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Intracavitary electrocardiography for tip location during central venous catheterization: A narrative review of 70 years of clinical studies

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Abstract

Intracavitary electrocardiography is an accurate and non-invasive method for central venous access tip location. Using the catheter as a traveling intracavitary electrode, intracavitary electrocardiography is based on the increase in the detected amplitude of the P wave while approaching the cavoatrial junction. Despite having been adopted diffusely in clinical practice only in the last years, this method is not novel. In fact, it has first been described in the late 40s, during electrophysiological studies. After a long period of quiescence, it is in the last two decades of the XX century that intracavitary electrocardiography became popular as an effective mean of central venous catheters tip location. But the golden age of this technique began with the new millennium, as documented by high-quality studies in this period. In fact, in those years, intracavitary electrocardiography has been studied broadly, and important achievements in terms of comprehension of the technique, accuracy, and feasibility of the method in different populations and conditions (i.e. pediatrics, renal patients, atrial fibrillation) have been gained. In this review, we describe the technique, its history, and its current perspectives.

Keywords

Intracavitary electrocardiography, tip location, tip navigation, central venous access, catheter-related complications, central venous access devices

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Introduction

The correct position of the tip of central venous access devices (CVADs) is essential in order to avoid catheter-related complications such as malfunction, thrombosis, vascular and valve erosions, or arrhythmias.[1–3] Intracavitary electrocardiography (IC-ECG) is a non-invasive, safe, inexpensive, and accurate method for intraprocedural verification of the correct position of the tip. First described by Hellerstein et al.[4] in 1949, its early use as a method for tip location is dated back in the 60s in the field of neuro-anesthesia,[5] with a subsequent exponential development only in the last 20 years. The year 2019 marked the 70th anniversary of the first study about IC-ECG.

Short description of the technique of IC-ECG

The IC-ECG method is based on the use of the catheter tip as a "travelling intracavitary electrode." The vector of the lead II of ECG is approximately co-axial to the vector of the atrial depolarization, so that—when one of the two electrodes of lead II is moving inside the superior vena cava (SVC)—the ECG trace shows a progressive increment of the height of the P wave, reaching the maximal positivity as the intracavitary electrode gets to the cavoatrial junction (CAJ), that is, when all the depolarized atrial mass is in front of the electrode. Advancing the catheter further into the right atrium (RA), the P wave becomes biphasic (negative/positive); at this point, the catheter tip

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(which we use as intracavitary electrode) can be withdrawn to the previous point of maximum P positivity—if the desired position is at CAJ—or left where the P is biphasic, if the desired position is in the atrium.

The catheter tip can be used as "intracavitary electrode" by two different methods: the "metal guidewire" method or the "column of saline" method. With the first method, a metal guidewire is inserted into the catheter so that the distal end reaches and slightly goes past the catheter tip, while the proximal end is connected to the right shoulder electrode, either directly via the ECG clamp or indirectly through a special connector (depending on the choice of the manufacturer). The second method—which has gained greater popularity because it is easier to perform and applicable to any CVAD—is based on the observation that when the catheter is filled with saline solution, its conductivity is optimal. Since the walls of the catheter are made of isolating material, when the saline inside the catheter is connected with the right shoulder electrode through an appropriate transducer, the voltage inside the saline solution will be comparable to the voltage at the open end of the catheter.

History of IC-ECG in the medical literature

Prehistory

Based on the electrophysiological studies previously conducted by Battro and Bidoggia[6] and Hecth,[7] in 1949, Hellerstein et al.[4] showed how a central venous catheter could record an IC-ECG. Electrical connection was achieved by the "saline column" method (in a previous 1948 report from Kisch and Schwartz,[8] a thin wire inside the catheter had been used). In his study, Hellerstein noted that the presence of air bubbles in the catheter may prevent electrical conduction, and for this reason, he recommended that flushes with saline solution were necessary during the procedure. He even mentioned a possible use of this technique for tip location, stating precisely:[4] "We have found that changes in the contour of the P and QRS complex may be a more reliable index of the location of the tip of the catheter than either the fluoroscope or the pressure curve."

