Electrocardiogram (EKG) Guided Peripherally Inserted Central Catheter Placement and Tip Position: Results of a Trial to Replace Radiological Confirmation

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Abstract

Background: *The current standard of care for Peripherally Inserted Central Catheters (PICCs) is radiological confirmation of terminal tip location. Tip location practices in Europe have used electrocardiographic (EKG) guided positioning for central venous catheters for more than twenty years with tip positioning safely confirmed over thousands of insertions (Madias, 2003). The goal of this group was to confirm the findings of a study performed by Pittiruti and his team; and to establish safe function in the use of EKG guidance for verification of terminal tip position with PICCs placed at McKenzie Willamette Medical Center.*

Methods: *In 2008/2009 McKenzie Willamette Medical Center conducted a study to determine whether or not EKG guidance can be used as a reliable means to accurately place and confirm terminal tip location of PICCs. A group of trained nurses performed PICC placement using EKG guidance followed by radiological confirmation of SVC position. All PICCs placed from October 2008 to December 2009 were included in the study. Tip location was confirmed using either radiological confirmation alone, EKG plus radiological confirmation, or EKG alone.*

Results: *A total of 417 PICCs were placed during the study period. EKG guidance alone was used in the placement and confirmation of 168 PICCs. Both EKG and chest x-ray confirmation were used in the placement of 82 of the PICCs; 240 of the PICCs were placed with the use of EKG and then position correlated using the traditional chest x-ray procedure.*

Discussion: *EKG guided PICC placement proved accurate in consistently guiding the terminal tip to the superior vena cava (SVC). The procedure was easily taught and duplicated by members of the PICC team. The study demonstrated a definite correlation between the height (size) of the P-wave and the location of the terminal tip within the SVC. With knowledge of this correlation, transition from placing PICCs using EKG guidance with chest x-ray confirmation to confirmation of tip placement using just EKG guidance without chest x-ray confirmation was attained. Application of EKG placement/confirmation performed during insertion saves time previously spent waiting for x-ray confirmation readings, saves cost of chest x-ray, prevents patient exposure to radiation and saves time required for tip repositioning of malpositioned tips found after the end of the procedure.*

Background

While radiographic imaging is the current standard of care for Peripherally Inserted Central Catheter (PICC) tip confirmation (Scott, 1995), electrocardiographic (EKG) guided positioning, which has been widely used throughout the world in conjunction with central venous catheters (CVCs), is applicable for position confirmation of PICCs (Chu, et al., 2004; Jalaeian, Mottahedi, Ghanad, & Peyvandi, 2005; Pittiruti, et al., 2008). With the number of PICC placements increasing, a more accurate and efficient means of tip confirmation is needed. PICCs are placed primarily through the veins of the arm. One of the primary reasons for chest x-ray (CXR) is to rule out the presence of insertional complications such as malposition (Jalaeian, et al., 2005). Use of EKG guidance for placement of PICCs can speed time to first usage by reducing time required for x-ray interpretation and by reducing repositioning delays (Francis, Picard, Fajardo, & Pizzi, 1992; Tiernay, Katke, & Langer, 2000).

Chest x-rays are used to verify the terminal tip after CVC

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placement as well as to rule out the presence of pneumothorax, a complication occurring with subclavian or internal jugular catheters. While EKG tip location does not address the presence of a pneumothorax, PICCs consistently demonstrate reduced insertional risk without pneumothorax. When patient symptoms demonstrate respiratory complications following CVC placement, a CXR is easily performed to identify the origin of the problem.

