Chinese Medical Journal®

Robotic surgical systems in plastic and reconstructive surgery

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To the Editor: Owing to the fact that robotic surgery has the advantages of being accurate, stable, and easy to control, the use of robotic systems in surgery is increasing. Despite this progress, the adoption of robotic technology in plastic and reconstructive surgery has been slower than many other specialties. Recent research has shown promise for the use of robotic assistance in plastic surgery, reconstructive surgery, and microsurgery.

Figure 1 summarized the main applications of robotic surgical systems in plastic and reconstructive surgery, which can be divided in the following five aspects: microsurgery, breast reconstruction, transoral robotic surgery, maxillofacial surgery, and hair transplantation.

Microsurgery is a branch of plastic surgery that requires high accuracy. The robotic surgical approach offers several advantages, such as improved three-dimensional (3D) visualization, dexterity of wristed instruments, and tremor elimination, thereby greatly promoting the development of microsurgery. Several companies are currently developing robotic systems exclusively designed for microsurgery, and their main clinical application is robotic microvascular and microneural surgery.

In 2000, ten 1-mm femoral arteries in rats were successfully anastomosed using a four-degree telemanipulator at up to 30× magnification, promoting the development and later clinical application of daVinci surgical system in robot-assisted microvascular anastomosis. In the confined anatomical space, the clinicians can use the robot to perform the anastomosis with better suture effects and less complications. The development of microneurosurgery is almost parallel to that of microvascular surgery. In 2009, the daVinci robot was innovatively used to repair peripheral nerves with 10–0 nylon. Subsequently, the feasibility of robot-assisted intraneural dissection and reconstruction in patients with peripheral nerve tumors and shoulder girdle nerve injuries was gradually demonstrated in the clinic.

In recent years, the indications for robotic surgery have expanded to supermicrosurgery, such as lymphedema surgical procedures including vascularized lymph node transfer (VLNT) or lymphaticovenous anastomoses (LVA), which require high precision and manual dexterity. Robot-assisted surgical systems can reduce issues related to human fatigue, accessibility, and ergonomic posture. The MUSA (MicroSure, Eindhoven, The Netherlands), the first dedicated robotic platform designed for microsurgery, was developed in 2014.[1] This system is small and light, can be installed on the operating table and microscope, and is compatible with existing microinstruments. van Mulken *et al* [1] confirmed the safety and feasibility of the MUSA in a preclinical test and carried out a randomized pilot study investigating patient outcomes and the quality of anastomosis in robot-assisted surgery for the treatment of breast cancer-related lymphedema (BCRL). The results showed improved patient outcomes and the absence of serious adverse events, and proved that it was feasible to complete supermicrosurgical anastomoses in patients with BCRL using the MUSA.

Robotic surgical systems are also used in the minimally invasive treatment of breast cancer and immediate breast reconstruction (IBR). In 2015, Toesca *et al*[2] first applied the daVinci robot platform for robotic nipple-sparing areolar mastectomy (RNSM) combined with IBR and later assessed the feasibility, reproducibility and safety. At present, medical centers in many countries have begun to carry out relevant research on RNSM combined with IBR. Current results show that, compared with conventional and endoscopic surgery, robot-assisted surgery has the characteristics of a clear operation field, flexible operation, less bleeding and high postoperative patient satisfaction.

In addition, flaps and autologous tissue transplantation are also important methods of breast reconstruction. In 2006, the Aesop (Computer Motion, Santa Barbara, CA, USA), a voice-activated robotic arm, was used for breast reconstruction. Unfortunately, the operation time in this

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Quick Response Code:

Website: www.cmj.org

DOI: 10.1097/CM9.0000000000002811

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Chinese Medical Journal 2024;137(11)

