. The contents and quantity of scientific literature can be used to analyze the history and current status of science and technology and to forecast trends [5]. Bibliometric technique is a useful tool for appraising research output quality [6], which is becoming a parameter for academic achievement to prioritize resources and funds support in academic institutions and funding sectors [7]. Bibliometric analysis has been performed in many medical fields such as head and surgery [8,9], dentistry [10,11], general surgery [12], cardiac surgery [13], neurosurgery [14], plastic and reconstructive surgery [15], arthroscopy [16], orthopedic surgery [17–19] and its subspecialty such as spine surgery [20]. Therefore, we conducted a bibliometric analysis to investigate the distributions and demonstrate the application of robotic surgery in different medical fields.

Table 1
Top 10 most-cited articles about robotic surgery.

Title	First author	Journals (IF[a] 2014)	Publication year	Country	Research field	Total citation
A prospective comparison of radical retropubic and robot-assisted prostatectomy: experience in one institution	Tewari, A	BJU Int (3.533)	2003	USA	Urology	277
Robotics in general surgery – Personal experience in a large community hospital	Giulianotti, PC	Arch Surg (4.926)	2003	Italy	General surgery	274
Force modeling for needle insertion into soft tissue	Okamura, AM	IEEE Trans Biomed Eng (2.347)	2004	USA	Engineering	266
Constitutive modeling of brain tissue: Experiment and theory	Miller, K	J Biomech (2.751)	1997	Australia	Engineering	258
Nerve-sparing robot-assisted radical cystoprostatectomy and urinary diversion	Menon, M	BJU Int (3.533)	2003	USA	Urology	233
Robot assisted partial nephrectomy versus laparoscopic partial nephrectomy for renal tumors: A multi-institutional analysis of perioperative outcomes	Benway, Brian M.	J Urol (4.471)	2009	USA	Urology	212
Feasibility of robotic laparoscopic surgery: 146 cases	Cadiere, GB	World J Surg (2.642)	2001	Belgium	General surgery	200
Transoral robotic surgery (TORS) for base of tongue neoplasms	O'Malley, Bert W.	Laryngoscope (2.144)	2006	USA	Otorhinolaryngology-head and neck surgery	197
Image-guided hypo-fractionated stereotactic radiosurgery to spinal lesions	Ryu, SI	Neurosurgery (3.620)	2001	USA	Neurosurgery	192
Satisfaction and regret after open retropubic or robot-assisted laparoscopic radical prostatectomy	Schroeck, Florian R.	Eur Urol (13.983)	2008	USA	Urology	181

[a] IF: impact factor.

2. Methods and materials

2.1. Electronic search

In November 25, 2015, we used the Science Citation Index Expanded (SCI-E) in the ISI Web of Science (WOS) (Thomson Reuters, Philadelphia, PA, USA) to conduct an electronic search with the key words "robot surgery" without any restrictions. The total number of literature extracted from the SCI-E was 4212, among which 3362 were original articles and the others were papers without original data such as review, editorial, comments etc. The work was reported in line with the PRISMA guideline [21].

2.2. Bibliometric analysis

We used the analysis tool in the WOS to record the basic information such as distributions in different medical departments, publication titles, authors, countries and journals. The number of available literature was considered as the parameter of quantity of research productivity. The number of citations was regarded as the quality indicator of published papers. The primary outcomes were the number of articles attributed to each year and each country, as well as the citations attributed to each paper and journal. The secondary outcomes were number of articles attributed to each medical field, and the correlations between the productivities of different countries and their Gross Domestic Product (GDP).

The descriptive analysis was used to summarized the top 10 most-cited articles, top 10 journals ranked by the number of original articles, top 10 authors publishing most literature, and top 10 medical field ranked by the number of original articles. To reveal the contributions of different countries, the countries were ranked according to their publication productivity. Based on the categories of World Bank, we obtained the data of these different countries' Gross Domestic Product (GDP) in 2014.

2.3. Statistical analysis

All statistical analyses were performed using SPSS software version 20.0 (SPSS, Inc., Chicago, IL, USA). Pearson correlation test was used to investigate the potential correlations between the publication productivity of different countries and their GDP. $P < 0.05$ was considered to be statistically significant.

3. Results

3.1. General information

There were 3362 original articles extracted from SCI-E of WOS (Fig. 1). The number of original articles published in 2005–2015 has a burgeoning increase of 572.87% compared with that published in 1994–2004. The average citation of all original articles was 13.16, which indicated a relatively high quality of overall literature. The highest cited article was "A prospective comparison of radical retropubic and robot-assisted prostatectomy: experience in one institution" (times cited = 277), followed by "Robotics in general surgery-Personal experience in a large community hospital" with 274. The top 10 most-cited articles were collected in Table 1.

