ANESTHESIOLOGY

Smart Glasses for Radial Arterial Catheterization in Pediatric Patients: A Randomized Clinical Trial

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EDITOR'S PERSPECTIVE

What We Already Know about This Topic

- Although ultrasound is becoming commonplace to guide arterial cannulation in children, there is still an appreciable failure to succeed on the first pass
- Head-mounted displays are a new technology finding novel applications in medical practice

What This Article Tells Us That Is New

- In a randomized controlled trial comparing radial artery cannulation in children, a head-mounted display, which projects the ultrasound screen in front of the operator's eye, had a greater first-attempt success rate and shorter times to cannulation compared to conventional ultrasound use

ABSTRACT

Background: Hand–eye coordination and ergonomics are important for the success of delicate ultrasound-guided medical procedures. These can be improved using smart glasses (head-mounted display) by decreasing the head movement on the ultrasound screen. The hypothesis was that the smart glasses could improve the success rate of ultrasound-guided pediatric radial arterial catheterization.

Methods: This prospective, single-blinded, randomized controlled, single-center study enrolled pediatric patients (n = 116, age less than 2 yr) requiring radial artery cannulation during general anesthesia. The participants were randomized into the ultrasound screen group (control) or the smart glasses group. After inducing general anesthesia, ultrasound-guided radial artery catheterization was performed. The primary outcome was the first-attempt success rate. The secondary outcomes included the first-attempt procedure time, the overall complication rate, and operators' ergonomic satisfaction (5-point scale).

Results: In total, 116 children were included in the analysis. The smart glasses group had a higher first-attempt success rate than the control group (87.9% [51/58] *vs.* 72.4% [42/58]; $P = 0.036$; odds ratio, 2.78; 95% CI, 1.04 to 7.4; absolute risk reduction, –15.5%; 95% CI, –29.8 to –12.8%). The smart glasses group had a shorter first-attempt procedure time (median, 33 s; interquartile range, 23 to 47 s; range, 10 to 141 s) than the control group (median, 43 s; interquartile range, 31 to 67 s; range, 17 to 248 s; $P = 0.007$). The overall complication rate was lower in the smart glasses group than in the control group (5.2% [3/58] *vs.* 29.3% [17/58]; $P = 0.001$; odds ratio, 0.132; 95% CI, 0.036 to 0.48; absolute risk reduction, 24.1%; 95% CI, 11.1 to 37.2%). The proportion of positive ergonomic satisfaction (4 = good or 5 = best) was higher in the smart glasses group than in the control group (65.5% [38/58] *vs.* 20.7% [12/58]; $P < 0.001$; odds ratio, 7.3; 95% CI, 3.16 to 16.8; absolute risk reduction, –44.8%; 95% CI, –60.9% to –28.8%).

Conclusions: Smart glasses-assisted ultrasound-guided radial artery catheterization improved the first-attempt success rate and ergonomic satisfaction while reducing the first-attempt procedure time and overall complication rates in small pediatric patients.

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It is becoming more common to use ultrasonography for vascular access because of its improved efficacy and safety[1–3]; however, peripheral arterial catheterization is still difficult in small pediatric patients because of their small vessel size.[4] Currently, the first-attempt success rate of radial arterial catheterization by well skilled medical personnel is 48 to 83% under ultrasound guidance in small pediatric patients.[4–7]

For successful ultrasound-guided vascular access, knowledge of anatomy and coordination skills between the hands, eyes, procedure field, and ultrasound screen are required.[8] During the procedure, frequent head and eye movements between the procedure field and the ultrasound screen are necessary to align the position of the target vessel, ultrasound probe, and tip of the needle. This extra head and eye movement increases procedure time and disturbs grip on the ultrasound probe, potentially causing loss of the image of the target vessel and inappropriate change in the needle direction.[9] If the procedure time is prolonged, this repetitive movement increases the operator's musculoskeletal fatigue. In a recent survey of pediatric, obstetric, and cardiothoracic anesthesiologists, 98.4% of respondents reported that they had work-related musculoskeletal pain during the past 12 months.[10]

This article is featured in "This Month in Anesthesiology," page A1. This article is accompanied by an editorial on p. 562. This article has a visual abstract available in the online version.

Submitted for publication March 31, 2021. Accepted for publication June 25, 2021. Published online first on August 5, 2021. From the Department of Anesthesiology and Pain Medicine, Seoul National University Hospital, Seoul National University College of Medicine, Seoul, Republic of Korea (Y.-E.J., S.-H.J., E.-H.K., J.-H.L., H.-S.K., J.-T.K.); and the Department of Anesthesiology and Pain Medicine, Konyang University Hospital, Daejeon, Republic of Korea (S.-A.C.).

