Original Article

Effect of local warming for arterial catheterization in adult cardiac surgery: a randomized controlled trial

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Background: The increase in internal diameter (ID) and cross-sectional area (CSA) may facilitate better arterial catheterization. Since an increase in body temperature can cause peripheral vasodilation, we aimed to determine if local warming of the radial artery (RA) catheterization site could improve the success rate of catheterization.

Methods: This randomized, controlled study enrolled 160 patients aged >18 years who were scheduled for heart surgery. They were randomized into non-warming palpation (NP), non-warming ultrasonography-guided (NU), warming palpation (WP), and warming ultrasonography-guided (WU) groups. After induction, the baseline RA ultrasonography images were collected. In the warming groups (WP, WU), local warming was applied on the catheterization site. Before catheterization, the RA ultrasonography images were collected. The primary outcome was the first-attempt success rate. The secondary outcomes included the ID and CSA of the RA and overall complications.

Results: Totally 152 adults were included in the analysis. The first-attempt success rates in each of the four groups were not significantly different (P=0.985). The rates in the non-warming (NP + NU) and warming (WP + WU) groups were also not different (P=0.827). Unlike non-warming group, the warming group had increased ID (3.34±0.78 *vs.* 3.02±0.73 mm; P<0.001) and CSA (6.9±2.8 *vs.* 5.8±2.4 mm^2; P<0.001) compared with baseline.

Conclusions: Local warming for peripheral artery catheterization does not increase the first-attempt success rate in adults undergoing cardiac surgery; however, it can increase the ID and CSA of the RA and prevent vasospasm.

Trial Registration: ClinicalTrials.gov NCT04969692.

Keywords: Cardiac surgical procedure; heating; peripheral arterial catheterizations; radial arteries (RAs); ultrasonography

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Introduction

Peripheral arterial catheterization is one of the most important clinical techniques used for real-time blood pressure monitoring or repeated blood draws. However, first-attempt success rates are decreasing due to multiple factors such as inexperienced operators; small, calcified, and tortuous arteries induced by underlying diseases; and systemic factors of patients such as hypotension, edema, and obesity (1). Moreover, multiple attempts may cause complications, such as bleeding, hematoma, vasospasm, dissection, and occlusion (2,3). To reduce these complications caused such as bleeding, hematoma, vasospasm, dissection, and occlusion by multiple attempts of arterial catheterization, various arterial catheterization techniques have been reported in many studies, particularly those that were guided by ultrasonography (1,3,4). Nevertheless, potential failures may still happen due to inexperienced operators using ultrasonography for arterial catheterization or poor condition of arteries with small diameter, or tortuous pathway.

An increase in body temperature can cause peripheral vasodilation by activating the cholinergic vasodilator system (5,6). Previous studies observed radial artery (RA) vasodilation or resolution of vasospasm under local warming; however, there are only few studies comparing the first-attempt success rate of peripheral arterial catheterization (7-9). Therefore, we aimed to compare the influence of local warming at the RA catheterization site in adult patients undergoing cardiac surgery. We present this article in accordance with the CONSORT reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/rc).

Highlight box

Key findings

- The internal diameter (ID) and cross-sectional area (CSA) of the radial artery (RA) was increased by local warming.

What is known and what is new?

- Potential failures may still happen due to inexperienced operators using ultrasonography for arterial catheterization or poor condition of arteries.
- Local warming does not increase the first attempt success rate of peripheral artery catheterization in adults undergoing cardiac surgery but increases the ID and CSA of the RA and prevents vasospasm.

What is the implication, and what should change now?

- Local warming the area surrounding the artery is easy technique, and can be employed to increase the ID and CSA of the RA for peripheral artery catheterization.

