Intra-operative imaging solutions for surgeons

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In minimally invasive interventional procedures such as laparoscopic surgery, surgeons do not have a direct view of the organ or tissue they are interacting with but are constrained to navigate the surgical instruments on the basis of image views provided by dedicated camera systems. Image-guided interventions have been on the rise in recent years as they are less invasive than traditional methods and are believed to enable more accurate surgical gestures. Yet, the surgeon’s brain needs to re-interpret the visual information available in the image given. This has to be achieved swiftly and reliably for controlling the instruments with the greatest ease and accuracy, yielding the most precise surgical gestures in the shortest time possible. How can we assess critical parameters of surgical skill and its evolution with time and training under different conditions imposed by different technological solutions?

The most adequate, comfortable, affordable, and sustainable interventional imaging technology should allow the largest possible number of domain surgeons to perform to the best of their skill, whether the given imaging system is assisted or not by a robot and regardless of the extent to which the system relies on assistance by Artificial Intelligence. We know from research in cognitive engineering that there is an exchange function between the accuracy, or the precision, and the timing of skilled performance. [1, 2]

Relating these two in the context of a real surgical task is anything but simple because of the lack of measurement criteria for surgical precision. Currently, time-to-task completion prevails in assessing high-level skills and their evolution with training. The field is struggling to find adequate methods and procedures for more comprehensive performance-based skill assessment, which has been the ‘holy grail’ for over a decade now. As a consequence, there are still no gold standards ensuring that the best technology for surgeons and patients will be developed and placed on the market, and no silver bullet for objectively assessing the adequacy and sustainability of different intra-operative imaging solutions for surgeons.

VR and AR viewing technology

Research in cognitive motor planning and control has highlighted some of the drawbacks of virtual reality headset viewing, found to negatively affect timing and precision of gestures in image-guided simulator tasks. [3, 4]

In virtual reality viewing, image representations need to be processed and interpreted by the brain to ensure the correct positioning of hands and tools while surgeons are looking at a three-dimensional (3D) reconstruction of the camera image through a computer-controlled virtual reality (VR) headset. A major problem with virtually viewed three-dimensionality is that depth information needs to be reconstructed by the brain, which has learnt to assess the visual depth and relative distances between real-world objects on the basis of how far they are away from the individual's own body. Reliable body-to-space data for depth and relative distance estimates are missing from virtual 3D image representations. As a consequence, time-to-contact anticipation, movement planning, and eye-hand coordination are made more difficult for the surgeon.

From the classic two-dimensional image views provided by high-resolution laparoscopic cameras to new types of processed, virtual, or augmented reality-enriched, nanotechnology-enhanced imaging solutions or scanned images superimposed on camera views, there now is a multitude of technological solutions that may be more or less appropriate for a given type of intervention. Augmented reality (AR) technology in image-guided surgery is developed on the premise that organs and tissues become more salient when enhanced by AR, i.e., spatial relationships can be visualized better by the surgeon. It is deemed that this advantage is bound to improve surgical accuracy, yet there seem to be no objective criteria for testing the validity of this assumption. In computer-assisted orthopaedic surgery, for example, bone location and CT data may be visualized in three-dimensional AR. To this effect, a target needs to be attached to the bone for tracking in a system with a very narrow focus of vision, rendering notoriously poor depth perception. [(5)]

Irreversible electroporation of tumours in the prostate or the pancreas, which is a needle-based intervention, may benefit from AR systems that provide visual guidance for planning needle insertion trajectories. These systems, however, produce tracking lags because they lack the precision to reliably access raw sensor data for tracking moving targets, and they also only have a limited field of vision. [(6)]

In vascular surgery, testing live views of the patient captured and merged with preoperative volume-rendered vessels, AR viewing was found to add little value to complex arteriovenous anomalies in terms of localizing the large draining vein, and sometimes arteries were mistaken for veins and vice versa. [(7)]

Proof-of-concept using a phantom model to allow the fusion of preoperative single-photon emission computed tomography (SPECT) and computed tomography (CT), also known as intra-operative SPECT/CT, generates a new breed of state-of-the-art augmented reality (AR) in a surgical guidance system for pelvic sentinel lymph node (SLN) detection in endometrial cancer patients. This innovative and promising approach opens novel perspectives. [(8)]

The potential of Artificial Intelligence (AI)

Artificial intelligence (AI) has been announced as having great potential in a wide variety of applications in interventional radiology for the support of decision-making and outcome prediction. New functions and improvements in fluoroscopy, ultrasound, computed tomography, and magnetic resonance imaging have been developed for image-guided interventions. The significant boost for fusion imaging, simulation, and robotic interaction promised by AI, however, is severely limited by the procedural nature, heterogeneity, and lack of standardisation of this technology. [(9)]

Whether a technological solution suits and will be pushed for further development and optimization is currently established by lead surgeons in the given field. The technology the stars of the profession deem the most promising then becomes the gold standard by default. While this seems to make sense to the extent that respected domain authorities will then adopt the technology of their choice to develop and refine it in the context of their institutions, it does not ensure that this will advance the most sustainable, affordable, effective, and comfortable solutions for surgeons in general. The mechanisms through which a surgeon’s brain adapts to any of the new technologies are currently not known, nor is it possible to tell which technology optimally empowers them to develop the finest of surgical skills possible. Finely tailored task designs with to-the-single-pixel measurement of hand-tool movement trajectory precision in task time captured at the millisecond level are currently possible only in simulator environments. [(10)]

Simulator training does not straightforwardly transfer to clinical scenarios. Multidisciplinary training and research programmes, within and between teams and within and across countries, will be necessary to help establish reliable protocols and training procedures. The multi-criteria assessment of surgeons’ skill progress during consecutive training days of a curriculum with exposure to different image-guided surgical training scenarios on several robotic systems sets the stage for international surgeon-led training programmes responding to the growing need to integrate domain competency in robotic approaches to national training programmes. [(11)]

Before being placed on the market, new technology should have been widely evaluated on the basis of objective, if not universal, benchmark criteria as the gold standard for training the largest possible number of dedicated surgeons toward professional excellence and success. This will lead to selecting the technological solutions that are the most adapted to surgeons’ needs for achieving reliable planning and execution of highly precise surgical gestures. Technology only a chosen few will be able to adapt to will not prevail in a domain that serves patients and healthcare systems worldwide. Both patients and caregivers need and deserve the best, safest, most widely accessible, affordable, and sustainable technology in the operating rooms of the future.

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