

Industry Status and Future Development Trend of Da Vinci Surgical Robot

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Abstract: *In this paper, we analyze the current industry status of the Da Vinci surgical robot in the medical field and its future development trend. As an advanced minimally invasive surgical tool, the Da Vinci surgical robot has been widely used in many types of surgery, including urology, gynecology, cardiothoracic surgery and general surgery, by providing high-precision surgical operations, three-dimensional high-definition views and greater surgical flexibility. First of all, we analyze the application status of Da Vinci surgical robot in the world. In addition, we explore the major challenges and limitations of Da Vinci surgical robotics. Subsequently, the key factors driving the development of the Da Vinci surgical robot are also analyzed. In terms of future development trends, we predict that the integration of artificial intelligence and surgical robotics, the development of remote surgery and the emergence of more personalized surgical solutions will further promote the progress of Da Vinci surgical robotics and the expansion of the surgical field.*

Keywords: Da Vinci, Surgical robot, Industry status, Surgical field analysis, Development trend.

1. Introduction

1.1 Background

The Da Vinci surgical robot is a high-end medical device produced by IntuitiveSurgical, Inc. It adopts advanced mechanical and handheld operating system and is operated by surgeons for precise positioning and fine operation [1]. Since its inception, Da Vinci surgical robots have been widely used worldwide and are known as the "gold standard" in the field of surgery [2]. Da Vinci surgical robot is an advanced technology with important influence in the medical field. It achieves high precision, stability and operability of minimally invasive surgery by operating robotic arms and high-precision instruments [3]. Since its first introduction into clinical applications, Da Vinci surgical robots have been widely used worldwide, greatly improving the quality of surgery and patient treatment.

1.2 Research Purpose

This paper aims to analyze the industry status of Da Vinci surgical robot, and discuss the future development trend and its impact on the medical industry. Through research, we can have a deeper understanding of the development trend, technological innovation and market competition of the surgical robot market, which will provide reference and inspiration for the development of China's surgical robot industry and contribute to the progress of medical technology and the well-being of patients [4].

2. Overview of Da Vinci Surgical Robot

2.1 Product Structure and Characteristics

Da Vinci surgical robot is an advanced intelligent robotic surgical platform designed to perform complex surgical operations through the use of minimally invasive methods [5]. The Da Vinci robot consists of three parts: the surgeon's console, the bedside robotic arm system, and the imaging system [6]. The surgical console allows the surgeon to control the robot to perform surgical operations by operating rods and

control buttons [7]. The manipulator arm is responsible for manipulating the movement of the surgical instrument. Its product features include high operational precision, high repeatability, high stability, and the ability to perform surgery through tiny holes, etc., and it can perform surgery in various parts of the mouth, chest, abdomen, etc., and is widely used in minimally invasive surgery with high precision requirements, enabling surgeons to accurately operate surgical instruments [8]. In addition, for surgeons, the use of Da Vinci surgical robots also has a certain occupational protection effect, which can reduce the damage caused by long-term surgical opponents and the body.

2.1.1 Robotic arm

Da Vinci surgical robot is designed with 4-arm structure, which has the advantages of flexibility, accuracy and controllability, and can perform complex surgical operations to improve surgical safety and success rate.

2.1.2 Operating system

The handheld operating system of the Da Vinci surgical robot is designed with a touch screen, allowing the surgeon to control the activities of the robot arm with finger taps and movements. The system is simple and intuitive in operation, which can greatly shorten the learning time and operation time of doctors [9].

2.1.3 Three-dimensional vision system

The Da Vinci surgical robot is equipped with a high-definition 3D vision system, which enables more precise control of the position of surgical tools through enhanced visual effects and depth perception [10], and the accuracy of operation can be improved to the micron level.

2.2 Technical Principles and Application Fields

The technical principle of Da Vinci surgical robot is mainly based on minimally invasive surgical technology and robotic technology [11]. The 3D imaging system provides doctors

with a high-definition, real-time surgical field of view, and the doctor can operate the robot arm on the console to achieve accurate removal of the patient's lesions. In addition, the robotic arm has flexible movement and extensive maneuverability, making the surgical procedure more stable and safe. Da Vinci surgical robot was initially mainly used in urology, and subsequently involved cardiothoracic surgery, gynecology and other fields [12]. With the development of technology and the expansion of market demand, its application fields continue to expand, including gastrointestinal surgery, hepatobiliary surgery, neurosurgery and so on.

