

REVIEW ARTICLE TECHNOLOGY AND IMAGING

Robotic surgery in plastic surgery: a review of its potential

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Keywords: robotic surgical procedures, plastic surgery, microsurgery, reconstructive surgical procedures, plastic surgery procedures

Submitted: March 9, 2020 AEST Revised: July 14, 2020, November 23, 2020, January 2, 2021, February 18, 2021, November 2, 2023 AEST Accepted: February 22, 2021 AEST

DOI: 10.34239/ajops.115362

Australasian Journal of Plastic Surgery

Vol 7, Issue 1, 2024

Abstract

Background: Robotic surgery currently offers a number of benefits in specific areas of plastic and reconstructive surgery such as head and neck and microsurgery, however, many subspecialties are yet to benefit from robotic operating techniques. In this paper we review recent developments in the use of robotics for head and neck, breast reconstruction, microneural, lymphoedema, craniofacial and aesthetic surgery.

Methods: A literature review of English-only articles on the use of robots in plastic and reconstructive surgery was conducted using the PubMed and Web of Science databases along with a free text search using the terms 'robotic surgery plastic surgery', 'robotic-assisted plastic surgery', 'robot-assisted reconstructive surgery', 'da Vinci plastic surgery', 'da Vinci reconstructive surgery' and 'supermicrosurgery'. No limitation was placed on time from publication.

Results: Of the studies reviewed, the most beneficial to reconstructive surgery is the area of the head and neck, with the most common procedures being transoral surgeries and microvascular procedures. Robotic assisted breast reconstructive surgery is a promising field. The main current limitations are the lack of adequate microsurgical instrumentation and the prolonged setting-up and operative time.

Conclusion: As technology improves, the outlook for robotic surgery is optimistic. Areas like microsurgery, head and neck, cleft palate, breast reconstruction, lymphatic and microneural surgery already demonstrate promising results. Further technological advances and evidence-based studies are necessary to address current limitations such as appropriate microsurgical instrumentation, high costs and prolonged operative time.

Introduction

The plastic surgery subspecialty of microsurgery is a well-established domain of robotic surgery requiring millimetric precision movements in mostly confined spaces. Since 2011, there has been an increase in the use of robots in several surgical specialties such as urology, cardiothoracic, gynaecology and general surgery. In plastic surgery the areas of reconstructive head and neck surgery and cleft surgery have seen significant advances in robotic-assisted procedures. However, robotic microsurgery is yet to prove its value and publications addressing its applications are rare.¹ Reports of robotic-assisted surgery in other subspecialties of plastic surgery, such as hand surgery, aesthetic surgery or craniofacial surgery, are even more limited.

The first report of a human robotic-assisted surgery was likely a neurosurgical brain biopsy performed in 1988 under programmed CT guidance.² Since then, other surgical specialties have adopted and validated the use of robotics in the operating theatre: cardiothoracic surgeons conducted cardiac bypass and valve replacement surgeries,^{3–5} urologists conducted prostatectomies and nephrectomies,^{6,7} general surgeons conducted intra-abdominal procedures such as cholecystectomies or gastric bypass surgeries,^{8–10} gynaecologists conducted procedures such as endometrial cancer surgery,^{11,12} and otolaryngologists and head and neck surgeons conducted transoral robotic approach for advanced oropharyngeal carcinomas.^{13,14}

Currently, the most commonly used robot is the da Vinci robot (Intuitive Surgical Inc, Sunnyvale CA, USA). Between the years 2000 to 2009, this robot received approval from the United States of America's Food and Drug Administration (FDA) for its use in humans for various procedures across several specialties. Since then, multiple software and hardware improvements have been implemented. In the latest version released in 2014, da Vinci Xi, the robot comprises four arms that help facilitate a multi-quadrant approach towards the surgical site. Every arm is equipped with an Endowrist (Intuitive Surgical Inc, Sunnyvale, California, USA) capable of up to seven degrees of freedom of movement.¹ This is beneficial as it compensates for the lack of manoeuvrability associated with incision constraints and ensures intervention under favourable conditions.¹

We propose to review the current status of robotic use in the wider field of plastic surgery and to explore and comment on potential future applications of robotic surgery within this field.

