ROBOTICS IN CARDIAC SURGERY: CURRENT STATUS AND FUTURE

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Abstract: *over the past years, cardiac surgery has evolved in numerous ways. From its inception to the current form, it has been at the forefront to provide cutting-edge therapy for patients. First animal experimentation was performed in 1996, using robotics (the Green Telepresence Surgery System, later commercialized as a da Vinci surgical system). The da Vinci system was approved for general surgery applications in July 2000. Since that robotic surgery has developed intensively in every field of surgery, including cardiac surgery. The utility of robotics in cardiac surgery is evolving. Robotic assistance allows minimally invasive techniques to be applied to ischemic and valvular heart diseases. These techniques allow complex cardiac procedures to be carried out through small incisions leading to faster recovery while preserving critical aspects of the surgical procedure. In this article current status of robotics in cardiac and presumptive future will be discussed.*
Keywords: *robotics, minimally invasive surgery, surgery, cardiac surgery, da Vinci system.*

РОБОТОТЕХНИКА В КАРДИОХИРУРГИИ: ТЕКУЩЕЕ СОСТОЯНИЕ И БУДУЩЕЕ

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Аннотация: *за последние годы кардиохирургия развилась по-разному. С момента своего создания до нынешней формы она была на переднем крае для предоставления передовой терапии пациентам. Первые эксперименты на животных проводились в 1996 году с использованием робототехники (the Green Telepresence Surgery System, позднее коммерциализированная как хирургическая система да Винчи). Система da Vinci была одобрена для применения в общей хирургии в июле 2000 года. Поскольку эта роботизированная хирургия интенсивно развивалась во всех областях хирургии, включая и кардиохирургию. Усиливается полезность робототехники в кардиохирургии. Роботизированная помощь позволяет применять минимально инвазивные методы при ишемических и клапанных заболеваниях сердца. Эти методы позволяют выполнять сложные кардиологические процедуры с помощью небольших разрезов, что приводит к более быстрому восстановлению, сохраняя при этом критические аспекты хирургической процедуры. В этой статье будет обсуждаться текущее состояние робототехники в кардиохирургии и в предполагаемом будущем.*
Ключевые слова: *робототехника, минимально инвазивная хирургия, хирургия, кардиохирургия, система да Винчи.*

Over the past years, cardiac surgery has evolved in numerous ways. From its inception to the current form, it has been at the forefront to provide cutting-edge therapy for patients. Currently, cardiac surgery is going through renaissance again as minimally invasive procedures are being added to the repertoire of operations available. With the development of more minimally invasive procedures in other principles of surgery, cardiac surgery has provided the impetus and momentum for minimally invasive robotic assistant surgery.

In the early 1980s, surgical technique experienced a revolution called minimally invasive surgery (MIS). The goal of MIS is to reduce patients’ pain and recovery time from surgical procedures by minimizing the trauma of the large incisions required by conventional open surgery.

In the beginning, MIS procedures have brought some difficulties in Cardiac surgery, according to anesthesia and cardiopulmonary bypass(CABP). Later establishing of total CABP via the femoral artery and femoral vein and fast-track anesthesia [1] impacted to develop totally thoracoscopic operations in cardiac surgery and surgeons demonstrated positive results of MIS procedures in this field [2, 3].

First animal experimentation was performed in 1996, using robotics (the Green Telepresence Surgery System, later commercialized as a da Vinci surgical system). In March 1997, the first clinical robotic procedure, cholecystectomy was performed by Cadiere and Himpens in Brussels, Belgium, using da Vinci robot [4]. The first robot-assisted Cardiac surgery was performed with the da Vinci system in May 1998 and the first closed-chest coronary artery bypass graft was performed in June 1998 [5]. The da Vinci system was approved for general surgery applications in July 2000. Since that robotic surgery has developed intensively in every field of surgery, including cardiac surgery.

In fact, it can be realized that widespread use of minimally invasive methods of surgery has brought significant benefits for patients as a reduced pain and shorter recovery time after these procedures. However, surgeons have found some technical complexities, which made MIS procedures more difficult than open surgery. We can enumerate some of them:

- Loss of depth perception – Vision on MIS is in two dimensions, removing some depth cues of normal binocular vision.
- Loss of neutral hand-eye coordination – MIS procedures force a surgeon to work with looking at the monitor instead of his own hands.
- Loss of intuitive movement – during usual MIS procedures surgeon holds an instrument outside of a patient, while tips of instruments are inside, and the surgeon should move his hand nonintuitive to move tips correctly.
- Loss of dexterity – endoscopic instruments do not have wrist like the human hand. The instrument can move only several directions and it can restrict a motion of surgeons.

Robotic surgery restored the feel of open surgery and reduced complexities of MIS procedures above. It has a high-quality stereo visualization (3D) which can help to perceive the depth, the alignment of the surgeon's hand motions to the motion of the surgical tool tips is both visual and spatial, which helps to a surgeon at hand-eye coordination and intuitive movement, the surgeon's handpiece enables the manipulate of instruments with seven degree of freedom, additionally the system controls the surgeon tremor, and helps to tooltips' movement to be steadier than human hand.

