The EKG method for positioning the tip of PICCs: results from two preliminary studies

Mauro Pittiruti¹, MD, Giancarlo Scoppettuolo², MD, Antonio La Greca¹, MD, Alessandro Emoli³, RN, Alberto Brutti⁴, RN, Ivano Migliorini¹, RN, Laura Dolcetti², RN, Cristina Taraschi², RN, Gennaro De Pascale², MD ¹Dept. of Surgery, ²Dept. of Infectious Diseases, ³Dept. of Oncology, ⁴Intensive Care Unit Catholic University Hospital, Rome, Italy

Abstract

Two preliminary studies were conducted to determine feasibility of using the electrocardiography (EKG) method to determine terminal tip location when inserting a peripherally inserted central catheter (PICC). This method uses the guidewire inside the catheter (or a column of saline contained in the catheter) as an intracavitary electrode. The EKG monitor is then connected to the intracavitary electrode. The reading on the EKG monitor reflects the closeness of the intracavitary electrode (the catheter tip) to the superior vena cava (SVC). The studies revealed that the EKG method was extremely precise; all tips placed using the EKG method and confirmed using x-ray were located in the superior vena cava. In conclusion, the EKG method has clear advantages in terms of accuracy, cost-effectiveness, and feasibility in conditions where x-ray control may be difficult or expensive to obtain. The method is quite simple, easy to learn and to teach, non-invasive, easy to reproduce, safe, and apt to minimize malpositions due to failure of entering the SVC.

Background

The importance of the position of the tip of any central venous access device (VAD) was stressed in 1998 by the Position Statement of the National Association of Vascular Access Network (NAVAN, now AVA). This position states the optimal position of the tip of a central VAD (excluding the VADs designed for hemodialysis) is the lower third of the superior vena cava (NAVAN, 1998; Scott, 1988; Scott, 1995). Though guidelines from other USA and European associations (Royal College of Nurses, Infusion Nursing Society, Society of Interventional Radiology, American Society of Parenteral and Enteral Nutrition, European Society of Parenteral and Enteral Nutrition, etc.) have offered different definitions of the optimal tip position, there is wide agreement that no central VAD should have its tip above the middle third of the superior cava vein or below the mid-portion of the right atrium (McGee and Gould, 2003; Taylor and Palagiri, 2007). In fact, positioning of the tip of a central line in an inappropriate site of the venous system is associated with a significant increase in the risk of malfunction, fibrin sleeve formation and venous thrombosis.

A ‘short’ catheter - i.e. a catheter whose tip is located in the upper or middle third of the superior vena cava (SVC) or in the innominate veins - has a 10 to 50 percent increased risk of central venous thrombosis (Caers et al., 2005) (Table I). Also, a high position of the tip of the VAD is associated with intimal damage due to mechanic irritation of the endothelium, with erosion and even perforation to the walls of the vein. Formation of a fibrin sleeve around the catheter occurs more frequently with a short catheter; this is typically associated with VAD malfunction (persistent withdrawal occlusion, or ball valve obstruction). In addition to these complications, the presence of a sudden or sustained increase of central venous pressure such as coughing, vomiting, etc. has been known to cause the ‘short’ catheter to dislocate, also known as ‘tip migration’ (Puel et al., 1993).

Conversely, a ‘long’ catheter, a catheter whose tip is in the lower portion of the right atrium or in the right ventricle or beyond, may carry the risk of arrhythmias, tricuspid valve dysfunction, erosion, or atrial thrombosis (Korones et al., 1996).

Finally, the tip of the catheter may be inadvertently positioned in the subclavian vein, in the internal jugular vein, or in other thoracic veins (internal mammary vein, azygos, etc.). This type of malposition is almost constantly associated with pain on infusion, early VAD malfunction and subsequent venous thrombosis.