Received: 31-05-2023; **Online:** 01-09-2023 **Edited by:** Jing Ni

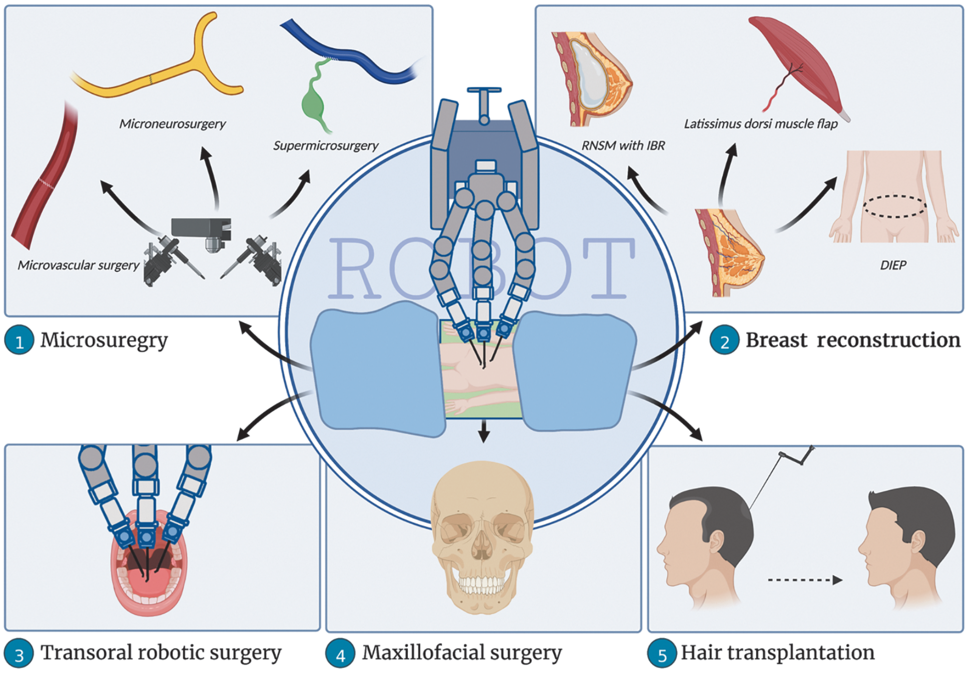

Figure 1: The application of robot surgical systems in plastic and reconstructive surgery. DIEP: Deep inferior epigastric artery perforator; IBR: Immediate breast reconstruction; RNSM: Robotic nipple-sparing areolar mastectomy.

group of cases was approximately three times longer than that of a normal surgical exposure. All patients needed to stay in the intensive care unit for three days after the operation, and the incidence of complications was unacceptably high, which caused widespread controversy. However, scholars' enthusiasm for robot-assisted breast reconstruction surgery has not been deterred. From 2009 to 2010, Shuck *et al*[3] performed ten robotic latissimus dorsi muscle harvests in eight cadavers, demonstrating the feasibility and reproducibility of robotic latissimus dorsi muscle surgery. After that, major medical centers began to carry out daVinci robot-assisted free latissimus dorsi surgery. In 2022, the results of a prospective, single-arm study of robot-assisted free latissimus dorsi surgery, carried out by Selber's team further confirmed the safety and efficacy of this surgery.[3]

Over the years, the deep inferior epigastric artery perforator (DIEP) flap has usually been the first choice for breast reconstruction in many medical centers. The use of the daVinci robotic surgical system for deep inferior epigastric vessel (DIEV) harvesting in DIEP flap breast reconstruction can decrease donor site pain as well as the risk of abdominal wall herniation or bulging, and minimize morbidity in the complex reconstructive procedure. The largest series of robotic DIEP flap harvests research to date showed that robotic DIEP can decrease postoperative pain, herniation, and bulging. Currently, the robotic DIEP procedure offers patients and doctors a minimally invasive approach for DIEP flap harvest in breast reconstruction.