Methods

Participants

This prospective, operator-blinded, randomized controlled trial was approved by the institutional review board of Pusan National University Yangsan Hospital (IRB No. 05-2021-117), and registered at ClinicalTrials.gov (NCT04969692). The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). A total of 160 patients aged >18 years who underwent cardiac surgery with RA catheterization were enrolled, and written informed consent was obtained. Exclusion criteria were: patients with unstable vital signs, pre-existing arterial catheter, and opting for other arteries because of surgical technique. After enrolment, patients with inappropriate ultrasonography images which means the quality of the acquired image is very low, making it difficult to accurately identify the boundary of RA, unstable vital signs during induction of general anesthesia, and initial body temperature over 39 ℃ were excluded from the study.

Randomization

The participants were allocated into non-warming palpation (NP), non-warming ultrasonography-guided (NU), warming palpation (WP), or warming ultrasonography-guided (WU) groups at an allocation ratio of 1:1:1:1 using a randomization software (http://www.randomizer.org). Sequentially numbered, opaque, and sealed envelope that contain the assignments was opened, and the assignment was revealed to the investigator. The anesthesiologist (A) who collected the ultrasonography images and performed RA catheterization was not blinded to the patients' group allocation because (A) can be in contact with the patient's skin. Another anesthesiologist (B) who measured the cross-sectional area (CSA), internal diameter (ID), and depth of the RA from the stored ultrasonography images was blinded to the group allocation.

Intervention

The temperature used for local warming (39 ℃) was based on that from previous studies (7,10). All participants

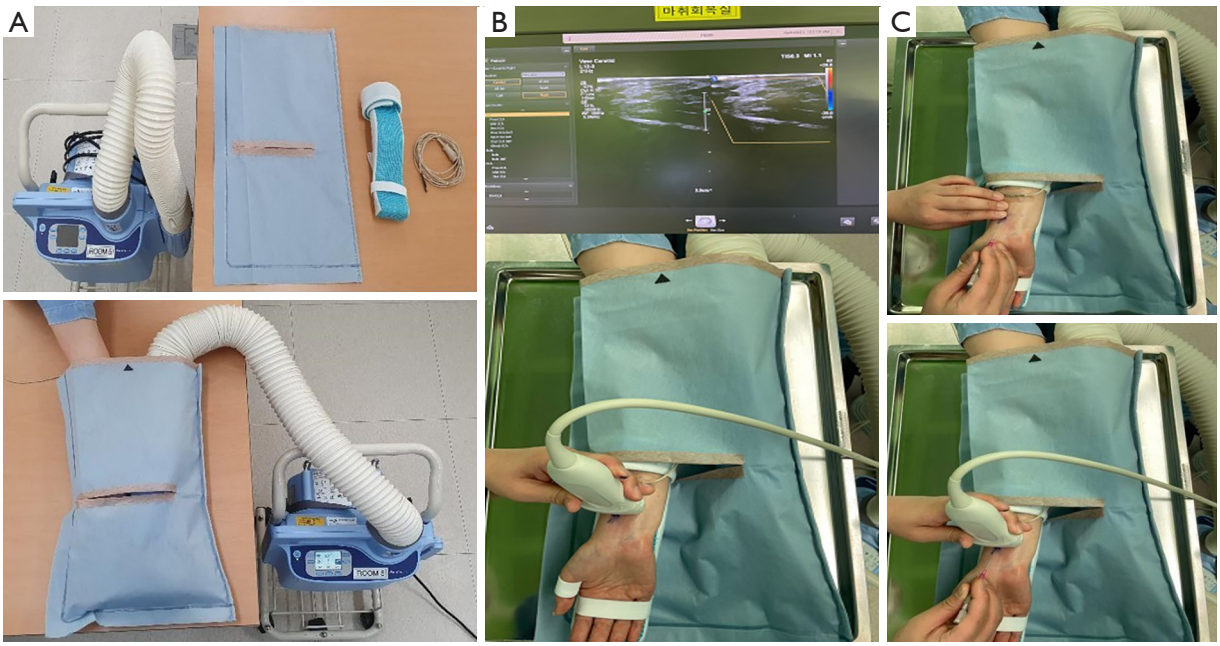

Figure 1 Schematic process of intervention. (A) Preparation and method of local warming. (B) Measurement of the radial artery by ultrasonography. (C) Palpation technique and ultrasonography-guided arterial catheterization.

had skin temperature probes (Philips Intellivue, Philips, Amsterdam, Holland) attached on their wrist. The warming groups (WP, WU) were subjected to a forced-air warmer (WarmTouch^{TM} WT 6000 Warming, Medtronic, USA). Ultrasonography images of the RA were obtained using a Philips L 12-3 MHz real-time linear-array ultrasound transducer (Philips Medical Systems, Andover, MA, USA). The CSA (mm^2), ID (mm), and depth (mm) in the short-axis views of the RA from the stored images were measured.