While correct positioning of the tip of the catheter is of great importance during any central venous cannulation, it plays a crucial role in mid-term and long term VADs such as peripher-
ally inserted central catheters (PICC), tunneled catheters and ports, which are frequently inserted in patients requiring chemotherapy with vesicant drugs or hyper-osmolar nutritional solutions. Standard of Care for central venous catheters (CVC) dictates in the United States that the position of the tip must be confirmed by x-ray prior to use (INS 2006; NAVAN 1998). When the tip location cannot be confirmed in the superior vena cava, the catheter must be repositioned. Tip verification techniques have focused primarily on the x-ray. Other forms of tip verification have been used throughout Europe, with or without x-ray, incorporating electrocardiogram interpretation.

Methods for Preventing Malpositions

At present, the ‘gold standard’ for preventing malpositions and verifying the tip of the catheter is through radiology, either as intra-procedural fluoroscopy or as a post-procedural chest x-ray. On the fluoroscopic monitor or on the radiological film, the tip must be seen in the area correspondent to the lower third of the superior vena cava, i.e. no more than 2 cm below the image of the main right bronchus.

While confirmation of tip placement in the superior vena cava is mandatory, the radiological assessment of the tip position does have a few limitations and disadvantages:

- any type of radiological assessment is associated with x-ray exposure for the patient and/or for the health operator; such exposure can be relevant for intra-operative fluoroscopy or with repeated chest x-rays;
- the radiological landmarks used to determine catheter tip location may be unclear or significantly affected by physiological or pathological anatomic variations, false perspectives, or errors of interpretation (this is particularly true for intra-procedural fluoroscopy). In the case of post-procedural control, greater accuracy can be achieved by studying the chest in both the anterior-posterior view and in the lateral view. The use of dual views, while it increases accuracy, requires longer x-ray exposure and higher costs.
- In most cases, the radiological assessment requires the availability of an expensive and logistically cumbersome machine plus a radiology technician and/or a radiologist all adding to the procedural cost. This gives us an inappropriate cost-effectiveness ratio. Radiological assessment a problem with a PICC insertion which, in the United States, is most frequently performed by nurses at bedside. In this situation, the intra-procedural fluoroscopy may be difficult or impossible to adopt while the post-procedural chest x-ray carries a significant burden in terms of costs, organization and time delay. Also, in most cases the nurse who has inserted the PICC must rely on the intervention of the radiologist to interpret tip location.*

*This aspect might be overcome in some countries such as UK or USA, where there is a growing tendency to authorize nurses, if specifically trained, to interpret the x-ray. In April 2008, the Association for Vascular Access (AVA) published a Position statement on this subject. (AVA, 2008).

Tip confirmation by chest x-ray is less expensive, safer and more commonly used than fluoroscopy, though, in some cases the catheter has to be repositioned. Catheter tip repositioning requires a new procedure, a second radiological assessment, major discomfort for the patient and for the nurse or physician who has implanted the device, a significant time delay, repeated x-ray exposure, and increased costs.

Some non-radiological methods which can be useful in reducing the risk of malposition of the tip of the catheter include establishing the proper choice for venous access, using ultrasound for guidance, establishing baseline anthropometric estimates from landmarks, and using electromagnetic tools to detect direction of insertion.

1) Proper choice of the venous approach

In centrally inserted VADs, the supraclavicular approach to the right internal jugular vein, to the right subclavian vein or to the right innominate vein (by ultrasound guidance) is characterized by a lower incidence of malposition since the catheter almost invariably enters the superior vena cava vein. Nonetheless, the risk of malpositioning with a ‘short’ or ‘long’ catheter still persists.

2) Ultrasound Guidance

The use of ultrasound for needle guidance with CVC placement is known to increase success and reduce complications. Soon after PICC insertion, while the stylet is still inside the PICC, ultrasound examination of the internal jugular veins is a simple and reliable method to rule out a gross malposition, though it cannot give information about the correct length of the catheter. Post-procedural ultrasound control of tip position can be done by surface or trans-esophageal echocardiography, but the cost is high and requires specially trained operators.

3) Anthropometric estimates and surface landmarks.