The challenge with small diameter PICCs is to locate the terminal tip and have consistent interpretation of where the distal superior vena cava is positioned. Radiographic films taken with portable equipment use the anterior/posterior (A/P) view to verify position of the terminal CVC tip. Radiographic interpretation variations occur with positioning, anatomic aberrations, arterial placement and obesity providing a false sense of security with the A/P view. A corresponding lateral view has been noted by several authors as necessary in determining accurate placement of CVCs and PICCs but is rarely employed in daily practice (Lum, 2004; Madias, 2003; Royer, 2001). Variation is also present in landmarks used to interpret radiographic results and distal SVC position on 2-D radiographic films (Vesely, 2003). A more accurate means of tip position confirmation has been extensively studied throughout the world, primarily with CVCs, but more recently with PICCs (Chu, et al., 2004; Jalaeian, et al., 2005; Pittiruti, et al., 2008). Pittiruti and his team of physicians and nurses performed multiple EKG confirmation studies on open and closed ended PICCs validating accurate distal SVC position. The methods used included guidewire and saline infusion for electrical conductivity represented in the p-wave of an electrocardiogram (EKG) rhythm. When a normal sinus rhythm is visible on an EKG monitor, the p-wave is seen just prior to the QRS complex (QRS). With intracavitary monitoring of electrical activity the p-wave changes and becomes amplified or taller as a catheter is advanced into the SVC. When the p-wave peaks, the tip is at the SVC/right atrial junction (SVC/RA). This study is thought to be the first published nursing- based PICC EKG tip location study performed in the United States (US), confirming the findings of Pittiruti and his team while demonstrating application with US based equipment.

Methods

In 2008/2009 McKenzie Willamette Medical Center conducted a study of EKG guided placement of PICCs followed by radiological confirmation of SVC position to determine if the procedure could be duplicated with accuracy and dependability. Peripherally inserted central catheters used in the study included both closed–ended (Groshong™ Bard Access, SLC Utah) and open-ended (Power PICC™ Bard Access, SLC Utah) catheters. A review of EKG literature available at the time of the study revealed 95-100% accuracy with EKG guided CVC or PICC placement into the superior vena cava (SVC) (Francis, et al., 1992; Hoffman, et al., 1988; Karaaslan, Altinisik, Peker, Nayir, & Ozmen, 2009; W. T. McGee, et al., 1993; Pittiruti, et al., 2008; Schummer, et al., 2004). The desire to recreate this study was based on the level of success reported in the literature.

Following a Critical Care Committee review and approval, patients undergoing PICC placement from October 2008 through December 2009 received verification of tip placement with either radiological confirmation alone, EKG and radiological confirmation, or EKG alone. The first ten patients involved in the study used the EKG tip location method and a secondary confirmation with chest x-ray method. After the initial ten patients, PICCs were placed using the EKG method only, with verification based on the judgment of the clinician reading the EKG during placement. When chest x-ray was necessary for other reasons, catheter tip location was also reviewed and findings were correlated with results of EKG tip location method.

Criteria for patients' inclusion with EKG tip location study included all of the following: a) any adult 18 years or older; b) with a normal sinus rhythm; c) a clearly visible p-wave; d) who were scheduled to receive a PICC for prescribed treatment. Criteria which excluded patients from the EKG placement study included: a) the presence of an arrhythmia resulting in lack of p-wave or indistinguishable QRS complex, or b) the dependency on a pacer for heart function. Initially a conservative approach was applied at this institution for selection of PICC candidates for use of EKG tip location. Placement of catheters was performed by PICC trained experienced radiological nurses using the guidewire and saline EKG location techniques. Radiographic confirmation was verified by interventional cardiologists for consistency with this study. EKG equipment included an EKG adapter (Pacerview, San Clemente, CA) and a cable with alligator clamp (Pacerview, Grabber, San Clemente, CA)

When placing a PICC using the EKG tip location method, a conductor is required within the tip of the catheter. Two methods of creating conductivity within the catheter include: use of a guidewire within the catheter or filling the catheter with a saline solution. Both of these methods are described below and were used as steps in the study.

