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Augmented reality significantly reduces the absolute error between achieved and planned inclination and version of the glenoid baseplate for reversed shoulder arthroplasty

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Background: To determine whether using augmented reality with a head-mounted display (AR-HMD) would reduce deviations between planned and achieved reverse total shoulder arthroplasty (rTSA) glenoid baseplate inclination and version.

Methods: Ten fresh frozen shoulders from 5 human cadavers, which were free from fractures or other bony pathologies were used. Computed tomography scans were acquired for each shoulder, and imported into image 3-dimensional processing software to plan rTSA, and notably to define the target inclination and version of the glenoid baseplate. Two experienced surgeons placed a 1.6-mm Kirschner wire on the glenoid baseplate insertion site in each shoulder (5 per surgeon) using conventional instruments, and the AR-HMD was used to measure the inclination, version, in addition to the number of outliers. Afterward, using the AR-HMD (Pixee Medical, Besançon, France) the surgeons drilled and inserted the Kirschner wire for the glenoid baseplate positioning, and computed tomography was used to measure the inclination, version, and number of outliers.

Results: Absolute deviations between planned and achieved inclination were significantly smaller when using AR-HMD (0.9° ± 1.6°, range 0°-5°) than without AR-HMD (5.1°± 3.7°, range 0°-10°) ($P = .007$), and there were fewer outliers with absolute deviation when using AR-HMD (n = 1) than without using AR-HMD (n = 7). Absolute deviations between planned and achieved version were significantly smaller when using AR-HMD (0.7° ± 0.5°, range 0°-1°) than without AR-HMD (5.5° ± 4.4°, range 0°-14°) ($P = .007$), and there were fewer outliers with absolute deviation when using AR-HMD (n = 0) than without using AR-HMD (n = 7). Mean distance from entry point was −1.1 ± 1.7 mm in the superior−inferior axis, and 0.5 ± 0.9 mm in the anterior−posterior axis.

Conclusion: AR-HMD significantly reduces the absolute error between achieved and planned inclination and version of the glenoid baseplate during rTSA, though further studies are required to confirm the benefits of this technology in clinical settings.

Implant positioning is of paramount importance for the success of reverse total shoulder arthroplasty (rTSA), as malpositioning can compromise shoulder function due to excessive retroversion, and exacerbate scapular notching due to excessive superior inclination.[4,8,20] Accurate implant positioning requires precise preoperative planning; however, due to the limited intraoperative view of the scapula, the final implant positioning depends considerably on surgeon experience.[6]

Augmented reality (AR) has promising potential to improve implant positioning for various joint arthroplasty procedures,[3,5] notably using head-mounted displays (HMD), which enable visualization of projected targets onto anatomic structures during

Ethical approval and informed consent was not needed as this is a cadaveric study.

