The FLUSH Study—Flush the Line and Ultrasound the Heart: Ultrasonographic Confirmation of Central Femoral Venous Line Placement

Russ Horowitz, MD, RDMS*; Jeffrey G. Gossett, MD; John Bailitz, MD, RDMS; David Wax, MD; Mary Clyde Pierce, MD

*Corresponding Author. E-mail: rhorowitz@luriechildrens.org.

Study objective: Inadvertent arterial placement of a femoral venous catheter may result in serious morbidity, including limb necrosis. The Flush the Line and Ultrasound the Heart (FLUSH) test is visualization of the heart by a subxiphoid ultrasonic view while the central catheter is flushed with agitated saline solution. We wish to determine whether the FLUSH test can verify proper femoral venous line placement.

Methods: We prospectively studied a convenience sample of children undergoing cardiac catheterization, for whom both femoral venous and arterial access were part of their standard care. The cardiologist flushed manually agitated saline solution through each catheter in randomized sequence while the blinded physician sonographer recorded the presence or absence of right atrial opacification. We calculated the sensitivity and specificity of the FLUSH test relative to our reference standard, the cardiologist’s fluoroscopic visualization of catheter wire placement.

Results: Of the 51 subjects enrolled, the FLUSH test was 100% sensitive (95% confidence interval 95% to 100%) and 90.3% specific (95% confidence interval 81% to 96%) in confirming femoral catheter placement. In no case was an arterial flush misidentified as a femoral flush. The interrater reliability of the test was strong: κ 0.82 for all images and 0.9 for those of good quality.

Conclusion: The FLUSH test is simple and reliable, and appears to accurately confirm femoral venous line placement.


Please see page 679 for the Editor’s Capsule Summary of this article.

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INTRODUCTION

Background

Femoral venous catheters are useful in the resuscitation and treatment of critically ill children for rapid administration of medications, blood, and fluids. Confirmation of venous line location is routinely conducted by blood gas analysis, invasive monitoring, manometry, or visual inspection of aspirated blood. However, in critically ill patients the results can be equivocal or difficult to interpret.1-3

Accidental arterial cannulation occurs in up to 1.0%4-7 of adults, with no pediatric-specific data reported, to our knowledge. Inadvertent arterial placement and intra-arterial medication administration can have adverse consequences, including arterial injury, arteriovenous fistulae, and limb necrosis.1-8

One of the most common complications in closed malpractice claims involving central catheters is arterial injury as a result of arterial puncture and cannulation.12 Anecdotal reports have described opacification of the right atrium after saline solution was flushed through an internal jugular vein catheter.13,14

Importance

Visualization of needle insertion with ultrasonographic guidance by the dynamic approach for central venous line placement is superior to the traditional landmark-based approach and reduces complication rates.15-18

Standard teaching is that the femoral artery lies lateral to the femoral vein; however, studies in both children and adults have shown that the femoral artery overlies the femoral vein in up to 65% of patients.19-22 This vascular alignment may result in inadvertent femoral arterial catheterization when ultrasonographic guidance is not used.

Despite standard safety measures and dynamic ultrasonographic guidance, accidental arterial cannulation does still occur.1-10,23,24 Multiple techniques have been suggested to improve confirmation of central venous line placement. Some
Editor’s Capsule Summary

What is already known on this topic
Central lines can be inadvertently placed within arteries.

What question this study addressed
Can one confirm femoral venous line placement in children with the Flush the Line and Ultrasound the Heart (FLUSH) test, ie, ultrasonic intracardiac visualization of agitated flushed saline solution?

What this study adds to our knowledge
In this cardiac catheterization laboratory study of 51 children with randomized flushes into the femoral artery or vein, blinded cardiac ultrasonography was 100% sensitive and 90% specific in identifying venous injection. Image interrater reliability was strong.

How this is relevant to clinical practice
The ultrasonic FLUSH test appears to accurately confirm femoral venous line placement in children.

Selection of Participants
When the physician sonographer was available, we recruited a convenience sample of subjects who were undergoing cardiac catheterization with both a femoral venous line and femoral arterial line in place as part of their standard care. We excluded children with abnormal cardiovascular anatomy lacking a direct connection of the inferior vena cava to the right atrium, including those status post–Fontan procedure and with an interrupted inferior vena cava.