Steps for placing EKG guided PICC with guidewire technique:

1. Attach 3 or 5 lead monitor to patient (always apply all new leads); determine if the patient is in Normal Sinus Rhythm (NSR), atrial fibrillation or is dependently paced. If the patient is in NSR, proceed with EKG guided PICC insertion.
2. Detach the left leg lead from the patient and attach it (red lead) to the EKG adapter lead button.
3. Select the vein for PICC insertion using ultrasound scanning.
4. Measure selected vein to estimated location of Superior Vena Cava (SVC).
5. Set up sterile field; prep and drape patient.
6. Don personal protective equipment (PPE).
7. Trim the PICC to the desired length making sure guidewire is at the very distal end of the PICC but not extended outside the catheter. Flush PICC with normal saline.
8. Place the EKG cable into sterile cover/sleeve. Remember the cable is unsterile and must be covered.
9. Insert the PICC using ultrasound guided modified Seldinger technique (MST).
10. When the PICC is approximately 50% to its intended goal of the distal SVC/caval atrial junction, attach the EKG Alligator cable to the guide wire in the PICC, carefully punching the tip of the grabber through the sterile sleeve and covering the connection with a sterile 4x4.
11. Flush the PICC again with normal saline.

12. An inverted QRS complex should appear on the monitor. The p-wave is normal size initially, increasing in amplitude as the PICC is advanced. Compare p-wave size from initial normal complex to peak level. (Note: Size may vary with QRS complex comparison with p-wave and be larger than QRS. The determinant is p-wave change measured to peak with biphasic notch.)
13. When the p-wave is about ¾ of the full peaked level, approx ¾ the size of the QRS, the PICC tip is in the lower or distal SVC (also known as proximal SVC in relation to the heart).
14. When the p-wave is fully peaked or at the highest amplitude, it is at the caval atrial junction (SVC/RA).
15. When a small positive wave spike is seen in the p-wave, the tip is in the right atrium.
16. When the p-wave becomes biphasic (expands beyond the baseline up and down), the PICC tip is in the low right atrium/high right ventricle. This is known as an atrial spike.
17. If no QRS pattern is seen during advancement of the catheter, the PICC has malpositioned in the internal jugular or contra-lateral in the opposite subclavian vein. Attempts to reposition can be made until the inverted QRS is seen on the monitor.
18. Print final strip with P-wave at the same amplitude as QRS to confirm location of the tip. Include this EKG strip as part of the patient's record.

(Note: You may see some respiratory variation in the wave form.)

Photo 1. *EKG Interpretation of PICC tip location. Note p-wave amplitude near amplitude of inverted QRS. This demonstrates PICC tip location near the Caval Atrial Junction.* ***G Dennis***

Steps for placing EKG guided PICC with saline filled lumen:

1. Attach 3 or 5 lead monitor to patient (always apply all new leads; do not use any currently in use with other monitors); determine if the patient is in Normal Sinus Rhythm (NSR), atrial fibrillation, or is dependently paced. If the patient is in NSR, proceed with EKG guided PICC insertion.
2. Detach the left leg lead from the patient and attach it (red lead) to the EKG adapter lead button.
3. Select the vein for PICC insertion using ultrasound scanning.
4. Measure selected vein to estimated location of Superior Vena Cava (SVC).
5. Set up sterile field; prep, and drape patient. Drop a sterile injection cap with needle penetration septum onto the sterile field.
6. Don personal protective equipment (PPE).
7. Prefill a 20cc syringe with saline and attach a steel needle.
8. Trim the PICC to the desired length; remove the guidewire and apply the injection cap with needle septum. Flush the PICC with normal saline.
9. Place the EKG cable in sterile cover/sleeve.
10. Insert the PICC using ultrasound guided modified Seldinger technique (MST).

