Abstract / Povzetek predavanja

Robotic abdominal surgery: past, present and future

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Robotic abdominal surgery has evolved from a conceptual innovation to a cornerstone of modern minimally invasive surgical practice. The history of robotic-assisted surgery began in the late 1980s and early 1990s with systems such as the PUMA 560 used for neurosurgical biopsies, followed by the AESOP robotic camera holder and the ZEUS surgical system. However, it was the introduction of the Da Vinci Surgical System that revolutionized clinical robotic surgery by enabling fully articulating instruments and stereoscopic 3D vision essential for advanced intra-abdominal procedures. Early adoption in urology and gynecology paved the way for broader applications in colorectal, hepatobiliary, bariatric and general surgery (1). Although there is growing evidence of improved surgeon ergonomics and certain clinical outcomes (e.g. lower conversion rates, shorter learning curves for complex procedures), concerns remain about cost, accessibility and inconsistent data on long-term benefits. Nevertheless, robotic technology is constantly evolving. The future of robotic abdominal surgery will be characterized by new technological innovations:

- Artificial intelligence (AI) will be integrated to support real-time decision making, image recognition, automatic alerts for anatomical structures and even semi-autonomous surgical tasks (2).

- Augmented reality (AR) and image-guided navigation are advancing the concept of "smart surgery" These tools enable real-time overlay of anatomical structures (e.g. vessels, tumors) using preoperative imaging (CT/MRI) to improve intraoperative orientation, especially in liver and pancreatic surgery (3).

- Single-port robotic platforms such as da Vinci SP allow further reduction of invasiveness and scar burden, while modular and open console systems (e.g. Medtronic Hugo™, CMR Versius™) promise cost competition and better global access.

- Tele-surgery, once demonstrated in the "Lindbergh operation" in 2001," is seeing renewed interest with advances in 5G and ultra-low latency networks. This could enable remote, real-time surgical care or even autonomous assistance in underserved areas (4, 5).

Another somewhat contentious area is also the autonomy of robotic platforms. The current generation of surgical robots are still purely master–slave systems that cannot make independent decisions or movements and are entirely dependent on human control. Recent advances, particularly in the field of artificial intelligence (AI), have enabled the first forms of task-level autonomy, including autonomous camera navigation, tissue tracking and supervised suturing. The Smart Tissue Autonomous Robot (STAR) has demonstrated that it can perform autonomous intestinal anastomosis with results comparable to experienced surgeons, signaling the emergence of semi-autonomous capabilities in narrowly defined procedural steps (6).

It is expected that the development towards full procedural autonomy will take place over the next two (probaly even more) decades. Intermediate stages will include partial autonomy in standardized tasks with low variability (e.g. cholecystectomy or hernia repair), evolving to complex procedures with real-time intraoperative decision making. The integration of AI-driven image recognition, workflow analysis and augmented reality (AR) will further improve the responsiveness and decision support of robotic systems. However, widespread clinical acceptance of autonomous surgical systems will depend on overcoming significant challenges related to anatomical variability, contextual assessment and intraoperative complication management.

These technological advances raise urgent medicolegal and ethical considerations. Before autonomous systems can be used safely and ethically, issues of liability, informed consent and data transparency need to be addressed. Current regulatory frameworks, including those of the FDA and the European Medical Device Regulation (MDR), lack specific pathways for the approval of autonomous surgical systems, highlighting the need for international consensus on safety standards, accountability and patient rights (7).

In summary, while full autonomy in robotic abdominal surgery remains a long-term goal, current developments in AI and robotics point to a gradual evolution towards more autonomy. Responsible innovation, guided by legal, ethical and clinical frameworks, will be crucial in shaping the future of intelligent surgical systems.

Ultimately, with its increasing integration into surgical training and improved recovery protocols, robotics will play a critical role in reshaping surgical standards, personalizing patient care and expanding global access to surgery. Ongoing evidence-based evaluation and equitable dissemination of the technology will be critical to maximizing its clinical benefits.

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