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Applicability and feasibility of intraprocedural tip location of femorally inserted central catheters by transhepatic ultrasound visualization of the inferior vena cava in adult patients

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Abstract

Background: The ideal intraprocedural method for tip location during insertion of femorally inserted central catheters (FICCs) is still a matter of debate. When the catheter tip is meant to be in the right atrium or in the supradiaphragmatic inferior vena cava (IVC), tip location by either intracavitary electrocardiography or transthoracic echocardiography may be accurate and easy to perform. When the catheter tip is planned to be placed in the subdiaphragmatic IVC, fluoroscopy—though inaccurate and unsafe—has been regarded as the only option for intraprocedural tip location.
Methods: We have investigated prospectively the applicability and feasibility of transhepatic ultrasound as intraprocedural method for assessing the location of the catheter tip in the subdiaphragmatic tract of IVC, during FICC insertion.
Results: We enrolled 169 consecutive patients undergoing FICC insertion by ultrasound guided puncture of the superficial femoral vein. In 165 out of 169 patients, the subdiaphragmatic IVC was visualized by the transhepatic ultrasound view. In all cases of IVC visualization, the catheter tip could be identified by ultrasound, either directly (direct evidence of the tip inside the vein) or indirectly (enhanced visualization of the tip after "bubble test"). There was no immediate or early complication, and very few late complications.
Conclusion: The intraprocedural method of tip location of FICCs by transhepatic ultrasound was applicable in 97.6% of cases and feasible in 100%. When the position of the catheter tip is planned to be in the subdiaphragmatic IVC, this method of tip location is accurate, safe, and inexpensive, and should be considered as an alternative to fluoroscopy.

Keywords

Femorally inserted central catheter, tip location, ultrasound, transhepatic ultrasound, superficial femoral vein, inferior vena cava

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Introduction

Femorally inserted central catheters (FICCs) are increasingly used in hospitalized patients and in outpatients, particularly when the approach to the deep veins of the arms or to the cervico-thoracic zone is not suitable or not safe. FICC insertion is typically indicated in patients with obstruction of the superior vena cava, in non-collaborative patients with cognitive disorders, in patients with chronic renal failure in hemodialysis and limited venous access in the supra/infraclavicular area, as well as in patients with helmet for non-invasive ventilation.[1] FICCs can be inserted through venipuncture either of the common femoral vein

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(at the groin) or of the superficial femoral vein (at mid-thigh).[2]

The definition of femorally inserted central catheter implies that the location of the tip must be either in the right atrium (RA) or in the inferior vena cava (IVC).[2] As for any other central venous catheter, the proper location of the tip of the FICC is of paramount importance for reducing the risk of thrombosis due to infusions which may damage the endothelium (antiblastic chemotherapy, parenteral nutrition, and other irritant or vesicant solutions). Recent guidelines[3–5] recommend that tip location of a central venous catheters should be verified by intraprocedural methods: post-procedural tip location should be avoided because not cost-effective, time-wasting, and potentially harmful to the patient. Intraprocedural methods currently available for tip location are intra-cavitary electrocardiography (IC-ECG), trans-esophageal echocardiography (TEE), trans-thoracic echocardiography (TTE) and fluoroscopy. TEE is highly accurate, but it is seldom used since it is invasive and expensive. The use of fluoroscopy is discouraged by current guidelines[3,5] because it is expensive, inaccurate, logistically difficult, and unsafe (since it implies exposure to ionizing radiation). Therefore, for peripherally inserted central catheters (PICCs) and centrally inserted central catheters (CICCs), the currently recommended intraprocedural methods for tip location are IC-ECG[6] and TTE,[7] since both are inexpensive, accurate, safe, and cost-effective.

As regards FICCs, the ideal method for tip location is still under debate. Also, the tip of the FICC may be located either in the RA in proximity of the junction between RA and IVC, or in the abdominal tract of the IVC, so that different tip location methods may be considered, depending on the planned position of the tip. Tip in the RA is often required in critically ill patients needing hemodynamic monitoring: in these cases, the position of the tip can be easily verified by IC-ECG (a diphasic P wave is associated with a tip at mid-atrium) or by TTE (the RA can be easily visualized by ultrasound using a convex probe with a subcostal view). On the other hand, in most adult patients with FICCs, the tip is preferentially located in the subdiaphragmatic tract of the IVC.[2] In such patients, the traditional approach for tip location consists in a pre-procedural length estimation based on surface landmarks plus a post-procedural radiological control by abdominal X-ray. Unfortunately, both methods are largely unreliable. Landmark measurements are unreliable because the exact distance between the inguinal groove and the origin of IVC has never been defined precisely and it has ample variations from patient to patient. Post-procedural X-ray is relatively inaccurate (since the position of the tip is interpreted only on the basis of radiological landmarks) and unsafe (since it implies X-ray exposure). Also, pre-procedural length estimation and post-procedural X-ray cannot prove the actual position of the tip inside the IVC: a catheter tip erroneously located in the right ascending lumbar vein may be easily interpreted as located in the IVC on an anterior-posterior radiological view of the abdomen.