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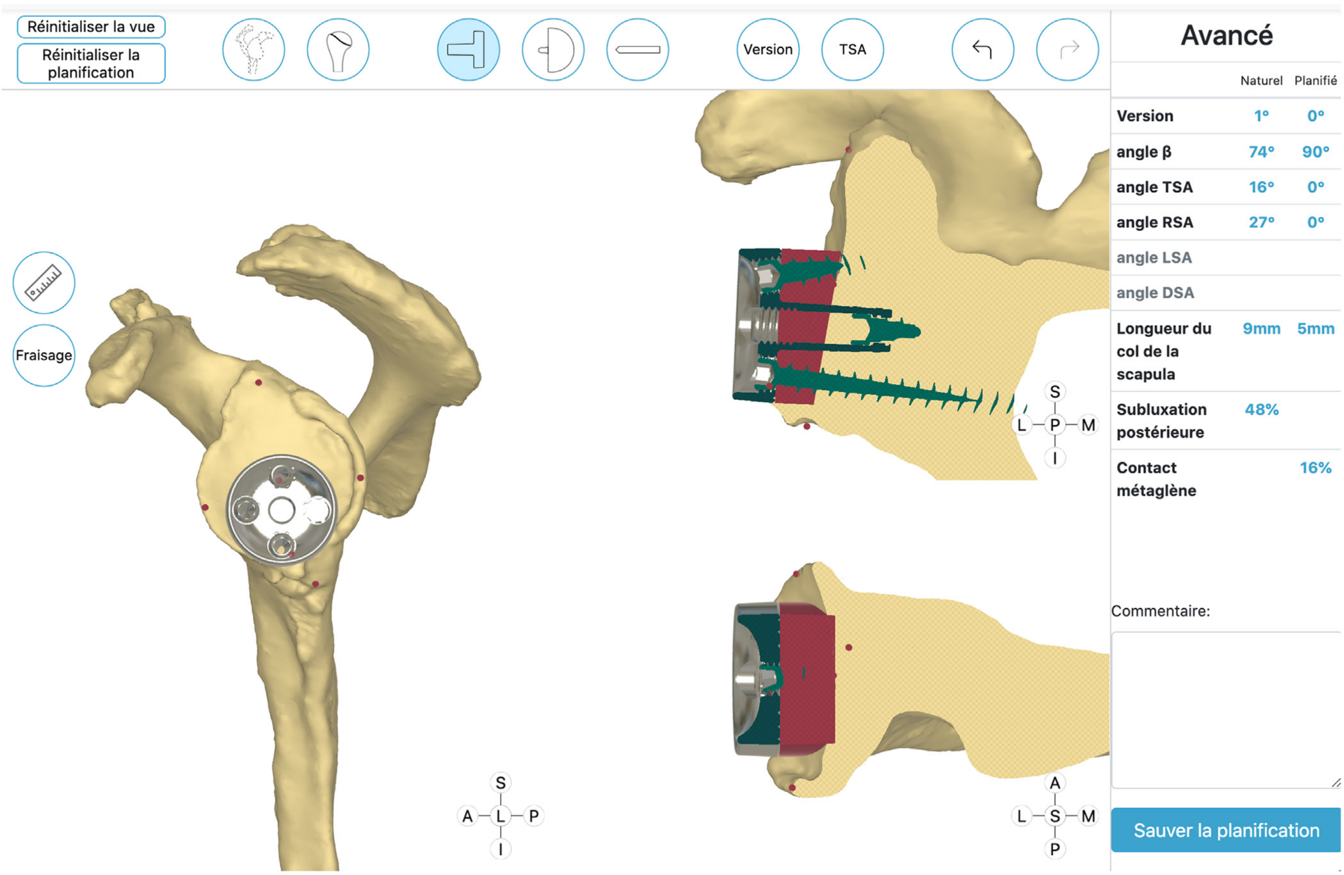

Figure 1 Preoperative planning.

surgery.[2,7,12,17] This technology is easy to use and cost-efficient, but very few studies have been published on its applications to shoulder surgery. Kriechling et al[9] found that AR seems reliable for baseplate guidewire positioning in cadaveric shoulders, but did not investigate the 3-dimensional (3D) inclination and version of the glenoid baseplate position. Schlueter-Brust et al[15] investigated the orientation of the guidewire placement, but only performed surgery on printed models.

The purpose of this study was therefore to determine whether using AR-HMD would reduce deviations between planned and achieved rTSA glenoid baseplate inclination and version. The null hypothesis was that there would be no significant differences in deviations between planned and achieved implant positioning in shoulders operated with versus without AR-HMD.

Methods

This study adheres to the QUality Appraisal for Cadaveric Studies assessment (Supplementary Appendix SI).[19] For this study, 10 fresh frozen shoulders from 5 human cadavers, which were free from fractures or other bony pathologies were used. Computed tomography (CT) scans were acquired for each shoulder (140 kV, 180 mAs and an image of 512 × 512 with 0.5-mm slice interval), and imported into image 3D processing software to plan rTSA (Fx SPS; Pixee Medical, Besançon, France) (Fig. 1), and notably to define the target inclination and version of the glenoid baseplate (Fig. 2). The accuracy of the AR-HMD system is dependent on the quality of the CT scans. The glenoid shape was A1 in 8 shoulders, A2 in 1 shoulder, and B1 in 1 shoulder. Each specimen was thawed for 24 hours at room temperature, and the surgery was performed using the whole shoulder including the soft tissues.