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Recently, head-mounted displays such as smart glasses have been widely used in medical practice.[9,11] With their connection to the ultrasound machine, smart glasses project the ultrasound screen right in front of the operator's eyes so that the operator can easily see both the procedure field and ultrasound screen simultaneously without head and eye movement. Previous studies have shown the effect of head-mounted display on head and neck movement during adult vascular access using a central venous catheterization simulator and a peripheral vascular phantom.[12,13] However, there have been no study on the use of smart glasses for arterial catheterization in pediatric patients. Smart glasses allow the practitioner to coordinate the ultrasound screen, ultrasound probe, and catheter needle without head movement. Considering the small internal diameter of the peripheral artery and other associated technical difficulties,[4] the application of smart glasses can improve the success rate of peripheral arterial catheterization in small pediatric patients. Therefore, we hypothesized that the use of smart glasses would increase the first-attempt success rate of radial arterial catheterization compared with the conventional ultrasound-guided catheterization in small pediatric patients.

Materials and Methods

Participants and Study Design

This prospective, single-blinded, parallel-arm, randomized controlled trial was approved by the Seoul National University Hospital Institutional Review Board (Chairperson Prof. Byung-Joo Park) on March 30, 2020 (approval No. H-2002-149-1105). The trial was registered before patient enrollment at ClinicalTrials.gov (NCT04329026; registered March 29, 2020, principal investigator Prof. Jin-Tae Kim) and was conducted at a single-site, tertiary teaching children's hospital in the Republic of Korea to evaluate the superiority of smart glasses over the conventional ultrasound screen. The investigators evaluated the eligibility of the pediatric patients and individually approached their parents or guardians to obtain written informed consent for enrollment before surgery. We included pediatric patients (less than 2 yr old) scheduled for elective surgery under general anesthesia who required invasive arterial blood pressure monitoring or blood sampling. Patients with a recent history of radial artery puncture, wound, infection, hematomas at the arterial cannulation site, peripheral vascular disease, insufficient collateral circulation, and unstable vital signs, including hypotension or arrhythmia, were excluded from the study.

Randomization

Participants were assigned to either the smart glasses group or the ultrasound screen (control) group at an allocation ratio of 1:1 by block randomization. Group allocations were generated using a computer-generated randomization software (https://www.randomizer.org) and sealed in sequentially numbered opaque envelopes. Each envelope was opened by a trained study nurse before the induction of general anesthesia. The operators of the ultrasound and radial artery cannulation were not blinded to the patients' group allocation. In contrast, another anesthesiologist who measured the depth and diameter of the radial artery from the stored images was blinded to the group allocation.

Application of Smart Glasses on the Ultrasound Machine

The binocular Moverio BT-35E (V11H935051, Seiko Epson Co., Japan) was used as a head-mounted display. The interface box of the smart glasses was connected to an E-CUBE i7 unit (ALPINION Medical Systems Co., Korea) using a digital visual interface to a high-definition multimedia interface cable to offer a simultaneous screen of the ultrasound screen without time delay. Because all operators had no experience of using the head-mounted display for ultrasound-guided arterial catheterization before the current study, they practiced needle manipulation on Blue Phantom pediatric 4 vessel ultrasound training block model (CAE Healthcare, USA) with the head-mounted display for approximately 10 min in addition to training for the basic operation method of the device.

Anesthesia and Ultrasound-guided Radial Artery Cannulation

After general anesthesia, the operators chose the radial artery at their discretion, and color Doppler ultrasound was performed to ensure patency of the radial and ulnar arteries. The patient's wrist was slightly extended over a roll to maintain the position during the procedure. Hand hygiene was performed before gloving, and a sterile barrier was placed. Skin preparation was performed using an alcohol-based chlorhexidine disinfectant.

Ultrasound-guided radial arterial cannulation was performed by one of four pediatric anesthesiologists (Y.-E.J., S.-A.C., S.-H.J., and J.-T.K.) who had performed more than 100 arterial cannulations in infants and pediatric patients. An E-CUBE i7 unit with a high frequency (8 to 17 MHz) and a linear hockey stick–shaped IO8-17T probe (Alpinion Medical Systems Co.) with a small footprint (31 × 6 mm) was used. In the control group, each operator could determine the location of the ultrasound screen, the height of the surgical table, and the posture during the procedure that were most familiar to him/her to increase the success rate. In the smart glasses group, the ultrasound machine was located behind the operator to remove the distraction, and the operator was not allowed to see the ultrasound screen during the procedure (fig. 1).

A short-axis view image was stored to measure the diameter and depth of the radial artery before cannulation. Arterial cannulation was performed using the long-axis

view in-plane technique with a 24-gauge, 0.7-mm × 1.9-cm over-the-needle catheter (Jelco, Smiths Medical, USA). The operator could use only the transfixion technique according to their preferences to eliminate the influence of other techniques on the success rate and procedure time in the study population.

Cannulation was considered complete when an invasive blood pressure waveform appeared on the monitor. If cannulation was unsuccessful within the second attempt or within 10 min, the case was considered a failure. After the failure, the contralateral radial artery or posterior tibial artery, dorsalis pedis artery, or the ipsilateral radial artery was used for cannulation. The procedure time of arterial cannulation was defined as the time interval from the first skin puncture by the over-the-needle catheter to the confirmation of the invasive blood pressure waveform on the monitor, irrespective of the attempt number of the arterial cannulation. Then, the diameter and depth of the radial artery and the occurrence of procedure-related complications, such as hematoma or vasospasm, were evaluated by ultrasonography. The function of the catheter was evaluated until the end of the anesthesia.