Photo 2. *Sterile sleeve covering the EKG alligator cable.* ***G Dennis***

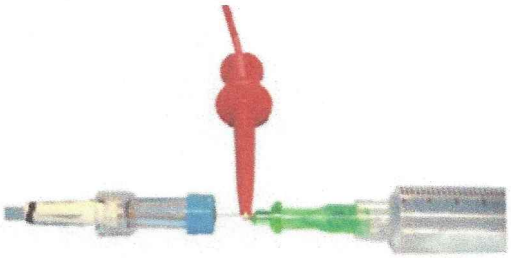
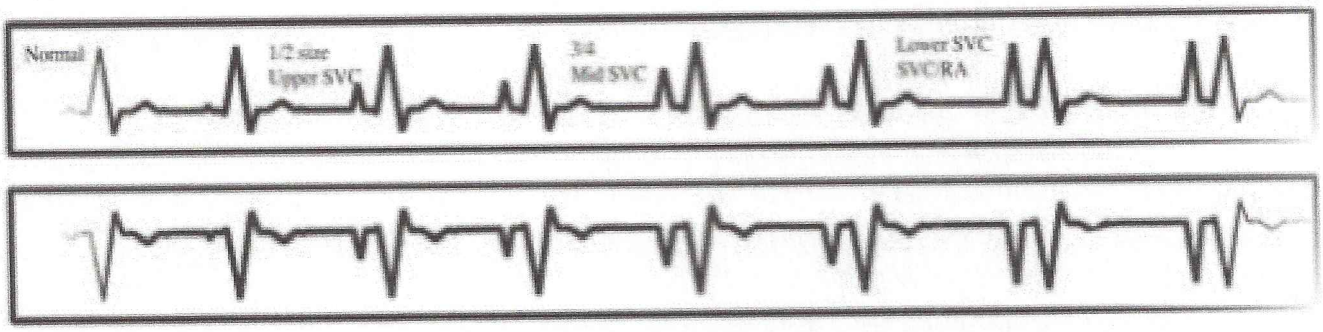


Photo 3. *Close up of EKG alligator cable clipped to steel needle shaft for saline-only method of EKG tip placement.* ***G Dennis***

11. When the PICC is approximately 50% to its intended goal of the distal SVC/caval atrial junction, attach the alligator cable to the needle shaft (the needle is inserted through the injection cap) carefully punching the tip of the grabber through the sterile sleeve, and covering the connection with a sterile 4x4.
12. Flush the PICC again with normal saline 5-10ml.
13. An inverted QRS complex appears on the monitor. The p-wave is normal size initially, increasing in amplitude as the PICC is advanced. Compare p-wave size from initial normal complex to peak level. (Note: Size may vary with QRS complex comparison with p-wave and be larger than QRS. The determinant is p-wave change measured to peak with biphasic notch.)
14. When the p-wave is about ¾ the size of the QRS, the PICC tip is in the lower SVC.
15. When the p-wave is the same amplitude as the QRS, it is at the caval atrial junction.
16. When a small positive wave spike is seen in the p-wave,

Figure 1: P-Wave Simulated Interpretation *(used with permission PICC Excellence, Inc.)*



the tip is in the right atrium.

17. When the p-wave becomes biphasic (expands beyond the baseline), the PICC tip is in the low right atrium/high right ventricle. This is known as an atrial spike.
18. If no QRS pattern is seen during insertion procedure, the PICC has malpositioned in the internal jugular or is contralateral in the opposite subclavian vein. Attempts to reposition can be made until the QRS is seen on the monitor.
19. Print final strip with P-wave at peak amplitude as QRS to confirm location of the tip. Include this EKG strip as part of the patient's record.

(Note: You may see some respiratory variation in the wave form)

Results

A total of 417 PICCs were placed from October 2008 through December 2009 in this 100 bed facility. EKG tip location was used in 250 (60%) of PICC placements. Of those correlated with CXR results by the interventional cardiologist, 240 agreed and 8 disagreed (3%) with optimal position in the SVC. Valved catheters composed the largest PICC group with 399 (96%).

Left-sided placements were in only 76 of the 417 placements (18%) and basilic vein was used in 346 (83%) placements. Position verified as distal/lower SVC or caval/atrial junction with 367 placements (88%). Other placement locations in 50 (12%) placements included SVC 2 (.4%), mid-SVC 18 (4%), axial 4 (.9%) and other 26 (6%).

The most common reasons for the inability to use EKG were:

a) The presence of atrial fibrillation
b) Rhythm that prevented or impaired p-wave interpretation
c) Patient dependence on a pacemaker.

The study confirmed when using the EKG method to place PICCs the terminal tip location could be predicted based on the size of the p-wave, relative to the peak level and QRS complex. These findings were confirmed through correlation with chest x-rays after placement with EKG.