There are several landmark methods for estimating the desired length of a central venous catheter or a PICC; usually, they are based on the assumption that the atrio-caval junction is located at the level of the third intercostal space, on the right parasternal border. The anthropometric methods utilized for central venous catheters apply formulas which are derived from large population studies. These measurements estimate the desired length of the catheter knowing the site of venipuncture and the height of the patient (Peres, 1990). Both anthropometry and surface landmark methods are quite precise in estimat-

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Table 1: Incidence of catheter-related thrombosis and catheter dysfunction, depending on tip position (modified from Caers et al., 2005)

<table>
<thead>
<tr>
<th>Tip position</th>
<th># cases</th>
<th>Thrombosis</th>
<th>Dysfunction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brachiocephalic vein</td>
<td>31</td>
<td>45.2%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Cranial 1/3 SVC</td>
<td>42</td>
<td>19%</td>
<td>16.7%</td>
</tr>
<tr>
<td>Middle 1/3 SVC</td>
<td>142</td>
<td>4.2%</td>
<td>1.4%</td>
</tr>
<tr>
<td>Caudal 1/3 SVC</td>
<td>66</td>
<td>1.5%</td>
<td>0%</td>
</tr>
<tr>
<td>RA or IVC</td>
<td>18</td>
<td>5.6%</td>
<td>5.6%</td>
</tr>
</tbody>
</table>
ing the length of the catheter in the adult patients, but not in children. Measurements provide a possible length for catheter placement in the SVC without adjustment for anatomical variations, directional or functional malpositioning.

4) Electromagnetic tracking methods.
These usually consist of an electromagnetic signal from a wire installed in the catheter by means of a surface apparatus connected to a monitor (Navigator, manufactured by Viasys; Sherlock, manufactured by Bard; Cath-Finder, manufactured by Pharmacia Deltec). They are primarily used with PICCs and need a specific technological design of the catheter and/or of its stylet. Some authors have demonstrated a significant reduction in the incidence of malposition, from 13.4% down to 2.5%, using such devices (Naylor, 2007). Their main limitation is that, while they do ascertain that the PICC is in the right direction, they do not give information about the correct location of the catheter (Royer and Earhart, 2007).

The Electro-cardiographic Method for Positioning the tip of Central Lines
The “ideal” method for checking the position of the tip should have the following features:
1. It should provide a way to check the position of the tip both during the procedure (to avoid repositioning manoeuvres) as well as after the procedure (to confirm tip position of the VAD);
2. The method should be easily and autonomously performed by the inserter of the VAD, either a nurse or a physician;
3. The method should be accurate enough to ascertain that the catheter has gone in the right direction (straight along the axis internal jugular vein – innominate vein – SVC) and to the right depth (not too long, not too short, but exactly at the atrio-caval junction);
4. It should be inexpensive, non-invasive, and easy to repeat with reproducible results;
5. It should be easy to learn and easy to teach;
6. It should provide a way to print and record the results to allow for documentation in the patient’s records.

Correct determination of catheter terminal location, in addition to identification and correction of malpositioning are all necessary components of PICC or CVC placement. Finding a method to perform these processes with ease during the insertion procedure will reduce time, speed usage, and save the patient from additional exposure and cost. We suggest the method that most closely meets all of these requirements is the location of terminal tip by use of the electrocardiographic (EKG) method. This method interprets the location of the catheter tip by using EKG with an intracavitary electrode (Corsten et al., 1994; Francis et al., 1992; Cavatorta et al., 1999; Gebhard et al., 2007; Antonaglia et al., 2008; David et al., 2005; Schummer et al., 2005; Cavatorta et al., 2001; Dionisio et al., 2001).

The basic principle of the EKG method is that the position of the tip inside the venous system can be detected by regarding the catheter itself (or a guidewire inside the catheter) as an intracavitary electrode which replaces the ‘red’ or ‘right shoulder’ electrode of the standard surface EKG (Figure 1). When the EKG monitor is connected to the intracavitary electrode, the reading of lead II will show a P wave whose shape and height will be a reflection of the closeness of the intracavitary electrode (i.e. the tip) to the seno-atrial nodus. A ‘giant’ P wave - as high as the QRS - indicates that the tip is inside the right atrium; when the P wave is as small as in the surface EKG, the
tip of the electrode is in the superior cava vein or above; a P wave whose height is half of the QRS is considered indicative of the atrio-caval junction. When the tip is in the lower part of the right atrium, the P wave may appear as bi-phasic or even negative (if close to the inferior vena cava) (Figure 2). Thus, simply by monitoring the height of the P wave, one can determine the location of the tip of the catheter as it travels through the superior vena cava, right atrial junction, and right atrium.

