Short communication

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Real-time ultrasound-guided thoracentesis simulation using an optical see-through head-mounted display: a proof-of-concept study

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Abstract

Aim: This study aimed to examine the feasibility and potential benefits of an optical see-through head-mounted display (OST-HMD) during real-time ultrasound-guided thoracentesis simulations. **Material and methods:** Six physicians performed a thoracentesis simulation using an OST-HMD and a wireless image transmission system. The time required, puncture needle visibility, pleural fluid collection success rate, and head movement during the procedure using a smart glass equipped with an inertial measurement unit were all recorded and compared with and without the HMD. **Results:** Study participants successfully extracted effusions in all procedures. The use of OST-HMD did not significantly affect the time of the procedure, but notably decreased the horizontal and vertical head movements during the procedure. **Conclusions:** The study demonstrated the feasibility of using an OST-HMD in a simulated real-time ultrasound-guided thoracentesis procedure and showed the potential of HMD in thoracentesis to improve ergonomics and accuracy. Further research is necessary to confirm these findings.

Introduction

Thoracentesis is a percutaneous procedure where pleural fluid is removed either through a needle or a small-bore catheter to determine the cause of effusion and relieve respective symptoms, such as dyspnea. Pneumothorax, procedure failure, and hemorrhage are among the potential complications of thoracentesis. Ultrasound helps to identify organs and pleural fluid, which determines the appropriate puncture site. Ultrasound-guided pleural aspiration has been associated with a lower rate of procedure failure and complications. The complication rate of pneumothorax during thoracentesis is reported to be 5.7%–15% without ultrasound and 2.7%–3.6% with ultrasound[1]. Ultrasound is used in thoracentesis either by marking the ultrasonically determined puncture site in advance or by ultrasound-guided puncture in real time. Several studies have revealed fewer pneumothorax complications in real-time ultrasound-guided thoracentesis than in ultrasound-marked procedure[2,3]. Therefore, the British Thoracic Society guideline strongly recommends thoracic ultrasound guidance for all pleural procedures for pleural fluid[1]. A physician must alternate between looking at the puncture site and the ultrasound display at a distance when performing the puncture while referring to the ultrasound image in real time, and it could potentially influence the physician's performance and safety of the procedure. The optical see-through head-mounted display (OST-HMD) allows the physician to view images on a monitor in front of him or her, while keeping both hands free, which is a promising solution that allows simultaneous viewing of the procedure site and ultrasound images[4]. However, there have been no reports examining the usefulness of HMDs in ultrasound-guided thoracentesis. Therefore, this study aimed to investigate the feasibility and potential benefits of OST-HMD in real-time ultrasound-guided thoracentesis simulation.

Methods

HMD device system and ultrasound equipment

An HMD, Moverio BT-35E (Seiko Epson Corp., Nagano, Japan), and a wireless imaging transmission system, GV-200 (Inbyte Co., ltd, Tokyo, Japan), were used for the thoracentesis simulation (Sup-

