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Research Hotspots and Frontiers of Robot-Assisted Thoracic Surgery: A Study Based on Bibliometric Analysis

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1. Abstract

1.1. Purpose: To analyze the research status and development trend of robot-assisted thoracic surgery, to dig deeper into the research of robotic systems, and to provide reference for the application of domestic robotic systems in the field of thoracic surgery.

1.2. Methods: The publications from 2000 to 2019 were retrieved from the Web of Science Core Collection database. VOSviewer, and CiteSpace software were used to analyze the publication outcomes, citation frequency, countries and institutions cooperation, keywords and emergent words.

1.3. Results: A total of 1102 articles of statistical analysis were included. The top 5 countries for publishing articles were the United States (US, 478 articles), China (123 articles), Germany (93 articles), Italy (80 articles) and Japan (65 articles). The citation frequency of the article in China is 5.29 times (0.00-9.13), which is lower than the world average of 15.71 times (1.89-22.59). Key words in this field include “lung cancer”, “esophageal cancer”, “lobectomy”, “esophagectomy”, “thymectomy”, “robot surgery”, “minimally invasive surgery”, “thoracic surgery”, etc. Emergent words are “cardiopulmonary bypass”, “axillary approach”, “randomized controlled trial (RCT)”, “database”, “quality of life” and so on.

1.4. Conclusion: The US is in a leading position in research in this field, and the quality of research in China needs to be further improved. Robot-assisted thoracic surgery for cancer treatment is a research hotspot. The establishment of a clinical database for robot-assisted thoracic surgery and randomized controlled studies are needed to improve. The quality of life of patients is the frontier of research in this field.

2. Introduction

The Da Vinci robot was certified by the U.S. Food and Drug Administration (FDA) in 2000 and is currently the most advanced minimally invasive surgical robot system which integrates many emerging disciplines to achieve the development of minimally invasive, intelligent and digital surgical operations [1]. The operation of chest surgery applied to this system was approved by the U.S. FDA in 2001. After 20 years of clinical practice, it has effectively solved the two-dimensional surgical field of vision in conventional thoracoscopic surgery, the “chopstick” operation of rod-shaped instruments, and the long learning curve, lack of tactile feedback and other issues [2]. This study adopts bibliometrics methods to analyze research papers in the field of thoracic surgery by robots in the Web of Science database. The research status and development trend of robot-assisted thoracic surgery are analyzed from the perspectives of number of papers, national/regional distribution and cooperation, research status, research hotspots and frontiers, and the research on robotic systems is deeply explored to provide a reference for the application of domestic robotic systems in the field of thoracic surgery.

3. Methods

3.1. Data Source

The data was retrieved through the Web of Science database from January 2000 to December 2019 with English language restrictions. The search terms "robot" and "thoracic surgery" were found with this specific combination. In this study, we excluded conference papers, letters, comments, duplicate papers, irrelevant papers, or papers with incomplete information

3.2. Data Analysis

The Thomson Data Analyzer software (TDA) was used for data cleaning and bibliometric analysis on basis of the retrieved articles. The software VOS viewer and CiteSpace were used for visual analysis. Through the establishment of time distribution map, national cooperation distribution map, institutional cooperation distribution map and keyword time zone map.etc, the knowledge base and research hotspots in the field of robot-assisted thoracic surgery were identified and found. CiteSpace software was used to analyze the emergent words to detect the rapid growth of professional vocabularies in a short time. With the time distribution and dynamic change characteristics of emergent words, it reflected the research frontier and development trend of this field.

4. Results

A total of 1,209 pieces of data were retrieved in the Web of Science database from January 2000 to December 2019, and 107 articles due to not meet the inclusion criteria were excluded. Finally, 1,102 papers were included in the statistical analysis. As shown in Figure 1, among the 1,102 articles, the top five countries for published articles were the US (478), China (123), Germany (93), Italy (80) and Japan (65). The number of articles published by the US was the highest worldwide than that of other countries, accounting for 43.38%.

As shown in Figure 2, in the past 20 years, the literature on robotic-assisted thoracic surgery research has been continued to grow worldwide, especially from January 2014 to December2019, 64.07% (706/1,102) articles were published in this period. The research trend of the US in this research field was similar with the overall development trend of the world. However, the research of robot-assisted thoracic surgery has been published in China until 2007.