Surgical navigation

The Shoulder + AR-HMD (Pixee Medical, Besançon, France) was used in this study to set up a hologram over the operative site to navigate the guidewire (Figs. 3 and 4), and each surgeon planned their 5 surgeries. To create the scapular reference system, the surgeon placed the pointer tip on 5 glenoid landmarks. The surface of the glenoid was acquired by placing the pointer tip on the surface. Once the landmarks and surface were adequately detected, the patients' anatomy was reconstructed in 3D, and was superimposed as augmented reality to the operative site. Using the AR-HMD, the surgeon is able to see the deviation between planned and real-time inclination and version of the drilling guide. After the drilling has been performed, the surgeon can download the deviations between planned and achieved.

Surgical technique and assessment

Two experienced surgeons placed a 1.6-mm Kirschner wire on the glenoid baseplate position in each shoulder (5 per surgeon) using conventional instruments. Following this, AR-HMD was used to measure the inclination and version, in addition to the number of outliers. Afterward, using the AR-HMD (Pixee Medical, Besançon, France) the surgeons drilled and inserted the Kirschner wire for the glenoid baseplate positioning (Fig. 3), and CT was used to measure the inclination, version, number of outliers. In addition, the distance from entry points were measured in 2 axes (superior–inferior and

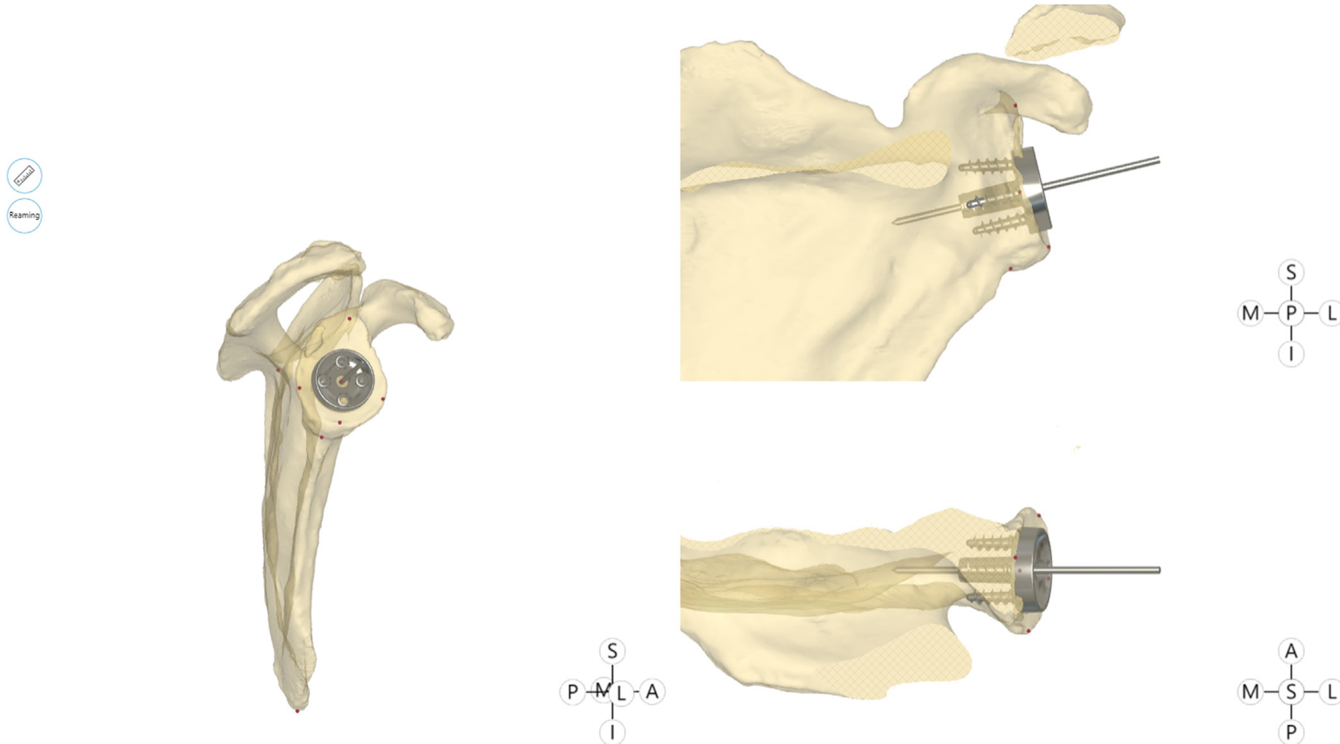

Figure 2 Preoperative planning.

Figure 3 Intraoperative use of the AR-HMD. *AR-HMD*, augmented reality with a headmounted display.

anterior–posterior), where superior and anterior were considered as positive values, while inferior and anterior as negative values.

