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SPECIAL ARTICLE

The transformative potential of virtual, augmented and mixed reality in colorectal surgery: opportunities and challenges.

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ABSTRACT

Evolving Landscape in Colorectal Surgery

In the past three decades, colorectal surgery has embraced a series of technological advancements focusing on precision preoperative planning, the adoption of minimally invasive laparoscopic, robotic, and endoscopic surgical techniques, and the formulation of personalized, patient-centric care. The main evidence-based drivers for such utilities are, reduction in postoperative pain and operative trauma, improvements in disease specific outcomes, the enhancement of patients' healthcare journey, and the safeguarding of intermediate and long-term quality of life measures[1,2].

Incorporation of these developments into mainstream clinical practice has presented several challenges. These include, the concerns related to patient safety, standardization of operative approach, as well as ensuring cost efficiencies and cost containment relating to surgical-care[3,4]. Furthermore, there are ethical, technical, and financial constraints associated with minimally invasive surgical (MIS) training, which has impacted a significant section of the existing workforce as well as new generations of surgeons[5-8].

Surgical colleges, such as the Royal College of Surgeons in England, believe that Virtual Reality (VR) will become a standardized feature in surgical training, with Augmented Reality (AR) exerting a greater role during operative interventions[1]. The appetite for these, and comparable plans is reflected by the current global AR and VR healthcare markets-investment, estimated at 2.5 billion U.S. Dollars. This market value is projected to increase by five-folds within the next ten years, with medical and surgical training seen to be the key drivers for this accelerated growth[9-10].

Nomenclature and Degrees Immersive Digital Experiences

Virtual Reality (VR) constitutes an immersive digital experience within a three-dimensional (3-D) computer-generated environment. User interaction, facilitated by a sensor-effector system, is controlled by eye gaze, hand gestures, and/or voice commands. In contrast, Augmented Reality (AR) overlays patient-specific reconstructed digital images with live visual data, creating a composite view for the observer. Mixed Reality (MR) refers to the dynamic use of AR in surgical fields, providing real-time holographic image-based interactions for the purpose of navigation and identification of subsurface anatomical structures. The delivery of these experiences require a series of processes, commencing with digital image acquisition and reconstruction from high-resolution preoperative computer-tomography (CT) and magnetic-resonance (MRI) scans. Advanced image-data-management system subsequently facilitate the integration of these 3-D reconstructed images, and their display in real time with patient-specific live video images on the surgeon's screen or head mounted displays[11,12].

VR, AR, and MR in Surgery

The exploration of head-up displays in clinical practice began in the 1990s, gaining regular utilization by 2009, particularly in the field of anesthesia for intraoperative monitoring purposes[13]. The first clinical application of AR in visceral surgery was documented by the IRCAD group in France in 2004[14]. As evidenced by the current published literature, the integration of AR and VR in surgical practice has found utility across multiple surgical specialties, spearheaded by disciplines such as neurosurgery, spinal surgery, maxillofacial surgery, and urology[13, 15].

In the field of colorectal surgery (CRS) the evidence on the utility of VR, AR and MR exhibits a more nuanced landscape, with a predominant focus directed towards minimally invasive surgical (MIS) training[11, 16-19] and the intraoperative assessment of visceral perfusion[20,21]. Nonetheless, the existing literature also reflect a broader scope for clinical applications. Potential benefits are described in areas such as preoperative anatomical precision planning[22,23], patient counselling[24], perioperative data extraction, intraoperative augmented navigation[25], and identification of anatomical structures[15, 26,27]. Furthermore, these technologies have shown promise in facilitating remote proctoring and preceptorship training[1,28].

CRC Training

Within the existing framework of Halstedian surgical training, CRS has benefited from additional training modalities, most notably the utilization of animal and human cadaveric training models. Both modalities offer superior level of fidelity and anatomical realism, garnering high appreciation among surgical trainees. In minimally invasive CRS, however, the learning curve is typically steep, necessitating multiple exposures to attain operative proficiency[29,30].

In reality, the frequent application of these modalities is constrained by ethical and legal frameworks, limitations in availability and access, as well as the financial costs, and complex logistical preperations[31].

In this regard, AR and VR are transformative tools. Their face-and-construct-validity have been firmly established in demonstrating an enhanced MIS operative perceptual awareness, smoothness of movement, navigation, object positioning, suturing, knot tying, and sharp dissection[16,31]. These simulation models have also facilitated the worldwide dissemination of training and assessment opportunities[17]. While the current fidelity of AR technology falls short in comparison to, and is unlikely to replace human cadaveric training, many investigators consider AR a crucial adjunct in preparing candidates to achieve specific operative metrics. This would enable them, in turn, to fully realize the tangible and transferable benefits from cadaveric and operative training models[31].