Limiting factors for this technique are in patients where alterations of cardiac rhythm change the presentation of the P wave as in atrial fibrillation, atrial flutter, severe tachycardia, and a pacemaker driven rhythm. The EKG method was first introduced in 1949 (Von Hellerstein et al., 1949) and has been successfully used for central venous catheter placement in Europe (especially Germany) since the’90s (Schummer et al., 2004).

During the last two decades, many clinical papers have demonstrated – with a few exceptions (Schummer et al., 2003; Schummer et al., 2004) – the accuracy of the EKG method, compared to the standard radiological assessment. Quite recently, other Authors (Gebhard et al., 2007) provided substantial research that has proven the EKG method is more specific and more precise when compared to conventional methods (i.e.: methods based on anthropometric measurements or standard formulas for estimating depth of catheter insertion, as available in the literature). In this clinical randomized study, all tips checked with the EKG method were in the superior vena cava or above, in contrast with other methods which showed 16% of those tips in the right atrium or in the right ventricle; also, only 3% of the tips checked by the EKG method were located above the superior vena cava (axillary, subclavian, internal jugular vein, innominate vein) versus 15% of the tips positioned with other methods.

This same clinical trial has shown that the EKG method did not significantly increase the length of time required to perform the procedure, and actually saved time by avoiding the need to reposition the catheter and get a second chest x-ray.

Many clinical trials have shown that the EKG method has clear advantages in terms of accuracy, cost-effectiveness and feasibility in conditions where X-ray control can be difficult or expensive to obtain (Corsten et al., 1994; Francis et al., 1992; Gebhard et al., 2007; Antonaglia et al., 2008; David et al., 2005). The method is quite simple, easy to learn and to teach, non-invasive, easy to reproduce, safe, and apt to minimize both malpositions due to failure of entering the superior vena cava (tip in internal jugular or subclavian or innominate vein) as well as malpositions due to error in the length of the catheter (catheter too short or too long). Though a thorough computation of the actual costs may differ, depending on the choice of technique and clinical setting, overall costs of the EKG method are consistently lower if compared to the standard check of the tip position by post-procedural X-ray. In fact, (a) the technique is inexpensive (the additional materials needed for the manoeuvre cost less than twenty dollars), (b) it can be performed at bedside, (c) the costs related to performing and interpreting chest X-ray are avoided, and (d) intra-procedural check of the tip position protects from expensive and timely repositioning manoeuvres sometimes needed after chest x-ray.

The trials concerning testing EKG have taken into consideration short term and long term central venous access devices inserted by puncture of the subclavian or the internal jugular vein (Chu et al., 2004; Cheng et al., 2002); in a few cases, the method
has also been tested in neonates (Biban et al., 2000; Tierney et al., 2000), with umbilical catheters and epicutaneo-caval catheters.

Considering demonstration of safety and cost-effectiveness of the EKG trial results carried out with central venous catheters within the past few years, we decided to apply this method, which appears so safe and cost-effective, to PICC placement.

The EKG Method for Positioning PICCs

In our 1200 bed University Hospital, PICCs are inserted by members of a dedicated team. The team consists of four physicians (two surgeons, two infectious disease practitioners) and ten nurses. Our team inserts approximately 1000 PICCs and 700 long term central venous access devices per year, and is committed to several clinical tasks, including monitoring VAD related complications, counselling in VAD indications and maintenance, education and training of nurses in our institution, and, most importantly, teaching on a national level. We provided more than 40 courses in 19 different Italian hospitals training clinicians to use ultrasound guided placement of PICCs.

Our experience with the EKG method for standard short term and long term central venous access devices began many years ago. In our hands, the method has proven to be safe and cost-effective, and it has dramatically reduced the number of chest x-rays necessary to check the position of the tip.