2.3 Market Competition Pattern and Major Players

The Da Vinci surgical robot market has long been dominated by IntuitiveSurgical, an American company whose products have a high market share worldwide. However, with the expiration of the first batch of Da Vinci robot patents in 2018, many companies have entered this field, such as Stryker, Gemay Bonme, Medtronic and so on. In addition, Chinese enterprises such as Tianzhihang are also gradually emerging. Globally, the Da Vinci surgical robot market still has great growth potential, and major enterprises have improved their position in the market competition through technological innovation, market expansion and win-win cooperation strategies [13]. In the future, the Da Vinci surgical robot industry will continue to maintain rapid growth, bringing more high-quality and efficient medical services to patients around the world.

3. The Application of Da Vinci Surgical Robot in the World

3.1 America

As the birthplace of Da Vinci surgical robots, the United States has become one of the countries in the world where Da Vinci surgical robots are most widely used [14]. According to data released by IntuitiveSurgical, by the end of 2019, the United States has more than 5,000 Da Vinci surgical robots, covering more than 4,000 medical institutions, achieving a breakthrough from the application of a single surgical field to gradually expand to multiple surgical fields.

3.2 Europe

Europe is an important creator and user of the global surgical robot market [15]. By 2020, there are about 1,000 Da Vinci surgical robots in Europe, covering many fields such as urology, cardiothoracic surgery and hepatobiliary surgery [16].

3.3 Asia

Asia is one of the fastest-growing regions in the surgical robot market [17]. At present, Asia has become the world's second largest surgical robot market, second only to the United States [18]. IntuitiveSurgical has launched about 1,000 Da Vinci surgical robots in Asia since 2010 [19]. Among them, China is one of the largest growth points of the surgical robot market in Asia.

4. Industry Status Analysis

4.1 Global Surgical Robot Market Size and Growth Trend

With the continuous progress of medical technology and the intensification of population aging, surgical robots have become a hot topic in today's medical field [20]. At present, the global surgical robot market has gradually matured and shows a steady growth trend. According to statistics from market research institutions, the global surgical robot market has increased from \$1.664 billion in 2015 to \$4.886 billion in 2020 [21]. This number is expected to continue to rise by 2025. Moreover, the scope of application of surgical robots is also expanding, no longer limited to cancer and cardiac surgery, but also widely used in urology, gastrointestinal surgery and other fields.

4.2 Market Size and Growth Trend of Surgical Robots in China

China's surgical robot market is still in its infancy, but it has shown a rapid growth trend [22]. According to the report released by China Medical Equipment Industry Association, the market size of surgical robots in China in 2019 was 3.92 billion yuan, with a growth rate of 96.2% [23]. However, compared with the scale and growth rate of the global surgical robot market, China's surgical robot market still has huge room for development. It is expected that in the next few years, China's surgical robot market will continue to maintain rapid growth.

4.3 Industry Policies, Regulations and Standards

All aspects of the research, development, registration, sales and use of surgical robots need to comply with relevant policies, regulations and standards. For example, in the United States, the Food and Drug Administration (FDA) has strict approval for surgical robots, requiring products to meet standards. In China, the State Food and Drug Administration also strictly regulates the research and development, registration, and import of implantable products. At present, China has issued relevant policies and regulations and established a perfect standard system to regulate the development of surgical robot industry to protect the safety and legitimate rights and interests of both doctors and patients. For example, the 13th Five-Year Plan for the Development of National Strategic Emerging Industries clearly proposes to support the development of high-end medical equipment and instruments, including surgical robots [24]. In addition, the State Food and Drug Administration (now renamed the State Drug Administration) has also issued relevant regulations on the registration, supervision and other aspects of surgical robots. These policies and regulations provide a strong guarantee for the development of the surgical robot industry.