In short, intra-procedural location of the tip inside the IVC requires the use of ultrasonography. Ultrasound visualization of the IVC is commonly utilized in the management of critically ill patients, for assessing intravascular volume in emergency situations. IVC can be visualized by three methods: subxiphoid long axis (SXLA), subxiphoid short axis (SXSA) and right transhepatic coronal long axis (THCLA). The latter has been defined as "rescue view"[8] and it has specific advantages, since it is not affected by factors (pericardial drainage, abdominal surgical wounds, gas distension of stomach or colon, non-invasive ventilation, percutaneous endoscopic gastrostomy, pregnancy, obesity) which may be an obstacle for the subxiphoid view.

The aim of this prospective study was to ascertain the applicability and feasibility of ultrasound identification of the tip of FICCs in the abdominal tract of the IVC, using the right transhepatic coronal long axis view (THCLA).

Methods

This prospective study investigated all FICCs inserted consecutively in adult patients from March to September 2022 in a large University Hospital. The study was approved by the local Ethics Committee. A specific consent form was developed and signed by each patient or by his/her tutor.

The primary endpoint of the study was to evaluate the applicability and the feasibility of ultrasound tip location by TCHLA, assuming that the desired position of the tip was the subdiaphragmatic tract of the IVC, below the hepatic veins and above the renal veins. When the desired position of the tip was the RA (for example, for the purpose of hemodynamic monitoring), the patient was excluded from the study.

Applicability of the method was evaluated as the percentage of cases in which IVC could be visualized by THCLA. Feasibility was evaluated as the percentage of cases in which the tip could be visualized inside the subdiaphragmatic tract of the IVC, either directly or indirectly (using the bubble test).

Secondary endpoints of the study were relevant post-procedural complications such as secondary malposition, catheter kinking, venous thrombosis, and catheter related infection.

Exclusion criteria were emergency insertion of FICC, insertion of dialysis/apheresis catheters, insertion in neonates or children, lack of patient's consent to participating in the study. All FICCs were inserted by trained operators of the local vascular access team, according to the hospital policies. FICCs were inserted according to the bundle

Figure 1. Wireless ultrasound probes used in this study (V-Scan, GE, on the left; Cerbero, ATL Milano, on the right). Both devices are provided with both a linear transducer (for venipuncture) and a convex transducer (for tip location).

developed by GAVeCeLT (the Italian Group for Long Term Venous Access Devices), previously described.[1,2] This insertion bundle includes (a) pre-procedural assessment of the deep veins of the groin and the thigh, according to the RaFeVA protocol (Rapid Femoral Vein Assessment)[9]; (b) hand hygiene, skin antisepsis with 2% chlorhexidine in alcohol, and maximal barrier precautions; (c) ultrasound-guided puncture/cannulation; (d) ultrasound-based tip navigation; (e) intra-procedural tip location; (f) sutureless stabilization of the catheter; (g) protection of the exit site with cyanoacrylate glue and semipermeable transparent membrane.

All catheters were inserted at bedside or in a dedicated procedure room. Each procedure required two operators, one performing the intravascular maneuver and the other one visualizing the IVC according to the THCLA method. Wireless portable ultrasound devices with two transducers of two different brands were used (Cerbero, ATL; V-Scan, GE) (Figure 1): the linear transducer (7–10 MHz) was used for preprocedural scan, venipuncture, and tip navigation, while the convex transducer (3.5–5 MHz) was used for tip location. Pressure injectable non-valved polyurethane catheters (length 50–60 cm) of different brands (Synergy CT, Healthline; ProPICC, MedComp; LifeCath PICC Easy, Vygon) were used.

All procedures were performed using a dedicated insertion pack. All catheters were inserted by ultrasound puncture of the SFV. After skin infiltration with few ml of local anesthetic (0.75% ropivacaine), the SFV was punctured and cannulated using micro-introducer kits (21 G needle, floppy straight tip 0.018″ nitinol guide wire and micro-introducer-dilator). When the SFV was located laterally or medially to the superficial femoral artery (SFA), a short axis visualization with “out-of-plane” puncture was adopted; when the SFV was located below the SFA or below the saphenous nerve, an oblique axis visualization with “in-plane” puncture was preferred.