Statistical analysis

A priori sample size indicated that, assuming an absolute deviation in version of 5.9°± 1.1 without AR-HMD,[18] and 1.0 ± 1.0 with AR-HMD, 3 patients per group would be required to detect a statistically significant difference with a power of 0.95. Outliers were defined as deviations >2°, based on a publication by Sanchez-Sotelo.[14] Descriptive statistics were used to summarize the data and Shapiro-Wilk test was used to assess the distribution of the samples. Values were expressed in mean and standard deviation. Differences between conventional and AR groups were assessed using Wilcoxon-Mann-Whitney for quantitative variables and Fisher's exact test for categorical variables. Statistical analyses were performed using R, version 4.1 (R Foundation for Statistical Computing, Vienna, Austria). *P*-values < .05 were considered statistically significant.

Results

The inclination and version achieved using AR-HMD (0.6° ± 1.6° and 0.3° ± 0.8°) were smaller than the inclination achieved without using AR-HMD (4.0°± 5.1° and 2.1°± 7.0°) (Table I).

The absolute deviations between planned and achieved inclination were significantly smaller when using AR-HMD (0.9 ± 1.6, range 0-5) than without using AR-HMD (5.1 ± 3.7, range 0-10) (*P* = .007). There were also fewer outliers with absolute deviation in inclination >2° when using AR-HMD (n = 1) than without using AR-HMD (n = 7).

The absolute deviations between planned and achieved version were significantly smaller when using AR-HMD (5.5 ± 4.4, range 0-14) than without using AR-HMD (0.7 ± 0.5, range 0-1) (*P* = .007).

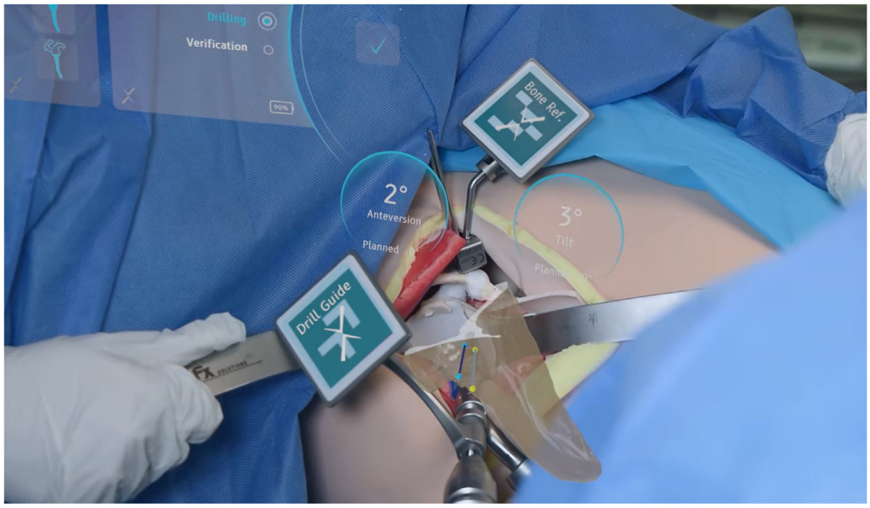

Figure 4 Intraoperative view through the AR-HMD. *AR-HMD*, augmented reality with a head-mounted display.

