Transthoracic echocardiography as bedside technique to verify tip location of central venous catheters in patients with atrial arrhythmia

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Abstract

Introduction: Transthoracic echocardiography with bubble test is an accurate, reproducible, and safe technique to verify the location of the tip of the central venous catheter. The aim of this study is to confirm the effectiveness of this method for tip location in patients with atrial arrhythmia.

Methods: Transthoracic echocardiography with bubble test was adopted as a method of tip location in patients with atrial arrhythmia requiring central venous catheter. If bubbles were evident in the right atrium in less than 2 s after simple saline injection, tip placement was assumed as correct. In cases of uncertain visualization of the bubble effect, the test was repeated injecting a saline–air mixture. Tip location was also assessed by post-procedural chest X-ray.

Results: In 42 patients with no evident P-wave at the electrocardiography, we placed 34 centrally inserted central catheters and 8 peripherally inserted central catheters. Transthoracic echocardiography with bubble test detected two centrally inserted central catheter malpositions. In four patients with peripherally inserted central catheter, transthoracic echocardiography with bubble test was positive only when repeated with the saline–air mixture. When the transthoracic echocardiography was positive, the mean (± standard deviation) time for onset of the bubble effect was 0.89 ± 0.33 s in patients with centrally inserted central catheter and 1.1 ± 0.20 s in those with peripherally inserted central catheter; such time difference was not statistically significant (p > 0.05).

Conclusion: Tip location of central venous catheter by transthoracic echocardiography with bubble test is feasible, safe, and accurate in patients with atrial arrhythmia. This method can also be applied in peripherally inserted central catheters; however, further studies may be needed to confirm its use in this type of catheters.

Keywords
Transthoracic echocardiography, tip location, central venous catheter, bubble test, atrial arrhythmia

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Introduction

Insertion of central venous catheters (CVCs), even if performed by trained personnel, is always associated with a not irrelevant risk of puncture-related complications (pneumothorax, accidental arterial puncture, etc.) and position-related complications (inappropriate position of the tip).¹ Ultrasound guidance improves success rate, reduces the number of attempts, and minimizes the risk of puncture-related complications.²

For both centrally inserted central catheters (CICC) and peripherally inserted central catheter (PICC), all international guidelines recommend placing the tip close to the cavo-atrial junction (CAJ), in the “safe” area that includes the distal third of the superior vena cava (SVC) and the upper portion of the right atrium. This is essential.

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to minimize catheter malfunction, venous thrombosis or arrhythmias. If an intra-procedural method of tip location is not adopted, the wrong placement of the tip of CICCs and PICCs may occur in 4–14% of the patients.

Intra-procedural methods to verify the correct tip position include fluoroscopy, intracavitary electrocardiography (IC-ECG), transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE).

According to current guidelines, chest radiography is not an appropriate method for tip location because it is post-procedural and not intra-procedural; also, all radiological methods (including intra-procedural fluoroscopy) are less accurate, less cost-effective and less safe (for radiation exposure) if compared to non-radiological methods.

IC-ECG is the ideal intra-procedural method of tip location: it is accurate, safe, inexpensive, easy to learn, and easy to teach. The only limit of IC-ECG is that it cannot be applied in patients with severe arrhythmias, more specifically in those situations when the P-wave is not detectable. Recent studies suggest that a modified IC-ECG method is applicable to atrial fibrillation patients, but not to other conditions characterized by the absence of the P-wave on the ECG trace (such as pacemakers or complex atrial arrhythmias).

TEE is the most accurate technique of tip location. Unfortunately, it is invasive, and logistically difficult or impossible in most clinical situations.

TTE is an advantageous intra-procedural tip location method: it is safe, non-invasive, cost-effective, accurate, and it can be performed at bedside. The subcostal four-chamber view is ideal for the visualization of the CAJ and direct assessment of the correct position of the tip. Alternatively, the apical four-chamber view can be helpful. The non-visualization of the catheter tip does not necessarily imply that it is wrongly positioned: in fact, the tip could be in a position that the probe is not able to detect. In this case, a better identification of the tip can be achieved by rapidly injecting a bolus of saline through the distal lumen of the catheter, this maneuver being associated with the ultrasound visualization of “bubbles” coming from the tip and entering the right atrium. Several studies have proven that this technique is accurate, reproducible, and without complications for the patients.

Weekes et al. evaluated 150 CICC tip locations and proved this “bubble” method has high specificity and sensitivity. Similar results were obtained during emergency CICC placement.

So far no study highlighted the feasibility of the use of TTE for tip location in patient with atrial arrhythmia. In addition, no study considered the bubble test technique for controlling tip location after PICC position.