Many studies have proven that transoral robotic surgery (TORS) in head and neck surgery yields excellent outcomes. Reconstruction for extensive mucosal defects after resection of a head and neck neoplasm and subsequent or simultaneous neck dissection is an important scenario for the application of TORS. Compared with traditional surgery, TORS is more sensitive to create mucosal and musculomucosal flaps. Flaps for TORS-assisted head and neck defect reconstruction have increasingly been exploited, including the radial forearm flap, mucosal muscle flap pedicled with the facial artery, and anterolateral femoral flap. TORS can achieve good esthetic outcomes with shorter operative time and fewer complications than conventional surgery.

The feasibility of robotic surgery for cleft palate was demonstrated by transplanting a posterior pharyngeal flap and inserting it into the palatal defect in three human cadaveric heads in 2013. Subsequently, the daVinci robot-assisted modified Furlow palatoplasty was performed in ten cleft palate patients with successful outcomes, highlighting the great dexterity and excellent 3D depth perception provided by TORS.

The development of a robotic surgical system for maxillofacial surgery has been relatively rapid in recent years. Lin *et al*[4] introduced the first craniofacial-plastic surgical robot (CPSR-I, developed by the Shanghai 9th People's Hospital, Shanghai Jiao Tong University School of Medicine) system for mandibular plastic surgery, which consists of the augmented reality (AR) navigation system and the robot system, providing young surgeons with direct perception of crucial structures and assisting in the development of preoperative plans. After a series of surgical experiments, this system was used in genioplasty and mandibular contouring surgery, and improved the accuracy of navigation position and angle in surgery.

Follicular unit extraction (FUE) has become a popular method of hair transplantation for the treatment of androgenic alopecia. However, there are some challenges in this technique, including the prediction of the changing angle of hair follicles within the scalp, operator fatigue from prolonged hand−eye coordination during the procedure, and avoidance of the appearance of a depleted density in the donor area. Hence, the new ARTAS Robotic System (Restoration Robotics, San Jose, CA, USA) was designed to improve the accuracy and efficiency of FUE. The ARTAS surgical system obtained approval by the U. S. Food and Drug Administration (FDA) for clinical application in 2011 and has become the most widely used hair implantation robot on the market, which could help physicians reduce transection rates and efficiently harvest high-quality grafts.[5] In 2018, the latest hair implantation robotic system certified by the U.S. FDA, ARTAS IX, has more advanced devices, such as an upgraded image processing software, a punch design, and a lightweight robot arm. This revolutionary new surgical system can perform much of the work only a trained surgical team could have done previously.

At present, robotic surgical systems improve surgical stability, accuracy, and visualization. However, robotic surgery still has many deficiencies in the field of plastic surgery. Most robotic systems used clinically can only be remotely controlled by the operators and lack automation of surgical movements. Moreover, in most existing research, robots have only been applied for several specific diseases in plastic surgery, and there is no proprietary and widely available robotic surgical system for plastic surgery. The main reasons for this are as follows: (1) Unlike departments that focus on endoscopic surgery, plastic surgery more commonly uses various surgical methods, making it difficult for traditional robotic surgical systems to be directly applied; (2) Most plastic surgery operations only involve soft tissues, which are anatomically complex compared with bone structures or solid organs and more challenging for robots in terms of navigation and positioning advantages; (3) The lack of specific instruments for robotic plastic surgery, which necessitates the redesign of miniaturized tools for robots and increases the cost and difficulty; (4) Technological monopolies, steep learning curves, complicated surgical procedures and high maintenance costs are other obstacles to robotic systems expanding into the field of plastic surgery. However, with the advancement of science and technology, the widespread use of robotic surgical systems in plastic and reconstructive surgery is inevitable.

Funding

This work was supported by grants from the National High Level Hospital Clinical Research Funding (No. 2022-PUMCH-B-042) and the CAMS Innovation Fund for Medical Students (No. 2018zlgc0625).

Conflicts of interest

None.

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How to cite this article: Wen JX, Yu NZ, Long X, Wang XJ. Robotic surgical systems in plastic and reconstructive surgery. Chin Med J 2024; 137:1366–1368. doi: 10.1097/CM9.0000000000002811