Anesthesia and RA catheterization

Standard monitoring (non-invasive blood pressure measurement, electrocardiogram, and pulse oximetry) was performed for the patients in the operating room. The insertion site of the right RA was selected if it had no abnormality; however, if the right wrist had a scar, wound, or infection, catheterization was performed in the left RA. The patient's wrist was extended over a wrist immobilizer (CAS, SHMEDICAL Co., Ltd., Korea) to maintain an angle of 45°, and a skin-temperature probe was attached. To exclude the vasodilatory effect caused by anesthetics, an initial ultrasonography view of the RA was obtained to measure its baseline after the administration of anesthetics, such as propofol, remifentanil, and rocuronium. The baseline blood pressure and skin temperature at the insertion site were also recorded. Local warming was then applied in the specified groups (WP, WU). In the warming groups, after local warming, the overall warming time, blood pressure, and skin temperature of the insertion site were noted, and short- and long-axis views of the RA were obtained at the same location to reassess the diameter and depth of the RA. In the non-warming groups (NP, NU), the blood pressure and skin temperature at the insertion site were noted approximately 10 min later, and short- and long-axis views of the RA were obtained (*Figures 1*,*2*).

After collecting the baseline and post-procedure (warming or non-warming process) ultrasonography views of the RA, skin preparation was performed with 83% alcohol. Arterial catheterization was performed using the conventional palpation or ultrasonography-guided out-of-plane technique. The catheter gauge, number of attempts, and procedure time (from the skin puncture by a catheter to confirmation of the arterial waveform) were recorded, and complications such as hematoma and vasospasm were evaluated using ultrasonography.

The RA size assessment and catheterization were performed by the two anesthesiologists (HYK and SP), who had both performed more than 100 arterial catheterizations.

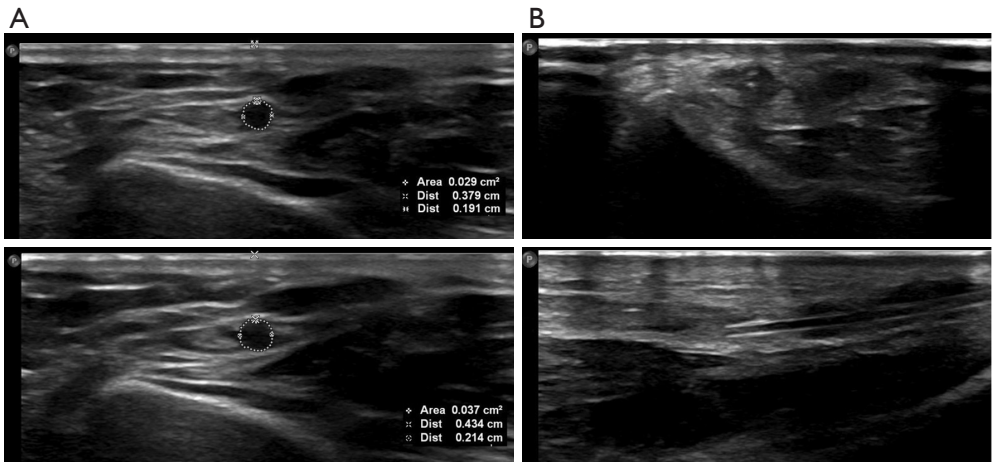

Figure 2 Ultrasonography images of the radial artery catheterization. (A) Examples of changes in the diameter of the radial artery after local warming. (B) Ultrasonography images of post-catheterization.