Table I
Measurements.

	Cohort n = 10 shoulders		*P* value
	Mean ± standard deviation	Range	
Glenoid type			
A1	8 (80%)		
A2	1 (10%)		
B1	1 (10%)		
Inclination			
Preoperative	4.8 ± 7.8	(−7 to 16)	
Planned	−0.3 ± 0.7	(−2 to 0)	
Postop without AR-HMD	4.0 ± 5.1	(−3 to 10)	
Postop with AR-HMD	0.6 ± 1.6	(−1 to 5)	
Absolute deviation (planned minus achieved inclination)			
Without AR-HMD	5.1 ± 3.7	(0-10)	.007
With AR-HMD	0.9 ± 1.6	(0-5)	
Version			
Preoperative	−3.2 ± 5.3	(−15 to 4)	
Planned	0.0 ± 0.0	(0-0)	
Postoperative without AR-HMD	2.1 ± 7.0	(−10 to 14)	
Postoperative with AR-HMD	0.3 ± 0.8	(−1 to 1)	
Absolute deviation (planned minus achieved version)			
Without AR-HMD	5.5 ± 4.4	(0-14)	.007
With AR-HMD	0.7 ± 0.5	(0-1)	
Distance from entry point			
Superior–inferior	−1.1 ± 1.7	(−3 to 2)	
Anterior–posterior	0.5 ± 0.9	(−1 to 2)	

AR-HMD, augmented reality with a head-mounted display.

There were also fewer outliers with absolute deviation in version >2° when using AR-HMD (n = 0) than without using AR-HMD (n = 7). The mean distance from entry point for AR-HMD was −1.1 ± 1.7 mm in the superior–inferior axis, and 0.5 ± 0.9 mm in the anterior–posterior axis.

Discussion

The most important findings of this study were that AR-HMD significantly reduces the absolute error between achieved and planned inclination and version of the glenoid baseplate. Notably, AR-HMD considerably reduced the proportions of outliers with errors >2°, from 70% to ≤10%. The present findings suggest that AR-HMD could be effective to improve accuracy of glenoid baseplate positioning during rTSA, though further studies are required to confirm the benefits of this technology in clinical settings.

To the authors' knowledge, the present study is the first to investigate the efficacy of using AR-HMD for rTSA, which is of great importance as malpositioning of the glenoid baseplate can compromise shoulder function, and affect the longevity of the implant due to increased instability. An increase in glenoid anteversion could result in anterior translation of the humeral head, which could cause excessive eccentric loading of the anterior part of the glenoid.[11] In contrast, retroversion could cause posterior displacement and posterior loading of the glenoid.[4,8,16,20]

Few studies have been published on the use of AR for glenoid baseplate positioning, but none have investigated the use of AR-HMD for the version and inclination of glenoid baseplate placement. Kriechling et al[9] investigated glenoid guidewire positioning using AR-HMD in a cadaveric model without a comparative group, and found a mean deviation from the planned entry point of 3.5 mm ± 1.7 mm, and deviation from the planned trajectory of 3.8° ± 1.7°. A previous study of Kriechling et al[10] investigated the feasibility of AR-HMD in 3D printed glenoids, and found that guidewire positioning for the later placement of glenoid components using AR is feasible and accurate. A study by Schlueter-Brust et al[15] also investigated the use of AR in 3D printed glenoids, and found that the discrepancy between the planned and the achieved glenoid entry point and guide-wire orientation was approximately 3 mm with a mean angulation error of 5°. Finally, Berhouet et al[1] performed a feasibility study of the different steps required to apply AR, from information preparation to its visualization, but found technical limitations that are related to the connected tool itself and the operating software.