Statistical Analyses and Outcome Variables

Data on age, sex, weight, American Society of Anesthesiologists physical status classification, and type of surgery were collected from each patient. The primary endpoint was the first-attempt success rate of radial artery cannulation. The number of attempts was the number of skin punctures required for radial arterial cannulation. Successful artery cannulation was confirmed by an invasive blood pressure waveform on the monitor.

The secondary endpoints included the procedure time to success within the first and second attempts, the second-attempt success rate (within 10 min), the overall procedure time, and the overall complication rate, including hematoma, vasospasm (more than 25% decrease in the diameter after cannulation without intraarterial hematoma), and distal ischemia. The incidence of catheter malfunction, which was defined as the monitoring or sampling failure despite flushing the catheter or changing the catheter dressing, was also measured during anesthesia. The overall procedure time and overall number of arterial cannulation attempts were recorded. An anesthesiologist (J.-H.L.) blinded to the group allocation measured the diameter and depth of the radial

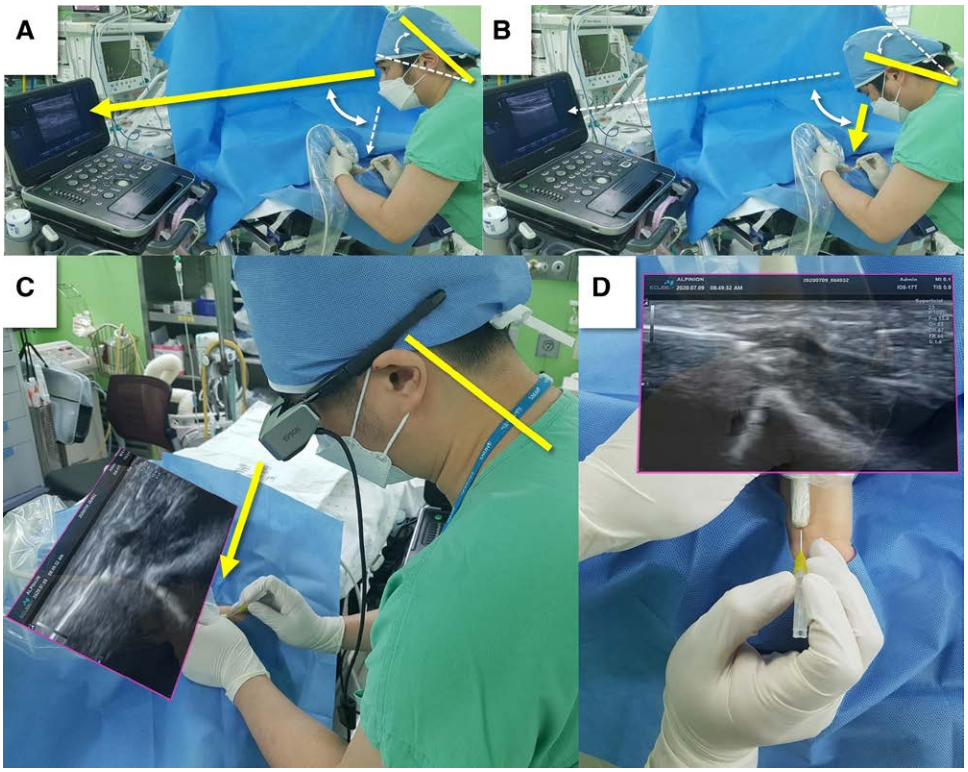

Fig. 1. Ultrasound-guided radial artery cannulation in the control group (*A*, *B*) and the smart glasses group (*C*, *D*). The *thick yellow lines* indicate the operator's cervical spine and gaze, and the *thin white lines* and *arrows* indicate the range of motion. (*A*) The operator is looking at the ultrasound screen to find the radial artery. (*B*) The operator moved his head, neck, and eyes to look at the procedure field (cannulation site). (*C*) With smart glasses, the operator can focus on the ultrasound screen and procedure field (cannulation site) simultaneously without moving his head. (*D*) Real-time ultrasound screen by smart glasses over the procedure field in the operator's view.

artery before and after cannulation using the stored ultrasound images.

To assess musculoskeletal fatigue during the procedure, the operators' ergonomic satisfaction was recorded on a 5-point scale, where 1 = worst (the procedure was halted because of musculoskeletal pain or very hard to obtain hand–eye coordination and alignment); 2 = poor (the procedure was prolonged because of musculoskeletal discomfort or poor hand–eye coordination and alignment); 3 = acceptable (the procedure was done with the usual degree of musculoskeletal discomfort and hand–eye coordination and alignment); 4 = good (the procedure was done with less musculoskeletal discomfort and better hand–eye coordination and alignment); and 5 = best (the procedure was successful with minimal musculoskeletal discomfort and significantly enhanced hand–eye coordination and alignment). The proportion of positive operators' ergonomic satisfaction (4 = good or 5 = best) was also calculated.