3.2. Distributions

The leading country with most publication counts was United States of America (USA) who has published 1402 pieces of original articles (41.701%), and the second productive country was Germany with 342 (10.173) followed by South Korea (n = 310, 9.221%) (Table 2). The world map revealed that the articles were focused on the Western Europe, Eastern Asia and North America (Fig. 2). The journal published the highest number of original articles was Journal of Endourology with 237 (7.049%), and Surgical Endoscopy and Other Interventional Techniques published 188 pieces of articles (5.592%), followed by the International Journal of Medical Robotics and Computer Assisted Surgery (n = 179, 5.324%) (Table 3). There were also articles published on the general medical journal with high impact such as Spine [1], and The Lancet [22]. The most productive author was RHA KH with 42 pieces (1.249%), followed by MENON M (n = 41, 1.220%) and GURU KA (n = 39, 1.160%) (Table 4). In the different medical departments, urology has the most number of articles (n = 878, 26.007%). The second one was radiology department (n = 148, 4.384%), followed by obstetrics and

Table 2
All countries that have published original articles about robotic surgery on SCI-E and ranked by record count.

Countries/territories	Record count	% of 3362
USA	1402	41.701%
GERMANY	342	10.173%
SOUTH KOREA	310	9.221%
FRANCE	243	7.228%
ITALY	234	6.960%
JAPAN	198	5.889%
ENGLAND	190	5.651%
PEOPLES R CHINA	186	5.532%
CANADA	113	3.361%
NETHERLANDS	80	2.380%
SWITZERLAND	71	2.112%
BELGIUM	68	2.023%
SINGAPORE	54	1.606%
TURKEY	53	1.576%
SWEDEN	50	1.487%
SPAIN	49	1.457%
AUSTRIA	48	1.428%
INDIA	42	1.249%
AUSTRALIA	31	0.922%
TAIWAN	31	0.922%
BRAZIL	25	0.744%
ROMANIA	23	0.684%
GREECE	22	0.654%
ISRAEL	22	0.654%
NORWAY	18	0.535%
SCOTLAND	17	0.506%
POLAND	12	0.357%
MEXICO	11	0.327%
EGYPT	10	0.297%
DENMARK	9	0.268%
SAUDI ARABIA	8	0.238%
CHILE	7	0.208%
CZECH REPUBLIC	7	0.208%
IRELAND	7	0.208%
VENEZUELA	7	0.208%
IRAN	6	0.178%
HUNGARY	5	0.149%
MALAYSIA	5	0.149%
PORTUGAL	5	0.149%
THAILAND	5	0.149%
U ARAB EMIRATES	5	0.149%
ICELAND	4	0.119%
LEBANON	4	0.119%
SLOVENIA	4	0.119%
BULGARIA	3	0.089%
COLOMBIA	3	0.089%
ESTONIA	3	0.089%
FINLAND	3	0.089%
NEW ZEALAND	3	0.089%
RUSSIA	3	0.089%
CYPRUS	2	0.059%
LUXEMBOURG	2	0.059%
MOROCCO	2	0.059%
NORTH IRELAND	2	0.059%
QATAR	2	0.059%

Fig. 2. The distribution map of published articles in the world (GoPubMed).

Table 3
Top 10 journals about robot surgery ranked by the number of original articles.

Journals (IF 2014)	Record count	% of 3362
JOURNAL OF ENDOUROLOGY	237	7.049%
SURGICAL ENDOSCOPY AND OTHER INTERVENTIONAL TECHNIQUES	188	5.592%
INTERNATIONAL JOURNAL OF MEDICAL ROBOTICS AND COMPUTER ASSISTED SURGERY	179	5.324%
BJU INTERNATIONAL	129	3.837%
EUROPEAN UROLOGY	84	2.499%
UROLOGY	80	2.380%
JOURNAL OF UROLOGY	63	1.874%
INTERNATIONAL JOURNAL OF COMPUTER ASSISTED RADIOLOGY AND SURGERY	56	1.666%
LECTURE NOTES IN COMPUTER SCIENCE	54	1.606%
JOURNAL OF LAPAROENDOSCOPIC ADVANCED SURGICAL TECHNIQUES	48	1.428%

Table 4
The top 10 authors with literature about robotic surgery ranked by the publication numbers.