The use of AR-HMD is demonstrating acceptable applicability and high accuracy in the guidewire positioning in the present study. To achieve high accuracy, there are many patient-specific instrumentation techniques and navigation systems available [16]. Recently, a meta-analysis that included 227 shoulders demonstrated a version of 2.7° ± 0.5° and inclination of 1.9° ± 0.4° when using patient-specific instrumentation techniques, which was better than conventional techniques which resulted in a version of 5.88° ± 1.10° and inclination of 5.78° ± 0.98 [10]. A systematic review by Sadoghi et al[13] included 247 shoulders, and found that navigation grants more accurate glenoid version of the baseplate, but that no differences in inclination were found. Finally, a recent systematic review by Sanchez-Sotelo et al[14] investigated mixed-reality for glenoid pin placement in cadavers and were able to place all pins with 2° of version and inclination, therefore the authors chose this threshold in the present study. Using thresholds of 5° and 10° would have led to more comparable results between AR-HMD and without AR-HMD, however ultimately leads to lower accuracy in clinical practice.

The findings of the present study must be interpreted with the following limitations in mind. First, this is a cadaveric study which does not allow direct extrapolation of the findings *in-vivo*. Second, only glenoids without bony deformations were used, and the use of AR-HMD in deformed or dysplastic glenoids should be investigated in future studies. Third, no information was available on the demographics of the cadavers. Fourth, the 2 surgeons performed 5 surgeries each, which might have introduced bias, but was done as the cadaveric lab was only available for 1 day. Finally, the deviation from entry point was only measured using CT after the Kirschner wire was inserted using AR-HMD, and not after placing the Kirschner wire on the glenoid baseplate position. Due to the study design, it was only possible to drill into the glenoid once, and therefore the measurement technique had to change. This might have influenced the study results, but due to the accuracy of both measurement techniques, the effects are minimal.

Conclusion

AR-HMD significantly reduces the absolute error between achieved and planned inclination and version of the glenoid baseplate. Notably, AR-HMD considerably reduced the proportions of outliers with errors >2°, from 70% to ≤10%. The present findings suggest that AR-HMD could be effective to improve accuracy of glenoid baseplate positioning during rTSA.

Disclaimers:

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Supplementary Data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jseint.2025.01.017.

