Issue Rehabil. Orthop. Neurophysiol. Sport Promot. 2024; 47: 25–30. ISSN 2300-0767
DOI: 10.19271/IRONS-000209-2024-47

ORIGINAL ARTICLE

RELIABILITY OF SCAPULAR MORPHOLOGY ASSESSMENT USING MIXED REALITY

RZETELNOŚĆ NARZĘDZI MIESZANEJ RZECZYWISTOŚCI W OCENIE MORFOLOGII ŁOPATKI

Szymon Stupnicki[1,A-E], Mikołaj Zakryś[1,2,B,D], Bartosz Gołembiewski[1,2,B,D], Stanisław Kommisarczyk[1,2,B,D], Jan Klincewicz[1,2,B,D], Anna Maria Kubicka[3,B], Bartłomiej Lubiatowski[4,B], Przemysław Lubiatowski[1,2,A,E-F]

[1]Sports Trauma and Biomechanics Unit, Rehasport Clinic, Poznan, Poland
[2]Department of Traumatology, Orthopaedics and Hand Surgery, Poznan University of Medical Sciences, Poland
[3]Department of Zoology, Poznań University of Life Sciences, Poland
[4]Research and Development Department, RSQ Technologies, Poland
A – Research concept and design
B – Collection and/or assembly of data
C – Data analysis and interpretation
D – Writing the article
E – Critical revision of the article
F – Final approval of the article

ABSTRACT
Recent advancements in Augmented (AR) and Mixed Reality (MR) have significantly impacted the orthopedic field, with hope of holographic tools to enhance surgical precision. This study explores the reliability of a specifically designed software tool, integrated with HoloLens, for measuring anatomical structures of the shoulder girdle in orthopedic surgery. Forty-two right scapulas were analyzed using CT scans, further converted into 3D models, which were then visualized as holograms and measured through augmented reality tools using the RSQ HOLO system. Three researchers performed measurements on three key distances: Glenoid Height (GH), Glenoid Width (GW), and Scapular Width (SW), across two sessions with a minimum 7-day interval. Statistical analysis using Intraclass Correlation Coefficient (ICC) revealed excellent intra-rater reliability for SW (0.96) and GW (0.91), and good reliability for GH (0.85). Inter-rater reliability also showed promising results, particularly for SW (0.91) and GW (0.78), although GH (0.72) showed moderate agreement. Descriptive statistics indicated minimal measurement differences across all groups, with the majority of differences being under 1 mm. These findings demonstrate holographic assessment of bone morphology is highly reliable, supporting its potential use in preoperative planning and intraoperative navigation. Further studies are needed to evaluate the software's performance in clinical settings and its comparison with physical and CT measurements.

Keywords: mixed reality, measurement tool, orthopedic surgery

Author responsible for correspondence:
Szymon Stupnicki 0009-0002-2263-5691 Sports Trauma and Biomechanics Unit, Rehasport Clinic, ul. Górecka 30, 60-201, Poznań, Poland;
Email: sszymon0303@gmail.com

Authors reported no source of funding
Authors declared no conflict of interest

Date received: 30th January 2025
Date accepted: 27th February 2025

STRESZCZENIE
Ostatnie osiągnięcia w dziedzinie Rozszerzonej (AR) i Mieszanej Rzeczywistości (MR) zaczynają wywierać znaczący wpływ na dziedzinę ortopedii, a narzędzia holograficzne dają szansę zwiększenia precyzji chirurgicznej. Celem poniższego badania była ocena rzetelności użycia specyficznego oprogramowania, zintegrowanego z HoloLens, do pomiaru struktur anatomicznych obręczy barkowej w chirurgii ortopedycznej. Przeanalizowano 42 prawych łopatek za pomocą tomografii komputerowej (CT), które następnie przekształcono w modele 3D, wizualizowane jako hologramy i mierzone przy użyciu RSQ HOLO. Trzech badaczy przeprowadziło pomiary trzech kluczowych odległości: Wysokości panewki (GH), Szerokości panewki (GW) oraz Szerokości łopatki (SW), w dwóch sesjach z minimalnym 7-dniowym odstępem. Analiza statystyczna za pomocą Współczynnika Korelacji Wewnątrzklasowej (ICC) wykazała doskonałą niezawodność intra-rater dla SW (0,96) i GW (0,91), oraz dobrą niezawodność dla GH (0,85). Niezawodność inter-rater również wykazała obiecujące wyniki, szczególnie dla SW (0,91) i GW (0,78), choć dla GH (0,72) uzyskano umiarkowaną zgodność. Statystyki opisowe wskazały minimalne różnice pomiarowe wśród wszystkich grup, przy czym większość różnic była mniejsza niż 1 mm. Wyniki te pokazują, że oprogramowanie RSQ HOLO zapewnia dokładne i spójne pomiary, wspierając jego potencjalne zastosowanie w planowaniu przedoperacyjnym oraz nawigacji śródoperacyjnej. Konieczne są dalsze badania, które ocenią wydajność oprogramowania w warunkach klinicznych oraz jego porównanie z pomiarami fizycznymi i CT.