Statistical analysis

The primary outcome was the first-attempt success rate of RA catheterization in the four groups. Secondary outcomes included the CSA, ID, and RA depth before and after local warming, overall procedure time, number of attempts, and procedure-related complications.

The sample size was calculated based on previous studies. The first-attempt success rates of palpation- and ultrasonography-guided RA catheterization in adult cardiac surgery were 57.5% and 95%, respectively (11). We assumed that the first-attempt success rate for RA catheterization was 90% in the WU group and 60% in the NP group. Assuming a power of 0.8 with a 25% difference and two-sided alpha of 0.05, the sample size for each group was calculated as 36. Considering the attrition rate of 10%, 160 patients were recruited.

All data are expressed as mean ± standard deviation or median (interquartile range), unless otherwise specified. Distribution was tested using the Shapiro-Wilk normality test. The primary outcome was evaluated using the χ^2-test. Secondary outcomes, such as CSA, ID, RA depth, and procedure time, were evaluated using the paired *t*-test and Mann-Whitney *U* test. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27 (IBM Corporation, Armonk, NY, USA). A two-sided P value <0.05 indicated statistical significance.

Results

A total of 152 adults were included in the analysis

A total of 160 patients were enrolled and randomized from July 6, 2021, to March 29, 2022. Eight patients (femoral artery catheterization instead of RA =1, palpation technique in ultrasonography group =4, low-quality ultrasonography image =1, and unstable vital signs during induction =2) were excluded. Hence, 152 patients were analyzed in this study. We analyzed the first-attempt success rate and ultrasonography images of the RA in the NP (n=38), NU (n=38), WP (n=39), and WU (n=37) groups (*Figure 3*). The baseline patient characteristics are summarized in *Table 1*.

The first-attempt success rates among the four groups, as well as between the non-warming and warming groups, were not significantly different

The primary outcome, first-attempt success rate, was not significantly different (P=0.985) among the NP [81.6% (31/38)], NU [84.2% (32/38)], WP [84.6% (33/39)], and WU [83.8% (31/37)] groups. The first-attempt success rates of the non-warming (NP + NU) and warming (WP + WU) groups were also not significantly different [82.9% (63/76) *vs.* 84.2% (64/76); P=0.827].

