Chapter 6
When Surgery Meets the Metaverse

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Nowadays, the main field of development of surgery is no longer technical, but technological. Modern surgery is enhanced by technologies which aim to improve safety, effectiveness, training, outcomes. These technologies are increasingly dependent on digital interfaces with the aim of empowering human action. Simulation training, robotic assisted surgery, patient-specific 3D surgical planning and reconstruction, remote assistance, up to 3D printing of individualized models or tissues and augmented reality operative scene with holograms are just some of the "extended reality" (XR) (or mixed or hybrid reality) possibilities that may influence our surgical activity [1].

The concept of XR starts from virtual reality and evolves to augmented reality and augmented virtuality up to the Metaverse.

Actually, XR support is primarily for training or perioperative planning, but its impact can be even more decisive, not only in the treatment of individual cases, but in particular in the global dissemination of surgical knowledge and in the shared decision making.

Training

Minimally invasive surgery has been accepted worldwide as the gold standard for many surgical procedures. However, its spread has made the development of specific skills even more necessary, which can only be gained through extensive

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Table 6.1 Comparison of different training approaches

	Physical reality	Virtual reality	Augmented reality
Realistic haptic feedback	X		X
Realistic instruments	X		X
Objective performance assessment		X	X
Interactivity		X	X
Easily sustainable costs	X		

training. Even if surgical training has traditionally been achieved by observation and apprenticeship in operating theaters, like any other craft activity, concern about patient safety, the need for learning not only technical elements but also familiarize with surgical tools, spatial 2D/3D relationship and instruments manipulation and the need of frequent repetition of single gestures, have made surgical training an area requiring innovation [2].

Moreover, developing these skills before entering an operating room, or strengthening the operating room activity by combining it with additional simulation, helps to enable a more focused and efficient performance. From the earliest homemade box trainer [3] up to the latest virtual/augmented reality simulators many systems have been proposed, making the literature about training the richest in the field of XR.

Compared to virtual reality, augmented reality has some potential advantages. In fact it adds virtual information to a real simulation field, combining them in a single system. It allows the trainees to use the same instruments currently used in the OR, providing a realistic haptic feedback and an objective performance assessment (Table 6.1).

Several augmented reality simulators have been developed over the recent years, rapidly improving and becoming progressively less expensive. However, virtual reality simulators are still the most studied, efficient, and cost-effective training method, waiting for the validation and effectiveness evaluation of the new augmented reality systems.

Even if the benefits of a virtual surgical training could impact our surgical approach (in particular in minimally invasive surgery), this has been usually suggested in low quality studies and the dissemination of this technology among clinically active surgeons still remains low [4].

Finally, simulation systems can also be used as a “warm-up” before surgery. If the activity is performed immediately before surgery a significant increase in subjective and objective performance was reported, especially for more complex procedures [5].

Visualization: From Glasses to Holograms

Another very promising field of application for XR is the support of perioperative evaluation, allowing surgeons to visualize patient data, 3D imaging scans, literature updates and enabling remote consultation and collaboration between surgeons [6, 7].

Table 6.2 Commercially available optical see-through head-mounted displays reported in clinical study [adapted from [8]]

			
	Google lens	Microsoft HoloLens	Magic leap
Optics	Beam splitter	Waveguide	Waveguide
Resolution	640 × 480 px	2048 × 1080 px	1280 × 960 px
Field of view	30° diagonal	43 × 29°	40x30°
Focal planes	Single fixed	Single fixed	Two fixed
Computing	On board	On board	External pad
Eye tracking	No	Yes	Yes
Weight	46 g	566 g	345 g
Design	Glasses-like	Hat-like	Glasses-like
Interaction	Touchpad	Head, eye, voice	Controller

For operative application of augmented reality during surgical performance a large number of devices and display modalities have been reported. These can be divided into three main groups: head-mounted displays, hand-held displays, and spatial displays.

Head-mounted displays (glasses-like or hat-like) (some examples in Table 6.2) can combine the information provided by augmented reality with the real world in two different ways: a video see-through, in which a video display merges virtual content with a video of real world, or an optical see-through, in which a transparent optical device can project into the field of view additional virtual contents [8]. The video see-through display does not allow the operator's visual field to have direct contact with the real world, giving a more immersive experience, while the optical see-through display does, allowing a better control of the environment.

Hand-held displays like mobile devices (smartphones or tablets) are now globally widespread. However, their use in surgery is limited by small screen size and requirement for hand-held interaction.