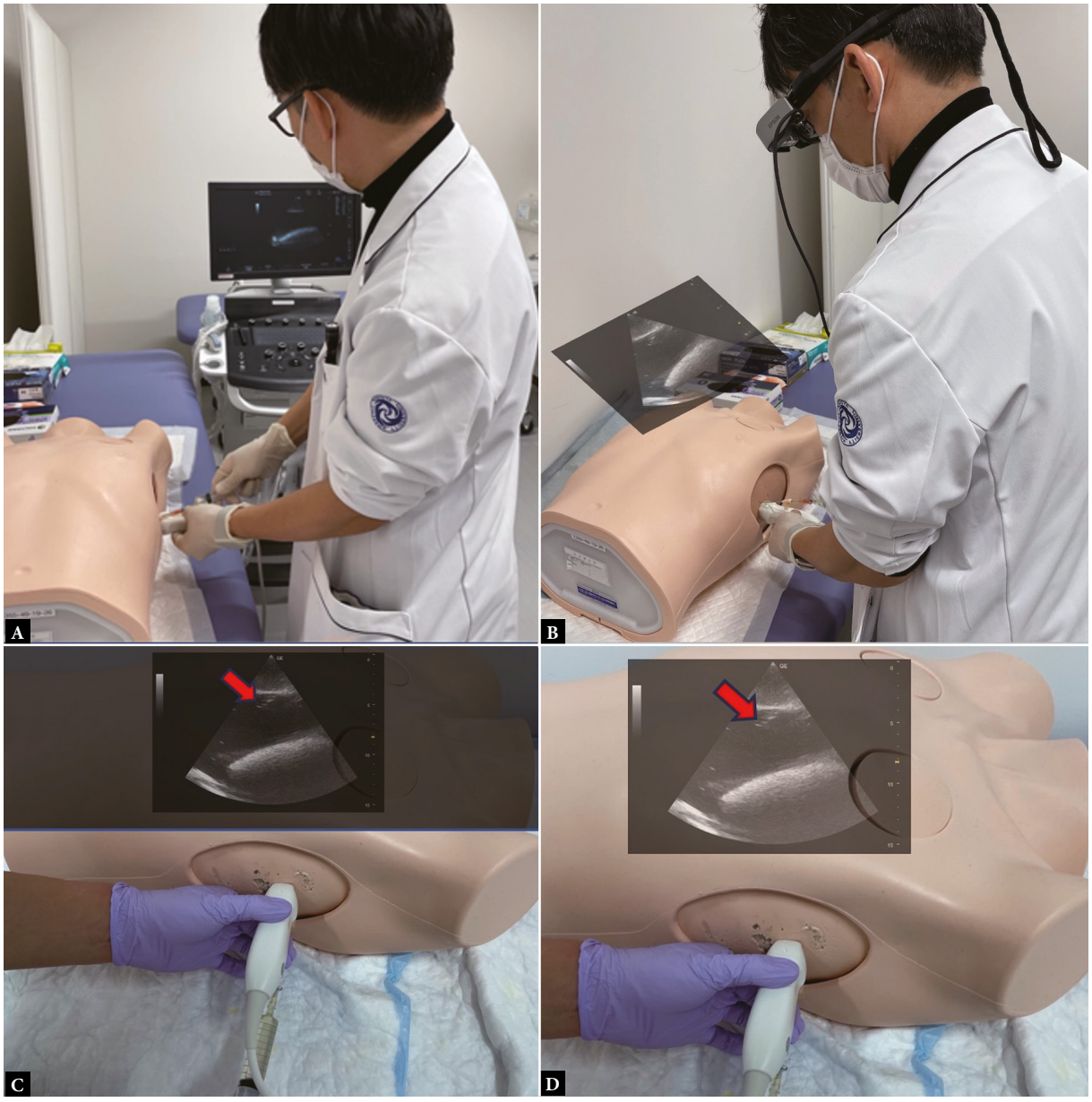

Fig. 1. *Real-time ultrasound-guided thoracentesis simulation using Moverio BT-35E and JINS MEME Glasses.* **A.** *The procedure refers to the standard ultrasound image display.* **B.** *The procedure refers to Moverio BT-35, showing a virtual inset image of the ultrasound screen.* **C, D.** *Virtual image of operator's visualization while wearing Moverio BT-35E, with (***C***) and without (***D***) flip-up shades. The red arrow indicates the location of the needle used for thoracentesis*

plementary Fig. S1). Moverio BT-35E is a binocular, see-through HMD, primarily used as an external device display. It generates images with a size equivalent to a 40-inch display at a virtual viewing distance of 2.5 meters. The echograph output is wirelessly transmitted by the GV-200 system, and the OST-HMD displays the received image. The communication delay of the GV-200 is approximately 0.07 s. Versana Balance echograph equipped with a 2–5 MHz convex array probe (GE Healthcare, Chicago, IL, USA) was used for the thoracentesis procedure. JINS MEME smart glasses (Jins Inc., Tokyo, Japan) equipped with a 6-axis inertial measurement unit, accelerometer, and gyroscope were used to measure head movements[5]. Data obtained with JINS MEME were transferred to the computer via Bluetooth and exported to a CSV file.