Methods

A review of the literature on the use of robotic surgery in plastic surgery was conducted by searching PubMed and Web of Science databases along with a free text search using the following terms: 'robotic surgery plastic surgery', 'robotic-assisted plastic surgery', 'robot-assisted reconstructive surgery', 'da Vinci plastic surgery', 'da Vinci reconstructive surgery' and 'supermicrosurgery'. Only articles in English were reviewed, and only those specifically reviewing the use of robots in plastic and reconstructive surgery were included and evaluated. No limitation was placed on time from publication, and articles published before October 2023 were included.

Results

Head and neck surgery

In 2009, the FDA approved the use of robots in performing oropharyngeal tumour resection, as it avoided the need for transmandibular buccopharyngectomy with its associated morbidity and aesthetic compromise, by allowing a direct transoral approach.¹³ Currently, the FDA limits the use of robots to tumours sized T1 and T2, wherein their resection and reconstruction is deemed impossible without a transmandibular approach.

Currently, head and neck reconstructive surgery is the leading field of plastic surgery using robotic assistance,¹⁵ with several studies conducted in the last decade reporting successful outcomes with the use of the da Vinci robot.^{16–18} A recent systematic review involving 26 studies and 260 patients who underwent transoral robotic surgery for head and neck cancer demonstrated favourable surgical outcomes.¹⁹

A case-control study published in 2016 assessed the safety and feasibility of transoral robotic surgery for the dissection and reconstruction of soft palatal clefts. The authors concluded that the precise dissections made with robotic assistance may reduce damage to tissues and neurovascular structures; thus, it would decrease complications such as fistulas, with the potential to improve palatal and Eustachian tube function.²⁰ This study was followed with a feasibility assessment utilising a realistic cleft palate simulator. The simulator demonstrated the advantages of the robotic approach, such as ability to manoeuvre instruments intraorally with superior visualisation, improved ambidexterity and improved ergonomics, when compared with use of standard instruments. However, the authors suggested modifications to the instrumentation in order to ensure safety and efficiency.²¹

Breast reconstruction surgery

In 2006, a group of plastic and cardiothoracic surgeons analysed the efficacy of robotic assistance in harvesting the internal thoracic artery for free-flap breast reconstructions.²² In 2008, another report from the Netherlands described the authors' experience with robot-assisted micro-anastomosis for free transverse rectus abdominis myocutaneous (TRAM) flaps.²³ Both reports failed to demonstrate superiority of robotic surgery over traditional microsurgical techniques, reportedly either due to a higher rate of complications or a prolonged surgical time when using robotic assistance (20 minutes without robot versus 40 minutes with the robot).

In 2017, Toesca and colleagues²⁴ reported on robotic nipple-sparing mastectomy with immediate breast reconstruction in 29 consecutive cases, demonstrating a low conversion rate to conventional surgery, a rapid learning curve and a low incidence of postoperative complications. Similar optimistic results were reported in 2019 in a small retrospective series of 22 patients with a total of 23 robotic nipple-sparing mastectomies in Taiwan, citing a 0 per cent rate of positive margin or nipple necrosis and a satisfactory cosmetic outcome.²⁵ Similarly, plastic surgeons from Korea reported on their initial results from four patients that underwent robotic nipple-sparing mastectomy and immediate reconstruction with robot-assisted expander insertion,²⁶ wherein they reported no complications.

Clemens and colleagues assessed the use of robots for harvesting of the latissimus dorsi flap in delayed reconstruction of the irradiated breast, wherein the authors concluded that robotic-assistance was associated with a low complication rate and displayed reliable results.²⁷ Struk and colleagues developed a technique using robots for nipple-sparing mastectomies and subsequent harvesting of the latissimus dorsi muscle from a single lateral position, resulting in a single scar for both the mastectomy and the flap harvest.²⁸ The use of robots in deep inferior epigastric artery perforator (DIEP) flap operations has been recently reported by Gundlapalli and colleagues.²⁹ In this study, the authors concluded that robotic assistance simultaneously enabled improved microsurgical precision, and decreased the donor-site morbidity by minimising the incision length of the anterior rectus sheath.