Recently, we began a project for verifying the feasibility of applying this method to PICC. Until 2006, our standard protocol for PICC positioning consisted (Pittiruti et al., 2005) of (a) anthropometric estimate of the desired length of the PICC by anatomical landmarks (from the site of puncture to the third intercostal space on the right sternal border); (b) ruling out the presence of the catheter in the internal jugular vein by direct ultrasound examination during the procedure; and (c) postoperative, chest x-ray.

After a few preliminary clinical experiments carried out in 2007, whose goal was to define the technical aspects of the method, in the first months of 2008 we performed two pilot studies, one on open ended PICCs and one on closed ended (Groshong) PICCs. The details of these studies are listed below.

First study: Open Ended PICCs*

The aim of the first study was to verify the feasibility of the EKG method to open-ended PICCs. After approval of the Ethical Committee of our University, twelve consecutive patients requiring PICC lines were enrolled in this study. Exclusion criteria were: atrial fibrillation or other supra-ventricular arrhythmias; presence of a pace-maker. Desired catheter length was pre-operatively estimated by means of anthropometric parameters. We used the VygoCard device (Vygon) as the electrical transducer between the catheter (filled with standard 0.9% saline solution) and the EKG cable. The VygoCard transducer is part of a 3-way stopcock connected with the catheter and with a cable going to lead III of a standard EKG monitor. The catheter acts as an intracavitary electrode which replaces the traditional ‘red’ electrode on the right shoulder. The PICCs were inserted in the basilic (first choice) or brachial (second choice) vein at mid-arm under direct ultrasound guidance. Then, the catheter was slowly advanced in the venous system while observing the morphological intracavitary EKG changes until the P wave reached the desired shape and amplitude (one-half of the QRS complex), corresponding to the atrio-caval junction (Fig. 3). The catheter was then secured to the skin by means of a sutureless device. All patients underwent a post-operative chest x-ray (postero-anterior and lateral views). X-ray films were evaluated by an independent radiologist not involved in the insertion procedure; the atrio-caval junction was radiologically identified as 2 cm below the carina.

In this study, all twelve PICCs were successfully inserted. The “atrio-caval junction p-wave” was observed in all cases, in one patient after withdrawing and re-introducing the catheter. Final position at the atrio-caval junction was confirmed by postoperative intracavitary EKG control and chest x-ray in all
patients. Consistently, no primary malpositions were observed on chest X-ray and all catheter tips appeared to be at the atrio-caval junction on X-ray films. In 3 cases the catheter length, as preoperatively estimated by anthropometric measurement, was significantly different (> 2 cm) from the length measured by the atrio-caval junction P wave; though, the final tip position was chosen according to the EKG measurement, and chest X-ray films were consistent with the EKG data.

**This study has been presented at the 2008 Meeting of the Infusion Nursing Society (Pittiruti, LaGreca, Scoppettuolo et al., 2008).**

Second study: Groshong PICCs**

In the second pilot study, six consecutive ICU patients requiring PICC lines were studied. The aim of this study was to verify the feasibility of the EKG method during the insertion of closed ended PICCs. Exclusion criteria were atrial fibrillation or other supra-ventricular arrhythmias, and/or the presence of a pace-maker. We used the Vygocard device (VYGON) as the electrical transducer between the catheter (filled with standard 0.9% saline solution) and the EKG cable. After ultrasound guided insertion in the basilic (first choice) or brachial (second choice) vein at mid-arm, each catheter was connected to an infusion line and a continuous saline infusion was started to keep the distal valve open. Baseline EKG rhythm was visualized. Then the catheter was slowly advanced in the venous system while observing the morphological changes of the P wave until the P wave reached the desired amplitude (one-half of the QRS complex), corresponding to the atrio-caval junction (Fig. 4). All patients underwent a post-operative chest x-ray (posterior-anterior and lateral views): the atrio-caval junction was radiologically identified as 2 cm below the carina. All x-rays confirmed EKG results of atrio-caval placement.

In this study, all six Groshong PICCs were successfully inserted. The “atrio-caval junction P wave” was observed in 5 patients. In one case, the baseline cardiac signal was disturbed by electrical artefacts and the patient was excluded from the protocol. No primary malpositions were observed on chest x-ray and all catheter tips appeared to be at the atrio-caval junction on x-ray films.