4.4 Technological Innovation and R&D Progress

The innovation and research and development of surgical robot technology is an important driving force for the development of this industry [25]. With the continuous development of science and technology, more and more new technologies are widely used in surgical robots. Robot surgery technology will usher in more technological innovation and

upgrading. In the future robotic surgery system, 5G technology, 3D printing technology, virtual and augmented reality technology and other emerging technologies are likely to be introduced [26]. At the same time, virtual technology can also be applied in surgical simulation training and other aspects to facilitate the training of doctors and the accuracy of surgical operations. Further improve the performance of surgical robots in terms of controllability, high precision and safety.

5. Analysis of the Surgical Field of Da Vinci Surgical Robot

5.1 Urology Field

The application of Da Vinci surgical robot in the field of urology is relatively mature [27]. Its characteristics of high precision, stability and controllability enable doctors to perform complex and high-risk operations while reducing surgical trauma and bleeding, especially in the radical resection of prostate cancer, partial nephrectomy, radical resection of bladder cancer, pyeloplasty, adrenalectomy and other urological surgery widely used. With the development of technology, the surgical robot market in the field of urology will continue to expand, providing more quality medical services to patients.

5.2 Cardiothoracic Surgery

In the field of cardiothoracic surgery, Da Vinci surgical robot also shows strong competitiveness [28]. Since cardiothoracic surgery requires high precision and stability, the advantages of Da Vinci surgical robot are particularly obvious [29]. Surgical types include lobectomy, thymoma resection, posterior mediastinal tumor resection, radical resection of esophageal cancer, etc. With the help of Da Vinci robot, doctors can achieve highly difficult minimally invasive surgery, reduce surgical risks and improve patient survival [30].

5.3 Gynecology Field

In the field of gynecology, Da Vinci surgical robots have also achieved remarkable results [31], such as robotic vagino-sacral fixation and robot-assisted total laparoscopic hysterectomy. Its application in gynecological minimally invasive surgery helps to reduce the risk of surgery, improve the success rate of surgery, and provide better treatment results for patients. With the enhancement of women's health awareness and the development of medical technology, the market demand for Da Vinci surgical robots in the field of gynecology will continue to rise.

5.4 Other Fields

The analysis of application fields of Davench surgical robot shows that it has a wide application prospect in urology, cardiothoracic surgery, gynecology and other fields [32]. At the same time, with the progress of technology and the expansion of market demand, the application of Da Vinci surgical robots in other fields will gradually increase. For example, in orthopedics, neurosurgery, hepatobiliary surgery, ophthalmology and other fields, Davench surgical robots have

certain application space [33].

6. Industry Challenges and Opportunities

6.1 Technical Problems and Breakthroughs

Da Vinci surgical robot, as an advanced intelligent surgical platform, has high technical content and difficult operation, which puts forward extremely high requirements for research and development and manufacturing. At the technical level, the industry faces many challenges, such as improving operational stability, reducing costs, shortening surgical time, and expanding application areas. To achieve these goals, companies and research institutions need to continuously break through key technologies, such as robot control, image recognition, sensor technology, and so on. In addition, there is a need to enhance compatibility with other medical devices and the ability to work together.

6.2 Policy Support

The Chinese government attaches great importance to the development of the medical and health field, especially in the surgical robot industry. In recent years, the government has introduced a series of policy measures, such as financial support, tax incentives, market access, etc., to encourage enterprises and research institutions to increase investment in R&D and promote the rapid development of the industry. The government's support policy for the Da Vinci surgical robot industry is an important factor to promote the development of the industry. In recent years, the Chinese government has issued a series of policies, such as the "13th Five-Year Plan for the Development of National Strategic Emerging Industries" and the "Guiding Opinions on Promoting the Development of the Medical and Health Internet of Things" [34], which provide a strong guarantee for the development of the Da Vinci surgical robot industry.

