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Examining the Role of Augmented Reality in Total Hip Arthroplasty

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Background

In 2023, it was reported that total hip arthroplasty (THA) was the main and effective surgical treatment for advanced hip osteoarthritis, osteonecrosis, and rheumatoid arthritis.[1] As the population ages, the number of annual THA procedures is projected to grow and reach 635,000 by the year 2030.[2] As such, further improving outcomes in THA will benefit this large population. On average age for individuals who sustain a hip fracture is 80 years old and the lifetime prevalence of hip fractures is 20% in women and 10% in men.[3] Fracture reduction and internal fixation or arthroplasty are often needed to treat hip fractures and end-stage osteoarthritis.[3] Since the 1960s, advancements in materials, design, bioengineering, developing less invasive surgical techniques, and computer-assisted procedures have further revolutionized THA.[4] Looking forward, Augmented Reality (AR) may provide an avenue to further improve several aspects of joint replacement procedures.

AR technology superimposes computer-generated images in a user's "real world" field of vision.[5] AR may play a key role in preoperative simulation, training of future surgeons, intraoperative navigation, and postoperative rehabilitation in the field of orthopedic surgery.[3] Several benefits of AR are currently being investigated including increased accuracy of acetabular cup placement, less distraction from computer screens outside of the surgical field, less radiation exposure, and alternative methods of surgical training. This article discusses AR technology's potential uses and limitations in orthopedic surgery with a focus on THA.

Potential Uses

Increased Accuracy

One critical question regarding the use of AR in THA is whether the implementation of the technology allows for more accurate placement of surgical implants. Malposition of the acetabular component is associated with increased rates of dislocation, impingement, pelvic osteolysis, cup migration, leg length discrepancy, and polyethylene wear in THA.[6] As such, precise acetabular anteversion and inclination angle are key for successful THA. A systematic review and meta-analysis, which included five studies analyzing 196 patients receiving conventional THA and 200 patients receiving AR-assisted THA, found that AR-assisted THA had better accuracy of inclination and anteversion than conventional THA, while the duration of surgery and intraoperative blood loss remained similar in the two groups.[1] These findings suggest AR may provide surgeons with tools to increase the accuracy of hardware placement. Additionally, AR equipment increases the ability to individualize implant design and reduce postoperative complications through increased accuracy.[3]

Reduced Surgeon Attention Shift:

AR technology visually presents anatomical information directly on the surgical field within the surgeon's line of vision rather than on separate screens. This uniquely provides surgeons with three-dimensional images superimposed in the "real world" surgical field through direct visualization of the patient's soft tissue and bone.[7] This could be a potential improvement from currently used computer-assisted navigation systems that display information on two-dimensional screens and require the surgeon to shift attention away from the surgical field.[8]

Reduced Ionizing Radiation

Additionally, the use of AR guidance in operating rooms does not require ionizing radiation while still providing necessary visual data to surgeons.[9] Radiation exposure for surgeons, operating room staff, and patients has been a concern for many years since the increase of surgeries utilizing fluoroscopy.[9] According to Bratschitsch et al., there has been over a 600% increase in radiation for diagnostic procedures in the United States since the 1980s.[10] AR may be an avenue to obtain sufficient accuracy in surgical procedures without the unwanted ionizing radiation associated with fluoroscopy and traditional imaging studies.

Increased Training Opportunities

Moreover, AR may provide an alternative or be used in conjunction with traditional surgical training methods. Advancing training methods in orthopedics is important as THA is a complex operation where low-volume or junior surgeons are often less accurate in acetabular cup placement.[11] Presently, the most commonly used training methods outside of the operating room are referred to as "conventional methods" and include reading technique manuals, using instruments of low-fidelity synthetic bone models, observing surgery, and simulation on human cadaver joints. To increase additional opportunities

for training, researchers are exploring the use of Extended Reality (XR), which includes virtual reality, augmented reality, and mixed reality in orthopedic training programs.

In one randomized controlled trial, Logishetty et al. randomized two groups of 4th-year medical students with no prior arthroplasty experience to undergo four training sessions in acetabular cup placement with either holographic guidance from a Hololens headset or one-on-one instruction from an arthroplasty surgeon.[12] In a final evaluation of simulated acetabular cup placement, both groups improved significantly from their baseline test and ended up equally accurate in acetabular cup placement.[13] Importantly, this work suggests that trainees may practice motor skills important in THA without expert surgeons.

An additional randomized controlled trial by Hooper et al. assessed the efficacy of VR simulation versus standard study materials for training orthopedic surgery residents in THA.[14] Primary outcomes of this study included improvement on baseline written pretests and cadaveric THA. It was found that there was no significant improvement in written test scores between the two groups, but the VR-trained group saw significant improvements in technical performance in cadaveric THA.[14]

A recent systematic review and meta-analysis found that XR training had better accuracy of inclination and shorter surgical duration than conventional methods in THA.[11] Although some research indicates that XR training is promising, it has been noted that 75% of important events in surgery are related to decision-making, 25% are related to dexterity, and no simulation can adequately replace the skills obtained within the actual operating room.[11]

Limitations

There are several limitations surrounding the use of AR. It has been reported that the use of AR headsets has been associated with simulator sickness, nausea, disorientation, eye strain, and oculomotor symptoms.[7,9] Avrumova et al. suggest that AR may cause sensory overload and be disorienting due to mixing real visual input with holographic data during surgery. As such, adaptation to using AR may require a generation of surgeons who "grew up playing video games," and a significant learning curve to adjust to simulator sickness is expected.[9] Another limitation of AR in arthroplasty is tissue may be disrupted during the procedure and the patient's anatomy may no longer reflect the preoperative imaging on which the initial image registration was based.[5] Lastly, the development of AR technology has been slower than expected, and awareness regarding AR within the surgical community is "still low."[5]

Conclusion

Although there are several limitations, AR has immense potential to provide surgeons with valuable visual information and students with additional avenues for training. Still, the future of AR in THA is not certain as further prospective studies investigating the utility, reductions in surgical complications, increase in surgical accuracy, and clear cost-effectiveness of the technology are greatly needed.

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