Słowa kluczowe: mieszana rzeczywistość, narzędzie pomiarowe, chirurgia ortopedyczna

Introduction

Advances in technology led to the integration of Augmented Reality (AR) and further Mixed Reality (MR) into the medical field, arousing significant attention in recent years (Gregory *et al.* 2018). Among the vast array of MR headsets available on the market, standing as one of the most promising is the Microsoft HoloLens (Gsaxner *et al.* 2023). With this device, one can visualize 3D models as holographic representations (created in advance and based on the patient's preoperative CT images) and interact with them (e.g. rotate in multiple planes, obtain measurements) in real-time environments, such as the operating theater.

Although holographic technology can be considered as relatively new, its potential to increase surgical precision, improve preoperative planning, and aid in intraoperative decision-making has been widely explored across various fields of medicine. Orthopedic surgery is one of these, where spatial understanding of a patient's anatomy and pathology is crucial for successful outcomes (Lubiatowski 2016, Chytas and Nikolaou 2021, Lubiatowski *et al.* 2021, Brzózka *et al.* 2022, Wawrzyniak *et al.* 2022). We know very well that three dimensional imaging is more resistant to experience in evaluation of shoulder structures (Kubicka *et al.* 2016, Stefaniak & Lubiatowski *et al.* 2020, Stefaniak & Kubicka *et al.* 2020, Nizinski *et al.* 2024) . Up to date research results show that dynamic, interactive visualizations of complex musculoskeletal structures, provided by AR and MR technologies, may facilitate more accurate implant placement (Yanni *et al.* 2021, Tanji *et al.* 2022, Sanchez-Sotelo *et al.* 2024). Additionally, surgeons can remotely contact their colleagues and ask for advice or feedback about the procedure with visible display of holograms (Gregory *et al.* 2018, Verhey *et al.* 2020).

However, despite these promising developments, there remains a need for further investigation into the application of new MR

technologies, as a reliable measurement tool in orthopedic surgery. The main challenge that may reject MR and AR technologies is calibration between the virtual content shown by the headset and the actual surroundings (Longo *et al.* 2024). This may discharge new technologies from their future practical, clinical use.

RSQ HOLO software integrated with Microsoft Hololens enables the creation of holographic orthopedic equipment components and the measurement tools pre and intraoperatively. This system is portable, sterile and allows for 3D visualization integrated with operation room reality. In this way, the surgeon can safely and freely project a holographic image (created based on a CT scan) onto the operation field during the procedure without having to turn their head. This allows for a comfortable, close-range visualization of the patient's anatomical structures overlayed by needed holographic images (Calem *et al.* 2024).

Aim

In this study, we aimed to determine whether holographic shoulder girdle measurements obtained from Microsoft HoloLens integrated with RSQ HOLO software could be accurately reproduced between different researchers (inter-rater reliability) and consistent with each one's data collected over certain interval of time (intra-rater reliability). Thus checking, if this software has a reliable measurement tool, that could be used efficiently in pre and intraoperative orthopedic surgery settings.

Materials and methods

Forty-two right human scapulas were obtained from the Department of Zoology, Poznań University of Life Sciences. At first, CT scans of collected scapulas were done. Based on these, 3D model reproductions (STL files) were generated using 3D Slicer software (Fedorov *et al.* 2012). Generated files were imported to the cloud that could be accessed using Microsoft HoloLens with RSQ HOLO software. Consequently, measurements were done using the Ruler tool on RSQ HOLO software (RSQ Technologies, Poznań, Poland) integrated with Microsoft HoloLens headset (Calem *et al.* 2024). Minimal interval of measurement was 0.1 cm. The distances assessed in this study were: **Glenoid height (GH)**: the distance between the highest and lowest points of the glenoid cavity; **Glenoid width (GW)**: the distance between the most anterior and posterior points of the glenoid cavity; **Transverse scapular length/ Scapular width (SW):** The distance between the medial margin of scapula and the inferior margin of the glenoid cavity.