The citation frequency of an article reflects the quality of the article. As shown in Figure 3, the cumulative average citation frequency of each article in the world from 2000 to 2019 was 15.71(1.89-22.59) times, and the cumulative average citation frequency of the U S articles was 18.57(1.00-36.29) times, which has been basically above the world average level from 2007 to 2019The cumulative average citation frequency of articles published in China from 2007 to 2019 was 5.29 (0.00-9.13) times, which was lower than the same period average level of worldwide.

The spatial distribution map of national cooperation on robotic-assisted thoracic surgery research was shown in Figure 4. The size of the circle represented the amount of published researches, and the connected lines represented the frequency of cooperation among different countries. The US (116 times) had the most connected lines with other countries, followed by Germany (63 times), Italy (55 times), Netherlands (54 times) and the United Kingdom (UK, 44 times). China ranked Number 10 with27 times cooperation with other countries worldwide (Supplement Table1).

There were 1,102 papers in the field of robotic-assisted thoracic surgery, covering a total of 15,176 cited references. Cited papers were imported into the VOS viewer software for co-citation clustering and visualization (Figure 5), and a total of three types of knowledge bases were obtained. The first category was the comparison of the safety and postoperative recovery of robotic pneumonectomy and thoracotomy and conventional thoracoscopic lung resection. The second category was the comparison of the short-term benefits after robotic esophagectomy and thoracotomy esophagectomy. The third category was the feasibility of the technical operation of the robot-assisted thoracic surgery system. Keywords are the author's refinement of the core research content. Cluster analysis of high frequency keywords could condense research hotspots in a field. According to the strength of association, the top 20 high frequency keywords are shown in Table 2.

The generated high-frequency words co-occurrence matrix was imported into VOS viewer for clustering and visualization, and the clustering results are obtained. Five research hotspots were obtained through clustering results analysis (Figure 5). The five research hotspots were perioperative safety and risk analysis of robotic manipulators in minimally invasive surgery in thoracic surgery, evaluation of short-term clinical efficacy of robot-assisted lobectomy compared with thoracotomy and conventional thoracoscopic surgery, robots experience sharing of assisted minimally invasive esophagectomy and lymph node dissection, system management of robot-assisted surgical resection of thymic diseases and analysis of postoperative results, and complications and learning curves in the application of CT-navigated surgical robots.

Using the word frequency increase algorithm provided by Citespace software, the words with high word frequency change rate were detected from a large number of keywords and arranged according to the time when the emergent words appear to observe the frontier and development trend of the robotic thoracic surgery research field. According to the time span and emergence intensity, the top 10 emergent words are shown in Table 3.

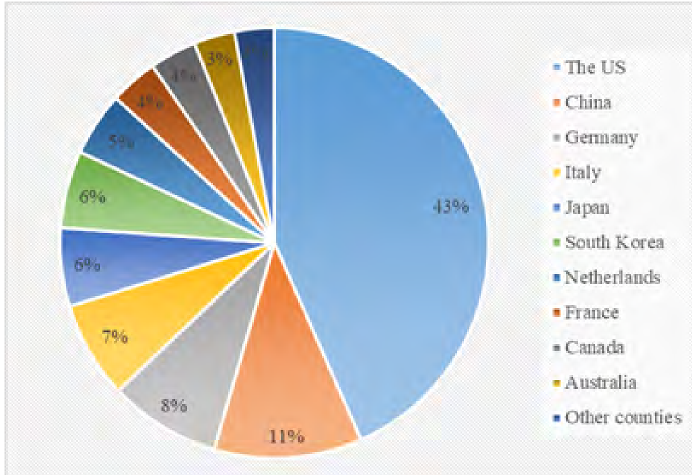

Figure 1: The proportion of the researches on robot-assisted thoracic surgery in different countries from January 2000 to December 2019.

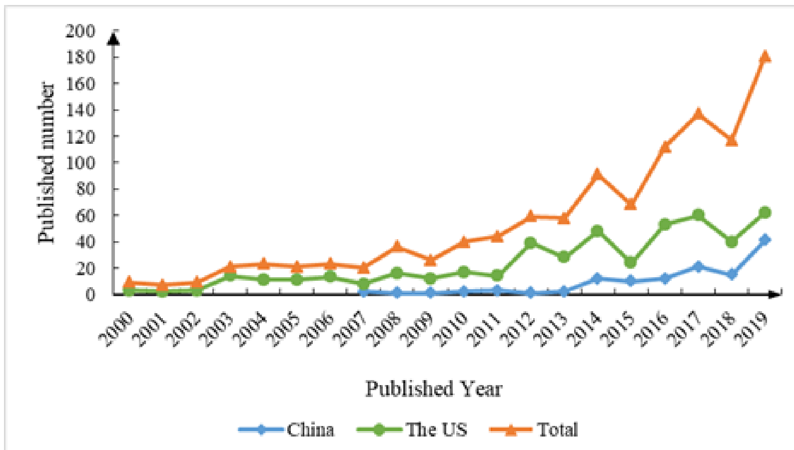

Figure 2: The number of published papers researched on robot-assisted thoracic surgery in each year from 2000 to 2019