The sample size was calculated based on previous studies, and the first-attempt success rate of ultrasound-guided radial artery cannulation was 48 to 65% in children less than 2 yr old.[4,5] The authors assumed that the first-attempt success rate for radial artery cannulation would be 80 and 55% in the smart glasses and control groups, respectively. Assuming a power of 0.8 for the 25% difference, with a two-sided α of 0.05, the sample size for each group was calculated as 52. Considering the 10% attrition rate, 116 patients were recruited.

All data are expressed as means ± SD or median (interquartile range), unless otherwise specified. The distribution was tested using the Shapiro–Wilk normality test. The baseline characteristics of the study population were evaluated using the independent *t* test and Mann–Whitney U test. The primary outcome was evaluated using the χ^2 test, whereas secondary outcomes were evaluated using the χ^2 test, independent *t* test, and Mann–Whitney U test. Using the proportional hazards assumption, the Kaplan–Meier analysis of the overall procedure time to successful cannulation of the chosen radial artery was performed, and the data were compared between the groups using the log-rank test. Statistical analyses were performed using IBM SPSS Statistics 22 (SPSS Inc., IBM Corporation, USA) and *R* software (version 3.4.4; R Foundation for Statistical Computing, Austria); the package "survival" was used for the Kaplan–Meier survival curves. Statistical significance was defined as a two-sided *P* value of <0.05.

Results

From April 7 to December 1, 2020, 116 pediatric patients were screened, recruited, and enrolled. No patient was excluded, and 116 patients were randomized into the smart glasses (n = 58) and control (n = 58) groups (fig. 2). No study protocol violations were reported during the entire study period, and there was no missing data for the primary and secondary outcomes.

The baseline patient characteristics are summarized in table 1. Cardiac surgery was the most commonly performed surgery in both groups, followed by neurosurgery and general surgery. Four anesthesiologists (Y.-E.J., S.-A.C., S.-H.J., and J.-T.K.) performed radial artery cannulation in 58 (29 in the smart glasses group and 29 in the control group), 19 (10 in the smart glasses group and 9 in the control group), 22 (11 in the smart glasses group and 11 in the control group), and 17 (8 in the smart glasses group and 9 in the control group) cases, respectively.

The primary outcome, which is the first-attempt success rate of radial artery cannulation, was significantly higher in the smart glasses group than in the control group (87.9% [51 of 58] *vs.* 72.4% [42 of 58]; $P = 0.036$; odds ratio, 2.78; 95% CI, 1.04 to 7.4; absolute risk reduction, −15.5%; 95% CI, −29.8 to −12.8%). The procedure time to the first-attempt success was shorter in the smart glasses group (median, 33 s; interquartile range [interquartile range], 23 to 47 s; range, 10 to 141 s) than in the control group (median, 43 s; interquartile range, 31 to 67 s; range, 17 to 248 s; P=0.007).

The second-attempt success rate of the radial artery was higher in the smart glasses group than in the control group (96.6% [56 of 58] *vs.* 81.0% [47 of 58]; $P = 0.008$; odds ratio, 6.6; 95% CI, 1.38 to 31.1; absolute risk reduction, −15.5%; 95% CI, −26.6 to −4.4%). The procedure time to success within the second attempt was shorter in the smart glasses group (median, 35 s; interquartile range, 23 to 56 s; range, 10 to 420 s) than in the control group (median, 50 s; interquartile range, 33 to 99 s; range, 17 to 355 s; $P = 0.012$). The use of the transfixion technique was not statistically different between the smart glasses and control groups (20.7% [12 of 58] *vs.* 20.7% [12 of 58]; $P > 0.999$).

The overall procedure time of arterial cannulation was shorter in the smart glasses group (median, 37 s; interquartile range, 24 to 57 s; range, 10 to 547 s) than in the control group (median, 58 s; interquartile range, 39 to 251 s; range, 17 to 981 s; $P < 0.001$). The overall number of attempts was smaller in the smart glasses group (median, 1; interquartile range, 1 to 1; range, 1 to 3) than in the control group (median, 1; interquartile range, 1 to 2; range, 1 to 5; $P = 0.027$).

The overall complication rate was lower in the smart glasses group than in the control group (5.2% [3 of 58] *vs.* 29.3% [17 of 58]; $P = 0.001$; odds ratio, 0.132; 95% CI, 0.036 to 0.48; absolute risk reduction, 24.1%; 95% CI, 11.1 to 37.2%), including hematoma (3.4% [2 of 58] *vs.* 20.7% [12 of 58]; $P = 0.004$; odds ratio, 0.137; 95% CI, 0.029 to 0.64; absolute risk reduction, 17.2%; 95% CI, 5.8 to 28.7%). Catheter malfunction occurred in 6 of 58 (10.3%) patients in the control group and 0 of 58 (0%) in the smart glasses group ($P = 0.012$; odds ratio, 0.47; 95% CI, 0.388 to 0.58; absolute risk reduction, 10.3%; 95% CI, 2.5 to 18.2%). Between the two groups, there was no difference in the