3 researchers performed measurements two times in an interval of minimum 7 days. Researchers did not have access to each other's results throughout the whole measuring process, so as not to be able to get influenced by them.

Statistical analysis of intra and inter-rater reliability was defined by Intraclass Correlation Coefficient (ICC) in absolute agreement mode. Additionally descriptive statistics as Mean, 95%CI and SD were used to compare groups of measurements. ICC was further defined as poor (< 0.5), moderate (0.5–0.75), good (0.75–0.9) or excellent (> 0.9) (Koo TK and Li M 2016).

Results

GH measurement intra-rater ICC was overall 0.85 (Separately: Rater no.1: 0.89 ; Rater no.2: 0.84 ; Rater no.3: 0.81). GW measurement intra-rater ICC was overall 0.91 (Separately: Rater no.1: 0.93 ; Rater no.2: 0.89 ; Rater no.3: 0.91). SW measurement intra-rater ICC was overall 0.96 (Separately: Rater no.1: 0.98 ; Rater no.2: 0.94 ; Rater no.3: 0.96). Moving to inter-rater reliability, GH measurement ICC was 0.72. For GW, ICC was 0.78. And for SW 0.91.

Descriptive statistics defined by Mean, 95%CI and SD showed no significant differences among intra and inter-rater groups. For intra-rater GH the mean of the first measure was: 3.6 cm (95%CI: 3.5–3.7; SD: 0.4). For the second measure mean was also: 3.6 cm (95%CI: 3.6–3.7; SD: 0.4). For intra-rater GW the

mean of the first measure was: 2.7 cm (95%CI: 2.6–2.7; SD: 0.3). For the second measure the mean was also 2.7 cm (95%CI: 2.6–2.8; SD: 0.3). For intra-rater SW the mean of the first measure was: 10.6 cm (95%CI: 10.5–10.7; SD: 0.7). For the second measure mean was also 10.6 cm (95%CI: 10.4–10.7; SD: 0.6). Moving to inter-rater comparison, mean measurement done by Rater no.1 for GH was 3.6 cm (95%CI: 3.5–3.7; SD: 0.4), by Rater no.2 mean was 3.7 cm (95%CI: 3.5–3.8; SD: 0.4), and by Rater no.3 mean was 3.6 cm (95%CI: 3.5–3.7; SD: 0.3). GW mean measurement done by Rater no.1 was 2.6 cm (95%CI: 2.6–2.7; SD: 0.3), by Rater no.2 mean was 2.7 cm (95%CI: 2.6–2.8; SD: 0.3), and by Rater no.3 mean was 2.7 cm (95%CI: 2.6–2.8; SD: 0.3). SW mean measurement done by Rater no.1 was 10.5 cm (95%CI: 10.3–10.8; SD: 0.7), by Rater no.2 mean also was 10.5 cm (95%CI: 10.3–10.7; SD: 0.6), and by Rater no.3 mean was 10.7 cm (95%CI: 10.5–11; SD: 0.7).

Discussion

RSQ HOLO software measurement tool proved to be reliable for measurement in orthopedic surgery. The best, excellent ICC agreement was achieved in SW measurement both in intra (ICC: 0.96) and inter-reliability comparison (ICC: 0.91). This was the longest measurement conducted in the study, defined directly by distinct bony edges. Likely for this reason, researchers observed the smallest differences in assessing this distance. In contrast, unlike the scapular edges, the edges of the glenoid are not as sharply delineated. The superior edge of the glenoid and the supraglenoid tubercle show great variety of morphology, hence this may be the explanation why GH was the weakest of our measurements (ICC intra-rater: 0.85; inter-rater 0.72). Furthermore, many patients may present glenoid margin diversity such as osteophytes or hypertrophy due to pathological or aging changes which may also lead to differences in inter-rater measurements originating from different interpretations of the glenoid rim (Zhou *et al.* 2022). Nonetheless, the consistency of GH and GW measurements was from good to excellent defined by ICC, with the sole exception of the aforementioned GH inter-rater agreement, being moderate. The mean measurement differences and the 95% CI limits differences in the vast majority of compared groups were below 1 mm. This value is smaller than the measurement error and the measurement interval of the RSQ HOLO program. Only for SW in the inter-rater group, the mean differences and 95% CI limits differences were greater than this value, yet still under 2 mm. This can be explained by the simple fact that this measurement represented the largest dimension in our study (generally > 100 mm). Therefore the 2 mm difference is not clinically significant in this case.