The da Vinci system consists of two major sub-systems: first – surgeon's console, housing the display system, surgeon's handles, surgeon's user interface, and electronic control system; and second – patient-side cart, consisting of fully sterilizable tools, the tool manipulators, camera manipulator, the surgical endoscope, and the assistant user interface.

The utility of robotics in cardiac surgery is evolving. Robotic assistance allows minimally invasive techniques to be applied to ischemic and valvular heart diseases. These techniques allow complex cardiac procedures to be carried out through small incisions leading to faster recovery while preserving critical aspects of the surgical procedure [6]. Experience from a number of centers across the world has shown that application of telemanipulation is safe and has acceptable results [7]. Although the operating room times are longer and the operation is not only demanding but also expensive because of the cost of the equipment, patient satisfaction in robotic procedures is higher owing to its minimally invasive nature. Because of telemanipulation and robotic surgical techniques, cardiac operations can now be done with alternative incisions with enhanced technological assistance [8].

Nowadays several types of cardiac operation are undergoing in several places in the world. Mains of them are followings:

- Robotic-assisted internal thoracic artery takedown – a traditional way of harvesting left internal thoracic artery (LITA) is using sternotomy, but recently various surgeons reported their experience on totally endoscopic coronary artery bypass. To perform that, robotic-assisted internal thoracic artery takedown is a significant stage. Nowadays, surgeons are reporting about the decrease of ITA takedown time [9].
- Coronary artery bypass grafting (CABG) – With the help of the robotic surgical system, single vessel or multivessel coronary revascularization can be performed via small anterior thoracotomy incisions. Loulmet and Carpentier performed robotic-assisted minimally invasive CABG firstly in 1998 [10] and since that several surgeons have reported their results on robotic-assisted CABG [11-13].
- Robotic mitral valve surgery – Mitral valve surgery was started to perform with da Vinci robotic manipulation system in 1998 by Chitwood and colleagues, after that they reported about performing this operation on 38 patients and all patients' repair was successful [14, 15].
- Resection of pericardial cyst – developing of robotic-assisted surgical procedures have made it possible to perform the resection of pericardial cysts via a minimally invasive approach. Bachetta with his colleagues reported about performing this kind of operation on a 43-year-old patient in 2003 [16].
- Robotic therapy of arrhythmias – arrhythmology is a relatively new field of cardiology and sometimes surgical procedures are used in this field also, we can see numerous of reports about robotic-assisted surgical therapy of arrhythmias now, including, robotic cardiac resynchronization therapy or obligation of a source of atrial fibrillation etc. [17, 18].
- Robotic correction of congenital heart defects – there are several types of congenital heart defects and a multitude of them requires surgical treatment. Traditionally, correction of CHD is performed via full sternotomy. Although surgeons reported robotic-assisted closure of ASD in the early XXI century [19], robotic procedures are not very famous in this field. However, recent reports about the robotic closure of VSD [20] and robotic-assisted correction of partial atrioventricular canal [21] are occurring occasionally. But unfortunately, nowadays complex congenital cardiac defects are treatable only via full sternotomy still. Even so, we should emphasize

that extracardiac defects, such patent ductus arteriosus or vascular rings have been correcting with da Vinci system widely [22, 23].

Before writing about this topic, I got acquainted several considers of specialists in the field of minimally invasive and robotic surgery according to prospects for the future [24, 25]. There are lots of robotic centers for cardiac surgery in developed countries of the world now, and a multitude of operations are performing there. Despite of benefits of robotics, which were described above, we should emphasize that there are some limitations still, which are waiting for their diminish. For instance, many surgeons usually complain about the lack of haptic feedback. In the future, it is likely to improve robotic instruments with strain sensors which would help surgeons to perceive and control of force of instruments to tissues. Size of instruments will be decrease and mobility of them will increase. This allows to perform operations with smaller incisions, and it is more likely to use a natural orifice or blood vessels to access to diminish negative influence of instruments to other organs or tissues and reduce recovery time. Variety of instruments will increase – this allows to expand operation options and improve dexterity. It is likely to predict that new instruments which can get interoperation image and send to console will add, for instance, 3D dimensional echocardiography. This can help the surgeon to get more information about heart and vessels during the operation. It is especially important in cardiac surgery. Difficulties with suturing during robotic procedures is another limitation of robotic surgery, therefore it can be predicted that using of reconstruction without suturing (for example, anastomotic connector, nitinol clips and balloon-deployed valves etc.) will increase and new reconstructions without suturing or new instruments, which make suturing easier, will be invented and developed. Of course, developing of the robotic system leads to the development of operating rooms, specialize surgeons, nurses and other staff of operating room and imagine of operating theatres will change.

To conclude, robotic systems in surgery emerged only two decades ago, but in this short period they demonstrated a huge progress (if we compare with their ancestors – laparoscopes) and entered all fields of surgery including cardiac surgery. Nowadays hundreds of cardiac surgery operations are performing with da Vinci system and it is believed that they will definitely show intensive development in the future. Therefore, despite of hesitations of surgeons about robotics [26], we can term robotic surgery as “the future of surgery”.