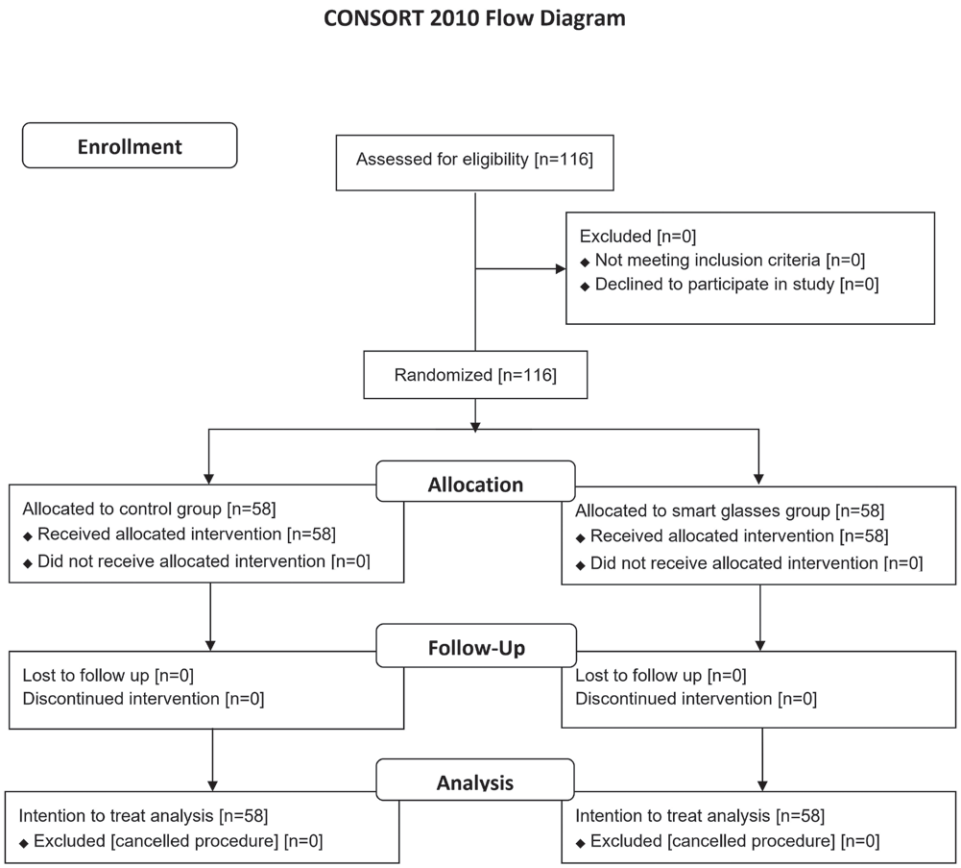

Fig. 2. The Consolidated Standards of Reporting Trials (CONSORT) flow diagram.

internal diameter and depth of the radial artery before and after cannulation. The proportion of positive ergonomic satisfaction (4 = good or 5 = best) was higher in the smart glasses group (65.5% [38 of 58] *vs.* 20.7% [12 of 58]; $P < 0.001$; odds ratio, 7.3; 95% CI, 3.16 to 16.8; absolute risk reduction, −44.8%; 95% CI, −60.9 to −28.8%; table 2). Kaplan–Meier analysis showed that the overall procedure time to successful cannulation of the chosen radial artery was shorter in the smart glasses group than in the control group ($P < 0.0001$; fig. 3).

Discussion

The primary finding of this study is that the use of smart glasses during radial artery cannulation increased the first-attempt success rate in small pediatric patients. We also found that the use of smart glasses increased the positive ergonomic satisfaction and decreased the number of cannulation attempts, procedure time, and procedure-related complications.

In pediatric patients with small body sizes, the space allowed for the anesthetic procedure is limited, and the position and posture of the operator must be adjusted

Table 1. Patient Characteristics of Ultrasound Monitor (Control) Group and Smart Glasses Group for Radial Artery Cannulation

	Control (n = 58)	Smart Glasses (n = 58)
Age, months	7.5 ± 5.7 (6.0 to 8.9)	7.5 ± 5.8 (5.9 to 9.0)
Male, %	26 (44.8%)	30 (51.7%)
Female, %	32 (55.2%)	28 (48.3%)
Weight, kg	7.4 ± 2.7 (6.7 to 8.1)	7.7 ± 2.6 (7.0 to 8.4)
Gestational age less than 50 weeks	12 (20.7%)	13 (22.4%)
ASA physical status		
I	6 (10.3%)	4 (6.9%)
II	32 (55.2%)	28 (48.3%)
III	19 (32.8%)	25 (43.1%)
IV	1 (1.7%)	1 (1.7%)
Surgery		
Cardiac surgery	30 (51.7%)	33 (57.9%)
Neurosurgery	21 (36.2%)	14 (24.6%)
General surgery	7 (12.1%)	10 (17.5%)

The values are means ± SD (95% CI) or number (proportion).
ASA, American Society of Anesthesiologists.

