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EDITORIAL

[Translated article] Digital orthopaedic surgery: Benefits and challenges of extended reality and spatial computing

Cirugía ortopédica digital: beneficios y desafíos de la realidad extendida y la computación espacial

The integration of extended reality (XR) technologies in orthopaedic surgery is marking a significant turning point in the field of digital surgery, within the 5p medicine paradigm. These technologies are revolutionising the way surgical procedures are planned and executed, providing significant improvements in the precision of both pre- and intraoperative planning. In particular, mixed reality (MR) and holographic devices are introducing significant innovations in surgical practice by allowing detailed, real-time, multimodal 3D visualisation of anatomical structures, complemented by different reference materials and information sources that are thus integrated into the surgery itself. These ''augmented capabilities'' enable surgeons to execute surgical tactics with a direct transfer from the screen to the operating table, minimizing risks and improving clinical indicators.[1,2]

This new ''extended surgery'' allows the specialist to record 3D holographic images of the patient's anatomy directly in the surgical field, with a sufficiently precise overlay or matching and with different levels of geometric and morphological detail, including as many layers of information as required. XR glasses, with their ability to project and manipulate 3D images using voice commands, hand tracking or directly by analysing eye movements (eye tracking), are transforming the surgical experience itself, reconfiguring human–machine interaction (HMI). Its application is growing in complex surgical procedures, allowing its hybridisation with other disruptive technologies such as 3D printing[3] or robotic-assisted surgery.

Mixed reality is a technology that combines elements of augmented reality (AR) and virtual reality (VR), integrating digital information with the user's physical environment and allowing real-time interaction with both worlds thanks to spatial mapping systems. Unlike AR, which simply superimposes digital images, MR allows for deeper and more dynamic interaction between virtual and physical objects. In the field of orthopaedic surgery, this technology, exemplified by devices such as Microsoft's HoloLens2® glasses, offers several advantages as an entry-level device, since its optics have a transparent visor that allows for a constant visualisation of the real world, restricting the immersive experience.[4]

For an advanced level, the spatial computing modality has recently been included within XR technologies, where interaction is not done by looking at a screen but ''through it'', viewing a virtual desktop that is fully integrated with real space. Unlike holographic systems, the real world is projected after being captured thanks to advanced sensorisation and the simultaneous recording of multiple cameras that allow 3D processing of the environment without latency. The main device within this new field is the Apple Vision Pro® recently introduced on the market. The display of these glasses fuses digital elements with those of the environment surrounding the surgeon, allowing for a much richer and more immersive experience, but since they are opaque lenses, they depend on a constant power supply and a high refresh rate to act like natural vision.[5]

In the field of orthopaedic surgery, XR technology, and especially spatial computing, offers multiple highly significant technical options, such as real-time spatial interaction, remote supervision or proctoring, immersive visualisation and monitoring of medical data, or positional recording itself. The new workflows in digital orthopaedic surgery require a holistic approach where the pre- and intraopera-

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tive stages converge, breaking the border between planning and execution, and between the virtual world and the real world. The first advantage of XR technology is found in patient-specific training, where these 3D environments allow a unique visual-spatial input. At this stage, cooperative and interdisciplinary work with medical imaging and biomedical engineering specialists becomes essential to integrate programming elements, 3D CAD design and the surgical tactics themselves, which will constitute the ''digital surgical scene'' available in the glasses.

When the operation takes place, this 3D project is transferred in real time, allowing its direct superposition on the surgical field, including the patient's digital twin, with its different morphological and anatomical elements, and its radiological imaging studies; positional markers, surgical instruments or the implants themselves. The glasses enable direct pass-through visualisation, preventing surgeons from having to focus their attention on heads-up systems. This direct recording of the patient, and feedback in real time, enables correction and verification options never before achieved, facilitating precise guidance during the intervention, and ensuring that the surgeon maintains complete situational awareness without having to look away, thus avoiding unnecessary distractions. Through control of the holographic scene itself, the operator can configure all its elements, limiting their number, order or composition. In this way, there is control at all times of the level of immersion and breadth of the projected information.

However, like any disruptive innovation, the adoption of this type of technology also presents challenges, both in its regulatory and organisational aspects. The specialised training of surgical staff and the integration of these devices into existing workflows are vital aspects to consider. In addition to this, the technological infrastructure must be continuously maintained and updated to support these innovations. The cost of these devices can be a significant barrier to their large-scale implementation, exacerbating inequities in access to advanced surgical care. It is critical to highlight that these technologies must be used as supervised assistance by the surgeon, as there are still risks associated with their use that require constant supervision and expert control. A major risk is the potential abstraction and distraction during surgery if the volume of information projected on the glasses is not controlled or if the experience becomes too immersive. Furthermore, for this technology to be truly effective, it should be used by the entire surgical team, allowing full participation in real time.

Regarding regulations, we must consider that the digital elements built into glasses for a given patient based on their imaging studies constitute a customised medical device (CMP), which has its own legislation and regulatory aspects. Both the prescription of this service, as well as its design and clinical implementation, must be carried out in qualified centres that have multidisciplinary teams, an accredited quality management system and certified technology providers.[6] The verification of these products and the validation of the tools used is the responsibility of the specialist, who must have the professional experience after completing the appropriate learning curve, and the necessary institutional support to face the technological challenge as a guarantor of patient safety.[7] A notable example of the successful implementation of these technologies can be found in university hospitals accredited for academic or point-of-care manufacturing of CMP, where XR technology has been integrated as another part of the surgical care process, and very notably in new 3D hybrid operating theatres.[8]

Extended reality has the potential to revolutionise orthopaedic surgery, especially in areas that require advanced and personalised planning, especially complex reconstruction, spinal procedures, or multi-approach surgeries such as oncology or polytraumatised patient surgery. The ability to plan and execute surgeries with unprecedented precision offers new possibilities, not only for innovation in surgical practice, but also in the training of resident physicians or the education of patients. Beyond considering this technology as a fad or trend, it represents a magnificent opportunity for the creation of new competency profiles and the implementation of regulated training programmes by health institutions and scientific societies, whose certification qualifies the professional for qualified and safe use within this new care paradigm.

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