References / Список литературы

1. *Zhang Z.-W. et al.* Technical Aspects of Anesthesia and Cardiopulmonary Bypass in Patients Undergoing Totally Thoracoscopic Cardiac Surgery. Journal of Cardiothoracic and Vascular Anesthesia, 2012. 26 (2): p. 270-273.
2. *Hua K. et al.* Minimally Invasive Cardiac Surgery in China: Multi-Center Experience. Medical science monitor: international medical journal of experimental and clinical research, 2018. 24: p. 421.
3. *Xu X.Z. et al.* Clinical experience of 2 543 cases of congenital heart diseases undergoing totally thoracoscopic cardiac surgery. Zhonghua wai ke za zhi [Chinese journal of surgery], 2016. 54 (8): p. 591.
4. *Kelley W.* Robotic surgery: The promise and early development. Laparoscopy, 2002. 1: p. 6-10.
5. *Gharagozloo Farid and Najam F.* Robotic Surgery. 2009, China: The McGraw-Hill Companies. *418.*
6. *Rayman R. Robot-assisted surg*ery. Semin Laparosc Surg, 2004. 11: p. 73-79.
7. *Boehm D. et al.* Incorporating robotics into an open heart program. Surg Clin North Am., 2003. 83: p. 1369-1380.
8. *Kypson A., Nifong L. and Chitwood W.* Robotic cardiac surgery. J Long Term Eff Med Implants, 2003. 13: p. 451-464.
9. *杨明 et al.* **机器人胸廓内**动脉游离后动脉桥血管中期通畅率随访. **中**华医学杂志, 2013. 93(6): p. 428-431.
10. *Loulmet D., Carpentier A. and d'Attelis N.* Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments. J Thorac Cardivasc Surg., 1999. 118: p. 4-10.
11. *Subramanian V.A. et al.* Robotic assisted multivessel minimally invasive direct coronary artery bypass with port-access stabilization and cardiac positioning: Paving the way for outpatient coronary surgery? Ann Thorac Surg, 2005. 79: p. 1590-1596.
12. *Currie M.E. et al.* Long-term angiographic follow-up of robotic-assisted coronary artery revascularization. The Annals of thoracic surgery, 2012. 93 (5): p. 1426.
13. *Sellke F., Chu L. and Cohn W.* Current State of Surgical Myocardial Revascularization, in Circ. J. 2010. p. 1031-1037.
14. *Nifong L.W. et al.* Robotic mitral valve repair: experience with the da Vinci system. The Annals of Thoracic Surgery, 2003. 75 (2): p. 438-443.
15. *Suri R.M. et al.* Mitral valve repair using robotic technology: Safe, effective, and durable. The Journal of Thoracic and Cardiovascular Surgery, 2016. 151 (6): p. 1450-1454.
16. *Bacchetta M.D. et al.* Resection of a symptomatic pericardial cyst using the computer-enhanced Da Vinci™ surgical system. The Annals of Thoracic Surgery, 2003. 75 (6): p. 1953-1955.

17. *Jansens J.-L. et al.* Robotic-enhanced biventricular resynchronization: an alternative to endovenous cardiac resynchronization therapy in chronic heart failure. The Annals of Thoracic Surgery, 2003. 76 (2): p. 413-417.
18. *Wolf R.K. et al.* Video-assisted bilateral pulmonary vein isolation and left atrial appendage exclusion for atrial fibrillation. The Journal of Thoracic and Cardiovascular Surgery, 2005**.** 130 **(**3): p. 797-802.
19. *Torracca L. et al.* Totally endoscopic atrial septal defect closure with a robotic system: experience with seven cases. Heart Surg Forum, 2002. 5(2): p. 125-7.
20. *Yang M. et al.* Clinical experiences on correction of congenital heart diseases with robotic technology: a report of 160 cases. National Medical Journal of China, 2012. 92 (32): p. 2261-2264.
21. *Mandal K. et al.* Robot-Assisted Partial Atrioventricular Canal Defect Repair and Cryo-Maze Procedure. The Annals of Thoracic Surgery, 2016. 101**(**2): p. 756-758.
22. *Nezafati M.H. et al.* Video-assisted thoracoscopic patent ductus arteriosus closure in 2,000 patients. Asian Cardiovascular and Thoracic Annals, 2011. 19(6): p. 393-398.
23. *Suematsu Y. et al.* Totally Endoscopic Robotic-Assisted Repair of Patent Ductus Arteriosus and Vascular Ring in Children. The Annals of Thoracic Surgery, 2005. 80 (6): p. 2309-2313.
24. *Mack M.* Minimally invasive cardiac surgery. Surgical Endoscopy And Other Interventional Techniques, 2006. 20 (2): p. S488-S492.
25. *Bryan B.,* Wiley *N.* and Randolph W. Chitwood, Jr. Robotics in Cardiac Surgery: Past, Present, and Future. Rambam Maimonides Medical Journal, 2013. 4 (3): p. e0017.
26. *Urso S. and Sadaba J.R.* Invasiveness in cardiac surgery: a question of age. Interactive cardiovascular and thoracic surgery, 2013. 1**7**(2): p. 413.