Table 2. Results of Radial Artery Cannulation in the Ultrasound Monitor (Control) Group and the Smart Glasses Group

Variables	Control (n = 58)	Smart Glasses (n = 58)	Odds Ratio	95% CI of Odds Ratio or Mean Difference	Absolute Risk Reduction (95% CI of Absolute Risk Reduction)	*P* Value
Radial artery cannulation at the first chosen radial artery						
First attempt success rate, %	42 of 58 (72.4)	51 of 58 (87.9)	2.78	1.04 to 7.4	–15.5 (–29.8 to –12.8)	0.036
Procedure time to success within the first attempt, s	43 (31 to 67) [17 to 248]	33 (23 to 47) [10 to 141]	N/A	N/A	N/A	0.007
Second attempt success rate within 10 min, %	47 of 58 (81.0)	56 of 58 (96.6)	6.6	1.38 to 31.1	–15.5 (–26.6 to –4.4)	0.008
Procedure time to success within the second attempt, s	50 (33 to 99) [17 to 355]	35 (23 to 56) [10 to 420]	N/A	N/A	N/A	0.012
Catheter malfunction, %	6 of 58 (10.3)	0 of 58 (0)	0.47	0.388 to 0.58	10.3 (2.5 to 18.2)	0.012
Use of another artery	8 of 58 (13.8)*	2 of 58 (3.4)	0.223	0.045 to 1.10	10.3 (0.3 to 20.4)	0.047
Contralateral radial artery	3 of 58 (5.2)	0 (0)				
Posterior tibial artery	5 of 58 (8.6)	2 of 58 (3.4)				
Dorsalis pedis artery	0 (0)	0 (0)				
Use of the transfixion technique, %	12 of 58 (20.7)	12 of 58 (20.7)	1.00	0.41 to 2.46	0.0 (–14.7 to 14.7)	> 0.999
Overall procedure time of arterial cannulation, s	58 (39 to 251) [17 to 981]	37 (24 to 57) [10 to 547]	N/A	N/A	N/A	< 0.001
Overall number of attempts	1 (1 to 2) [1 to 5]	1 (1 to 1) [1 to 3]	N/A	N/A	N/A	0.027
Overall complication at first chosen radial artery, %	17 of 58 (29.3)	3 of 58 (5.2)	0.132	0.036 to 0.48	24.1 (11.1 to 37.2)	0.001
Vasospasm, %	6 of 58 (10.3)	1 of 58 (1.7)	0.152	0.018 to 1.31	8.6 (0.1 to 17.1)	0.051
Hematoma, %	12 of 58 (20.7)	2 of 58 (3.4)	0.137	0.029 to 0.64	17.2 (5.8 to 28.7)	0.004
Distal ischemia, %	0 (0)	0 (0)	N/A	N/A	N/A	N/A
Radial artery						
Diameter, before cannulation	1.3 ± 0.3 (1.2 to 1.3)	1.3 ± 0.3 (1.2 to 1.3)	N/A	–0.1 to 0.1	N/A	> 0.999
Diameter, after cannulation	1.1 ± 0.3 (1.0 to 1.2)	1.2 ± 0.3 (1.1 to 1.3)	N/A	–0.3 to 0.1	N/A	0.226
Depth, before cannulation	2.6 ± 0.9 (2.4 to 2.9)	2.7 ± 0.8 (2.5 to 2.9)	N/A	–0.4 to 0.2	N/A	0.602
Depth, after cannulation	3.3 ± 1.1 (3.0 to 3.6)	3.1 ± 0.9 (2.9 to 3.4)	N/A	–0.3 to 0.5	N/A	0.550
Operators' ergonomic satisfaction (5-point scale)						< 0.001
1 (Worst)	2 of 58 (3.4)	0 of 58 (0)				
2 (Poor)	16 of 58 (27.6)	3 of 58 (5.2)				
3 (Acceptable)	28 (43.8)	11 of 58 (19.0)				
4 (Good)	7 of 58 (12.1)	12 of 58 (20.7)				
5 (Best)	5 of 58 (13.5)	32 of 58 (55.2)				
Ergonomic satisfaction = 3, 4, 5	40 of 58 (69.0)	55 of 58 (94.8)	8.3	2.28 to 29.9	–25.8 (–39.1 to –12.7)	< 0.001
Ergonomic satisfaction = 4, 5	12 of 58 (20.7)	38 of 58 (65.5)	7.3	3.16 to 16.8	–44.8 (–60.9 to –28.8)	< 0.001

The values are means ± SD (95% CI), median (interquartile range) [range], or number (proportion).

*For three patients in the control group, we used the first chosen radial artery after cannulation failure (more than two attempts or more than 10 min).