6.3 Social Ethical and Legal Issues

With the continuous popularization and application of surgical robot technology, the social ethical and legal problems brought by it have attracted more and more attention. First of all, the application of surgical robots in clinical surgery is directly related to the safety and health of patients, so its safety and effectiveness are extremely high requirements. Enterprises should strictly abide by relevant regulations and standards to ensure product quality. Secondly, the application of surgical robots may cause medical disputes, such as operational errors and equipment failures. In the face of such problems, how to define the liability has become a legal problem to be solved. In addition, surgical robots are expensive, and how to ensure fairness and accessibility in the selection and use of patients and medical institutions is also an ethical problem [35]. In summary, the Da Vinci surgical robot industry is facing many challenges, but also has huge development opportunities. Through continuous breakthroughs in key technologies, strengthening market competition, striving for policy support and paying attention to social ethical and legal issues, the industry is expected to achieve sustainable development and make greater contributions to China's medical cause. Only in this way can the Da Vinci surgical robot industry move towards a broader

development prospect.

7. Future Development Trend

7.1 Technological Innovation Direction

With the continuous development of artificial intelligence technology, the technological innovation direction of Da Vinci surgical robot in the future will pay more attention to technological innovation with artificial intelligence as the core. This includes the continuous improvement and upgrading of autonomous decision-making during operation, optimization of surgical plans, and accurate surgical assistance.

7.2 Market Expansion and Application Scenarios

With the gradual expansion of the application scope of Da Vinci surgical robot in the surgical medical industry, it will be applied in more medical fields in the future, such as routine urology, gastrointestinal surgery, cardiac surgery, neurosurgery, gynecology and other fields, not only that, but also may be widely used in thoracic surgery, cyst excision, pancreas excision and other special fields. In addition, it will be gradually promoted and applied in other countries and regions in the future.

7.3 International Development and Cooperation

In the future, with the acceleration of globalization and the continuous development of international trade, Da Vinci surgical robot will further expand its international layout. At the same time, cooperation with international counterparts will also be strengthened to realize the complementary advantages of all parties, thus promoting the development and progress of the entire industry.

8. Conclusion

8.1 Da Vinci Surgical Robot Industry Status Summary

The Da Vinci surgical robot has achieved remarkable results in the field of surgery and is gradually becoming an important tool in medical institutions around the world. At present, many hospitals around the world have adopted Da Vinci surgical robots for surgery, and its advantages include accuracy, flexibility and remote operation. However, due to the high cost of equipment and technical complexity, the current application of Da Vinci surgical robots is still mainly concentrated in developed countries and large medical institutions. In addition, related training and certification are also a major challenge in promoting and popularizing the technology.

8.2 Future Development Trend Outlook

Although the Da Vinci surgical robot has achieved some success, its development still faces some challenges and opportunities. First of all, with the continuous innovation and progress of technology, Da Vinci surgical robot is expected to further improve the surgical accuracy and effect [36]. Secondly, with the continuous decline in costs and the popularization of technology, more medical institutions and

countries are expected to adopt Da Vinci surgical robots for surgery. In addition, the combination of technologies in other fields, such as artificial intelligence and virtual reality, will also provide new opportunities for the development of Da Vinci surgical robots.

8.3 Suggestions for the Development of Surgical Robot Industry in China

As an advanced medical technology, Da Vinci surgical robot plays an important role in the field of surgery. The current situation of its industry shows that its application has certain limitations, but the future development trend gives us more expectations. In view of the development of surgical robot industry in China, this paper puts forward the following suggestions: First, accelerate the research and development and innovation of related technologies, and improve the independent research and development and production capacity [37]. Second, we should strengthen training and certification mechanisms to train more professionals and technicians. In addition, it is also necessary to actively promote academic exchanges and international cooperation, cooperate with leading international institutions and enterprises, and accelerate the introduction and development of local technologies. In this process, hospitals that have carried out surgical robot technology in China should keep up with the trend of the development of surgical technology, continuously accumulate experience, and explore surgical indications and promotion paths suitable for application in our country, focusing on improving the cost performance of surgery. Hospitals that have such conditions but have not yet carried out should also actively make preparations in all aspects and intervene in this field when the time is ripe [38]. We believe that the development of surgical robots will be better and better and have a bright future.