Field: Authors	Record count	% of 3362
RHA KH	42	1.249%
MENON M	41	1.220%
GURU KA	39	1.160%
KAOUK JH	35	1.041%
HEMAL AK	33	0.982%
OLEYNIKOV D	33	0.982%
AUTORINO R	26	0.773%
HABER GP	26	0.773%
MOTTRIE A	24	0.714%
TAYLOR RH	24	0.714%

gynecology department (n = 132, 3.910%) (Table 5). Based on the categories of World Bank, we obtained the data of different countries' Gross Domestic Product (GDP) in 2014 (Table 6) and ranked by their GDP. Pearson correlations analysis revealed that there was a strong correlation between the publication numbers and GDP of different countries ($r^2 = 0.889$, $p < 0.001$).

4. Discussion

Minimally invasive surgery is burgeoning around the world because of its minimal injury of normal tissue, less blood loss and non-inferior efficacy to open surgery [23–25]. There were many novel precise location system and new-developed radiographic techniques enabling the minimally invasive surgery in different fields of medicine [26–28], among which robot was the most advanced technology [29]. Our bibliometric analysis demonstrated that the number of original articles published in the last decade has a burgeoning increase of 572.87% compared with that published in the former decade. In addition, the average citation of all 3362 original articles was 13.16 from 1994 to 2015. These findings indicated a skyrocket development of robotic surgery in medical field with an active research activity.

Bibliometric analysis could avoid the influence of subjective factors, and make objective evaluation when it was used to evaluate the quality of scholarly work. Citation rate was used in this analysis to authenticate the value of different articles. To some degree,

Table 5
Top 10 medical field ranked by the number of publications.

Medical field	Record count	% of 3362
UROLOGY NEPHROLOGY	878	26.007%
RADIOLOGY NUCLEAR MEDICAL IMAGING	148	4.384%
OBSTETRICS GYNECOLOGY	132	3.910%
OTORHINOLARYNGOLOGY	128	3.791%
ONCOLOGY	119	3.525%
CLINICAL NEUROLOGY	93	2.755%
CARDIAC CARDIOVASCULAR SYSTEMS	87	2.577%
GASTROENTEROLOGY HEPATOLOGY	78	2.310%
MEDICINE GENERAL INTERNAL	69	2.044%
ORTHOPEDICS	63	1.866%

Table 6
The data of 48 different countries with publications from the World Bank.

Countries	GDP ($)
USA	17,419,000,000,000.00
CHINA	10,360,105,247,908.00
JAPAN	4,601,461,206,885.00
GERMANY	3,852,556,169,656.00
FRANCE	2,829,192,039,172.00
BRAZIL	2,346,118,175,194.00
ITALY	2,144,338,185,065.00
INDIA	2,066,902,397,333.00
RUSSIAN FEDERATION	1,860,597,922,763.00
CANADA	1,786,655,064,510.00
AUSTRALIA	1,453,770,210,672.00
KOREA,REP	1,410,382,943,973.00
SPAIN	1,404,306,536,058.00
MEXICO	1,282,719,954,862.00
NETHERLANDS	869,508,125,480.00
TURKEY	799,534,963,354.00
SAUDI ARABIA	746,248,533,333.00
SWEDEN	570,591,266,160.00
POLAND	548,003,360,279.00
BELGIUM	533,382,785,676.00
VENEZUELA RB	509,964,084,931.00
NORWAY	500,103,094,419.00
AUSTRIA	436,343,622,435.00
IRAN, ISLAMIC REP	415,338,504,536.00
UNITED ARAB EMIRATES	401,646,583,173.00
COLOMBIA	377,739,622,866.00
THAILAND	373,804,134,912.00
DENMARK	341,951,607,730.00
MALAYSIA	326,933,043,801.00
SINGAPORE	307,871,907,186.00
ISRAEL	304,226,336,270.00
EGYPT, ARAB REP	286,538,047,766.00
FINLAND	270,673,584,162.00
CHILE	258,061,522,887.00
IRELAND	245,920,712,756.00
GREECE	237,592,274,371.00
PORTUGAL	229,583,711,490.00
QATAR	211,816,758,242.00
CZECH REPUBLIC	205,522,871,251.00
ROMANIA	199,043,652,215.00
HUNGARY	137,103,927,313.00
MOROCCO	107,004,984,357.00
BULGARIA	55,734,676,435.00
SLOVENIA	49,416,055,609.00
LEBANON	45,730,945,274.00
ESTONIA	25,904,874,312.00
CYPRUS	23,226,158,986.00
ICELAND	17,071,004,499.00