The aim of this study is to confirm the effectiveness of TTE with bubble test for tip location of CICC and PICC in patients with atrial arrhythmia, that is, in clinical situations where the conventional IC-ECG method is not applicable.

**Methods**

**Design of the study**

We performed a prospective observational study. We assessed the clinical efficacy of a TTE with bubble test in ensuring the proper tip location of CICC and PICC in patients for whom IC-ECG method is not applicable.

After CICC and PICC insertion, the tip location of the catheter was evaluated by TTE with bubble test. The test was considered positive (i.e. correct tip placement) when the micro-bubbles were evident in the right atrium in less than 2 s after the beginning of the injection. The test was negative if the micro-bubble effect did not appear in the right atrium, or if it appeared with a delay of more than 2 s after the injection.

The value of 2 s for the threshold between injection of saline solution and its visualization in the right atrium was chosen according to the data of Vezzani et al., then confirmed by Weekes et al. and Cortellaro et al.

A post-procedural chest X-ray was carried out in all cases; the tip location was considered correct when it was in the distal third of SVC or in the CAJ, or in the superior portion of right atrium, and the catheter did not show a loop in the vascular axis; in any other condition, it was considered misplaced. The CAJ was assumed to be located 3 cm below the level of the carina.

**Patients**

We enrolled patients admitted in the intensive care unit (ICU) and in the Vascular Access Unit of the Central Hospital of Macerata between January 2018 and February 2019.

Inclusion criteria of patients were evidence of atrial arrhythmias, age more than 18 years, clear clinical indication to a CICC or a PICC, and written informed consent about the procedure from the patient. Pregnant patients were excluded.

We took note of the demographic characteristics of the patients (i.e. age, gender, and body mass index (BMI)), and of the catheter type and diameter.

**Technique**

All CICCs and PICCs were placed under real time ultrasound guidance, in real time for vein identification, cannulation, and confirmation of intraluminal position of the guidewire. Ultrasonography was performed by Mindray M5 machine using a 7.5–10 MHz linear transducer for visualization of central veins (for CICC insertion) and upper arm veins (for PICC insertion).
After CVC placement, we performed TTE for evaluating tip location. B-mode cardiac ultrasound examination was carried out using a 2–4 MHz cardiac sector probe, through the subcostal four-chamber view (Figure 1(a)). If this view was not feasible, we adopted an apical four-chamber view, so to visualize right atrium and right ventricle at the same time (Figure 2(a)). We quickly injected 5 mL of saline through the distal lumen line, at the same time starting the video recording of 6 s. If the micro-bubbles were evident in the right atrium within 2 s from the injection, the tip location was considered correct (Figures 1(b) and 2(b)). In cases of uncertain visualization of the bubble effect, the test was repeated with a saline–air mixture, so to increase the visual contrast. The saline–air mixture was obtained connecting two 10 mL syringes, one with 9 mL of saline and one with 1 mL of air, in a three-way stopcock, repeatedly flushing until the mixture was homogeneous.

At the end of the procedure, we performed a lung ultrasound examination to rule out pneumothorax: the pleural space was examined using a 7.5–10 MHz linear probe (Mindray M5), from the third to the fifth intercostal space both at the parasternal line and laterally to the anterior axillary line. The ultrasound evidence of lung sliding in all
The type of catheter implanted, anthropometric characteristics, and parameters of patients are reported in Table 1.

Table 1. Patients data and catheters characteristic.

<table>
<thead>
<tr>
<th>Patients data and catheters characteristic</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, (yr) (Mean ± SD)</td>
<td>78.8 ± 10.5</td>
</tr>
<tr>
<td>Sex, male/female</td>
<td>29/13</td>
</tr>
<tr>
<td>Body mass index, kg/m² (mean ± SD)</td>
<td>27.6 ± 4.6</td>
</tr>
<tr>
<td>Catheters</td>
<td></td>
</tr>
<tr>
<td>CICC</td>
<td></td>
</tr>
<tr>
<td>Three-lumen, 9 Fr (n = 5)</td>
<td></td>
</tr>
<tr>
<td>Two-lumen, 7 Fr (n = 14)</td>
<td></td>
</tr>
<tr>
<td>One-lumen, 6 Fr (n = 15)</td>
<td></td>
</tr>
<tr>
<td>PICC</td>
<td></td>
</tr>
<tr>
<td>One-lumen, 4 Fr (n = 8)</td>
<td></td>
</tr>
<tr>
<td>Cannulated vein</td>
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<tr>
<td>Internal jugular vein</td>
<td></td>
</tr>
<tr>
<td>Axillary 3</td>
<td></td>
</tr>
<tr>
<td>Basilica 6</td>
<td></td>
</tr>
<tr>
<td>Brachial 2</td>
<td></td>
</tr>
<tr>
<td>TTE view</td>
<td></td>
</tr>
<tr>
<td>Subcostal (28)</td>
<td></td>
</tr>
<tr>
<td>Apical (14)</td>
<td></td>
</tr>
<tr>
<td>Ventilated/non-ventilated (n)</td>
<td>18/24</td>
</tr>
<tr>
<td>Systolic pressure (mmHg) (mean ± SD)</td>
<td>126.4 ± 21.5</td>
</tr>
<tr>
<td>Diastolic pressure (mmHg) (mean ± SD)</td>
<td>64.1 ± 6.7</td>
</tr>
<tr>
<td>Heart rate (bpm) (mean ± SD)</td>
<td>78.5 ± 22.2</td>
</tr>
</tbody>
</table>