In the 60s, IC-ECG was tested in the field of neuroanesthesia. Robertson described it as a valid tool for the placement of ventricular-atrial shunts.[5] For this purpose, catheter tip was positioned at mid-atrium, where P wave was biphasic.

Only in the last two decades of the XX century, however, IC-ECG became popular as an effective and inexpensive method for tip location of CVADs, as documented by many publications of this period. The first clinical experiences in this regard were carried out in Japan,[9,10], in Germany,[11–13] in Spain,[14–17] in Norway,[18] in the Netherlands,[19] in the United States,[20,21] and in Russia.[22] In 1992, Francis et al.[20] found a clear advantage of IC-ECG versus "blind" tip location (96% of success vs 59%). A few years later, Corsten et al.[19] and Calabuig et al.[17] came to the same conclusion, even suggesting that when the P wave is clearly visible on IC-ECG, further control by chest X-ray (CXR) may not be required. Most studies of the XX century suggested that the metal guidewire might be preferred over the column of saline. Also, practically all of these studies verified the accuracy of IC-ECG for tip location by means of a post-procedural CXR.[20] However, what emerged from these studies was clear: the technique was accurate, easy to perform, and above all, inexpensive. Nonetheless, in this period, the clinical use of IC-ECG for tip location was mainly limited to a few European hospitals (particularly in Germany, Belgium, Austria, and Italy).

The golden age of IC-ECG

With the beginning of the new millennium, we entered the so-called "golden-age" of IC-ECG. In 2004, Pawlik et al.[23] compared the guidewire and column of saline techniques, suggesting that the guidewire technique was better in terms of quality of ECG recording, being comparable in terms of accuracy, while the risk of arrhythmias related to the introduction of the wire into the right atrium seemed minimal. A few years later, in 2011, Kremser et al.[24] designed a similar study, finding that, while for catheterization on the right side, there was no significant difference in accuracy between the two techniques, but when the CVAD was inserted on the left side, the guidewire method yielded an underestimation of the length of the catheter.

At the beginning of the XXI century, IC-ECG was investigated more closely. In a few interesting studies, Schummer and colleagues[25,26] described three possible pitfalls of the technique: (a) IC-ECG is not able to detect accidental intra-arterial positioning of the catheter; (b) during insertion of CVADs on the left side, P wave may sometimes increase before reaching CAJ; in particular, this occurs with the guidewire method, as the metal guidewire touches the lateral wall of the SVC, where this vein is wrapped in the pericardial reflection;[27] and (c) IC-ECG cannot discriminate an extravascular placement of the catheter, as the one resulting from vessel perforation. The current methods of ultrasound guided venipuncture, ultrasound-based tip navigation, and correct interpretation of the changes of the P wave pattern have minimized the clinical relevance of these pitfalls.

A few years later, three very important clinical studies—Chu et al.,[28] Jeon et al.,[29] and Ender et al.[30]—finally validated IC-ECG using trans-esophageal echocardiography (TEE) as standard reference, demonstrating that IC-ECG was more accurate than CXR for CAJ identification. These studies also concluded that the use of the IC-ECG was as accurate as TEE, but preferable because less invasive, less expensive, and more routinely applicable.

Using TEE imaging, IC-ECG patterns of the different explorable areas were finally described with precision: (a) a normal P wave identifies a position in the upper portion of the SVC, (b) a growing P wave identifies a position in the lower portion of the SVC, (c) the maximum peak of the P wave identifies exactly the CAJ, and (d) a biphasic P wave identifies the entry into RA.

In addition, Ender found that the tip of peripherally inserted central catheters (PICCs) inserted via basilic or axillary veins can move even 3–4 cm during arm movement,[31,32] while the tip of centrally inserted venous catheters (CICCs) inserted in the right internal jugular vein does not move more than 1 mm with head movements.