According to a 2023 review by Egan and Selber from the MD Anderson Cancer Centre, robotic mastectomy and reconstructive surgery have been shown to be safe and a viable alternative to

conventional surgery, which was corroborated by a recent systematic review of 17 articles conducted by Roy and colleagues who concluded that robotic surgery is a promising alternative to breast reconstructive surgery.^{30,31}

Microneural surgery

In 2009, Nectoux and colleagues³² published the first successful report of a robotic microneural repair. The authors concluded the robot provided a safer and more precise peripheral nerve repair. Since then, further experiments involving the management of brachial plexus injuries have shown that robot-assisted surgery could improve precision and allow for a minimally invasive approach, thus highlighting the need for further development in specialised robotic microsurgery tools.^{33–35}

Lymphoedema surgery

Anastomosis between lymphatic vessels or a lymphatic vessel and a venule is considered one of the most challenging operative tasks in microsurgery, as it requires the use of miniscule instruments and sutures.³⁶ According to Ibrahim and colleagues, these high-precision procedures could potentially benefit from the robot's superior level of accuracy, especially when combined with technological aids such as near-infrared fluorescence (NIRF) microscopy, which allows for better intraoperative visualisation of lymphatic insufficiency and pressure gradients.³⁷

A prospective randomised clinical trial published in 2020 compared clinical outcomes for lymphoedema surgery in 20 female patients with upper limb lymphoedema following axillary lymph node dissection due to breast cancer. These patients were randomised to receive either manual microsurgery lymphaticovenous anastomosis, or robotic-assisted 'supermicrosurgery'. The author concluded that manual anastomosis and microsurgical skills were associated with higher surgeon satisfaction and patient convenience. However, due to the small cohort size, no statistically significant conclusions could be made; hence, further studies are needed.³⁸

Hand surgery

Hand surgery as a subspecialty has not widely experimented with robotic assistance. Aside from cadaveric experiments,^{39,40} there are only two clinical case reports addressing robotic-assisted hand surgery. One case report detailed a carpal tunnel release,⁴¹ where the authors concluded there were no improvements with the use of the

robot, but increased operating time and cost; the second report detailed the use of robotic microsurgery in venous grafting of a wrist ulnar artery in the treatment of bilateral hypotenar hammer syndrome.⁴²

Craniofacial surgery

In 2007, Rahbar and colleagues⁴³ detailed the first attempt to use robotic surgery in cleft palate repair on four paediatric cadaveric models. The study concluded that, despite technical limitations, there was potential for improvement. Subsequently, in 2014, Leonardis and colleagues successfully performed a transoral laryngeal cleft repair in five paediatric patients.⁴⁴ Nadjmi and colleagues performed a cleft palate repair using the da Vinci robot in 10 consecutive patients, citing a prolonged operative time, but no complications recorded during the six-month follow up period.²⁰ There is a need for further technological improvements, as reported by Rahbar and colleagues,⁴³ Nadjmi and colleagues,²⁰ Podoslky and colleagues²¹ and the 2019 literature review by Al Omran and colleagues.⁴⁵

Aesthetic surgery

There is limited literature addressing the role of robotic assistance in aesthetic surgery. Only two reports could be found. In 2014, Taghizadeh and colleagues presented a case series wherein the da Vinci Si robot was used to conduct six platysmaplasties in cadaveric models.⁴⁶ The group concluded that robotic-assisted platysmaplasty was not only feasible and reproducible, but also held potentially superior cosmetic outcomes. The second report was published by Mohamed and colleagues in 2015, when the group successfully conducted a robotic-assisted retroauricular thyroidectomy with a concomitant platysmaplasty on a 59-year-old female patient.⁴⁷

Discussion

The main theoretical advantages of robotic-assisted microsurgery include: improved dexterity and manoeuvrability within confined spaces; elimination of tremor and involuntary movements by the surgeon; provision of motion scaling capabilities; use of real-time 3D visuals and visualisation of sites at up to 15 times magnification.⁴⁸

One prevalent limitation identified in many reports was the limited accessibility to robot training facilities. As surgical robotic systems are costly to purchase, use and maintain, and harbour further direct and indirect costs including consumables, training, specialised staffing and

servicing, very few plastic surgery departments are currently willing to invest in surgical robotic systems; thus, cost is a key contributing factor to limited accessibility.¹⁶

In 2014, Alrasheed and colleagues developed and validated an assessment tool, and investigated the learning curve for robotic microsurgery skills.⁴⁹ Participating surgeons at all levels of training, ranging from surgeons with minimal microsurgical experience to expert microsurgeons, gained significant skills over the course of five training sessions. The study results demonstrated an improvement in all skill areas and a decrease in operative time for all participants.