SD: standard deviation; CICC: centrally inserted central catheter; PICC: peripherally inserted central catheter; TTE: transthoracic echocardiography.

After CICC placement, no pneumothorax was detected by ultrasound scanning of the pleural space.

Tip location by TTE was feasible in all patients except one, with a BMI of 29, where both the subcostal view and the apical four-chamber view were not satisfactory. In this patient—who needed a PICC for parenteral nutrition—tip location was assessed by post-procedural chest X-ray only.

In 25 patients (21 with CICC and 4 with PICC), the subcostal view was satisfactory; in the other patients (11 with CICC and 3 with PICC), we preferred to use the apical 4-chamber view: in this subgroup, three patients had surgery abdominal medication, and four patients had a BMI between 28 and 35 kg/m².

No patient in the PICC group was mechanically ventilated, while 18 patients of the CICC group were mechanically ventilated. There was no significant difference between ventilated versus non-ventilated patients, regarding the time of flush visualization. The apical view was chosen in five ventilated patients and in six non-ventilated patients.

At TTE evaluation, all tips of PICC were in the proper location. On the contrary, 2 of the 42 CICC (4.76%) were initially misplaced according to TTE: one tip was in the ipsilateral axillary vein, and the time for onset saline flush turbulence was 2.23 s (Figure 3); the other tip was in the left internal jugular vein after a catheter loop, and the time for onset saline flush turbulence was 5.07 s (Figure 4).

In 32 patients with CICC, the bubble test was carried out with 5 mL of saline solution with a good vision at first attempt. In those two cases of wrong position of the tip, the saline flush was viewed after more than 2 s, and the same result was obtained with saline–air mixture.

In seven patients with PICC, the simple saline injection yielded a good visualization of the tip in three cases (42.8%), while in four patients (57.2%), the test was repeated with the saline–air mixture.
When the tip was well positioned, the mean (±SD) time for onset of the bubble effect was 0.89 ± 0.33 s in patients with CICC and 1.1 ± 0.20 s in those with PICC; this time difference was not statistically significant (p > 0.05).

At post-procedural chest X-ray, the mean distance of the tip of the catheter below the carina was 2.3 ± 1.5 cm in CICC group and 2.6 ± 2 cm in PICC group; this difference was not statistically significant (p > 0.05).

Discussion

As regards position-related complications, international guidelines recommend using a method of intra-procedural tip location. Chest X-ray—though widely used—is not appropriate anymore, since it is inevitably post-procedural, apart from many other disadvantages (inaccuracy; long delay between request, execution, and reporting; X-ray exposure; and relevant cost).5,14

The use of TEE and TTE to verify the correct placement of the catheter has been widely evaluated.4,6,11,13–15

In a large meta-analysis, Smit et al.3 focused the accuracy and feasibility of TTE in 2548 patients, to verify the positioning of the tip. They reported a high specificity (98.9%) and a sensitivity rate of 68.2% for TTE. Other authors have also recorded a lower sensitivity of the method, in particular of TTE with bubble test.4,6 This is probably due to the limited number of tip malposition or the imperfect accuracy of the chest X-ray taken as a reference technique.5

On the contrary, the feasibility of ultrasound (i.e. the proper visualization of the anatomical structures of specific interest for the location of the tip) is very high, and in many studies, it is estimated up to 100%.6,14,15

In a recent meta-analysis,12 4 out of 5 misplacements were identified by TTE with bubble test, and bedside ultrasound was faster than radiography in identifying pneumothorax after CVC insertion.