Interventions
The interventional cardiologist performed 3 vascular flushes on each subject, with sequence determined by a random-number generator: either 2 arterial flushes and 1 venous flush or 2 venous flushes and 1 arterial flush. The quantity of normal saline solution flushed was weight based (5 mL for patients <10 kg and 10 mL for patients ≥10 kg).

The sonographer was a pediatric emergency physician who had completed an emergency medicine ultrasonographic fellowship and was certified by the American Registry of Diagnostic Medical Sonography. While blinded to flush sequence, he imaged the heart with a standard subxiphoid view (Figure 1) while the cardiologist rapidly flushed each catheter with manually agitated normal saline solution. When the physician sonographer saw opacification in the right atrium, he verbally reported “vein” (positive FLUSH test result) (Figure 2A; Video E1, available online at http://www.annemergmed.com); when he saw no opacification in the right atrium, he verbally reported “artery” (negative FLUSH test result) (Figure 2B). The cardiac catheterization laboratory nurse recorded his interpretations on the data collection sheet alongside the predetermined flush sequence. Video clips were captured in real time.

The physician sonographer used a SonoSite M-Turbo system (SonoSite, Bothwell, WA), with either a C60x curvilinear (5-2 MHz) or P10x phased-array (8-4 MHz) transducer, chosen according to the patient’s body habitus. Surgical towels obscured the physician sonographer’s view of the femoral catheters. In

Goals of This Investigation
The primary objective of this study was to assess the test characteristics of the FLUSH test to confirm venous line placement in children. Our secondary objective was to determine interobserver agreement between physician sonographers.

MATERIALS AND METHODS

Study Design and Setting
We performed a prospective, single-blinded, randomized study from February 2012 to November 2012 in the cardiac catheterization laboratory of a tertiary care pediatic hospital (volume 550 cardiac catheterizations per year). The hospital’s institutional review board approved the study. The parent or guardian provided written consent. Children aged 12 to 18 years provided written assent.

Figure 1. Subxiphoid probe positioning.
some cases, the entire abdomen was surgically prepped, a sterile cover was used over the ultrasonographic probe, and the physician sonographer was in complete sterile dress.

Methods of Measurement
For our primary outcome, we contrasted sonographer interpretations to our reference standard of the interventional cardiologist’s fluoroscopic visualization of catheter wire placement.

For our secondary interrater reliability outcome, a second American Registry of Diagnostic Medical Sonography–certified emergency physician performed a blinded secondary review of the deidentified and randomly reordered video clips.

Primary Data Analysis
We used descriptive statistics for our primary outcome and the $\kappa$ coefficient for our secondary outcome. All analyses were performed with SAS (version 9.3; SAS Institute, Inc., Cary, NC).

To obtain a power of 80% and a significance level of .05 for an expected accuracy of 95%, a sample of 75 artery and 75 vein flush measurements was needed (1-sided z test). Accordingly, we enrolled 50 patients to obtain 150 measurements.

RESULTS
Characteristics of Study Subjects
Patient flow is shown in Figure 3. The right atrium was visualized with the subcostal approach in all 51 patients enrolled, with 153 flush measurements successfully accomplished as planned.

Twenty-two subjects (43%) were female and 29 were male (57%). Their median age was 4.4 years (interquartile range 1.5 to 12.5 years), and median height was 105 cm (interquartile range 80 to 154 cm). Their underlying cardiac conditions are shown in Table 1. The saline solution flushes and sonography were well tolerated in all patients.

Main Results
Test characteristics of the FLUSH test are shown in Table 2. All 3 flush measurements were accurate in 45 patients (88%), 2 of 3 were accurate in 5 patients (10%), and 1 of 3 was accurate in 1 patient (2%). Each of these inaccuracies was a venous flush falsely identified as an arterial flush, with no arterial flushes falsely identified as venous flushes. There were zero false-positive and 7 false-negative FLUSH test results. Children with inaccurate measurements were male and were older than those with accurate measurements (mean 12.8 versus 5.8 years; difference 6.9 years; 95% confidence interval [CI] 2.2 to 11.6 years). They were also taller (mean 164 versus 107 cm; difference 57 cm; 95% CI 40 to 74 cm). The cardiac lesions of patients with accurate versus inaccurate flush examination results are shown in Appendix E1 (available online at http://www.annemergmed.com).