In 2017, two systematic reviews were published, assessing the use of robotics in plastic and reconstructive surgery.^{16,50} Both reviews had similar conclusions, reporting that the commonest procedures which utilised robotic assistance were transoral surgeries and microvascular procedures. Both reviews also concluded that robotic assistance in plastic and reconstructive surgery offers several benefits in specific areas including head and neck surgery and microsurgery. Though there are multiple areas in plastic surgery that have not adopted robotic surgery, these areas hold great potential in benefiting from robotic operating techniques in the future. These areas may include: hand surgery, burn surgery, craniofacial surgery, and aesthetic surgery. In a subsequently published review addressing the application of robotics in microsurgery,¹⁵ of the 43 articles reviewed, only 14 articles involved the use of robots in humans. Thus, this review concluded that robotic-assisted microsurgery currently displays no advantages over conventional techniques, but holds potential for positive impact if systems were to be adapted to specifically address the standard instrumentation and technicalities of microsurgery.

The main criticisms of robotic surgery focus on lack of adequate instrumentation specifically designed for microsurgery, and the degree of magnification of the optical system (which are still inferior to optical microscopes). The absence of haptic feedback has also been noted by authors as a further limitation.¹⁵ Nevertheless, other authors report advantages including improved cosmesis through smaller incisions and greater surgeon comfort. These advantages are offset by longer operating and set-up times, the need to retrain both surgeons and operating theatre personnel, the increased space requirements, and the high cost.^{15,16} New robotic systems are currently being developed, addressing the limitations mentioned above.¹

As technology advances, it is likely robotic-assisted surgery will continue to advance, with the development of several new adjunctive tools. Some tools include enhanced optical magnification and projection systems such as augmented and virtual reality systems, NIRF and other imaging technologies, and concomitant use of confocal microscopy, which may potentially provide imaging at a near-cellular level. The potential addition of integrated micro-doppler probes with artery and vein mapping capabilities, robotic hydro-jet dissection tools, laser-ablation and coagulation devices with minimal thermal spread, as well as multi-functional biofeedback sensors are promising technologies which may have future applications for robotics in plastic surgery.^{48,51} By combining these developments with advances in intraoperative localisation systems and the implementation of preoperative imaging data (CT, MRI, US or PET), facilitation of real-time intraoperative anatomical navigation may be feasible. These technological advances will likely arrive alongside the introduction of artificial intelligence (AI) to the robotic systems,^{52,53} which carry the potential to permanently alter the discipline of surgery by enabling new treatment possibilities and outcomes.⁵³ This will pose a great challenge towards specialist training and education, patient confidentiality, data privacy and patient safety, which will all require regulatory oversight. Furthermore, guidelines will need to address the possibility of robot malfunction and system hacking.

Conclusion

Robotic surgery remains an evolving field with interesting and innovative technologies, as new commercial interests enter the arena. However, it is a common agreement between the authors that prior to introduction of robotic surgery into newer surgical specialties such as plastic and reconstructive surgery, further technological advances and evidence-based studies are necessary to firstly ensure the safety of robotic-assisted surgeries in these areas, and secondly, ensure outcomes are at least equivalent or superior to those achieved by conventional surgery.

While not yet an established instrument in plastic surgery, robots are already being used in areas

including microsurgery, head and neck surgery, cleft surgery, breast surgery, lymphatic surgery and neural surgery, showing promising outcomes.

Disclosure

The authors have no conflicts of interest to disclose.

Financial declaration

The authors received no financial support for the research, authorship, and/or publication of this article.

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