The earliest study had already shown that adequate ultrasound images are necessary to correctly evaluate the position of the tip, and the special training given to physicians is crucial in the execution of the technique.13

The most practical method for tip location is the IC-ECG technique. However, this technique has a limit that has not been completely overcome, that is, it is applicable only when the P-wave is evident on the basal ECG trace. Recent studies9 have shown that when the P-wave is not visible due to atrial fibrillation, a modified IC-ECG method can be adopted. Although, when the P-wave is not visible because of other types of arrhythmia, IC-ECG is not applicable. For this particular category of patients, TTE may be the best option for tip location.

This study is the first in evaluating TTE in patients with atrial arrhythmia, and our results confirm that it is a simple, safe, and accurate technique also in this population of patients. Moreover, in our study TTE was equally feasible in intubated patients and in spontaneously breathing patients.

In addition, this is the first study to evaluate TTE as tip location in patients with PICC. Both in CICC and in PICC tip location, we adopted consistently TTE with bubble test. As in all of the previous studies,4,6,7,14 we adopted the 2-s cutoff proposed by Vezzani et al.;13 though, all the authors who calculated the time during the infusion of the flush found that—when the tip is in the correct position—the appearance of the bubble effect is consistently shorter than 2 s.

Weekes et al.7 recorded the visualization of the flush after 1.1 ± 0.3 s, and this finding was confirmed in our study; in fact, our mean time of appearance was 0.89 ± 0.33 s for CICCs, and 1.1 ± 0.2 s for PICCs. Our results, similarly to other studies4,6,15 highlighted that a prompt vision of bubble effect is essential to evaluate a correct tip location, and any delay in the visualization diagnoses malpositioning. Our data and that of Weekes7 agree that 2 s is an excessive time range to verify the correct tip location both in CICCs and in PICCs.

Meggiolaro et al.15 reduced this threshold by calculating more precisely the time—defined by the authors as “push to bubbles”—by connecting an ECG cable of the ultrasound machine to the syringe, so that at the beginning of the infusion, a spike appeared on the monitor, allowing the authors to calculate the latency time more precisely. According to these authors, the real cutoff should be 0.5 s if the catheter is positioned in the lower third of the SVC, and to 0.15 s if it is inside the right atrium. This technique is certainly more accurate, but it requires an ultrasound device equipped with ECG cables.
In our study, we have seen a slight delay in the vision of the flush in the PICC compared to the CICC. In addition, in PICC, the vision was less clear with simple saline solution, while a better image was achieved with the saline–air mixture. Probably this is due to the smaller diameter (4Fr) and the longer length of PICC if compared to the CICC.

This is the first study that evaluated TTE for tip location in PICC catheters. Recently, Nakamuta et al.16 have evaluated the tip location of PICC by ultrasound, but they have not used TTE with bubble test. These authors used vascular ultrasound to exclude the wrong position of the tip, evaluating the absence of the catheter tip in the jugular and axillary veins. The same authors highlighted that it was difficult to visualize the tip of the catheter in the SVC and CAJ. We have shown that ultrasound by TTE with bubble test can directly assess the correct tip location in PICC.

A limitation of TTE is that it is difficult to distinguish whether the tip of the catheter is in the lower third of the SVC or in the upper atrial portion. Probably, some authors have recorded a low sensitivity of the technique because they consider that the intra-atrial position is inappropriate, and they were not always able to rule it out.

In our study, we did not make this distinction because the 2009 European Society for Clinical Nutrition and Metabolism (ESPEN) guidelines17 and the 2016 Infusion Nurses Society (INS) guidelines consider that the tip is correctly positioned both if it is located between the lower part of the SVC and in the upper portion of the right atrium.

In addition, Pittiruti and Lamperti18 have mitigated the assumption that the atrial positioning could involve the risk of late cardiac tamponade, defining it as “urban legend.” In the absence of contraindications, repositioning the PICC tip simply because it resides in the right atrium was rated as inappropriate also by the Michigan Appropriateness Guide for Intravenous Catheters (MAGIC).19

**Conclusion**

In conclusion, TTE with bubble test is feasible, safe, and accurate in verifying bedside correct tip location at the CAJ in patients with atrial arrhythmia. When the tip is in the correct position, the appearance of bubbles in the right atrium is immediate, and the time from the injection is much fewer than 2s. Tip location by TTE can also be applied in PICC, but further studies may be needed to confirm its use in this type of catheter.

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

**Ethical approval**

Our study did not require an ethical board approval because we verified, in a selected population, the applicability of the intra-procedural method of tip location by TTE, according to the indications in international guidelines. Moreover, in our ICU, the use of TTE has been approved by the internal protocol of our hospital for tip location in all patients.

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