The procedure time of first-attempt arterial

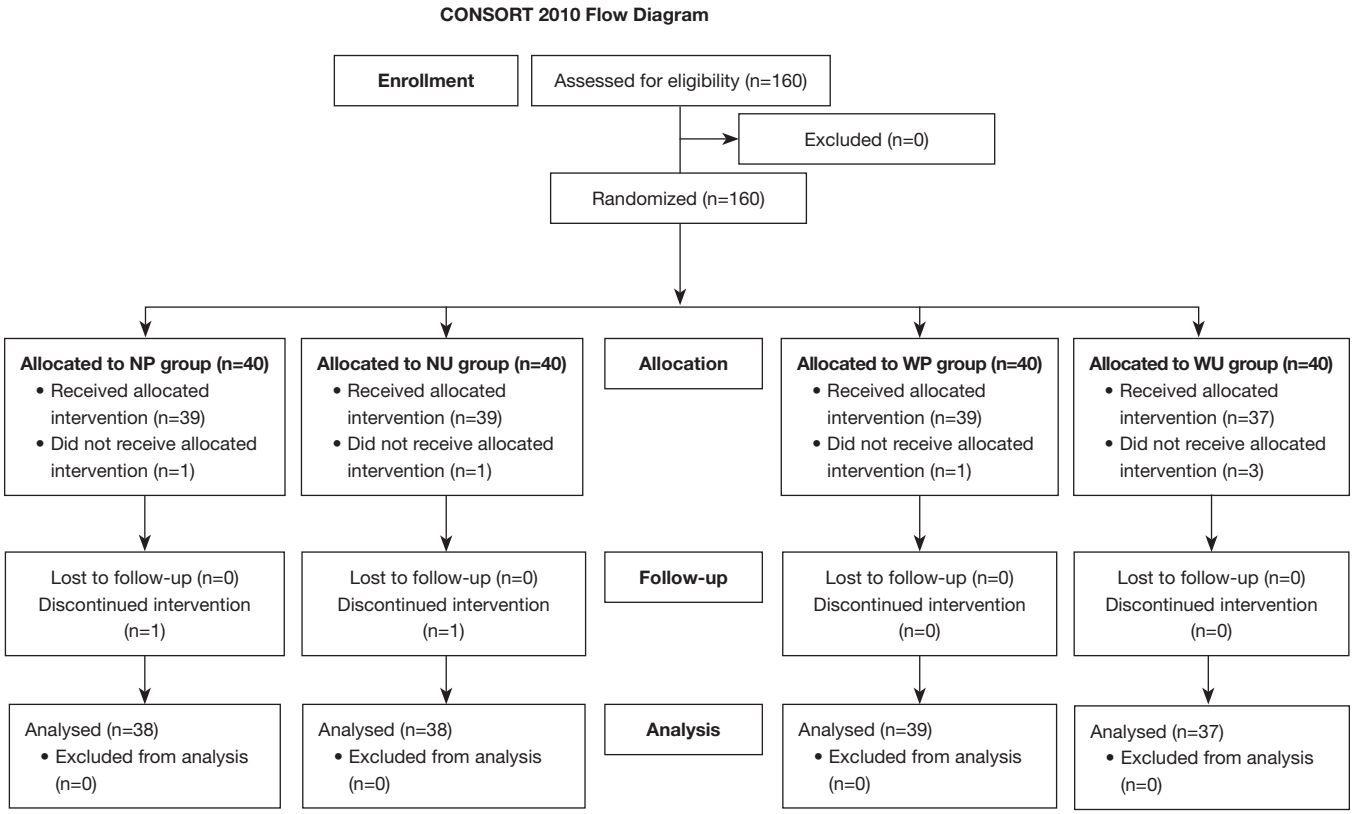

Figure 3 CONSORT flow diagram. NP, non-warming palpation; NU, non-warming ultrasonography-guided; WP, warming palpation; WU, warming ultrasonography-guided.

Table 1 Patient characteristics

Characteristic	NP group (n=38)	NU group (n=38)	WP group (n=39)	WU group (n=37)
Age (years)	62±15	64±11	64±13	65±12
Male	26	18	19	22
Female	12	20	20	15
Height (cm)	164.4±9.2	161.1±9.2	162.6±11.2	163.3±8.1
Weight (kg)	67.3±12.3	64.3±11.0	64.9±17.6	67.0±11.4
ASA				
I	0	0	0	0
II	5	6	3	3
III	28	26	32	30
IV	5	6	4	4

Values are presented as mean ± standard deviation or number. NP, non-warming palpation; NU, non-warming ultrasonography-guided; WP, warming palpation; WU, warming ultrasonography-guided; ASA, American Society of Anesthesiologists.

Table 2 Results of radial artery catheterization

Procedural data	NP group (n=38)		NU group (n=38)		WP group (n=39)		WU group (n=37)		P value
	K (n=18)	P (n=20)	K (n=15)	P (n=23)	K (n=17)	P (n=22)	K (n=12)	P (n=25)	
First-attempt success rate	81.6% (31/38)		84.2% (32/38)		84.6% (33/39)		83.8% (31/37)		0.985
	82.9% (63/76)				84.2% (64/76)				0.827
Procedure time to success (s)	22 (15 to 35)		32 (25 to 40)		23 (20 to 31)		28 (23 to 41)		0.409†
	[12 to 98]		[12 to 130]		[12 to 101]		[11 to 174]		0.752‡
Hematoma	1		4		5		3		
Vasospasm	1	1	1						
Overall number of attempts									
First	31		32		33		31		
Second	5		3		3		2		
Third	1		2		3		2		
Fourth	1		0		0		2		
Fifth	0		1		0		0		

Values are presented as median (interquartile range) [range], or number (proportion). †, comparison of palpation groups; ‡, comparison of ultrasonography-guided groups. NP, non-warming palpation; NU, non-warming ultrasonography-guided; WP, warming palpation; WU, warming ultrasonography-guided; K, anesthesiologist HYK; P, anesthesiologist SP.