Thoracentesis simulation using a training model

Six physicians, each with a different experience in thoracentesis, participated in the simulation. The institutional review board approved this study (Approval No. 2022-0234). All participating physicians gave their signed informed consent for the study. Each participant performed thoracentesis four times in total, twice with and without the HMD, respectively, using a thoracentesis training model (Limbs & Things Ltd., Bristol, United Kingdom) (Fig. 1 A and B). The physicians wearing the OST-HMD could view the procedural site and their hands below the ultrasound image projected on the virtual screen. This could be done either with or without using the flip-up shades, as shown in Fig. 1 C and D. The time required, punc-

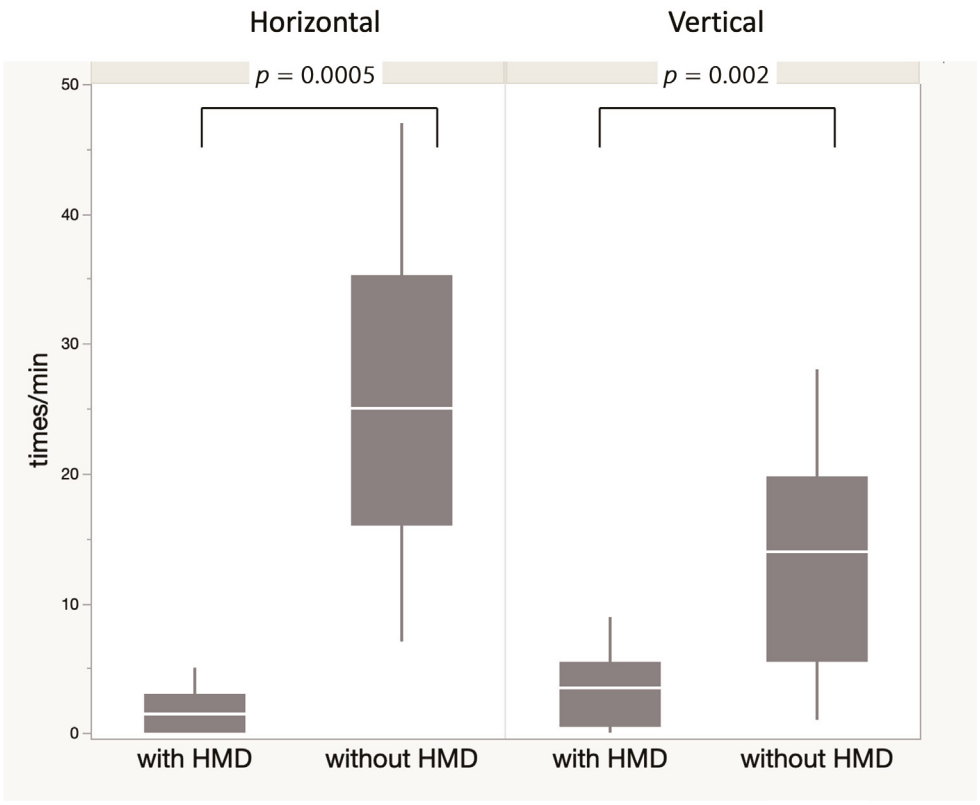

Fig. 2. *Box-and-whisker plots comparing the median values of head movements (horizontal and vertical) in times per minute for two groups: with and without a head-mounted display*

ture needle visibility, and pleural fluid extraction success rate were recorded for each procedure. Additionally, JINS MEME Glasses, which can be worn simultaneously with the OST-HMD, were worn to measure head movements during all procedures.

Statistical analysis

Variables with and without HMDs were compared using the Wilcoxon signed-rank test. A p-value of <0.05 was considered statistically significant. All statistical calculations were performed using JMP Pro v16.1.0 (SAS Institute Inc.).

Results

Participants successfully extracted effusions regardless of HMD used in all procedures. The needle was visible in all but one case each in the HMD and control groups. The procedure time was not significantly different with and without HMD (72 s and 68 s, respectively, $p = 0.719$).

The median horizontal and vertical head movements without HMD were 25 times/min (range: 7–47) and 14 times/min (range: 1–42), respectively. These were significantly reduced to 1.5 times/min (range: 0–8) and 3.5 times/min (range: 0–9) with HMD ($p = 0.0005$, and $p = 0.002$) (Fig. 2). No participant interrupted the procedure or reported any symptoms of discomfort associated with wearing the OST-HMD or adverse events such as vertigo or nausea during the procedure.

Discussion

To our best knowledge, this is the first report proposing OST-HMD application for image reference during real-time ultrasound-guided thoracentesis. A review of surgical HMD applications demonstrated image guidance and augmented reality as the most frequently reported HMD applications, with see-through HMDs, such as Moverio BT-35E, being the most frequently reported surgery-related application[6]. In a previous study, we also simulated and reported on the feasibility of using Moverio BT-35E for image reference purposes during flexible bronchoscopy[7].