N/A, not applicable.

accordingly. Because of their small vessel size, the technical difficulty of vascular access in children is also higher than that in adults. A recent study reported that the mean internal diameter of the radial artery is 1.2 ± 0.3 mm in children aged less than 2 yr, and 37.2% of patients had a radial artery diameter of 1 mm or less.[4] Therefore, sophisticated techniques are required, and minimizing unnecessary head movements is important while maintaining proper hand–eye coordination during the radial artery cannulation in pediatric patients.[8]

Previously, smart glasses, which are alternative video displays for medical practice, decreased the head movement between the ultrasound screen and procedure field in simulated adult vascular access.[12,13] However, smart glasses failed to show any positive effects on success rate, procedure time, and number of attempts. Factors such as small sample size, less experienced participants such as medical students or residents in ultrasound-guided vascular access, low technical difficulty of the central venous catheterization simulator and peripheral vascular phantom, and the time lag of the head-mounted display would have caused negative results.

In the current study, smart glasses without time lag were useful for radial artery cannulation in small pediatric patients performed by well experienced pediatric anesthesiologists. Because the operator can focus on the ultrasound screen and procedure field simultaneously, the first-attempt success rate of radial artery cannulation was increased with less procedure time. Because vasospasm and hematoma are common after failed artery cannulation attempts in pediatric patients,[4] a higher first-attempt success rate might increase the overall success rate and reduce the overall procedure time, number of attempts, complication rate, and catheter malfunction in the smart glasses group.

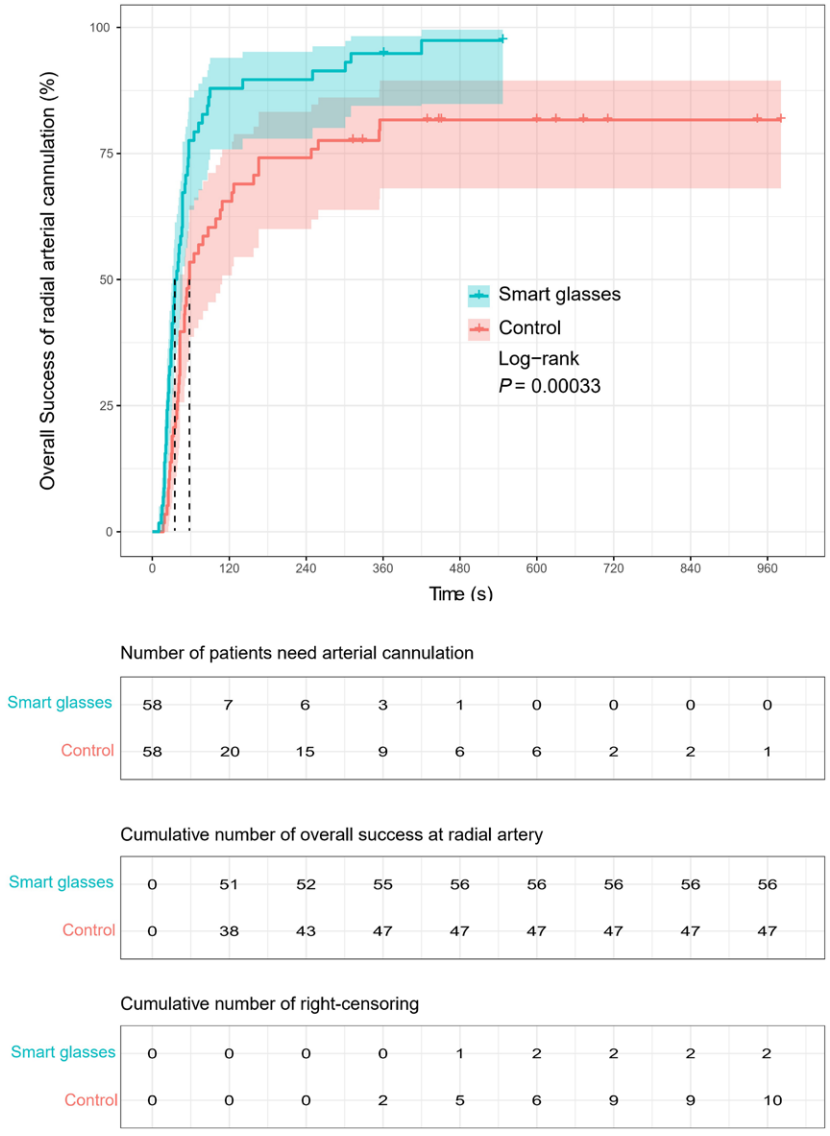

Fig. 3. Kaplan–Meier estimates for the overall procedure time to successful cannulation radial artery within two attempts and 10 min (smart glasses *vs.* control group, $P = 0.00033$). The median cannulation time of the chosen radial artery was 37 s (interquartile range, 24 to 57 s) in the smart glasses group and 58 s (interquartile range, 39 to 257 s) in the control group.

Smart glasses increased positive ergonomic satisfaction by decreasing repetitive head, neck, and eye movements between the ultrasound screen and procedure field during radial arterial cannulation. There are many factors that can be ergonomically improved during medical procedures but are currently considered acceptable. Pediatric anesthesiologists are more likely to report work-related musculoskeletal pain in most of their body parts.[10] Therefore, awareness of body positioning and surrounding operating room environment is important during anesthetic practice.