Table 3 Results of radial artery in non-warming group and warming group

Parameters of the RA	Non-warming group			Warming group		
	Baseline, non-warming	After non-warming (10 min after baseline assessment)	P value	Baseline, warming	After warming	P value
Diameter (mm)	3.21±0.63	3.21±0.68	0.783	3.02±0.73	3.34±0.78	<0.001
Depth (mm)	3.06±1.09	3.09±1.10	0.528	3.24±1.16	3.23±1.21	0.775
CSA (mm^2)	6.4±2.5	6.5±2.5	0.378	5.8±2.4	6.9±2.8	<0.001

Values are mean ± standard deviation. RA, radial artery; CSA, cross-sectional area.

catheterization was not statistically different between the NP (median, 22 s; 25^{th}–75^{th} percentile, 15–35 s; range, 12–98 s) and WP (median, 23 s; 25^{th}–75^{th} percentile, 20–31 s; range, 12–101 s; P=0.409) groups. Also, there was no difference in the time between NU (median, 32 s; 25^{th}–75^{th} percentile, 25–40 s; range, 12–130 s) and WU (median, 28 s; 25^{th}–75^{th} percentile, 23–41 s; range, 11–174 s; P=0.752) groups (*Table 2*).

Significant increases in ID and CSA were observed in the warming (WP + WU) group

Significant changes in ID and CSA were not observed in the non-warming (NP + NU) group; however, the warming (WP + WU) group had increased ID (3.34±0.78 *vs.* 3.02±0.73 mm; P<0.001) and CSA (6.9±2.8 *vs.* 5.8±2.4 mm^2; P<0.001) compared with the baseline values (*Table 3*, *Figure 4*).

Complications

There were three cases of vasospasm in the non-warming (NP + NU) group; however, there was no case of vasospasm in the warming (WP + WU) group.

Discussion

The primary outcome of this study was that local warming for peripheral arterial catheterization did not increase the