CRC Surgical Planning

In the context of preoperative surgical planning, VR models have gained recognition as a crucial asset for providing detailed anatomical and pathological visual mapping. Surgeons can manipulate these models by adding or deleting, magnifying or minimize individual anatomical structures. A study by Lyuksemburg et al. demonstrated the role of preoperative 3D-VR images in significantly enhancing the safety of resection margins and reinforcing surgeons' confidence[22]. Furthermore, research by Guerriero et al, underscored the significance of VR in delineating vascular anatomy of the colon, identifying anatomical anomalies, and thereby permitting safe and adequate colonic resections[23].

Operative Potentials and Challenges

The integration of Mixed Reality (MR) in CRS is envisioned to offer precise navigational certainty, enhance operative experience, and a boost to surgeon’s confidence. This, in turn, would result in improvements in operative efficiencies, completeness of surgical objectives, and reduction in intraoperative errors. Such a vision is yet to be realized. To date, the incorporation of MR into CRS remains in its preliminary phase[33]. Transitioning to these technologies would require overcoming a number of technical challenges posed by the inherent mobile and multicompartmental nature that typifies colorectal surgical fields. Such technical challenges include the rendering of high-definition 3-D preoperative images to enable accurate and subtle differentiation of adherent and close tissue plains[22]. Improvements in image tracking systems, and solving issues related to image latency and information loss are also critical to further enhance the accuracy, scale, and orientation of projected virtual objects onto the physical operative field[26]. Furthermore, experiences of dizziness, disorientation, and motion sickness following extended use of head-mounted display-sets[13], will also need to be addressed to improve the user interface experience.

An alternative MR strategy involves the utilization of molecular fluorescence-image guided surgery (FIGS)[20]. In this approach, an intraoperative fluorescence dye is used to highlight specific anatomical or pathological structures. The emission from these structures is then captured by a fluorescence-capable laparoscope or a wide-field cameras. Within the context of CRS, indocyanine green dye is increasingly used by surgeons to assess visceral perfusion prior to surgical anastomosis as a safeguard against anastomotic leaks[20,21]. Other intraoperative applications include the identification of specific anatomical and pathological structures such as ureters, lymph nodes, vessels and malignant tissue. Development of specific dyes to target specific organs offer an exciting future and the potential to broaden the scope for FIGS applications. Early studies show promis and have demonstrated the cost efficiency and safety profile of this technology. However, current, and future prospective randomized control trials will shed further light on FIGS' efficacy, and short- and long-term benefits[20,21,34-37].

The Future Ahead

Despite the challenges highlighted earlier, the future for augmented and immersive realities in CRS remain very promising. Advancements in robotic surgery with stereoscopic volume-rendered image pairing capabilities, is a step forward enabling augmented- reality robot-assisted surgery[38]. Furthermore, greater computational and image processing powers, should provide reconstructed images with greater fidelity and the potential for adaptabilities to operative fields. Innovations in artificial intelligence and machine learning, together with fluorescence guidance will seamlessly assist surgeons in the identification of anatomical structures and the determination of dissection plains. These new developments will additionally have implications for training and operative skill acquisition, as well as assessment in MIS training[39-40]. This future is likely to be shaped by operators willing to embrace these new technologies and influence their development to meet the needs of current and future surgical care.

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References:

1. Future of Surgery. futureofsurgery.rcseng.ac.uk. 2021.

2. Marescaux J, Diana M. Inventing the Future of Surgery. *World J Surg*. 2015; 39: 615–622. DOI 10.1007/s00268-014-2879-2

3. Cleary R, Mullard A, Ferraro J, et al. The cost of conversion in robotic and laparoscopic colorectal surgery. *Surg Endosc*. 2018; 32(3): 1515–1524. doi:10.1007/s00464-017-5839-8.

4. Miskovic D, Ahmed J, Bissett-Amess R, et al. European consensus on the standardization of robotic total mesorectal excision for rectal cancer. *Colorectal Disease*. 2019; 21(3), 270-276.