articles with high citation numbers are of particular impact. Thus, analysis of top-cited articles may demonstrate useful information in a specific research filed [30]. Multiple medical fields have used a rank list of citation rate to evaluating a paper's impact in particular field [18,31]. We also ranked the top 10 most-cited articles about robotic surgery and summarized their basic information such as title, first author, journals, publication year, country, and research field. One of the interesting findings was that 80% of the top 10 most-cited articles were in medical filed such as urology, general surgery, and neurosurgery, which indicated high citation activity in medical field. Moreover, the average impact factor of the journals in these 10 articles was 4.395 (6 of 10 journals have an impact factor over 3), which indicated that these journals in these 10 articles could be regarded as high level journals.

The present study found that the number of original articles from USA was far more than any other country during the last two decades, which confirmed the major influence of USA in the field of robot surgery. Publications of USA accounted for 41.7% of all 3362 papers, and it was more than the amount of combing the articles from the second country to the fifth (Germany, South Korea, France, Italy, and Japan). Besides, it had 7 papers among the top 10 most-cited articles. That was to say, articles originating from USA had both large quantity and high quality. Our worldwide map has demonstrated that the researching productivity focused on Western Europe and North America. However, the share of some Asian countries, including South Korea, the Republic of China and Japan were also prominent. In addition, Pearson correlations had indicated that countries with high GDP tended to make more contributions to the medical field of robotic surgery. It might not be a surprise low income countries tended to have less productivity of robot surgery, because of the lack of research fund, government policy, and medical infrastructures [32,33]. In this case, more support is required for keeping the increasing tendency of publications and growing knowledge of robotic surgery [12]. Only in this way, policy maker and healthcare practitioners could conduct better interventions and thus improved clinical practice with the support of these strong-evidence studies.

In the different medical fields, urology has the most number of articles (n = 878, 26.007%), which was nearly equal to the amount combining the articles from the rest of top 9 medical fields. The other medical fields with papers over 100 included radiology (n = 148, 4.384%), obstetrics and gynecology (n = 132, 3.910%), otorhinolaryngology (n = 128, 3.791%) and oncology (n = 119, 3.525%). Moreover, there were some potential field of with the application of robotic surgery, including clinical neurology, cardiac cardiovascular system, gastroenterology hepatology, medicine general internal and orthopedics. These findings revealed the wide applications of robotic surgery and most active medical research field. The most productive author was RHA KH with 42 pieces (1.249%), followed by MENON M (n = 41, 1.220%) and GURU KA (n = 39, 1.160%). The journal published the highest number of relative articles was Journal of Endourology with 237 (7.049%), and Surgical Endoscopy and Other Interventional Techniques published 188 pieces of articles (5.592%), followed by the International Journal of Medical Robotics and Computer Assisted Surgery. Generally speaking, this bibliometric analysis provides a macroscopic view about robotic surgery, which might be potential to guide the future funding policy and research trends.

There were some limitations should be noted in this study. First, we only searched a single electronic SCI-E database, which might resulted in omission of articles that were not SCI-E articles. Second, some researchers didn't think that the highly cited articles always meant they were of high quality, because of some arguable articles. What's more, self-citation bias was not taken into account in our study. However, we still considered that SCI articles might be more representative and qualified, because most of the SCI-E journals had a strict peer-review process. Last but might not least, we only analyzed the original articles, and some other types of articles (e.g. review, comments, editorial) might also have very high citations. However, we regarded that the original articles were more qualified to clarify the contributions of a particular research field.

5. Conclusions

There is a skyrocket trend of robotic surgery in medical research over the last two decades, and countries with high GDP tend to make more contributions to the medical field of robotic surgery. The publication productivity of USA was far more than any other country during the last two decades, which confirmed the major influence of USA in the field of robotic surgery. Urology has the most number of articles, which was nearly equal to the amount combining the articles from the rest of top 9 medical fields.

Ethical approval

Not applicable.

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None.

Author contribution

Guoxin Fan and Shisheng He designed the study.
Guoxin Fan and Zhi Zhou wrote the manuscript.
Zhi Zhou and Hailong Zhang conducted the investigation.
Xin Gu, Guangfei Gu, Xiaofei Guan conducted the analysis.
Guoxin Fan and Yunshan Fan revised the manuscript.

Conflict of interests

There are no conflicts of interests. The authors had full control over all the data. The study will not be published elsewhere in any language without the consent of the copyright owners.

Trial registry number

Not applicable.

Guarantor

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