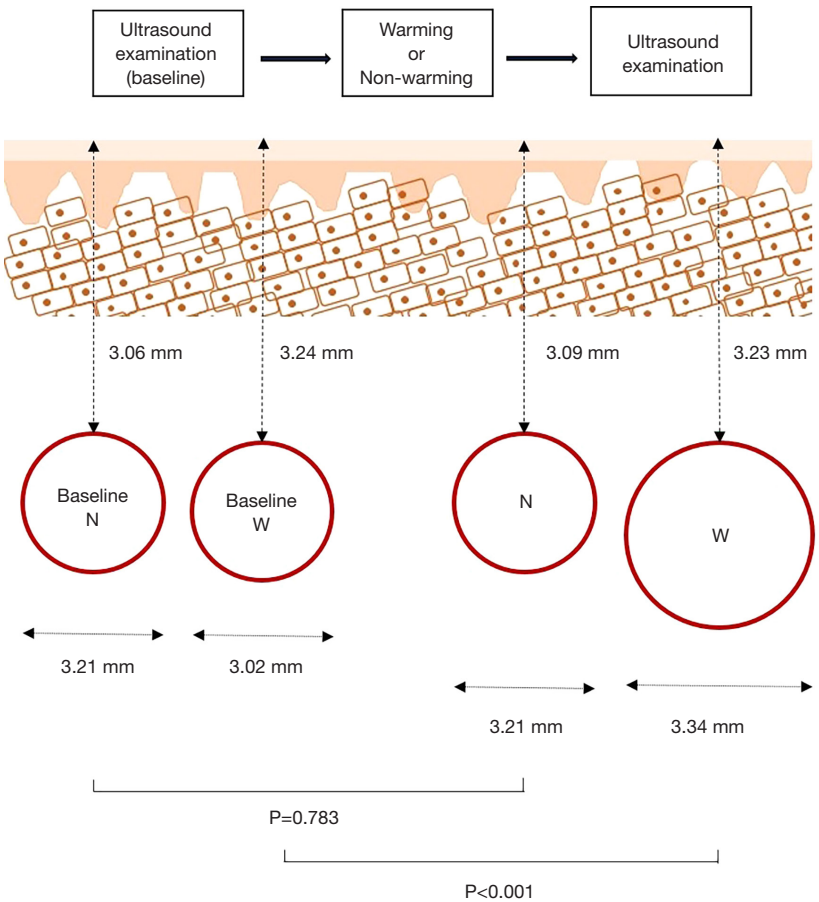

Figure 4 Diagram of the diameter and depth of the radial artery throughout the procedure. After local warming, the warming group showed significant vasodilation (3.34±0.78 mm) compared with the baseline (3.02±0.73 mm; P<0.001). The non-warming group showed no significant difference (3.21±0.68 mm) compared with the baseline values (3.21±0.63 mm; P=0.783).

first-attempt success rate in adult patients undergoing cardiac surgery. In addition, the procedure time for first-attempt arterial catheterization was not different; however, the ID and CSA of the RA increased in the warming group. Although the mechanism of vascular dilatation is different, the results of the study were different from those of the subcutaneous injection of nitroglycerin, which increased the first-attempt success rate by increasing the ID of the RA in pediatric patients (3). We were not able to increase the first-attempt success rate through the vasodilatory effect of local warming, and there may be various reasons, one of which may be the differences in participants (children *vs.* adults).

In various studies, the first-attempt success rate of pediatric peripheral arterial catheterization (18–56% on palpation and 48–83% in ultrasonography-guided methods) is low and variable compared with the rate in adults undergoing cardiac surgery (57.5% on palpation and 95% in ultrasonography-guided methods) (3,11). The mean ID of the RA in children under 2 years old is 1.2±0.3 mm, which is smaller than that of adults (3). Unlike adults with large-sized RAs, children with small-sized RAs can have effective vasodilation due to local warming. Therefore, the vasodilatory effect in pediatric patients increases the first-attempt success rate. Further studies are needed to clarify the effects of local warming on peripheral arterial catheterization in children. The conventional success rate in adult patients is relatively high, and the ID of the RA is larger; therefore, we could not obtain significant clinical results. In another study in adult patients undergoing transradial cardiac catheterization, Ünal *et al.* compared the drug treatment group (200 mg nitroglycerin + 2 mg diltiazem subcutaneous injection) to the manual heating

group (Balbay maneuver: heating the RA site for three minutes with the palm) and reported that the manual heating of the RA site significantly reduced the number of radial puncture attempts (9). The vasodilatory effect of manual heating was suggested; however, evidence was not certain because the study did not present the changes in the vascular size of each group after drug treatment or manual heating. Therefore, the effect of the local warming of the puncture site in adult patients in the success rate of arterial catheterization requires further investigation.

In our study, the ID and CSA of the RA increased in the warming group. Although the mechanism of cutaneous active vasodilation by local warming is unclear, it seemed to occur due to the activation of the sympathetic cholinergic active vasodilator system (6). Nerve stimulation regulates blood vessel tone by releasing mediators, such as nitric oxide, prostacyclin, endothelin, and prostanoids, from the vascular endothelial cells (5). The RA is more vulnerable to vasospasm than other arteries because it is rich in smooth muscles and has a relatively small diameter. The risk factors for RA vasospasm are female sex, age, RA diameter, and number of attempts. It also has an incidence of 7.8% to 25% (12). Vasospasm did not occur in the warming group; however, it occurred in the non-warming group. Therefore, local warming appears to prevent RA vasospasm. Some studies have reported that local heating resolves RA vasospasm during transradial cardiac catheterization (8,13,14).

Several points were noted in our study. First, skin puncture and catheter insertion in the warming group was performed smoothly, owing to lower resistance compared with the non-warming group. This appeared to be due to the relaxation effect in the soft tissues after local warming. One study reported that soft tissue relaxation after heating the arteriovenous fistula site for hemodialysis in patients with chronic kidney disease reduced the pain during thick-needle insertion (15).