Spatial display systems are the most common in operating rooms, although often not implemented with XR functions, and usually include a 2D/3D screen-based video monitor. Their main limitations can be considered the static nature of the display and the requirement of a remote control of the content displayed. The evolution of these systems leads to the use of projection devices, which find their greatest expression in the creation of holograms.

As modern medicine is moving toward personalized precision treatment, patient-specific holographic MRI/CT 3D reconstruction, projected on the anatomical working area or on head-mounted displays could further enhance individually customized surgical plans and improve surgical performance. However, holograms should still not be considered for navigation, but only for simulation. Their use has already been reported in liver surgery [9], rectal cancer surgery [10], but also neurosurgery, orthopedics, maxillofacial, cardiac, and vascular surgery.

When discussing XR application to these devices, human factors such as perception, mental mapping, spatial awareness, attention shift, and ergonomics are usually considered, beside technical factors such as resolution, occlusion, tracking accuracy, delayed transmission, or other technical drawbacks.

On this subject, much is yet to be written. To date, most studies on the topic of user interface improvement have been experimental or feasibility tests. So far, there is still no evidence of added value for patient care.

Navigation: Intraoperative Guidance

The idea of a system that allows us to optimize incisions, see through structures, and make our gestures increasingly precise has always been on the minds of surgeons. However, a major issue is the accuracy and reliability of the XR system, mainly in integrating patient data and matching virtual and real views. In particular, the main limitation to the use of navigation systems is tissue movement. Respiratory motion, patient positioning, CO_2 insufflation, surgical tissue manipulation, or other deformation can make any traditional landmark-based registration algorithm useless [11].

Liver surgery is the area where intraoperative navigation systems have been most widely applied, aiming to avoid unnecessary liver resection that may subsequently impact on liver function and postoperative outcome [12]. By rendering transparent or holographic superimposed virtual images of the organ and the lesions, ER application can minimize the lack of tactile sensation, usually experienced during video-assisted procedures.

Even if ultrasonography or computed tomography imaging is commonly used for intraoperative evaluation, the inability to provide real-time continuous imaging data does not allow an adequate construction of a three-dimensional mental image of the intrahepatic structures.

Display methods used for augmented reality intraoperative navigation include a see-through display, a video-based display, and a projection-based display, which are used to present the virtual reconstructed images overlaid on the surgical field in a 3D visual environment [13]. Main characteristics are summarized in Table 6.3.

Even if promising results on shorter operative times, less blood loss and reduced radiation required have been reported [14–16], especially for orthopedic surgery, suggesting a more precise surgical approach, most of the ER guided navigation studies are experimental development approaches rather than clinical studies, still leaving open questions about their effective impact in clinical and surgical practice.

However, information that can be integrated within XR systems is not limited to radiological images (CT, MRI, ultrasound, etc.), but they can also take advantage of tracer-based molecular imaging strategies (fluorescence, radio-markers, etc.), providing a more comprehensive view of the potential role of XR in the future of precision surgery [17].

Table 6.3 Display methods used for augmented reality intraoperative navigation

	See-through display	Video-based display	Projection-based display
Features	• Semitransparent display • Autostereoscopic 3D technology	• Images shown on a screen • External or head-mounted video display	• Images projected on the surgical field • Optimal for superficial structures
Advantages	• Larger field of view • No tactile feedback limitation	• Visual perspective shared by the OR team • Easy control of resolution and brightness	• Minimize operation time • Avoid repetitive imaging
Disadvantages	• Discomfort after long session • Continuous vergence-accommodation conflict	• Resolution of the camera • Inverse proportion between precision of registration and area of the surgical field or distance from the landmarks	• Frequent tracking and calibration required • 2D projected images may affect perception

Simulation: From 3D Reconstruction to Printing

The possibility of three-dimensional virtual reconstruction from radiological images is now commonplace and integrated into many radiological image processing software. The next step is to make this reconstruction available for analysis and study by the surgeon, in order to analyze and optimize the surgical strategy, using virtual reality or XR systems. Moreover, the same technology could be used to take a further step, creating realistic, patient-specific 3D models, which would potentially be superior to 2D or 3D images on a computer monitor or projection screen.

Three-dimensional printing may help advance surgical practice in terms of preoperative planning, education and training, construction of specific surgical instruments and, in particular, creation of 3d printed personalized implants and prostheses [18].