A learning curve was present in gaining proficiency in interpretation and with application of all advantages of EKG PICC tip guidance. Specific details for the learning period in this study were the following:

- Four catheters required repositioning in December 2008. Three PICCs were located in the right atrium, and one looped in the innominant vein extending contralateral. All four locations required retraction or repositioning of the catheter.
- Two catheter placements failed to visualize QRS complex or p-wave changes with one curled in the basilic vein and the other repositioned from azygos vein twice prior to correct positioning with EKG. Both placements were then confirmed using chest x-ray.
- One of the eight PICCs listed as uncorrelated from EKG to CXR had a position in the distal SVC; retraction of 5cm was originally advised by radiologist.

Discussion

Throughout the 15 month period of this study, EKG guidance was used in positioning and confirming placement for PICCs. In the most difficult placements, EKG reduced the number of chest x-rays needed and provided immediate feedback to the clinician to speed placement. Analysis of p-wave amplitude to note peak configuration and biphasic activity during advancement through the SVC and RA junction requires training and experience to reach 100% accuracy in interpretation.

Respiratory variations, ventilator vibration and action, muscle twitching or excessive patient movement caused signal interruptions or inability to interpret tracing of EKG and p-wave. Closed ended catheters require a continuous infusion of saline or flushing of saline to keep the valve open and the signal somewhat consistent. Even with a steady infusion, breaks may occur with valved catheters where signal is lost but should return with continued flow of saline to reopen valve. Application of new leads to each patient resulted in improved signal.

Variables to this study included:

1. Poor initial understanding of biphasic spike and presentation of p-wave in right atrium at the beginning of the study period.
2. Adding 4 new clinicians during the course of the 2008/2009 study may have caused variation and reduction of accuracy in data interpretations.
3. Multiple physicians interpreting PICC tip chest x-rays in different acceptable locations.
4. Use of the data category "other" with failure to specify in 4% of final tip location results. Data collection categories overlapped, (distal SVC, Caval atrial junction, mid SVC, lower SVC, SVC, axial, other) and greater clarity was needed in the study for correct final placement.

Photo 4. *Pacerview device. Note EKG lead LL attached to Pacerview unit.* ***G Dennis***

Photo 5. *Vygon/Advanced Medical Vygocard and cable connection for catheter and EKG monitor.* ***PICC Excellence, Inc***

Table 1

EKG Device Company	Name of Device	FDA Indication/European CE
Arrow International www.arrowintl-europe.com	Adapter: Arrow-Johans™* JAdapter for Right Atrial Electrocardiography	FDA Clearance: pending CE Mark: Yes
B. Braun www.cvc-partner.com	Certodyn, Alphacard	FDA Clearance: unknown CE Mark: Yes
Pacerview www.pacerview.com	Pacerview device and Grabber	FDA Clearance: Yes No longer available for purchase
Romedex International SRL www.romedex.com	Sapien Tip Location System TLS	FDA Clearance: pending CE Mark: Yes
Vasonova www.vasonova.com also has doppler	Vasonova Visual Positioning System (VPS)	FDA Clearance: Yes CE Mark: unknown
Vygon/Advanced Medical www.vygonusa.com	Vygocard and cable	FDA Clearance: pending CE Mark: Yes

Photo 6. *B Braun Alphacard.* ***PICC Excellence, Inc.***

The current standard of radiographic interpretation of CVC/PICC tip location by chest x-ray is often imprecise and subject to observer variability. In this study, variation was noted in the tip determinations by different radiologists and in their definition of optimal placement location. Differing anatomic landmarks (carina, right superior heart border) are used to identify optimal location in the SVC with interpretation changing from person to person, some desiring SVC/RA junction and others opting for mid-SVC rather than deeper placement (Vesely, 2003). When viewing a chest x-ray flat film or even a digital film, the exact desired location is difficult to pin-point; typically there is a range of acceptable options and even those can be debated. Manufacturer recommendations for central line placement specify placement in the SVC and not the right atrium. FDA central venous catheter working group identified distal SVC as optimal location for non-dialysis catheters (Scott, 1995). EKG guidance provides a precise SVC position in more than 95% of placements (Francis, et al., 1992; D. McGee & Gould, 2003; W. T. McGee, et al., 1993; Schummer, et al., 2004) also reducing the need to reposition catheters (Gebhard, et al., 2007). In this study accuracy of correlated EKG/CXR position reached 97%. Validation of EKG positioning correlates with the gold standard for positioning when using the transesophageal imaging (Chu, et al, 2004). While it is