So far, there have only been a few papers confirming the effectiveness of MR in shoulder girdle surgeries. These studies substantiate that technologies, congruent with RSQ HOLO could have clinical benefits. A study by Gregory *et al.* was first to describe a patient who underwent a reverse total shoulder arthroplasty (rTSA) using AR guidance and perioperative planning. Authors reported that the aid of AR headset enabled better visualization of a patient's anatomy thus making the procedure safer and more efficient (Gregory *et al.* 2018). Other studies proved better glenoid component placement with MR support (Verborgt *et al.* 2011, Nashikkar PS *et al.* 2019, Moreschini *et al.* 2020). This is crucial because scapular notching associated with glenoid component malposition has been revealed to be one of the most relevant sources of complications after rTSA (Zumstein *et al.* 2019) . Sanchez-Sotelo *et al.* proved that MR based navigation can be considered as a good alternative to traditional navigation and shows satisfying reliability and accuracy in terms of total shoulder arthroplasty. Authors of the paper mention some advantages of the MR utilization, which include efficient glenoid component placement, cost and time efficiency, universal applications and space effectiveness compared to alternative planning methods. They state, however, that the

learning curve and initial cost of MR devices may be their disadvantages (Sanchez-Sotelo *et al.* 2024). Moving to scapula fractures Guo *et al.* evidenced that through pre-operative virtual simulation and intra-operative navigation patients can benefit from shorter operation time and less blood loss (Guo *et al.* 2022). Moving to elbow joint, another study, to our knowledge first comparing conventional methods of Total Elbow Arthroplasty with AR-based techniques, have demonstrated significant improvements in both translation and rotation accuracy especially for the placement of humeral components (Tanji *et al.* 2022). Despite aforementioned sufficient support of MR and AR, there is a lack of big number studies conducted in surgery settings. Some current technologies can have difficulty with the superimposition of the scene to the physical world (reality). This may be their main limitation (Berhouet *et al.* 2019, Longo *et al.* 2024). These facts prompt us to fully investigate the utility of RSQ HOLO, as we plan to conduct further studies in clinical settings, in procedures like TSA or rTSA. Moreover we intend to compare RSQ HOLO measurements with physical and CT measurements.

This study had potential limitations. First of them is the fact that we conducted measurements in pre-operative conditions. Therefore we were not negatively influenced by limited visibility, as it could be in the operating field. Another aspect is that some of the obtained scapulas were eroded through a natural degradation process of bone tissue, hindering the measurement process.

Conclusion

This study shows that bone morphology can be reliably assessed and measured using mixed reality tools. Overall, MR technologies compared to traditional visualization and measurement methods have plenty of practical advantages and they continue to improve.

REFERENCES

Berhouet J, Slimane M, Facomprez M, *et al.* (2019) *'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.'* Orthopaedics; Traumatology: Surgery; Research.;105(2):211–218.

Brzóska R, Laprus H, Wałecka J, Mostowy M, Ebisz M, Lubiatowski P. (2022) *'Management Of The First-Time Anterior Shoulder Dislocation. Analysis Of A Survey Conducted Among Members Of The Polish Shoulder And Elbow Society.'* Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion – IRONS.;38:31–45.

Calem DB, Lubiatowski P, Trenhaile S, et al. (2024) *'Mixed reality applications in upper extremity surgery: the future is now.' EFORT Open Reviews.*;9(11):1034–1046.

Chytas D, Nikolaou VS. (2021) *'Mixed reality for visualization of orthopedic surgical anatomy.'* World Journal of Orthopedics.';12(10):727–731.

Fedorov A, Beichel R, Kalpathy-Cramer J, *et al.* (2012) *'3D Slicer as an image computing platform for the Quantitative Imaging Network.'* Magnetic Resonance Imaging.;30(9):1323–1341.

Gregory TM, Gregory J, Sledge J, *et al.* (2018) *'Surgery guided by mixed reality: presentation of a proof of concept.'* Acta Orthopaedica. ;89(5):480–483.

Gsaxner C, Li J, Pepe A, *et al.* (2023) *'The HoloLens in medicine: A systematic review and taxonomy.'* Medical Image Analysis.;85:102757.

Guo Q, Li X, Tang Y, Huang Y, Luo L. (2022) *'Augmented reality and three-dimensional plate library-assisted posterior minimally invasive surgery for scapula fracture.'* International Orthopaedics.;46(4):875–882.