After venipuncture, the catheter was inserted by the modified Seldinger technique. No catheter was trimmed since the total catheter length (50–60 cm) was required—as it happens in most adult patients—to cover the distance between puncture site (mid-thigh) and desired site of tip location (IVC between renal veins and hepatic veins).

IVC visualization by THCLA was performed placing the convex probe between the anterior and the middle axillary lines, at the 9th–10th intercostal space. The probe was tilted so to visualize the IVC in long axis, using the liver as acoustic window. The ultrasound view by THCLA allows the visualization of the hepatic veins inside the liver and of the IVC in the subdiaphragmatic tract above the renal veins. In particular, the junction between IVC and hepatic veins is easily visualized, and the image of the right kidney is also easily identified. The tract between these two structures corresponds to the area where the tip must be located. Ultrasound by THCLA often allows direct identification of the catheter tip in this area (Figure 2). If the catheter tip could not be identified with certainty, a bubble test was performed by rapid infusion of 10 ml of “shaken” saline containing microbubbles of air, according to a technique already described[7,10]: the location of the tip was easily identified as the site where the microbubbles appeared inside the vein. As the location of the catheter tip was clearly identified by the appearance of the microbubbles (Figure 3), the catheter was secured in that position. If the microbubbles did not appear in the tract of IVC visualized by ultrasound, or if they appeared with delay, the catheter was retracted and repositioned until the location of the tip was successfully assessed. In case of failure of tip visualization, a post-procedural abdominal radiography was required.

All major catheter-related complications occurring during hospitalization (infection, venous thrombosis, catheter dislodgment, irreversible lumen occlusion) were reported and recorded. The diagnosis of catheter-related blood stream infection (CRBSI) was based on paired cultures (from the lumen of the catheter and from the peripheral blood), according to the method of Differential Time to Positivity (DTP)[11]; the diagnosis of catheter-related venous thrombosis (CRT) was based on ultrasound examination of the veins, performed only in case of local signs or symptoms suggestive of venous thrombosis; secondary malposition and catheter kinking were diagnosed by appropriate imaging procedures (ultrasound and/or radiology), performed in case of catheter malfunction.

Results

In the year 2022, from March to September, a total of 169 FICCs were included in the study (102 in male and 67 in female patients). Mean age of patients was 70 (range

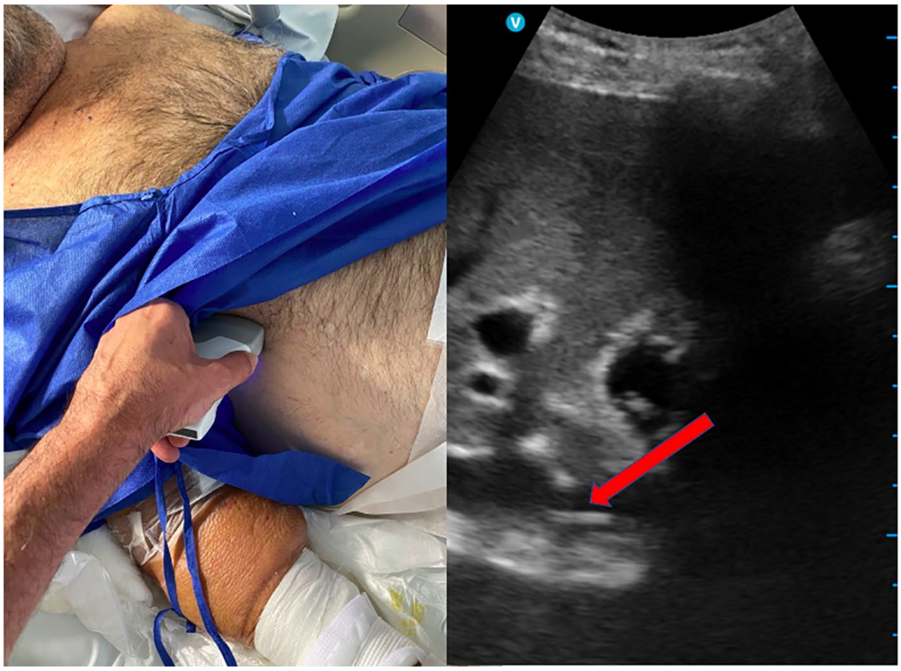

Figure 2. Direct visualization of the catheter tip (red arrow) inside the inferior vena cava, by transhepatic ultrasound view. The convex probe is placed on the right flank of the patient.