In 2007, the first randomized controlled trial on IC-ECG was published: in 290 patients, Gebhard et al.[33] showed that the CVAD tip was correctly positioned at postoperative CXR in 96% of the IC-ECG group versus 76% of controls. Also, they found an intra-atrial or intraventricular placement of the tip of the CVAD in 10% of controls versus none in the study group. The authors concluded emphasizing the safety of IC-ECG, as well as the reduction of costs associated with the decreased need for repositioning.

Between 2008 and 2010, the first studies specifically focused on using IC-ECG during PICC insertions were published. Pittiruti and coworkers[34] published a comparison study with CXR, followed by Moureau et al.;[35] both studies demonstrated the feasibility and the accuracy of IC-ECG for PICC insertions, pointing out that, since pleuro-pulmonary complications were virtually impossible after PICC insertion, post-procedural control with CXR would become unnecessary. As stated in a review published a few years later:[36] “the IC-ECG method removes the need for post-procedural CXR if there is no expected risk of pleuro-pulmonary damage to be ruled out (i.e. any kind of PICC; US guided central venipuncture).”

In 2009, the ESPEN (European Society of Parenteral Nutrition) guidelines were the first international guidelines to recommend the use of IC-ECG for tip location, stressing the great advantage of an intra-procedural assessment as opposed to the post-procedural CXR.[1] From 2009 on, the first ECG monitors specifically dedicated to the IC-ECG appeared on the market. In the following decade (2009–2019), many more clinical studies on IC-ECG were published, discussing the use of IC-ECG for different types of CVADs. In an interesting study by Pelagatti et al.,[37] IC-ECG was more effective than anthropometric measurement in placement of ports and, notably, was associated with a lower incidence of catheter-related thrombosis, in particular when insertion was on the left side. In 2012, the first multicenter study on IC-ECG was published:[38] IC-ECG proved to be feasible, safe, and as accurate as CXR for tip location of different types of CVADs (ports, PICCs, tunneled-cuffed catheters, etc.) in 1440 patients from eight different Italian centers.

In the last decade (2009–2019), many more clinical studies have been published—mostly from Europe,[39–44] but also from the United States[45,46]—utilizing IC-ECG for different types of CVADs, including centrally inserted central catheters (CICCs), PICCs, ports, and tunneled-cuffed catheters. Thanks to this intense publishing activity, many issues has been clarified: (a) the maximal height of the P wave represents faithfully CAJ (i.e. the crista terminalis); (b) the maximal height of the P wave is not related to the location of the sinus node, but to the site of transition between electrically inactive tissue (SVC) and electrically active tissue (RA); and (c) the best way to identify maximal P wave, avoiding false positives, is to look at the “typical” pattern of P wave changes when the catheter is pushed from the SVC into the atrium (rising P–peak–decreasing or biphasic P).

In these same years, the clinical use of IC-ECG has spread from Europe to the United States, and more recently to China, as testified by a relevant amount of clinical studies on IC-ECG carried out in this latter country.[47–53]

IC-ECG in pediatrics

In the span of four decades, IC-ECG has been tested in many studies on pediatric patients, for different types of CVADs: epicutaneo-caval catheters (ECCs), umbilical venous catheters (UVCs), and CICC, in neonates; CICC and PICC, in children. The first clinical experiences in this area are very old (XX century) and they can be traced in Russia,[54] Italy,[55,56] Canada,[57] Germany,[58–60] the United States,[61] Spain,[62] and France.[63] Many more studies have been published in XXI century,[64–68] some of them dealing specifically with UVC[69] or with ECC.[70–72] In 2015, the first multicenter study on IC-ECG in pediatrics was published,[73] and in the same year the AIEOP (Italian Association of Pediatric Hematology and Oncology[71]) guidelines recommended that in children “tip location should be ideally verified in real time during the procedure (by fluoroscopy, by intracavitary electrocardiography or by echocardiography) or—as a second option—soon after the procedure (by chest x-ray or by echocardiography).” All of these studies demonstrated the wide range of applicability, feasibility, safety, and accuracy of IC-ECG in pediatric patients. IC-ECG can be applied in UVC and in ECC, though there might be some technically issues related to the small caliber of ECC (the column of saline inside catheters <3Fr may have a lower conductivity).[74] The use of IC-ECG for tip location of ECC and UVC may be limited by the observation that ultrasound-based tip location by transthoracic echocardiography (TTE) is particularly easy and accurate in neonates; thus, in this setting, CXR (less accurate, more expensive, and less safe) will eventually be replaced by TTE rather than by IC-ECG.[74] However, for CICCs $\geq$3Fr in neonates and for all CVADs in children, IC-ECG is the ideal tip location method, being simpler than

