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OPINION ARTICLE

Evolution of Robotic Systems Utility in Anatomy and Surgery

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Overview

As early as 1982, robotics systems such as the PUMA 200 were used in neurological fields to perform biopsies but at the time were limited by functional capabilities and large size. At this time in the early 20th century, telerobotics systems (or the ability to semi-automate or control from a distance) were being developed with the help of NASA technology. These early systems gave way to late 20th-century robotics technology such as telepresence (head-mounted virtual reality systems) and telesurgery (manipulation of tissue from a distance) [1]. These systems laid a strong foundation for more advanced and surgically applicable robotics in the following century.

Throughout the first decade of the 21st century, we witnessed the FDA approval of complex robotics systems such as the Da Vinci, the Da Vinci S, followed by the Da Vinci Si, each of which required FDA approval for the advancement. The original Da Vinci consisted of three main parts: the surgeon console, the patient trolley or robot that held the 3 robotic arms and the imaging system [2].

The various applications of robotics have also evolved in different fields of surgery. Robotics, which was first used in urology, is now being applied to more surgical subfields. Limitations of the Da Vinci were noted by a neurosurgery team at the Imperial College of London [3].

In 2014, they investigated the feasibility and safety of cadaveric use for performing craniotomies for various types of neurosurgery; parameters like ergonomics and haptic characteristics were evaluated [3].

The disadvantages included cramped spacing for robotic arms and instrument shortages for arm movement. Its large size prevented endoscopic movements through the mentioned keyholes. They noted that illumination, magnification and angle of view of the endoscopy were limited and concluded that there was room for improvement in terms of the safety and feasibility of the Da Vinci system [3].

Since the publication of this study in 2014, new improvements such as force feedback technology, improved instrumentation, enhanced console ergonomics, more precise operative imaging and the integration of smart commands for streamlined surgical control have been implemented [4].

In addition, more and more variations in robotic

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systems have been adapted to the varying fields and types of procedures that patients are presenting with. Besides Da Vinci, other surgical systems include Senhance®, Versius® and Hugo™ RAS [5].

The Da Vinci, however, continues to be the most widely used surgery robot in the world. Throughout the last decade. After the Si, we have witnessed the advancement of 5 newer models, including the Si-e, Xi, X, SP and [4,5]. A full list of the various robotic systems can be found in (Table 1) [6].

TABLE 1

Evolution of prominent robotic systems used in surgery.

Year	Robotic system
1982	PUMA 200
1985	PUMA 560
1992	ROBODOC
1994	AESOP 1000
1998	ZEUS
1999	DaVinci (first generation)
2006	Da Vinci S
2009	Da Vinci Si
2014	Da Vinci Xi
2017	Senhance
2018	Da Vinci SP
2024	Da Vinci 5

Some of the more advanced systems have software such as the Da Vinci OS4, which provides new software to help improve technology in terms of adding more guidance for the user, improved data managing systems and analytical capability and improved virtual reality and simulation technology that enables users to attain hands-on practice and gain experience with basic skills with the goal of improving surgery outcomes [4].

The newer systems are distinguished for their more pronounced haptic feedback technology. Haptics generally describes touch feedback, which may include kinesthetic (force) and cutaneous (tactile) feedback [7]. In non-robotic surgery, surgeons have tactile limitations because of direct instrument interaction, leading to impediments to tissue sensitivity. This emphasis on improved force feedback can help to decrease tissue damage and improve the immersive experience for users [8].

Some of the newer aspects of force feedback technology include more defined sensors at the tip of instrument arms, which can help to improve perceptions of tissue variability and variations in anatomy [9]. This type of perception can be particularly useful for minimizing error and obstacles in surgical procedures resulting from anatomical variations in a patient.

Researchers have recently looked into different possibilities to improve the 6-DOF force feedback control scheme utilizing double force-torque sensors and admittances that are able to be manipulated [10]. These mechanisms reduce any force that threatens the integrity of the bone due to the force feedback provided by the sensors to the operating surgeon as well as the position of the robot, which is dependent on the force measured from the sensors (this relationship between measured force and movement is referred to as admittance control) [10].

In addition, to complement all the new developments with force feedback technology, newer systems have improved stapling mechanisms, such as the Sure Form staple added to the Da Vinci.

Conclusion

The models have evolved favourably over time and have addressed limitations associated with precision. With each model, surgery accuracy continues to improve. In the future, more AI interaction technology along with data-driven computing is expected to further improve the haptic feedback of the systems. With these advancements in instrumentation, it is expected that anatomical variation identification will also improve, especially with newer integrations of AI in robotics used for surgery and medicine.

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