References

- [1] Jiang Shan, WU Haoran, WANG Jiaojiao. Research progress and clinical application of ophthalmic microsurgical robot [J]. Journal of Robotic Surgery, 2024, 5(01):80-84.
- [2] Chu Yan, GAO Shuzhuo, LIU Yunfang. The world's first robot on the operating table doctors outside "command" [N]. Xiamen Daily, 2023-12-30(A05). DOI:10.28890/n.cnki.nxmrb.2023.003311.
- [3] Wu Peng, HUANG Pengcheng, ZHONG Jialei. Preclinical evaluation of the Versius Surgical system: a novel robot-assisted surgical device for minimally invasive treatment of kidney and prostate surgery [J]. Journal of Robotic Surgery, 2020, 1(01):70-71.
- [4] Hai Han. Overview of research status and future development trend of oral medical robot [J]. Electronic Journal of General Stomatology, 2018, 5(34):18-19. DOI:10.16269/j.cnki.cn11-9337/r. 2018.34.008.
- [5] Chen ZJ, Wang D, Fan SD, Ren SQ, Zhou F, Nie Y, Lv Q, Tian JZ. DaVinci robotic-assisted laparoscopic resection of parapelvic cavernous hemangioma: a case report. BMC Surg. 2020 Aug 13;20(1):186. doi: 10.1186/s12893-020-00834-4. PMID: 32791964; PMCID: PMC7430835.
- [6] Ravendran K, Abiola E, Balagumar K, Raja AZ, Flaih M, Vaja SP, Muhidin AO, Madouros N. A Review of