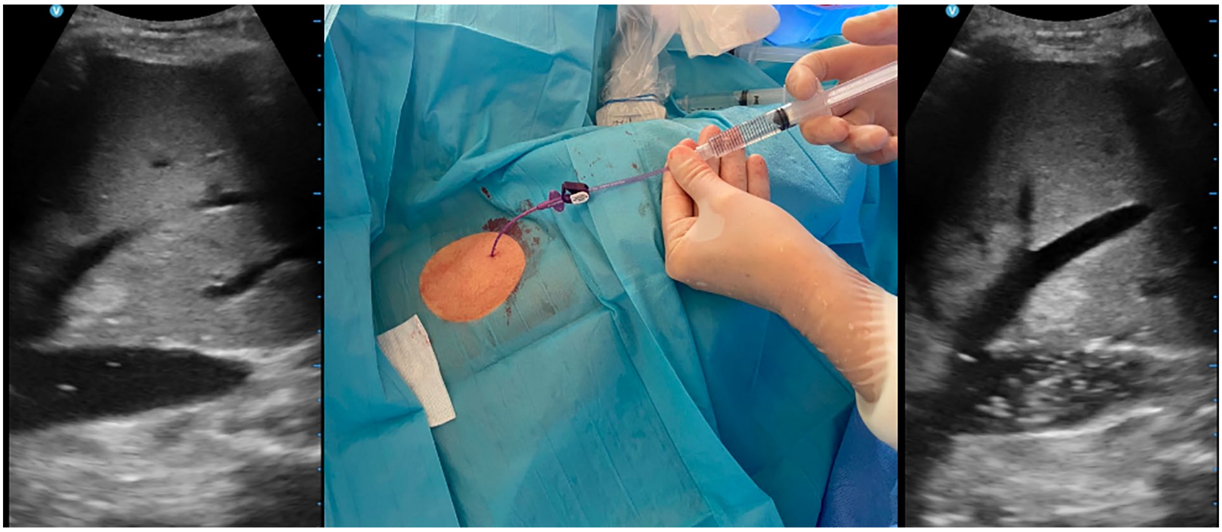

Figure 3. Indirect visualization of the catheter tip. After transhepatic visualization of the inferior vena cava (left image), 10 ml of shaken saline are rapidly injected in the catheter (middle image) and the appearance of the microbubbles inside the vein (right image) identifies the location of the tip.

40–91 years). The right SFV was accessed in 123 patients, and the left SFV in 46 patients. The inserted catheters were single lumen 4 Fr ($n=101$), double lumen 5 Fr ($n=62$), or triple lumen 6 Fr ($n=6$). The SFV was punctured by the short axis/out of plane technique in 80 patients and by the oblique axis/in plane technique in 89 patients.

Applicability of the method was 97.6%, since transhepatic visualization of the IVC was possible in 165 out of 169 cases. In four patients with roto-scoliosis, the IVC could not be visualized by THCLA, so that tip location was assessed by intra-procedural length estimation and post-procedural X-ray. In one of these four patients, X-ray showed that the tip was too high (close to the hepatic veins), and the catheter was partially retracted.

When the THCLA method was applicable, its feasibility was 100%. In 163 out of 165 cases the catheter tip was clearly identified in the IVC directly, and further confirmed by the bubble test. In two patients, the caliber of the IVC was very small, and the catheter could not be seen directly inside the vein; nonetheless, the position of the tip was assessed indirectly by the bubble test, since the appearance of the bubbles allowed the visualization of the tip.

No immediate or early complication occurred. Few late complications were recorded: two malfunctions due to tip migration; one CRBSI (due to Staph. Capitis, diagnosed by DTP); three cases of persistent withdrawal occlusion (PWO); one CRT (non-occlusive symptomatic thrombosis of the SFV at the puncture site). In all cases of PWO, the THCLA with bubble test confirmed that the catheter tip was still in the appropriate location. In one PWO patient, the catheter was removed because of suspected but not documented CRBSI (positive culture from peripheral blood only, since blood could not be withdrawn by the catheter). The catheter with CRT was left in place and used for infusion and blood withdrawal; appropriate antithrombotic treatment was started (LMWH, 100 units/kg/12 h) and continued until catheter removal for end of use. Thus, unscheduled removal because of late complication occurred in four cases (2.4%) (two tip migrations, one CRBSI, one suspected infection).