A wide range of 3D printed devices have been developed and studied, mainly anatomical models for preoperative planning or intraoperative guiding, especially in the field of maxillofacial or orthopedic surgery [19].

General surgery has been quite slow in the adoption of 3D reconstruction models, even if some applications have been reported in particular in liver surgery [20], but also in colorectal [21] or gastroesophageal surgery [22]. This may reflect both limited resource availability as well as image related organ specific complexities. In fact, visceral organs are more difficult to reconstruct compared to bone or vessels.

Moreover, the relatively high costs (100–215$ per patient [23]) and the time needed to develop and print a 3D model (up to 160 h [24]), besides to errors of measurements or materials, make such application still difficult to sustain on a large population.

Nevertheless, as 3D printing continues to evolve and develop, most of these limitations may be resolved in the future and new applications of this method will undoubtedly emerge.

According to the World Health Organization, only 5–15% of people in lower-income countries have access to prostheses, largely due to low availability of materials and high costs of prostheses. In addition to this, the availability of surgical or daily clinical practice materials is also often limited. The easiest accessibility of 3D printing techniques can offer the creation of customized objects (basic medical supplies, laboratory equipment, operating room equipment, etc.) and patient-specific components, reducing or bypassing the current manufacturing and post-processing steps [25, 26].

Moreover, in the field of 3D printing, inkjet techniques have been implemented to construct functional body parts and organs with high degree of accuracy and various applications of implants have already been approved by the Food and Drug Administration, such as the mandible bone, dental prostheses or hip, femoral and knee functional parts, taking advantages of one of the most important benefit of this technology: no latency between design and final production.

This means that in the future it may be possible to reproduce entire functional organs, or possibly hybrid systems where the printed anatomical component acquires function through implementation with technological devices.

However, attempts to predict the clinical application of 3D printing are currently highly speculative. Literature analysis shows that a wide range of 3D-printed devices have been clinically reported, but few papers have rigorously assessed their efficacy or effectiveness. Because 3D-printed devices can have different safety and efficacy issues than the equivalent devices, further testing and studies may be required to confirm the available results.

Patient

Potential benefits of XR application are not limited to improved precision surgery but they extend to various other moments in the patient's surgical journey.

One of these benefits can be related to anxiety and pain reduction. Various studies suggest a potential role of immersive virtual reality systems in reducing anxiety before medical procedures, anxiety and pain during medical procedures and post-surgical pain and use of analgesics [27].

It is well known that the patient's psychological state of mind can influence the dosage of sedatives needed to achieve the target sedation level.

When patients were exposed to sessions of meditative virtual reality applications focused on calmness and relaxation, performed once daily for up to 7 days, they improved their intensive care unit experience with reduced levels of anxiety and depression [28]. The same result was reported for virtual reality interventions for colonoscopy-induced anxiety and pain that revealed a similar effect as conventional sedation and a statistically significant reduction in non-sedated patients [29].

Moreover, virtual reality therapy demonstrated potential improvements in both the patient-clinical outcomes and patient-reported experiences of those undergoing surgical procedures [30, 31].

Another very promising application of the XR is in the physician–patient relationship and patient information. 3D virtual reality can help surgeons and patients in building a better relationship before surgery and immersive 3D-supported informed consent improves patients' comprehension of their condition without increasing anxiety [32].

Moreover, another potential application of technology is the use of patient-specific 3D printed models to improve education for patients. For example, the use of personalized 3D models was reported for stoma care education, allowing the patients to practice with their own 3D printed ostomies, cutting the plate and attaching it to the stoma bag [33]. This means fewer skin problems associated with daily stoma care, but most importantly an improved awareness and self-reliability.

Patient information, problem sharing, and shared decision making are increasingly relevant topics that will shape the surgery of the future. Being able to access increasingly precise and personalized surgery without the patient being able to understand its significance, its value and its advantages will risk slowing down the spread of the surgery of the future and the technological advances that will make it possible.

Conclusion

Although XR is predicted to revolutionize surgery, several challenges that involve surgeons, administrations, and patients still need to be addressed to ensure a widespread adoption. Despite many papers having been published in recent years from a variety of surgical disciplines on this topic, heterogeneous methodologies, lack of comparison, and few results with clinical impact have not yet allowed us to really understand the clinical impact of this technology.

However, future studies will surely demonstrate that we can change the fantasy into reality.

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