5. Buckley C, E. Ryan N, Neary P. Virtual Reality – A New Era in Surgical Training. *Virtual Reality in Psychological, Medical and Pedagogical Applications*, Chapter 7. 2012: 140-166. https://doi.org/10.1111/codi.14502

6. Flynn J, Larach J, Kong J, et al. The learning curve in robotic colorectal surgery compared with laparoscopic colorectal surgery: a systematic review. *Colorectal Disease*. 2021; 23(11), 2806-2820. https://doi.org/10.1111/codi.15843

7. Jamali F, Soweid A, Dimassi H, et al. Evaluating the Degree of Difficulty of Laparoscopic Colorectal Surgery. *Arch Surg*. 2008; 143(8): 762-767. doi:10.1001/archsurg.143.8.762.

8. Gaitanidis A, Simopoulos C, Pitiakoudis M. What to consider when designing a laparoscopic colorectal training curriculum: a review of the literature. *Tech Coloproctol*. 2018; 22: 151–160. DOI https://doi.org/10.1007/s10151-018-1760-y

9. Kinjoll D. Augmented Reality Market Size, Share & Trends Analysis Report By Component, By Display (HMD & Smart Glass, HUD, Handheld Devices), By Application, By Region, And Segment Forecasts. Market Research Future. November 2023: 2021-2028, https://www.grandviewresearch.com/industry-analysis/augmented-reality-market

10. Dey K. Augmented Reality in Healthcare Market Research Report By Component (Hardware and Software), By Device Type (Head-Mounted Display and Handheld Device), By Application (Fitness management, Medical training and education, and Others), And By Region (North America, Europe, Asia-Pacific, And Rest Of The World) – Market Forecast Till 2032. Market Analysis Report, Grand View Research. 2021. Report ID: 978-1-68038-820-6. https://www.linkedin.com/shareArticle, 2023

11. J. Sánchez-Margallo etal. Application of Mixed Reality in Medical Training and Surgical Planning Focused on Minimally Invasive Surgery. *Front. Virtual Real*. 2021; 2: 692641. doi: 10.3389/frvir.2021.692641.

12. Vávra P, Roman J, Zonča P, et al. Recent Development of Augmented Reality in Surgery: A Review. *Journal of Healthcare Engineering*. 2017; Article ID 4574172, 9 pages. doi: 10.3389/frvir.2021.692641.

13. Yoon J W, Chen R E, Kim E J, et al. Augmented reality for the surgeon: Systematic review. *Int J Med Robotics Comput Assist Surg*. 2018; 14(4): e1914. https://doi.org/10.1002/rcs.1914

14. Marescaux J, Rubino F, Arenas M, et al. Augmented-reality-assisted laparoscopic adrenalectomy. J Am Med Assoc. 2004; 292: 2214–2215.

15. Cartucho J, Shapira D, Ashrafian H, et al. Multimodal mixed reality visualisation for

intraoperative surgical guidance. *International Journal of Computer Assisted Radiology and Surgery*. 2020; 15: 819–826. https://doi.org/10.1007/s11548-020-02165-4

16. Barsom E, Graafland M, Schijven M, et al. Systematic review on the effectiveness of augmented reality applications in medical training, *Surg Endosc*. 2016; 30: 4174–4183. DOI 10.1007/s00464-016-4800-6

17. Forgione A, Guraya S. The cutting-edge training modalities and educational platforms for accredited surgical training: A systematic review. *J Res Med Sci*. 2017; 22: 51. DOI: 10.4103/jrms.JRMS_809_16.

18. Training with cognitive load improves performance under similar conditions in a real surgical task, G Sankaranarayanan, Am J Surg. 2020 September; 220(3): 620–629.

19. Marescaux J, Soler L. Image-guided robotic surgery. *Seminars in Laparoscopic Surgery*. 2004; 11(92): 113–122.

20. Yeung T. Fluorescence imaging in colorectal surgery. *Surgical Endoscopy*. 2021; 35: 4956-4963. https://doi.org/10.1007/s00464-021-08534-7

21. Meijer R P , Faber R A, Bijlstra O D, et al. AVOID; a phase III, randomised controlled trial using indocyanine green for the prevention of anastomotic leakage in colorectal surgery, *BMJ Open*. 2022; 12: e051144. doi:10.1136/bmjopen-2021-051144

22. Guerriero L, Quero G, Diana M, et al. Virtual Reality Exploration and Planning for Precision Colorectal Surgery. *Dis Colon Rectum*. 2018; 61: 719–723. DOI: 10.1097/ DCR.0000000000001077.