TTE, but safer, more accurate, and less expensive than CXR or fluoroscopy.

IC-ECG in nephrology

Another specific field of application of IC-ECG has been the placement of CVADs for dialysis. The first clinical studies in this area came mainly from Italy,[75–80] and more recently from some non-Western countries.[81,82] All of these studies showed consistently that the IC-ECG is easy, inexpensive, and accurate also for dialysis catheters. The main advantage of IC-ECG for dialysis catheters is the possibility of comparing the ECG tracing between the two lumens, even long time after insertion. Although, the accuracy of IC-ECG may be limited when one lumen has different holes located at different distances from the tip.

IC-ECG coupled with tip navigation

All of the previous studies have investigated IC-ECG as a method for tip location. At the appearance of the first ECG monitors specifically dedicated to the IC-ECG technique, some of them were equipped with the special feature of coupling the ECG-based tip location with some methods of tip navigation. Although, the association between IC-ECG and doppler-based navigation,[83–86] as well as between IC-ECG and electromagnetic navigation,[87–91] does not seem to yield significant advantages if compared to IC-ECG alone in terms of cost-effectiveness. In particular, should tip navigation be required, ultrasound-based tip navigation is more accurate, easier, and more cost-effective than electromagnetic tip navigation.[92]

IC-ECG in atrial fibrillation

Very recently, the possibility of adapting the IC ECG methods to patients with atrial fibrillation (AF), who have no detectable P wave, has also been addressed. This was a relevant limitation of IC-ECG, considering that AF is present in 7%–11% of the hospitalized patient.[93–95]

In a study conducted in 1989, Engelhardt et al.[96] hypothesized that, in AF patients, the highest level of electrical activity detected in the TQ tract could be a valid surrogate of the P wave, thus identifying the CAJ. The rationale for this assumption is that the depolarization of the atrium in AF is represented by the so-called "f" waves, a cluster of irregular waves clearly visible in the TQ tract. In other words, in this "modified" IC-ECG method, the "f" waves should be used as surrogate of the P wave. This finding was confirmed by more recent reports,[97,98] but none of these were conclusive, since this "modified" IC-ECG technique was compared with CXR, which is not the most accurate method of tip location.

In 2018, Calabrese et al.[99] could finally verify the accuracy of the modified IC-ECG method in AF patients using TEE as reference. An IC-ECG trace was recorded with the catheter tip at three different positions identified by TEE: in the SVC (2 cm above the CAJ); at the CAJ; and in the RA (2 cm below the CAJ). This study demonstrated that a "modified" IC-ECG method based on the maximal electrical activity of the TQ tract (i.e. the height of the "f" waves) could accurately detect the location of the tip of CVADs in AF patients. The authors concluded,[97] "modified IC-ECG should replace other tip location methods currently used in AF patients, such as fluoroscopy or post-procedural chest x-ray, since such radiological techniques are less accurate, more expensive and less safe than IC-ECG."