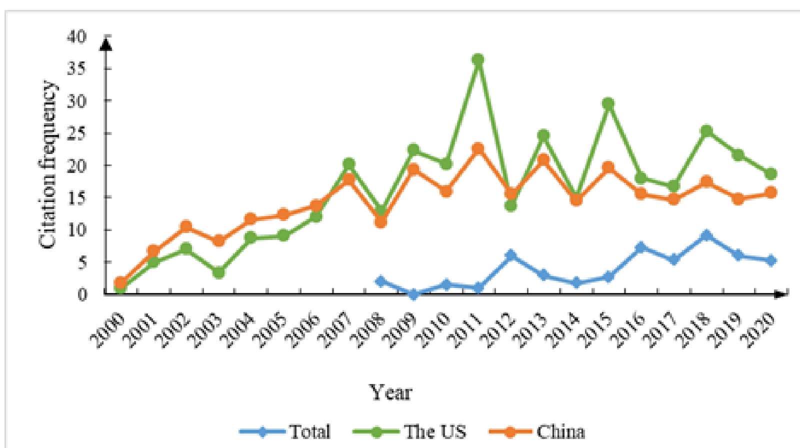

Figure 3: The citation frequency of researched on robot-assisted thoracic surgery in China, the US and worldwide.

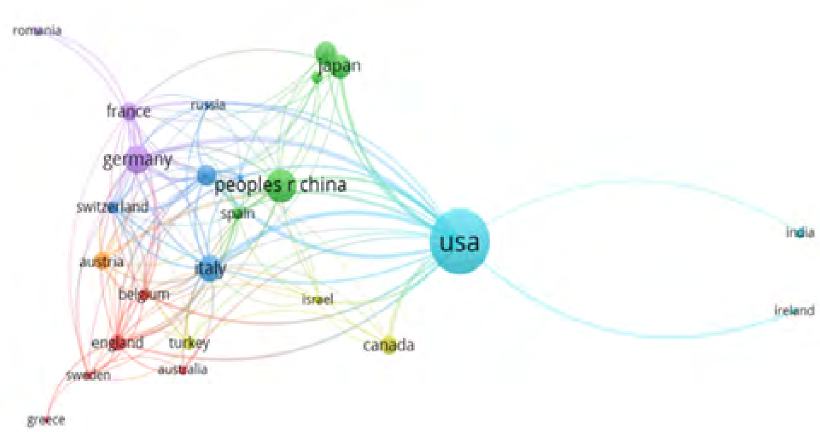

Figure 4: The spatial distribution map of national cooperation on robot-assisted thoracic surgery