Koo TK, Li MY. (2016) *'A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research.'* Journal of Chiropractic Medicine.;15(2):155–163.

Kubicka AM, Stefaniak J, Lubiatowski P, *et al.* (2016) *'Reliability of measurements*

performed on two dimensional and three dimensional computed tomography in glenoid assessment for instability.' International Orthopaedics.;40(12):2581–2588.

Longo UG, Lalli A, Gobbato B, Nazarian A. (2024) *'Metaverse, virtual reality and augmented reality in total shoulder arthroplasty: a systematic review.'* BMC Musculoskeletal Disorders.;25(1).

Lubiatowski P. (2016) *'Recurrence Of Instability After The Latarjet Procedure.'* Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion - IRONS.;(14):29–38.

Lubiatowski P, Wałecka J, Stefaniak J. (2021) *'Imaging In Anterior Shoulder Dislocation.'* Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion – IRONS.;37:25–32.

Moreschini F, Colasanti GB, Cataldi C, *et al.* (2020) *'Pre-Operative CT-Based Planning Integrated With Intra-Operative Navigation in Reverse Shoulder Arthroplasty: Data Acquisition and Analysis Protocol, and Preliminary Results of Navigated Versus Conventional Surgery.'* Dose-Response. 2020;18(4).

Nashikkar PS, Scholes CJ, Haber MD. (2019) *'Role of intraoperative navigation in the fixation of the glenoid component in reverse total shoulder arthroplasty: a clinical case-control study.'* Journal of Shoulder and Elbow Surgery.;28(9):1685–1691.

Nizinski J, Kaczmarek A, Antonik B, *et al.* (2024) *'Reliability of glenoid measurements performed using Multiplanar Reconstruction (MPR) of Magnetic Resonance (MRI) in patients with shoulder instability.' International Orthopaedics*.;48(8):2129–2136.

Sanchez-Sotelo J, Berhouet J, Chaoui J, *et al.* (2024) *'Validation of mixed-reality surgical navigation for glenoid axis pin placement in shoulder arthroplasty using a cadaveric model.'* Journal of Shoulder and Elbow Surgery.;33(5):1177–1184.

Stefaniak J, Lubiatowski P, Kubicka AM, Wawrzyniak A, Wałecka J, Romanowski L. (2020) *'Clinical and radiological examination of bony-mediated shoulder instability.'* EFORT *Open Reviews*.;5(11):815–827.

Stefaniak J, Kubicka AM, Wawrzyniak A, Romanowski L, Lubiatowski P. (2020) *'Reliability of humeral head measurements performed using two- and three-dimensional computed tomography in patients with shoulder instability.'* International Orthopaedics.;44(10):2049–2056.

Tanji A, Nagura T, Iwamoto T, *et al.* (2022) *'Total elbow arthroplasty using an augmented reality–assisted surgical technique.'* Journal of Shoulder and Elbow Surgery.;31(1):175–184.

Verborgt O, De Smedt T, Vanhees M, *et al.* (2011) *'Accuracy of placement of the glenoid component in reversed shoulder arthroplasty with and without navigation.'* Journal of Shoulder and Elbow Surgery.;20(1):21–26.

Verhey JT, Haglin JM, Verhey EM, Hartigan DE. (2020) *'Virtual, augmented, and mixed reality applications in orthopedic surgery.'* The International Journal of Medical Robotics and Computer Assisted Surgery.;16(2).

Wawrzyniak A, Harasymczuk M, Lubiatowski P. (2022) *'Shoulder arthropathy secondary to syringomyelia – new x-ray classification of shoulder degeneration.'* Issues of Rehabilitation, Orthopaedics, Neurophysiology and Sport Promotion – IRONS.;39:7–20.

Yanni DS, Ozgur BM, Louis RG, *et al.* (2021) *'Real-time navigation guidance with intraoperative CT imaging for pedicle screw placement using an augmented reality head-mounted display: a proof-of-concept study.'* Neurosurgical Focus.;51(2):E11.

Zhou J, Zhong B, Qu R, *et al.* (2022) *'Anatomic measurement of osseous parameters of the glenoid.'* Scientific Reports.;12(1).

Zumstein MA, Pinedo M, Old J, Boileau P. (2019) *'Problems, complications, reoperations, and revisions in reverse total shoulder arthroplasty: A systematic review.'* Journal of Shoulder and Elbow Surgery.;20(1):146–157.