Current perspectives

The correct location of the tip of CVAD is of paramount importance and should be verified before starting any intravenous infusion. Although both post-procedural and intra-procedural methods for tip location exist, the latter should be preferred, since they are more accurate, more cost-effective, and they allow immediate initiation of infusion therapy, avoiding the risks and costs of catheter repositioning.[2]

After its first description in 1949, the IC-ECG method has been studied and brought into clinical practice in the XX century, and it is now becoming more and more popular in the XXI century. After decades of clinical studies, the evidence of its accuracy, safety, and cost-effectiveness has become so strong that current guidelines recommend it as the method of choice for CVADs tip location.[2] In fact, among the intra-procedural methods, IC-ECG has demonstrated many advantages. If compared to fluoroscopy, it is more accurate, simpler, safer, more readily available and more cost-effective. If compared to TTE, it is simpler and requires less training. The main theoretical advantage of TTE over IC-ECG is its wider applicability, since the echocardiographic finding is not affected by disturbances of the cardiac rhythm.[100] Quite recently, a modified version of the IC-ECG technique has been developed for AF patients, and it appears to be applicable, feasible, and accurate; though, in a small minority of cases—typically in non-AF cardiac patients where the P wave might be difficult to identify for different reasons—both the standard IC-ECG and the "modified" IC-ECG cannot be applied, and TTE may be the only choice for an accurate, safe, intra-procedural tip location.

In conclusion, while the role of radiology for tip location of CVAD is inevitably becoming more marginal, the next challenge will be the appropriate definition of the advantages and disadvantages of IC-ECG versus TTE in different clinical situations and different CVADs.