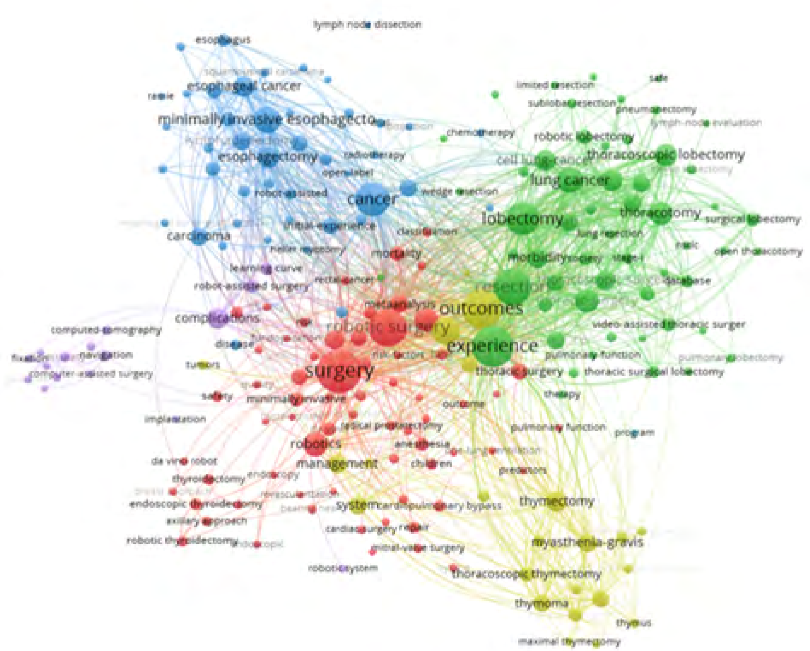

Figure 5: Research hotspots of robot-assisted thoracic surgery

Table 1: Top 10 countries in international cooperation frequency

Number	Country	Cooperation Frequency
1	The US	116
2	Germany	63
3	Italy	55
4	Netherlands	54
5	The UK	44
6	France	36
7	Switzerland	34
8	Belgium	31
9	Australia	28
10	China	27

Table 2: The top 20 keyword strengths of robot-assisted thoracic surgery

No.	Keywords	Frequency	Correlation strength
1	Outcomes	182	1138
2	Experience	202	1105
3	Resection	156	1030
4	Surgery	229	1004
5	Robotic surgery	163	843
6	Lobectomy	132	785
7	Cancer	136	761
8	Minimally invasive esophagectomy	87	565
9	Lung cancer	81	547
10	Minimally invasive surgery	90	518
11	Thoracotomy	63	464
12	Thoracoscopic lobectomy	60	407
13	Assisted thoracic-surgery	57	392
14	Thoracic-surgery	66	368
15	Robotic	64	365
16	Esophagectomy	55	362
17	Cell lung-cancer	53	352
18	Robotics	71	336
19	Esophageal cancer	50	326
20	thymectomy	50	321

Table 3: Emergent words in the research field of robot-assisted thoracic surgery

No.	Keywords	Strength	Start Year	End Year	2010 - 2019
1	cardiopulmonary bypa	2.74	2010	2014	
2	axillary approach	3.2	2010	2012	
3	myasthenia gravi	2.61	2010	2011	
4	quality of life	3.08	2011	2014	
5	thoracoscopic thymectomy	2.51	2013	2014	
6	randomized controlled trial	3.11	2014	2017	
7	open thoracotomy	2.55	2014	2016	
8	thoracic surgical lobectomy	3.06	2016	2017	
9	esophageal neoplasm	2.4	2016	2017	
10	database	3.32	2017	2019	

5. Discussion

5.1. The research of robot assisted thoracic surgery in the United States has maintained a leading position, while in Chinathe research quality needs to be further improved and international cooperation needs to be strengthened.

According to the number of published articles and citation frequency, it can be seen that the amount of published articles in the United States was much higher than that of other countries, and the quality of articles has been above the world average level since 2007. The Da Vinci robot was certified by the US FDA in 2000. In 2002, robot-assisted lung surgery was reported for the first time. The surgical procedures included lobectomy and wedge resection [3]. Later, it was further explored that Da Vinci robot surgery has many advantages in the thoracic cavity, including benign and malignant esophageal surgery, mediastinal mass resection, the rare operations including diaphragm operation and reconstruction, and pleura stripping, were feasible and effective in clinical practice [4]. The surgical robot system has developed four generations (standard, S, Si, Xi). In April 2014, the latest fourth generation Xi robot was released, which has the advantages of three-dimensional high-definition surgical field, flexible mechanical wrist and tremor filter system [5], and has a qualitative improvement in flexibility, accuracy, imaging clarity, etc. The Da Vinci robot system has the characteristics of a three-dimensional picture, a range of motion close to a human hand, and a movement of more than 360 degrees in a very small space (internal wrist technology) [6], which not only overcomes the shortcomings of conventional thoracoscopic surgery, but also retains the advantages of minimally invasive surgery, such as small trauma, fast recovery and short hospital stay. Moreover, studies have proved that robot surgery has more advantages than conventional thoracoscopic surgery in lymph node dissection, high difficulty and high risk thoracic surgery, which reduces the difficulty of surgery and allows surgeons to complete the operation more comfortably [2]. Since 2007, some articles have been published in the field of robotic surgery in China, which started later than foreign countries [7]. There is also a large gap between the citation frequency of Chinese articles and the world average level so that the quality of research needs to be further improved. The frequency of international cooperation is only in the 10th place. Compared with other top 10 countries in the number of published articles, China has less cooperation between counties. In the future, it is necessary to further strengthen international cooperation and exchange, learn from foreign advanced experience and technology, and improve the research level of domestic articles. Meanwhile, the advantages of domestic surgical technology will be displayed to the world to increase China's international influence.