prudent to recheck tip position with a chest x-ray when abnormal symptoms arise following CVC or PICC placement, consensus is that EKG virtually eliminates the need to confirm tip position by chest x-ray (Madias, 2003). CXR may be necessary for CVCs other than PICCs and certainly for those patients in which the p-wave is not discernable. EKG guidance has demonstrated superior performance in guiding a catheter to the right location and confirming safe position.

Recommendations

During the process of this study, certain pinpointed actions saved time and improved accuracy of the process. Key points included:

1. Always use new leads that you apply to the patient even if this means you add a second set. It is better not to use leads of a monitored patient since connection to your monitor may cause the telemetry staff to lose their signal.
2. Connect to the same monitor for all patients. Use of a single monitor reduces variation and inaccuracies in interpretation.
3. Do not hold cables or EKG connectors; attach them and move on to other things. If the signal continues to be noisy and difficult to interpret, move the contact point of the alligator connector by sliding it down on the wire or needle confirming firm connection.
4. Understand that the presence of biphasic activity of the p-wave at the opposite side under baseline denotes entry into the right atrium. A negative or biphasic spike with elongation indicates advancement through the right atrium into the ventricular region. Identification and evaluation of biphasic activity is crucial to accurate position of the catheter tip.
5. If no Normal Sinus Rhythm is present, the catheter is not in the area of the SVC or if no p-wave variation occurs, the patient is on a dependent pacer.

EKG guidance provided other time saving benefits. On the average, time to release of the PICC resulted in time reduction of 30 minutes when EKG confirmation was used rather than waiting for chest x-ray confirmation. With an average of 10% repositioned for PICCs in prior months, use of EKG reduced repositioning after placement for time savings of 21 hours (417 x 10% reposition rate x 30 minutes/reposition). Time savings would likely be more significant for larger non-radiology PICC based facilities.

EKG adapter unit and cable used for positioning are available through multiple companies (see Table 1). The device used for this study (Pacerview) is no longer commercially available. Other companies carry CE mark for European usage (similar to FDA clearance) and are pending with the United States with Food and Drug Administration (FDA) submission.

Conclusion

EKG guided PICC placement proved accurate in consistently guiding the terminal tip to the superior vena cava (SVC). The procedure was easily taught and duplicated by members of the PICC team. The study demonstrated a definite correlation between the peak height (size) of the p-wave and the location of the terminal tip within the distal SVC. With knowledge of this correlation, transition from placing PICCs using EKG guidance with chest x-ray confirmation to confirmation of tip placement using just EKG guidance without chest x-ray confirmation was easily attained. The incorporation of EKG guidance to current PICC and CVC insertions provides improvements in flow process by reducing delays. Application of EKG placement/confirmation performed during insertion saves time previously spent waiting for x-ray confirmation readings and saves time required for tip repositioning of malpositioned tips found after the end of the procedure by allowing the inserter to guide the terminal tip to the desired location by watching the p-wave activity. Additionally, EKG placement saves the cost of a chest x-ray and saves the patient exposure to radiation by eliminating the need for x-ray confirmation of tip position. The EKG guided PICC placement confirmation used in this study provided precise positioning demonstrating that previous studies are clearly reproducible.

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References

Chu, K.-S., Hsu, J.-H., Wang, S.-S., Tang, C.-S., Cheng, K.-I., Wang, C.-K., et al. (2004). Accurate Central Venous Port-A Catheter Placement: Intravenous Electrocardiography and Surface Landmark Techniques Compared by Using Transesophageal Echocardiography. *Anesth Analg, 98*(4), 910-914.