- Robotic Surgery in Colorectal Surgery. Cureus. 2023 Apr 9;15(4):e37337. doi: 10.7759/cureus.37337. PMID: 37182014; PMCID: PMC10169093.
- [7] Palep JH. Robotic assisted minimally invasive surgery. J Minim Access Surg. 2009 Jan;5(1):1-7. doi: 10.4103/0972-9941.51313. PMID: 19547687; PMCID: PMC2699074.
 - [8] Liao Zhuxiu, Zhang Boyu, Zhu Mingyu, et al. Application and prospect of novel minimally invasive technique in fetal surgery [J]. Medical Equipment, 2018, 39(02):7-12.
 - [9] Zhan Xiong, Zhang Piao Yi, Zhou Gang, et al. A novel robotic system for bronchoscopic surgery [J]. Chinese Journal of Medical Devices, 2023, 47(01):19-25.
 - [10] Li Xuejing. Development of robotic surgery system and nursing management strategy [J]. Journal of Nursing Science, 2016, 31(04):108-112.
 - [11] Yang Ming. Research and Development of Surgical Robot End-effector Control System [D]. Shenyang University of Technology, 2018.
 - [12] Chai Xun-Chun. Comparative analysis of short-term efficacy of Da Vinci robotic and video-assisted thoracoscopic segmentectomy for stage I non-small cell lung cancer [D]. Dalian Medical University, 2021. DOI:10.26994/d.cnki.gdlyu.2021.000667.
 - [13] Zhang Qiaoye. Da Vinci Surgical Robot System and its Application [J]. Medical Equipment, 2016, 29(09):197-198.
 - [14] Jin Zhenyu. Clinical application of Da Vinci surgical Robot in China [J]. Chinese Journal of Medical Devices, 2014, 38(01):47-49.
 - [15] Ju Hao. Research on control system of laparoscopic Minimally invasive surgery robot [D]. Nankai University, 2009.
 - [16] Li Wangang, Wang Jianjun, Cui Jing, et al. Surgery has ushered in the age of robots [J]. Medicine and Philosophy (B), 2012, 33(04):33-34+38.
 - [17] Liang Wenli. Statistical Data Analysis of Global Robot Market [J]. Robot Technology and Application, 2020, (03):47-48.
 - [18] Liu Zhaoyang. Analysis of global scientific research Cooperation in the field of Surgical Robot [D]. Tianjin University, 2020. DOI:10.27356/d.cnki.gtjdu.2020.001768.
 - [19] Ding Damin. Research and Implementation of Motion Control System of Surgical Robot Manipulator [D]. Shanghai University of Engineering Science and Technology, 2015.
 - [20] Ouyang An. Current Situation and Problem Analysis of orthopedic Surgical robot industry [J]. China Instrumentation, 2022, (06):26-30.
 - [21] Cheng Li-Rui, Zhu Zhi-gang, Yan Hao, et al. Research on Application quality and safety evaluation standard system of laparoscopic surgical robot [J]. Advances in Biomedical Engineering, 2024, 45(01):27-33.
 - [22] Li Jinglong. Application Research of Intelligent Service Robot in medical treatment [J]. Enterprise Technology Development, 2018, 37(07):4-7+13. DOI:10.14165/j.cnki.hunansci.2018.07.002.
 - [23] Zhu Zhongrui, MA Hui. Research on Tort Liability of surgical robot Designer in China [J]. Medicine and Society, 2024, 37(01):124-129+144. DOI: 10.13723/j.yxysh.2024.01.019.
 - [24] Ma Weijia, Zhu Xiaolong, Liu Qingyao, et al. Application of Artificial intelligence in robot-assisted surgery [J/OL]. Journal of Mechanical Engineering:1-18[2024-05-13].http://kns.cnki.net/kcms/detail/11.2187.TH.20240401.0922.006.html.
 - [25] Duan Xingguang. Core Technology and Industry Development of Medical Robot [J]. Robot Industry, 2023, (04):1-4.
 - [26] Zhao Xuan, Xu Junjie, Bian Zhiqi, et al. Application research of surgical robot combined with 5G in sports medicine [J]. China Digital Medicine, 2022, 17(06):20-25+36.
 - [27] Xu Zhi, Chen Guojun. Application of Da Vinci surgical Robot in Urology [J]. World Latest Medical Information Digest, 2017, 17(52):123-124+127.
 - [28] Jin Zhenyu. Clinical application of Da Vinci surgical Robot in China [J]. Chinese Journal of Medical Devices, 2014, 38(01):47-49.
 - [29] Feng Gang, LI Gang. Application of Da Vinci surgical Robot in thoracic surgery [J]. Clinical Journal of Practical Hospital, 2015, 12(01):32-34.
 - [30] Hou Juanru, Zhou Shan, Zhang Hongmei, et al. Application progress and prospect of Da Vinci surgical robot [J]. Journal of Modern Medicine and Health Research Electronic, 2017, 1(04):161.
 - [31] Zhou Fan, Chen Xiang. Meta-analysis of the efficacy of Da Vinci surgical robot in gynecological surgery [J]. Chinese Medicine Guide, 2015, 13(06):7-9. DOI:10.15912/j.cnki.gocm.2015.06.004.
 - [32] Liu Zhongming, Li You, GONG Jianping. Application of Da Vinci surgical Robot in hepatobiliary surgery [J]. Journal of Laparoscopic Surgery, 2015, 20(07):556-560. DOI:10.13499/j.cnki.fqjwkzz.2015.07.556.
 - [33] Cao Yue, Yang Hedi, Miao Miao, et al. Current Situation and future of Medical Surgical robot [J]. China Science and Technology Information, 2021, (10):123-125.
 - [34] Shi Xuelian, Chen Min. Research on Medical Artificial Intelligence standard System [J]. Chinese Journal of Health Information Management, 2019, 16(06):759-762.
 - [35] Wu Bozhen, Gu Jinxian. Research on ethical risks and countermeasures of clinical application of surgical robots [J]. Chinese Journal of Medical Ethics, 2020, 33(01):17-20.
 - [36] Zhong Lizhe. New Development of minimally invasive surgery in thoracic surgery -- Da Vinci surgical Robot [J]. Medical Information (Junten-day Issue), 2011, 24(08):3901.
 - [37] Zhu Qingyi, Wei Yong, GU Min. Development and prospect of robot-assisted single-hole laparoscopy in urology [J]. Journal of Robotic Surgery, 2024, 5(01):1-6.
 - [38] Ji Wu, Li Ning, Li Jieshou. Opportunities and challenges of surgical robotic surgery in China [J]. Chinese Journal of Minimally Invasive Surgery, 2012, 12(07):577-579.