During surgery, sudden intraarterial or intravenous catheter malfunction or unexpected unstable vital signs that require invasive blood pressure monitoring, blood sampling, or massive fluid resuscitation can occur. However, when surgical drapes and instruments are already applied to small pediatric patients, it is difficult to access the cannulation site and to place the ultrasound machine where the operator can see during the vascular procedure. Therefore, in our clinical experience, the success rate of urgent vascular procedures during surgery is lower than that of elective procedures during the induction of anesthesia. Smart glasses can be an attractive option in urgent bedside procedures in the operating room or intensive care unit because they can project the ultrasound screen without the limit of space or interruption of view.

There are some technical issues associated with smart glasses. First, the weight of smart glasses used in this study (119 g) is heavier than the usual glasses (25 to 50 g). Therefore, long-term use of smart glasses may cause discomfort in the nose, ears, and neck. Additionally, for those who already wear glasses, wearing smart glasses over them can cause discomfort. Second, the Bluetooth technology (version 4.1) of the smart glasses in the current study showed a short time lag (less than 0.1 s) during wireless screen projection. Therefore, we used a digital visual interface to a high-definition multimedia interface cable. A recently introduced Bluetooth technology (version 5.0 and after) allows real-time connection without time lag. Third, the cost of the head-mounted display in the current study (Moverio BT-35E,V11H935051, Seiko Epson Co.) is approximately $800 U.S. dollars. The weight of the device, the delay in the wireless connection, and the cost are limitations of smart glasses.

The current study has some limitations. First, the operators were not blinded to group allocation. Although they were allowed to use their preferred settings to maximize the success rate in the control group, the nonblindness might result in biased estimates of ergonomic satisfaction scores. Second, the number of head or eye movements was not recorded. Because each operator has a familiar posture during radial artery cannulation, it was difficult to quantify the head or eye movement. Instead, the operators' ergonomic satisfaction score was recorded. Third, the time to obtain an ultrasound image of the radial artery was not recorded. Because the operators in the current study were experienced in ultrasound-guided arterial cannulation of pediatric patients, obtaining the image of the radial artery took only a few seconds. Therefore, the effect of smart glasses on pediatric radial artery cannulation by physicians with less experience is unknown. Fourth, the statistical significance of multiple secondary outcomes should be regarded with caution because they were not adjusted for multiplicity. Fifth, secondary outcomes including the diameter and depth of the radial artery and the procedure-related complications were evaluated with ultrasonography, which is operator-dependent and subjective to interpretive error. Finally, the primary outcome could be underpowered because the first-attempt success rate of ultrasound-guided radial arterial cannulation of the control group (72.4%) was higher than the success rate (55%)[4,5] used in the sample size calculation.

In conclusion, smart glasses during radial artery cannulation improve the first-attempt success rate and ergonomic satisfaction and lower procedure time, the number of attempts, and procedure-related complications in pediatric patients aged less than 2 yr.

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Competing Interests

The authors declare no competing interests.

Reproducible Science

Full protocol available at: jintae73@gmail.com. Raw data available at: jintae73@gmail.com.

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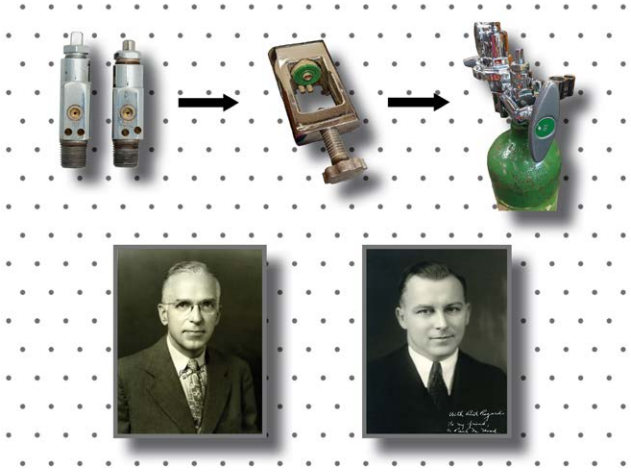
Beyond Woodbridge and Tovell: Connecting the Dots to Anesthetic Safety!



From its very founding, the American Society of Anesthesiologists (ASA) has helped connect the dots between one person's idea and systemic change. An insightful engineer and anesthesiologist, Philip D. Woodbridge, M.D. (1895 to 1978, *lower left*), recognized the hypoxic risk posed by carelessly interchanging compressed gas cylinders on anesthesia machines. With elegant ingenuity, he designed a system of pinned yoke connectors (*upper middle*) to fit into geometrically arranged sockets on the gas cylinders (*upper left*). In 1939, Woodbridge unsuccessfully petitioned equipment manufacturers to incorporate this Pin Index Safety System (*upper right*), which prevented incorrect gas delivery from anesthesia machines. Fourteen years later, Ralph M. Tovell, M.D. (1901 to 1967, *lower right*), a past ASA president, initiated discussions between an ASA delegation and the Compressed Gas Association. The ASA's endorsement bolstered Tovell's negotiations, leading to the approval of the Pin Index Safety System—a milestone in safe anesthetic delivery. (Copyright © the American Society of Anesthesiologists' Wood Library-Museum of Anesthesiology.)

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