One participant in the NU group received an infusion of high-dose norepinephrine (0.2 mcg/kg/min) due to low blood pressure during the induction of anesthesia. Consequently, the participant's blood pressure became higher than baseline; however, the CSA of the RA decreased from 0.6 to 0.4 mm^2, and arterial catheterization failed. It seemed to be affected by the size of the peripheral artery, which contracted due to the effect of the high-dose drug (16). All baseline values were measured after the administration of anesthetics to minimize the vasodilatory effect of anesthetic agents. The skin temperature of one participant each in the NP and NU groups increased after the administration of anesthetic agents. This could be due to the rapid distribution of core body temperature due to the vasodilation effect of anesthetic agents (17).

Generally, the body mass index (BMI) correlates with RA diameter; therefore, we used a 22-gauge catheter (outer diameter: 0.9 mm) for patients with a BMI of 18.5 kg/m^2. However, in our study, the relationship between RA diameter and BMI was weak in some patients. Although these patients had a high BMI, they had a small RA ID. Instead of BMI or age, ultrasonography investigation of the RA may ensure a better choice of catheter gauge and increase the first-attempt success rate. Varga *et al.* recommended measuring the ID of the RA in children prior to the insertion of an intra-arterial catheter, because some participants may have a small RA unlike their peers (18). Blood pressure during catheterization in the four groups tended to be significantly lower than that at baseline. Factors, such as hypertension, diabetes, kidney disease, hemodialysis, and systemic nitroglycerin infusion, did not affect the first-attempt success rate.

Nevertheless, our study has several limitations. First, the overall warming time varied from 2 to 15 min, with an average of 6.3±4.4 min. There may have been cases of insufficient warming, such as a short warming time due to the position of the skin thermometer near a warmer resulting in insufficient heat conduction which may have led to insufficient vasodilation. In one study, vasodilation occurred at 5–10 min after the application of heat (7). In another study, at temperatures between 37–42 ℃, the blood flow increased steadily and reached a maximum at 1 h; the peak flow at 45 ℃ was presented at 30 min (10). This means that the local warming time for vasodilation is affected by the warming temperature. Moreover, the blood flow steadily diminished after 1 h of heating; thus, applying heat for a long duration does not produce the best effect of vasodilation. Also, caution is needed because applying heat up to 45 ℃ can cause pain in the fingers (10). Therefore, an appropriate warming temperature and duration should be considered. If we set the proper warming duration and the temperature higher than 39 ℃, the primary outcome may be better. Second, the warming and non-warming groups were blinded only to the researcher (anesthesiologist B) who measured the size of the RA on the stored ultrasonography images; however, the researcher (anesthesiologist A) who took the images of the RA and performed arterial catheterization was not blinded. This limitation may have affected the ultrasonography assessment of the RA and its

catheterization because localized RA could have influenced the first-attempt success rates significantly even in palpation groups. Therefore, it may be necessary to conduct a study in which the researcher who acquires the images of the RA, and the researcher who performs arterial catheterization are separated, and blinded. Similarly, the ultrasonography assessment of the RA before arterial catheterization in all groups had provided information on the location and pathway of the RA, so the palpation technique was not completely blinded. Thus, the first-attempt success rates in all groups may be similar.

Conclusions

Local warming for peripheral arterial catheterization does not increase the first-attempt success rate in adult patients undergoing cardiac surgery; however, it can increase the ID and CSA of the RA and prevent vasospasm.

Acknowledgments

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Footnote

Reporting Checklist: The authors have completed the CONSORT reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/rc

Trial Protocol: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/tp

Data Sharing Statement: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/dss

Peer Review File: Available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/prf

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://jtd.amegroups.com/article/view/10.21037/jtd-23-820/coif). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the institutional review board of Pusan National University Yangsan Hospital (IRB No. 05-2021-117), and informed consent was obtained from all individual participants.

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