Discussion

Central venous catheterization requires a proper assessment of the position of the tip. While any location the tip inside the SVC, IVC or RA is compatible with the infusion of irritant/vesicant solutions and with blood withdrawal, the use of the central line for hemodynamic monitoring (central venous pressure, oxygen saturation in mixed venous blood) is appropriate only if the tip is in the RA. This implies that CICCs and PICCs may have the tip either in the SVC or in the RA, depending on the clinical situation; the location of the tip at the junction between SVC and RA is usually recommended as standard.[3] On the other hand, FICCs may have the tip either in the RA or in the IVC; though this topic is object of debate, since few evidence is available, it is usually recommended that the tip should not be placed at the junction between IVC and hepatic veins, because of the risk of thrombosis.[2]

As regards the method for assessing the proper tip location, current guidelines recommend adopting intraprocedural methods[3–5,12] and avoiding fluoroscopy as much as possible.[3,5]

On this basis, the recommended methods of tip location for CICCs and PICCs are IC-ECG and TTE. Several clinical studies have demonstrated that IC-ECG is more accurate than radiological methods when compared to the TEE[13–15]; the method is also easy and inexpensive, and it can be applied in adults,[6] in children[16] and in neonates.[17] The other main intra-procedural method for tip location is TTE: ultrasound-based tip location is based on the ultrasound visualization of the right atrium using a convex or a sectorial probe, adopting different acoustic windows (the subxiphoid longitudinal view, the subxiphoid bi-caval view, and the apical view); this method of tip location has been standardized in adults,[7] in children[18] and in neonates.[19]

Tip location of FICCs still remains a matter of debate. If the tip of the catheter is planned to be in the RA or at the junction between IVC/RA, both IC-ECG and TTE can be used. The presence of the tip in the middle of RA is associated with a diphasic wave at IC-ECG. Also, if TTE is adopted, the subxiphoid views allow to easily visualize the last portion of the IVC, the IVC/RA junction, and the RA. On the other hand, if the catheter tip is planned to be in the subdiaphragmatic IVC, other ultrasound views must be considered. In this regard, the right lateral transhepatic view is specifically interesting, since it allows to visualize the subdiaphragmatic tract of the IVC in most patients. THCLA has been described in the literature[20–22] as an effective method for visualizing IVC and measuring its diameter in hypovolemic patients.

In this prospective study, the THCLA view allowed to visualize the IVC in most patients (97.6%): only in 4 out of 169 patients the IVC was not visible because of severe roto-scoliosis, which was probably associated with an abnormal anatomic location of the IVC. Most importantly, in all patients with proper visualization of the IVC the catheter tip was directly visible inside the vein (163/165) or could be identified by bubble test (2/165).

To the best of our knowledge, this is the first report investigating the use of the THCLA view of the IVC for tip location of FICCs. This method of tip location has several advantages:

(a) it is intraprocedural (as recommended by current guidelines);
(b) it is completely safe if compared to fluoroscopy (it does not imply X-ray exposure);
(c) it is inexpensive (far less expensive than fluoroscopy);
(d) it is applicable in most patients (97.6%);
(e) when applicable, it allows the identification of the catheter tip in 100% of cases;
(f) it is more accurate than fluoroscopy, since it allows to assess the catheter tip inside the IVC, and to assess its relationship with the hepatic veins (on the contrary, fluoroscopy allows visualization of the catheter, but its location inside the IVC is assumed only indirectly, on the basis of radiological landmarks). Interestingly, while the THCLA method could be theoretically used without bubble test, the

bubble test plays a major role in confirming the identification of the catheter tip, and it may be essential when the caliber IVC is very small, and the catheter is difficult to identify directly.

Limitations of the method are the following:

(a) two operators are required;
(b) two probes are needed, a linear probe for venipuncture and tip navigation plus a convex probe for tip location (in this study, this limitation was absent, since we consistently used a wireless ultrasound probe with two transducers);
(c) specific training in performing THCLA is required (though, training is fast and easy, at least in the experience of the authors of the study);
(d) the method is obviously not applicable when inserting 20–25 cm long catheters (such as non-tunneled dialysis catheters) or when the desired location of the tip is above the diaphragm (RA or junction between RA/IVC). In the latter case, tip location does not require THCLA: it can be easily obtained by intracavitary ECG or by ultrasound visualization of the tip by a subxiphoid view of the right chambers of the heart.

Last, though in our study this tip location method has been applied exclusively to FICCs inserted by ultrasound guided cannulation of the superficial femoral vein, it can be obviously applied also to FICCs inserted in the common femoral vein, if they are long enough to reach the subdiaphragmatic tract of the inferior vena cava.

Conclusions

When inserting FICCs in adult patients, If the planned position of the tip is the subdiaphragmatic IVC, the right transhepatic ultrasound view allows an easy, accurate, safe, and inexpensive method for intraprocedural tip location. We suggest that the use of this method of ultrasound-based tip location should be included in the SIF protocol[2] and in the ECHOTIP protocol.[7]

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