A system storage malfunction prevented 17 video clips from being recorded, leaving 136 for the assessment of interrater reliability. The second physician reviewed these deidentified and randomly reordered clips and characterized them as either good ($n=107$) or poor ($n=29$) quality according to ease of interpretation and video quality. The $\kappa$ was 0.82 (95% CI 0.72
to 0.92) for all videos and 0.90 (95% CI 0.82 to 0.99) for those of good quality (Appendix E2, available online at http://www.annemergmed.com).

**LIMITATIONS**

Our study was limited by its convenience sampling and its use of stable cardiac patients rather than emergency department patients.

We used 2 expert sonographers, so our results may be better than those of sonographers with less experience. However, the FLUSH test uses the standard subxiphoid view from the Focused Assessment with Sonography in Trauma (FAST) examination, and no unique imaging views or advanced techniques.

Finally, given our blinded study design, the same physician did not perform both central line placement and the FLUSH test. We believe that in clinical practice, both procedures can be performed by the same physician.

**DISCUSSION**

We found the FLUSH test to be highly accurate in confirming femoral venous line placement compared with direct

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**Table 1. Cardiac lesions.**

<table>
<thead>
<tr>
<th>Cardiac Lesions</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart transplant</td>
<td>24</td>
</tr>
<tr>
<td>Patent ductus arteriosus</td>
<td>7</td>
</tr>
<tr>
<td>Tetralogy of Fallot</td>
<td>2</td>
</tr>
<tr>
<td>Transposition of great vessels+septal defect</td>
<td>2</td>
</tr>
<tr>
<td>Cardiomyopathy</td>
<td>1</td>
</tr>
<tr>
<td>Total anomalous pulmonary venous return</td>
<td>1</td>
</tr>
<tr>
<td>Aortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Coronary artery fistula</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary artery stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Transposition of the great vessels+peripheral stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Coarctation of the aorta+ventricular septal defect+aortic stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Double outlet right ventricle+atrioventricular canal defect</td>
<td>1</td>
</tr>
<tr>
<td>Double outlet right ventricle+ventricular septal defect+transposition</td>
<td>1</td>
</tr>
<tr>
<td>of the great vessels+pulmonary artery stenosis</td>
<td>1</td>
</tr>
<tr>
<td>Double outlet right ventricle+tetralogy of Fallot</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary artery stenosis+truncus arteriosus</td>
<td>1</td>
</tr>
<tr>
<td>Patent foramen ovale+pulmonary atresia</td>
<td>1</td>
</tr>
<tr>
<td>Pulmonary hypertension+atrial septal defect</td>
<td>1</td>
</tr>
<tr>
<td>Patent foramen ovale+patent ductus arteriosus</td>
<td>1</td>
</tr>
<tr>
<td>Ebstein’s anomaly, atrial septal defect, hypoplastic right</td>
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</tr>
<tr>
<td>ventricle+atrioventricular atresia</td>
<td></td>
</tr>
<tr>
<td>Hypoplastic left heart+double outlet right ventricle+mitral valve atresia</td>
<td>1</td>
</tr>
</tbody>
</table>

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**Table 2. Results of FLUSH test compared with the reference standard.**

<table>
<thead>
<tr>
<th>FLUSH Test Result</th>
<th>Venous Catheter</th>
<th>Arterial Catheter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive FLUSH test</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>Negative FLUSH test</td>
<td>7</td>
<td>81</td>
</tr>
</tbody>
</table>

*Specificity: 100% (95% CI 95% to 100%). Sensitivity: 90.3% (95% CI 81% to 96%). Positive predictive value: 100% (95% CI 94% to 100%). Negative predictive value: 92.1% (95% CI 84% to 97%).

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fluoroscopic visualization by an interventional cardiologist. We found no false-positive results, ie, no femoral arterial line was misidentified as being venous.