Previous studies have demonstrated a significant reduction in head movements with an OST-HMD during real-time ultrasound-guided aspiration in the neck region[8], and found that OST-HMD used during ultrasound-guided breast tumor puncture simulation for medical students reduces the time to puncture and stress on the participants[9]. In this study, detailed head movement data was collected using motion-sensor-equipped smart glasses, and it was confirmed that the use of the HMD significantly reduced vertical and horizontal head movements in real-time ultrasound-guided thoracentesis simulation. Reduced head movements in our HMD group indicate the potential of the device to minimize physical strain and improve the procedure's ergonomic aspects. Additionally, less head movement may reduce the risk of an unsteady hand and subsequent procedure inaccuracy, which is a concept warranting future investigation.

The exploratory nature of this study and small sample size necessitate cautious interpretation. Future studies should aim for a bigger

sample size and a diverse range of practitioners, from novice to experienced. Moreover, this approach would be best evaluated in real-world clinical settings with actual patients.

In conclusion, this proof-of-concept study has demonstrated the feasibility of using an OST-HMD in simulated real-time ultrasound-guided thoracentesis procedures. HMD potentially helps reduce complications associated with thoracentesis by facilitating focused attention on the procedure site. However, further research is needed to validate these findings in a broader context and assess the effect of the technique on patient outcomes.

Conflict of interest and funding

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Author contributions

Original concept of study: SO, TM, MF. Writing of manuscript: SO. Analysis and interpretation of data: SO, TM, TI, MM, KI, MI, MF. Final approval of manuscript: SO, TM, MS, TI, MM, KI, MI, MF. Collection, recording and/or compilation of data: SO, TM, MS, TI. Critical review of manuscript: KI, MI, MF.

References

1. Havelock T, Teoh R, Laws D, Gleeson F: Pleural procedures and thoracic ultrasound: british thoracic society pleural disease guideline 2010. Thorax 2010; 65: 61–76. doi: 10.1136/thx.2010.137026.
2. Rodriguez Lima DR, Yepes AF, Birchenall Jiménez CI, Mercado Díaz MA, Pinilla Rojas DI: Real-time ultrasound-guided thoracentesis in the intensive care unit: prevalence of mechanical complications. Ultrasound J 2020; 12: 25. doi: 10.1186/s13089-020-00172-9.
3. Helgeson SA, Fritz AV., Tatari MM, Daniels CE, Diaz-Gomez JL: Reducing iatrogenic pneumothoraces: using real-time ultrasound guidance for pleural procedures. Crit Care Med 2019; 47: 903–909. doi: 10.1097/CCM.0000000000003761.
4. Qian L, Barthel A, Johnson A, Osgood G, Kazanzides P, Navab N *et al.*: Comparison of optical see-through head-mounted displays for surgical interventions with object-anchored 2D-display. Int J Comput Assist Radiol Surg 2017; 12: 901–910. doi: 10.1007/s11548-017-1564-y.
5. JINS MEME: JINS MEME Glasses Specifications. Available online: https://jins-meme.com/en/researchers/specifications/ (accessed on 22 June 2023).
6. 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. doi: 10.1177/1553350619871787.
7. Okachi S, Ito T, Sato K, Iwano S, Shinohara Y, Itoigawa H *et al.*: Virtual bronchoscopy-guided transbronchial biopsy simulation using a head-mounted display: a new style of flexible bronchoscopy. Surg Innov 2022; 29: 811–813. doi: 10.1177/15533506211068928.
8. Kaneko N, Tsunoda M, Mitsuhashi M, Okubo K, Takashima T, Sehara Y *et al.*: Ultrasound-guided fine-needle aspiration in the neck region using an optical see-through head-mounted display: a randomized controlled trial. J Ultrasound Med 2017; 36: 2071–2077. doi: 10.1002/jum.14237.
9. Shimizu T, Oba T, Ito K: The advantage of using an optical see-through head-mounted display in ultrasonography-guided needle biopsy procedures: a prospective randomized study. J Clin Med 2023; 12: 512. doi: 10.3390/jcm12020512.