23. Lyuksemburg V, Abou-Hanna J, Marshall J, et al. Virtual Reality for Preoperative Planning in Complex Surgical Oncology: A Single-Center Experience, *Journal of Surgical Research*. 2023; 291: 546-556. https://doi.org/10.1016/j.jss.2023.07.00

24. Ugras G, Kanat C, Yaman Z, et al. The Effects of Virtual Reality on Preoperative Anxiety in Patients Undergoing Colorectal and Abdominal Wall Surgery: A Randomized Controlled Trial, *Journal of PeriAnesthesia Nursing*. 2023; 38: 277−283. https://doi.org/10.1016/j.jopan.2022.07.005

25. Liu D, Jenkins S, Sanderson P. Clinical implementation of a head-mounted display of patient vital signs. *2009 International Symposium on Wearable Computers*; 2009: IEEE. DOI: 10.1109/ISWC.2009.36

26. Monsky W, James R, Seslar S, et al. Virtual and Augmented Reality Applications in Medicine and Surgery- The Fantastic Voyage is here. *Anat Physiol*.2019; 9(1): 313.

27. Lee S, Huntbatch A, Pratt P, et al. In vivo and in situ image guidance and modelling in robotic assisted surgery. *Mechanical Engineering Science*. 2010; 224: 1421–1434. DOI: 10.1243/09544062JMES2122

28. Lenihan J, Brower M. Web-connected surgery: using the inter- net for teaching and proctoring of live robotic surgeries. *J Robotic Surg*. 2012; 6(01): 47–52. DOI: https://doi.org/10.1007/s11701-011-0304-5

29. Miskovic D, Ni M, Wyles S, et al. Learning Curve and Case Selection in Laparoscopic Colorectal Surgery: Systematic Review and International Multicenter Analysis of 4852 Cases. *Dis Colon Rectum*. 2012; 55(12): 1300-1310. DOI: 10.1097/DCR.0b013e31826ab4dd

30. Schlachta C, Mamazza J, Seshadri P, et al. Defining a learning curve for laparoscopic

colorectal resections. *Dis Colon Rectum*. 2001; 44: 217–222. https://doi.org/10.1007/BF02234296

31. Leblanc F, Champagne B, Augestad K, et al. A Comparison of Human Cadaver and Augmented Reality Simulator Models for Straight Laparoscopic Colorectal Skills Acquisition Training, *J Am Coll Surg*. 2010; 211: 250–255. doi:10.1016/j.jamcollsurg.2010.04.002

32. Shanmugan S, Leblanc F, Senagore A, et al. Virtual Reality Simulator Training for Laparoscopic Colectomy: What Metrics Have Construct Validity? *Dis Colon Rectum*. 2014; 57: 210-214. Doi: 10.1097/DCR.0000000000000031.

33. Brockmeyer P, Wiechens B, Schliephake H. The Role of Augmented Reality in the Advancement of Minimally Invasive Surgery Procedures: A Scoping Review. *Bioengineering*. 2023; 10: 501. https://doi.org/10.3390/

34. de Valk K, Handgraaf H, Deken M et al. A zwitterionic near-infrared fluorophore for real-time ureter identification during laparoscopic abdominopelvic surgery, *Nature Communications*. 2019; 10: 3118. https://doi.org/10.1038/s41467-019-11014-1

35. Yeung T, Volpi D, Tullis I, et al. Identifying Ureters In Situ Under Fluorescence During Laparoscopic and Open Colorectal Surgery. *Ann Surg*. 2016; 263; e1-e2. DOI: 10.1097/SLA.0000000000001513.

36. Harlaa N, Koller M, de Jongh S, et al. Molecular fluorescence-guided surgery of peritoneal carcinomatosis of colorectal origin: a single-centre feasibility study. *Lancet Gastroenterol Hepatol*. 2016; 1: 283–90. http://dx.doi.org/10.1016/

37. Peltrini R, Podda M, Castiglioni S, et al. Intraoperative use of indocyanine green fluorescence imaging in rectal cancer surgery: The state of the art. *World J Gastroenterol*. 2021; 27(38): 6374-6386. DOI: 10.3748/wjg.v27.i38.6374.

38. Volonté F, Pugin F, Buchs N, et al. Console-Integrated Stereoscopic OsiriX 3D Volume-Rendered Images for da Vinci Colorectal Robotic Surgery. *Surgical Innovation*. 2013; 20(2): 158–163. DOI: 10.1177/1553350612446353.

39. Quero G, Mascagni P, Kolbinger F, Artificial Intelligence in Colorectal Cancer Surgery: Present and Future Perspectives. *Cancers*.2022; 14: 3803. https://doi.org/10.3390/

40. Mirnezami R, Ahmed A. et al. Surgery 3.0, artificial intelligence and the next-generation surgeon. *BJS*. 2018; 105: 463–465. DOI: 10.1002/bjs.10860