New Frontiers in Robotic-Assisted Microsurgical Reconstruction

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KEYWORDS

• Robotic surgery • Minimally invasive surgery • Reconstructive microsurgery • Da Vinci system • Lymphedema surgery • Microvascular surgery

KEY POINTS

- Designed 30 years ago for a neurosurgery biopsy, robotic surgery has revolutionized the field of minimally invasive surgery.
- It has recently been introduced into reconstructive surgery with burgeoning applications in microsurgery.
- Robotic surgery combines properties of conventional microsurgery, endoscopic surgery, and telesurgery, making it an ideal platform for challenging microsurgery cases.
- We present the clinical applications of robotic microsurgery, highlighting its distinct advantages over conventional microsurgery.
- We outline the main limitations preventing its widespread use, and the salient research and educational projects aiming at overcoming these limitations.

The use of robotics in surgery has been on an exponential increase over the last 10 years. With its enhanced precision, greater degrees of freedom, superior 3-dimensional vision, improved resolution, and tremor elimination, robotic surgery has opened a new era of minimally invasive procedures. Its use has spread across various surgical specialties, including plastic and reconstructive surgery, with demonstrable efficacy and patient safety. One of the most encouraging application of robots in reconstructive surgery is microsurgery. Microsurgery is a unique field that requires the highest levels of precision for optimal outcomes and success rates. In no surgical field is this level of precision more crucial than in microsurgery. The advent of robotic surgery and its unique features (including complete tremor elimination and up to 5:1 motion scaling) has offered microsurgeons "suprahuman" levels of precision. In addition, with its high-definition 3-dimensional optics and up to 10× magnification, robotics provide a potentially ideal setup for performing the delicate manipulations required in microsurgery. Its minimally invasive possibilities also allow microsurgeons to operate in confined spaces, obviating the need for open, more morbid approaches, which in turn can enhance functional outcomes. Finally, owing advanced computerized imaging systems, robotic surgery is able to incorporate additional

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visual guidance (fluorescence and near infrared imaging), which benefits cases that use navigation of various types.

In view of all these strategic advantages over conventional microsurgical, 3 main applications of robotic microsurgery have been established: (1) robotic microvascular surgery used principally in transoral reconstruction, (2) robotic microneural surgery used mainly in shoulder and brachial plexus surgery, (3) robotic lymphaticovenous bypass used for lymphedema surgery. In this paper, we provide a critical appraisal of these 3 applications based on the literature and on our own experience in the field. We also present new clinical applications of robotic microsurgery in urology, neurosurgery, ophthalmology, and otology, underscoring the versatility of this novel microsurgical technology. Finally, we outline our curricular strategy for an effective and tailored robotic microsurgical training that might propagate the use of this new technology and further expand the boundaries of microsurgery.

ROBOTIC MICROVASCULAR SURGERY

In 2010, the senior author reported his first series of transoral robotic reconstruction of oropharyngeal defects showing favorable results with good functional outcomes.[1] The first robotic microvascular anastomosis was performed in this series, and exemplified the distinct advantages of the robot for microsurgery.[2] These included 100% tremor elimination, motion scaling (up to 5:1), and the possibility to work with full precision in confined spaces. The facial artery (a common recipient artery in head and neck reconstruction) is difficult to access, because it is sheltered by the mandibular ramus, coursing obliquely beneath the digastric and stylohyoid muscles. When a tracheostomy and ventilator tubing are also present, the space available to perform the anastomosis may be further restricted. The robot's enhanced precision and superior visualization, as well as long slender arms allow such anastomosis in confined spaces to be performed more easily, and can sometimes limit additional access incisions (**Fig. 1**). Song and colleagues[3] also made use of these key features of robotic surgery to perform a microvascular anastomosis of a radial forearm flap (recipient vessel: facial artery) to reconstruct an oropharyngeal defect after resecting a tonsillar tumor (T3 N0 M0, stage III). In this case, the neck dissection was performed through a retroauricular incision, which made conventional microsurgery very difficult to perform through that narrow space.

ROBOTIC MICRONEURAL SURGERY

Despite great advances in techniques, satisfactory functional recovery after peripheral nerve repair is seldom achieved. Part of the problem resides in the microimperfections of such a delicate repair. An imprecise nerve coaption impedes neuroregeneration. It is technically challenging to perfectly match the internal nerve fascicles (an essential requirement emphasized by Millesi[4–6]) using standard microsurgical techniques. Furthermore, it is equally important to ensure gentle handling of the injured stumps during the repair of the various layers of the nerve. The benefits of robotic surgery over conventional microsurgery (disappearance of physiologic tremor, 3-dimensional vision, high definition/magnification, superior ergonomics, and amplification of surgeons' dexterity) have generated interest in microneural surgery. This application in robotic microsurgery was pioneered by Livernaux[7] who demonstrated the feasibility of robotic microneural repair on fresh nerves using either an anatomic (epiperineural repair) or a neurotrophic technique (nerve regrowth guide). These promising results allowed the same group to perform robotic intraneural microdissection of peripheral nerve tumors, allowing them to identify of the fascicles with greater accuracy and safety.[8]

Livernaux's group also tested the robotic platform in brachial plexus reconstruction.[9] The brachial plexus is a complex anatomic environment composed of an intricate, weblike array of nerves and multiple intertwined connections, all of which pose challenges for dissection, exposure, and coaptation. Traditionally, access to the brachial plexus necessitated a long incision with a considerable amount of dissection; this has often resulted in substantial scarring and adhesions, which compromised the quality of repair and decrease functional outcomes. For these reasons, closed injuries are frequently not explored acutely and rather managed with observation. This strategy however leads to a delay of 3 to 6 months before exploration and nerve repair, which might not only result in denervation muscle atrophy, but might also decrease the intrinsic ability of the nerve to regenerate.[10] Although endoscopic approaches might alleviate the morbidity of early exploration by reducing the incision size, the technique does not allow meticulous nerve dissection and finely tuned microneural repair. Because of the ability to perform minimally invasive repair, robotic microsurgery might facilitate early exploration (**Fig. 2**).

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