*This study has been presented at the 2008 Meeting of the European Society of Intensive Care Medicine (Pittiruti, LaGreca, Brutti et al., 2008)*

**Discussion**

At present, the most common technique utilized for checking the position of the tip of CVCs by the EKG method employs the use of a guidewire inserted in the catheter as an intracavitary electrode, with the tip of the guidewire free in the bloodstream.

To adapt the EKG method to PICC insertion, we chose the alternative technique (already described for dialysis catheters and umbilical catheters), where the intracavitary electrode is the column of saline contained in the catheter itself (Pawlik et al., 2004; Madias, 2003; Madias, 2004). This is made possible by two different options: (a) With the first option, the PICC is closed proximally with a needle-injectable cap; a blunt needle or blunt ended connector is partially inserted in the cap, and an extension cable is connected to the access (Fig. 5); (b) The second option is more simply done with the proximal end of the PICC connected to a special device consisting of a 3-way stopcock with a transducer (Vygocard, Vygon, Fig. 6) or in a transducer directly attached to a syringe (AlphaCard, BBraun, Fig. 7); the transducer has an extension cable which connects to the EKG monitor.

The manoeuvre is further simplified by utilizing a specific commuter (Certodyn, BBraun, Fig. 8) connected to both the standard ‘red’ surface electrode on the right shoulder of the patient and to the intracavitary electrode. Changing the position of the switch, it is possible to read the EKG either as standard surface EKG or as intracavitary EKG. The changing morphology of the P wave is best appreciated reading D II.
Before reading the P wave change but after removal of the internal stylet, the PICC is filled with normal saline. If the PICC has a closed end, in order to maintain a column of fluid which may act as continuous intracavitary electrode, it is necessary to have a continuous infusion of saline through the system. Open ended PICCs have not additional requirements other that connection and saline flushing.

The best way to precisely locate the atrio-caval junction is to advance the PICC inside the venous system downward to the superior vena cava and beyond, until the typical ‘giant’ P wave (as high as the QRS) appears. This full sized P wave indicates that the right atrium has been reached. Once the P wave reaches full height, the PICC is slowly drawn backward until the P wave progressively reduces its height to $\frac{1}{2}$ of the QRS: this corresponds to the atrio-caval junction. The PICC can then be secured to the skin in this position with the knowledge that the terminal end is at the caval-atrial junction.

Disadvantages of this method for checking the position of the tip of PICCs are:

- The method assumes the presence of a P wave on the standard EKG; in situations where the P wave is not present or not readable (atrial fibrillation, atrial flutter, marked tachycardia, pacemaker-driven rhythm), the method cannot be used;
- In some cases of closed ended PICCs, the Groshong valve may not open easily or continuously; intermittent flow across the valve may be consistent with a good infusion, but it causes intermittent EKG reading because the column of saline is interrupted.

Advantages of the EKG method:

- The method is accurate, safe, simple, non-invasive, easy to perform, easy to learn and easy to teach;
- It is inexpensive since it only requires an EKG monitor and a disposable sterile transducer (either Vygo card or Alphacard) with the extension cable;
- The manoeuvre can be performed at bedside, like most PICC insertions, and can easily be carried out by a nurse after minimal training;
- The method gives definitive information about the position of the tip directly during the procedure, thus saving time and resources;
- The costs as well the x-ray exposure associated with the radiological assessment are avoided in most cases;
- The correct position of the tip can be documented in the medical chart by appropriate printing of the EKG track.

**Conclusion**

The EKG method for determining caval-atrial junction terminal tip location is well documented in Europe and, through this study, has demonstrated accurate and safe use with PICCs. Though more studies are needed to standardize the procedure and to evaluate the accuracy of the method in different clinical situations and for different types of PICCs, we think these two pilot studies are very promising. This research suggests that the EKG method may strongly improve both the cost-effectiveness and the safety of the procedure for terminal tip interpretation on insertion and potentially, any time evaluation is desired.

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