5.2. Robot-assisted thoracic surgery for cancer treatment is a research hotspot, with particular attention to the sharing of surgical experience and the evaluation of perioperative surgical results.

Through keyword analysis, it can be seen that robot-assisted surgery was used for research in the field of cancer. Commonly used in the surgical treatment of "lung cancer", "esophageal cancer" and mediastinal tumors, "lobectomy", "esophagectomy", and "thymectomy" were common surgical procedures for radical tumor surgery and appeared as keywords many times, which indicated the treatment of cancer was the research hotspot of robotic technology in thoracic surgery. The research of robot-assisted thoracic surgery mainly focused on two aspects. On the one hand, it focused on sharing experience with robotic surgery. Thoracic surgery had a narrow operating space and was close to important organs. In surgical operations, it was necessary to perform fine anatomy of blood vessels and other parts so that robotic technology was very beneficial [8]. According to different types of thoracic surgical diseases, different postures and approaches were selected for preoperative evaluation, and the application of manipulators, surgical operation and other precautions were shared [9]. Some studies believed that, especially for esophageal surgery, because it involved multiple important anatomical parts of neck, chest and abdomen, compared with multiple incisions of conventional surgery, robotic surgery was more attractive [10]. It also included research on learning and training of robotic surgery [11]; On the other hand, comparing the recent results of "robotic surgery" with conventional "minimally invasive surgery" and "thoracotomy surgery" [12, 13], domestic and foreign scholars have basically reached a consensus in terms of relieving pain, shortening hospital stay, reducing postoperative complications and lung function damage [14], and robotic surgery has certain advantages in increasing the number of lymph node dissections and stations [15]. Certainly, compared with conventional minimally invasive surgery and thoracotomy, the operation cost was significantly increased, which was also an important factor limiting robotic surgery [2]. However, there were few reports on the comparison of the long-term effects of patients. Whether there is a difference between the five-year overall survival rate and the five-year disease-free survival rate remains to be seen [13, 16].

5.3. Robot-assisted surgical treatment of esophageal tumors has a good prospect. The establishment of a clinical database of robot-assisted thoracic surgery, and the development of randomized controlled studies to improve the quality of life of patients are the frontier research directions in this field.

From the analysis of emergent words, it can be found that future research will mainly focus on two directions. Firstly, in terms of treatment of diseases and surgical techniques, diseases such as tumors in the esophagus, lung and thymus, myasthenia gravis, and other diseases are still research hotspots. Robotic surgery will continue to be used in surgical applications such as esophagus, lung lobes, and thymectomy. Surgical approaches such as "cardiopulmonary bypass" and "axillary approach" are still research hotspots in the future, especially, and robot-assisted surgical treatment of esophageal tumors is the frontier of research. Robotic technology has been applied to the surgical treatment of esophageal tumors in the early stage [17]. With the development of robotics, robotic surgery has been skillfully applied in the surgery of the neck, thoracic cavity and abdominal cavity [18, 19], which has laid a foundation for robot assisted surgical treatment of esophageal tumor. At the same time, compared with open surgery, the clinical outcome of robot-assisted esophageal surgery was better, the incidence of surgery and cardiopulmonary complications was reduced, the pain was less, and the functional outcome was also improved [20]. Robot-assisted esophagectomy has advantages in ensuring clean margins, R0 resection rate of lymph nodes, and thoracic anastomotic leakage [15]. Therefore, robot-assisted surgical treatment of esophageal tumors is the frontier direction of research. Secondly, to establish a database for robot-assisted thoracic surgery, to carry out randomized controlled studies, and to emphasize the improvement of patients' quality of life and the long-term effect of surgery, which is an important direction for future research. From the analysis of hot spots, it can be found that at present, the research on improving the quality of life of patients with robot-assisted thoracic surgery was mostly retrospective research or experience sharing [4]. With the accumulation of experience in robotic surgery, a complete database such as the national database of American Society of thoracic surgeons was established [21]. Randomized controlled studies of robotic surgery and open thoracic surgery and traditional minimally invasive surgery in lung cancer and esophageal cancer [19, 22, 23] can effectively improve the quality of life of patients. In addition, some randomized controlled studies focusing on recent clinical outcomes and long-term survival are ongoing [24, 25], which will provide strong evidence for the advantages of robotic surgery and will be the frontier of future research.

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