Mixed Reality Guidance Improves Humeral Head Cut Accuracy

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INTRODUCTION:

The humeral head cut is a critical step in shoulder arthroplasty, as it determines prosthesis alignment including neck-shaft angle (NSA), retroversion, and component height. The humeral head cut is often performed freehand or with an extramedullary guide. Mixed reality (MR) technology has shown potential to enhance accuracy in preoperative planning and intraoperative guidance. However, its role in improving the accuracy of humeral head osteotomy remains unexplored.

METHODS:

A total of 45 Sawbones models of arthritic proximal humeri were created using 3D printed ABS filament with 30% infill. Each individual model was an identical copy of the same arthritic proximal humerus, including identical osteophytes (Figure 1). Nine residents were matched by experience level and randomized into three separate groups to perform humeral head cut: freehand, 135° extramedullary guide (EG). and MR guidance using Microsoft HoloLens 2 (Redmond, WA, USA) application that displayed a manipulatable 3D hologram of the proximal humerus and the planned cut. Each participant performed five cuts targeting a 135° NSA and 30° retroversion. Pictures replicating normal preoperative planning were posted in the room to assist the resident volunteers with the planned humeral head cut (Figure 2). For the MR guidance group, the hologram could be manipulated in space and size as needed by the study participant during each humeral head cut attempt (Figure 3). Participants were not allowed to see or judge the accuracy of their cuts after each attempt to minimize potential learning effects. 3D scanning and software analysis were employed to measure deviations from planned NSA, retroversion, and cut height. These were imported and compared with the desired preoperative plan using professional 3D graphics software (Blender version 4.3, Amsterdam) and aligned with a gold-standard model using the iterative closest point (ICP) method (Figure 4). Statistical analysis were performed using ANOVA and Tukey HSD tests.

RESULTS:

Average deviations from target NSA, retroversion, and cut height were analyzed among all models and surgeons, as shown in Table 1. MR guidance significantly reduced deviations in NSA ($4.8° \pm 4.3°$) and cut height (4.1 ± 2.0 mm) compared to freehand ($10.4° \pm 6.1°$, 7.6 ± 3.0 mm) and EG ($10.1° \pm 5.0°$, 7.5 ± 3.4 mm) techniques ($p < 0.01$). No significant differences in retroversion accuracy were observed between the three groups ($p = 0.94$).

DISCUSSION AND CONCLUSION:

Mixed reality holographic guidance enhances the accuracy of humeral head osteotomies, particularly for NSA and cut height, compared to traditional techniques. These findings support MR's potential as a transformative tool for shoulder arthroplasty, warranting further investigation in live surgical settings and broader clinical applications.

Figure 1: 3D printed arthritic proximal humerus model.

Figure 2: images of the planned humeral head cut with 135 neck shaft angle and 30 degrees of retroversion.

Figure 3: surgeon point-of-view using mixed reality via the Microsoft Hololens to assist with the humeral head cut intra-operatively.
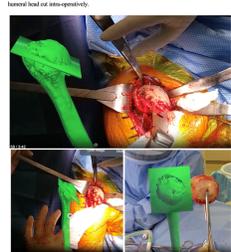

Figure 4: digitized 3D model and the deviation from the planned cut measurement using the iterative closest point (ICP) method.
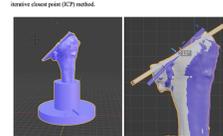
Table 1: Humeral head osteotomy accuracy by group

	Free hand (n = 15)	Extramedullary guide (n = 15)	Mixed Reality (n = 15)	P-value
Deviation from target 135 NSA (degrees)	10.4 ± 6.1	10.1 ± 5.0	4.8 ± 4.3	< 0.01
Deviation from target -30 retroversion (degrees)	5.4 ± 3.8	5.5 ± 5.2	5.2 ± 5.3	0.94
Deviation from target cut height (mm)	7.6 ± 3.0	7.5 ± 3.4	4.1 ± 2.0	< 0.01