The Agency for Healthcare Research and Quality identified real-time ultrasonographic guidance for central vein catheterization as one of the top 11 interventions to improve patient safety.29 Ultrasonographic guidance for central line placement has been shown to improve success rate, decrease cannulation time, and reduce traumatic complications in both children and adults compared with landmark-based techniques.16,17,30-34 One study by Alten et al35 specifically found a decreased rate of inadvertent femoral artery puncture in children with the use of ultrasonographic guidance.

Ultrasonographic guidance of central venous line placement unfortunately does not eliminate inadvertent arterial puncture and cannulation. Studies with phantom models have shown arterial puncture and cannulation despite ultrasonographic guidance in central venous line placement.23,36 Blaivas1 detailed a case series of 6 patients who underwent inadvertent arterial cannulation despite dynamic ultrasonographic guidance. Blood from the central line catheters was venous in character (ie, “dark,” “slow flow,” “nonpulsatile,” and “slow trickle”) and presumably supported the physicians’ supposition that the lines were intravenous.

One particular technical detail, probe slicing, may be to blame for inadvertent arterial line puncture and insertion. With the short-axis approach, the shaft of the needle can be mistaken for the tip, and the needle may puncture through the vein into the underlying or neighboring artery.

Other studies have attempted to identify line location by visualizing the guidewire within the central vein37,38 because guidewires are more easily and consistently seen within vessels than needles.39 However, this technique may be difficult for novice sonographers to learn.28 In addition, this technique simply identifies a wire within a vessel but does not confirm in which vessel that wire resides, which requires additional techniques, including Doppler flow or blood analysis.

Traditional confirmation methods (visual inspection of aspirated blood, blood gas analysis, and manometry40) may not always be reliable in children with septic shock, volume depletion, or severe hypoxia. Standard radiographs are helpful to confirm line placement but are not feasible during active patient resuscitation, are time consuming,25 and expose children to ionizing radiation.

Some investigators have attempted to confirm internal jugular and subclavian central line placement,25-27,41 using multiple probes to examine the neck vessels and heart. However, these evaluations took up to 11 minutes to perform and prefer the left lateral decubitus position.27-41,42 Matsushima and Frankel43 found that 29% of the images were technically inadequate for interpretation and that half of the malpositioned catheters were missed. Zanobetti et al25 found that 45% of catheter tips could not be visualized.

Lanza et al41 performed the only pediatric study to date, to our knowledge, with central lines placed by critical care physicians and sonography by radiologists. They used both
standard B mode and color Doppler; each imaging study took 10 minutes. They found sonography to be 84.6% sensitive and 100% specific relative to radiograph confirmation.

In contrast to these more complicated approaches, we used the standard subxiphoid view used in the FAST examination and routinely taught to all emergency medicine residents. Novel sonographers are adept at the subxiphoid view even after brief didactic sessions. Further study is necessary to assess FLUSH test accuracy of novice sonographers. We incidentally noted that forceful agitation produced a brighter sonographic appearance, suggesting a way to potentially further improve accuracy. Additionally, the FLUSH test was more accurate in younger and shorter children, suggesting size as a contributing variable to success.

Although we conducted this study with the catheters already in place, the FLUSH test could be performed immediately after needle insertion and before dilatation and cannulation, serving as an adjunct to dynamic ultrasonographic guidance. Because central lines are routinely flushed to ensure patency, the FLUSH test requires no additional procedures. We propose an algorithm for FLUSH test implementation (Figure 4).

In summary, the FLUSH test is a rapid, safe, noninvasive, and immediately interpretable method to confirm femoral venous line placement, using common techniques and standard ultrasonographic skills. The FLUSH test has the potential to reduce inadvertent arterial line use in children.

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Author affiliations: From the Department of Pediatrics (Horowitz, Pierce, Gosset, Wax), Divisions of Emergency Medicine (Horowitz and Pierce), Critical Care (Horowitz), and Cardiology (Gosset, Wax), Feinberg School of Medicine, Northwestern University, Chicago, IL; and Cook County Hospital Emergency Medicine, Rush College of Medicine, Chicago, IL (Bailitz).

Author contributions: RH conceived the study, RH, JGG, JB, and MCP designed the study and prepared the study proposal. RH, JGG, and DW supervised the conduct of the trial, patient recruitment, and data collection and managed the data, including quality control. RH drafted the article and all authors contributed substantially to its revision. RH takes responsibility for the paper as a whole.

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