Dionisio, P., Cavatorta, F., Zollo, A., Valenti, M., N, C., & Bajardi, P. (2001). The placement of central venous catheters in hemodialysis: role of the endocavitary electrocardiographic trace; case reports and literature review. *Journal of Vascular Access, 2*, 80-88.

Francis, K., Picard, D., Fajardo, M., & Pizzi, W. (1992). Avoiding complications and decreasing costs of central venous catheter placement utilizing electrocardiographic guidance. *Surg Gynecolo Obstet, 175*(3), 208-211.

Gebhard, R. E., Szmuk, P., Pivalizza, E. G., Melnikov, V., Vogt, C., & Warters, R. D. (2007). The Accuracy of Electrocardiogram-Controlled Central Line Placement. *Anesth Analg, 104*(1), 65-70.

Hoffman, M., Langer, J., Peral, R., Superina, R., Wesson, D., Ein, S., et al. (1988). Central venous catheters - no X-rays needed: A prospective study in 50 consecutive infants and children. *Journal of Pediatric Surgery, 23*(12), 1201-1203.

Jalaeian, T. R., Mottahedi, B., Ghanad, M., & Peyvandi, A. (2005). Use of Intravenous Electrocardiogram in Placement of the Tip of Peripherally Inserted Central Catheters in an Optimum Position. *IRANIAN JOURNAL OF SURGERY 13(2 (35)):36-42. , 13*(2(35)), 36-42.

Karaaslan, D., Altinisik, U., Peker, T. T., Nayir, E., & Ozmen, S. (2009). External Jugular Vein Catheterization Using 'Intra-Atrial Electrocardiogram'. *Yonsei Med J, 50*(2), 222-226.

Lum, P. (2004). A New Formule-Based Measurement Guide for Optimal Positioning of Central Venous Catheters. *JAVA, 9*(2), 80-85.

Madias, J. (2003). Intracardiac (Superior Vena Cava/ Right Atrial) ECG's Using Saline Solution As The Conductive Medium For The Proper Positioning Of The Shiley Hemodialysis Catheter: Is It Not Time To Forgo The Postinsertion Chest Radiograph? *Chest, 124*, 2363-2367.

McGee, D., & Gould, M. (2003). Preventing Complications of Central Venous Catheterization. [Complications]. *New England Journal Medicine, 348*(12), 1123-1133.

McGee, W. T., Ackerman, B. L., Rouben, L. R., Prasad, V. M., Bandi, V., & Mallory, D. L. (1993). Accurate placement of central venous catheters: A prospective, randomized, multicenter trial. *Critical Care Medicine, 21*(8), 1118-1123.

Pacerview, T. (2009). For Central Venous Catheter Tip Location. *Directions for Use*, 1-2

Pittiruti, M., Scoppettuolo, G., LaGreca, A., Emoli, A., Brutti, A., Migliorini, I., et al. (2008). The EKG method for positioning the tip of PICCs: results from two preliminary studies, JAVA. pp. 179-186. *JAVA, 13*(4), 179-186.

Royer, T. (2001). A case for posterior, anterior, and lateral chest x-rays being performed following each PICC placement. *JVAD Journal of Vascular Access Devices, 2001*(Winter), 9-11.

Schummer, W., Schummer, C., Schelenz, C., Brandes, H., Stock, U., Muller, T., et al. (2004). Central venous catheters - the inability of intra-atrial ECG to prove adequate positioning. *Br J Anaesth, 93*(2), 193-198.

Scott, W. L. (1995). Central venous catheters. An overview of Food and Drug Administration activities. *Surg Oncol Clin N Am, 4*(3), 377-393.

Tiernay, S., Katke, J., & Langer, J. (2000). Cost Comparison Of Electrocardiography Versus Fluoroscopy For Central Venous Line Positioning In Children, J. Am. Coll. Surg. Pp.209-211. *Journal of American College of Surgeons, 191*(2), 209-211.

Vesely, T. (2003). Catheter Tip Placement: The Controversy Continues. *J Vasc Interv Radiol, 14*, 527-534.