References

1. Berhouet J, Slimane M, Facomprez M, Jiang M, Favard L. Views on a new surgical assistance method for implanting the glenoid component during total shoulder arthroplasty. Part 2: from three-dimensional reconstruction to augmented reality: feasibility study. Orthop Traumatol Surg Res 2019;105:211-8. https://doi.org/10.1016/j.otsr.2018.08.021.
2. Berryman DR. Augmented reality: a review. Med Ref Serv Q 2012;31:212-8. https://doi.org/10.1080/02763869.2012.670604.
3. Blackwell M, Morgan F, DiGioia AM 3rd. Augmented reality and its future in orthopaedics. Clin Orthop Relat Res 1998;354:111-22.
4. Franta AK, Lenters TR, Mounce D, Neradilek B, Matsen FA 3rd. The complex characteristics of 282 unsatisfactory shoulder arthroplasties. J Shoulder Elbow Surg 2007;16:555-62. https://doi.org/10.1016/j.jse.2006.11.004.
5. Goradia VK. Computer-assisted and robotic surgery in orthopedics: where we are in 2014. Sports Med Arthrosc Rev 2014;22:202-5. https://doi.org/10.1097/JSA.0000000000000047.
6. Iannotti JP, Greeson C, Downing D, Sabesan V, Bryan JA. Effect of glenoid deformity on glenoid component placement in primary shoulder arthroplasty. J Shoulder Elbow Surg 2012;21:48-55. https://doi.org/10.1016/j.jse.2011.02.011.
7. Jud L, Fotouhi J, Andronic O, Aichmair A, Osgood G, Navab N, et al. Applicability of augmented reality in orthopedic surgery – a systematic review. BMC Musculoskelet Disord 2020;21:103. https://doi.org/10.1186/s12891-020-3110-2.
8. Kadum B, Wahlström P, Khoschnau S, Sjödén G, Sayed-Noor A. Association of lateral humeral offset with functional outcome and geometric restoration in stemless total shoulder arthroplasty. J Shoulder Elbow Surg 2016;25:e285-94. https://doi.org/10.1016/j.jse.2016.02.021.
9. Kriechling P, Loucas R, Loucas M, Casari F, Fürnstahl P, Wieser K. Augmented reality through head-mounted display for navigation of baseplate component placement in reverse total shoulder arthroplasty: a cadaveric study. Arch Orthop Trauma Surg 2023;143:169-75. https://doi.org/10.1007/s00402-021-04025-5.
10. Kriechling P, Roner S, Liebmann F, Casari F, Fürnstahl P, Wieser K. Augmented reality for base plate component placement in reverse total shoulder arthroplasty: a feasibility study. Arch Orthop Trauma Surg 2021;141:1447-53. https://doi.org/10.1007/s00402-020-03542-z.
11. Nyffeler RW, Sheikh R, Atkinson TS, Jacob HA, Favre P, Gerber C. Effects of glenoid component version on humeral head displacement and joint reaction forces: an experimental study. J Shoulder Elbow Surg 2006;15:625-9. https://doi.org/10.1016/j.jse.2005.09.016.
12. Rahman R, Wood ME, Qian L, Price CL, Johnson AA, Osgood GM. Head-mounted display Use in surgery: a systematic review. Surg Innov 2020;27:88-100. https://doi.org/10.1177/1553350619871787.
13. Sadoghi P, Vavken J, Leithner A, Vavken P. Benefit of intraoperative navigation on glenoid component positioning during total shoulder arthroplasty. Arch Orthop Trauma Surg 2015;135:41-7. https://doi.org/10.1007/s00402-014-2126-1.
14. Sanchez-Sotelo J, Berhouet J, Chaoui J, Freehill MT, Collin P, Warner J, et al. Validation of mixed-reality surgical navigation for glenoid axis pin placement in shoulder arthroplasty using a cadaveric model. J Shoulder Elbow Surg 2024;33:1177-84. https://doi.org/10.1016/j.jse.2023.09.027.
15. Schlueter-Brust K, Henckel J, Katinakis F, Buken C, Opt-Eynde J, Pofahl T, et al. Augmented-reality-Assisted K-wire placement for glenoid component positioning in reversed shoulder arthroplasty: a Proof-of-Concept study. J Pers Med 2021;11:777. https://doi.org/10.3390/jpm11080777.
16. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. https://doi.org/10.2106/jbjs.F.00226.
17. Ukimura O, Gill IS. Image-fusion, augmented reality, and Predictive surgical navigation. Urol Clin 2009;36:115-23. https://doi.org/10.1016/j.ucl.2009.02.012.
18. Villatte G, Muller AS, Pereira B, Mulliez A, Reilly P, Emery R. Use of patient-specific instrumentation (PSI) for glenoid component positioning in shoulder arthroplasty. A systematic review and meta-analysis. PLoS One 2018;13:e0201759. https://doi.org/10.1371/journal.pone.0201759.
19. Wilke J, Krause F, Niederer D, Engeroff T, Nürnberger F, Vogt L, et al. Appraising the methodological quality of cadaveric studies: validation of the QUACS scale. J Anat 2015;226:440-6. https://doi.org/10.1111/joa.12292.
20. Zumstein MA, Pinedo M, Old J, Boileau P. Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: a systematic review. J Shoulder Elbow Surg 2011;20:146-57. https://doi.org/10.1016/j.jse.2010.08.001.