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References

1. Pittiruti M, Hamilton H, Biffi R, et al. ESPEN guidelines on parenteral nutrition: central venous catheters (access, care, diagnosis and therapy of complications). *Clin Nutr* 2009; 28(4): 365–377.
2. Gorski L, Hadaway L, Hagle ME, et al. Infusion therapy standards of practice. *J Infus Nurs* 2016; 39(Suppl. 1): S1–S159.
3. Zanello M. Linee guida SINPE per la nutrizione artificiale ospedaliera 2002: introduzione. *Riv Ital di Nutr Parenter ed Enterale* 2002; 20: s21–s22, s29–s33.
4. Hellerstein HK, Pritchard WH and Lewis RL. Recording of intracavity potentials through a single lumen, saline filled cardiac catheter. *Proc Soc Exp Biol Med* 1949; 71(1): 58–60.
5. Robertson JT, Schick RW, Morgan F, et al. Accurate placement of ventriculo-atrial shunt for hydrocephalus under electrocardiographic control. *J Neurosurg* 1961; 18: 255–257.
6. Battro A and Bidoggia H. Endocardiac electrocardiogram obtained by heart catheterization in the man. *Am Heart J* 1947; 33(5): 604–632.
7. Hecht HH. Potential variations of the right auricular and ventricular cavities in man. *Am Heart J* 1946; 32(1): 39–51.
8. Kisch B and Schwartz BM. A method of obtaining intracardial electrograms during cardiac. *J Mt Sinai Hosp NY* 1948; 15(4): 257–259.
9. Ohta C, Ohkusa T and Tamada T. Central venous catheterization using ECG monitoring and its obstetrical application. *Acta Obstet Gynaecol Jpn* 1981; 33(7): 1025–1034.
10. Nakatani K, Nishikawa K, Funao T, et al. Accurate placement of central venous catheter—ECG-guided method vs patient height method. *Japanese J Anesthesiol* 2002; 51(1): 34–38.
11. Baar H, Danhauser I and Rothhammer A. Control of the position of central venous catheters by intracardial ECG: a presentation of the method and its advantages compared to roentgen control. *Fortschr Med* 1984; 102(29–30): 755–756.
12. Johans TG. Multiorificed catheter placement with an intravascular electrocardiographic technique. *Anesthesiology* 1986; 64(3): 411–413.
13. Hausser J. Clinical use of a new cava catheter with an ECG lead over a steel mandrin. *Anaesthesist* 1990; 39(4): 240–242.
14. Garcia Lizzaralde J. The placement of a PVC catheter under intracavitary ECG control. *Rev Enferm* 1984; 7(75): 16–17.
15. Alvarez J, Cabrera J, Bigorra S, et al. The intracavitary electrocardiogram for checking catheters in the right atrium. *Rev Esp Anestesiol Reanim* 1988; 35(1): 22–25.
16. Garutti I, Olmedilla L, Pérez-Peña JM, et al. Intracavitary electrocardiography: a useful method for checking the correct localization of central venous catheters. *Rev Esp Anestesiol Reanim* 1993; 40(2): 90–93.
17. Calabuig R, Sueiras A, Galtera MJ, et al. Comprobación de catéter central por electrocardiografía endocavitaria: La alternativa a la radiografía de tórax. *Med Clin* 1997; 109(9): 324–327.
18. Kjelstrup T, Ludwig M and Hüsch M. Positioning of central venous catheters using ECG. *Tidsskr den Nor laegeforening* 1991; 111(5): 599–601.
19. Corsten SA, van Dijk B, Bakker NC, et al. Central venous catheter placement using the ECG-guided cavafix-certodyn SD catheter. *J Clin Anesth* 1994; 6(6): 469–472.
20. Francis KR, Picard DL, Fajardo MA, et al. Avoiding complications and decreasing costs of central venous catheter placement utilizing electrocardiographic guidance. *Surg Gynecol Obstet* 1992; 175(3): 208–211.
21. Lanier WL. Failure to attain electrocardiogram-facilitated positioning of right atrial catheters when using the Arrow® antecubital central venous catheterization kit. *J Neurosurg Anesthesiol* 1998; 10(4): 241–243.
22. Tsygankov VN, Kontakevich MM and Zuevskaia EB. Method of determining the position of the catheter end in the central vein. *Anesteziol I Reanimatol* 2000(1): 52–55.
23. Pawlik MT, Kutz N, Keyl C, et al. Central venous catheter placement: comparison of the intravascular guidewire and the fluid column electrocardiograms. *Eur J Anaesthesiol* 2004; 21(8): 594–599.
24. Kremser J, Kleemann F, Reinhart K, et al. Optimized method for correct left-sided central venous catheter placement under electrocardiographic guidance. *Br J Anaesth* 2011; 107(4): 567–572.
25. Schummer W, Schummer C, Paxian M, et al. Extravasale lage von zentralen venenkathetern bei korrekter EKG-ableitung. *Anasthesiol Intensivmed Notfallmedizin Schmerztherapie* 2005; 40(2): 91–96.
26. Schummer W, Schummer C, Müller A, et al. ECG-guided central venous catheter positioning: does it detect the pericardial reflection rather than the right atrium? *Eur J Anaesthesiol* 2004; 21(8): 600–605.
27. Schuster M, Nave H, Piepenbrock S, et al. The carina as a landmark in central venous catheter placement. *Br J Anaesth* 2000; 85(2): 192–194.
28. Chu KS, Hsu JH, Wang SS, et al. Accurate central venous port-a catheter placement: intravenous electrocardiography and surface landmark techniques compared by using transesophageal echocardiography. *Anesth Analg* 2004; 98(4): 910–914.
29. Jeon Y, Ryu HG, Yoon SZ, et al. Transesophageal echocardiographic evaluation of ECG-guided central venous catheter placement. *Can J Anaesth* 2006; 53(10): 978–983.

30. Ender J, Erdoes G, Krohmer E, et al. Transesophageal echocardiography for verification of the position of the electrocardiographically-placed central venous catheter. *J Cardiothorac Vasc Anesth* 2009; 23(4): 457–461.
31. Kasten GW, Owens E and Kennedy D. Ventricular tachycardia resulting from central venous catheter tip migration due to arm position changes: report of two cases. *Anesthesiology* 1985; 62(2): 185–187.
32. Nadroo AM, Glass RB, Lin J, et al. Changes in upper extremity position cause migration of peripherally inserted central catheters in neonates. *Pediatrics* 2002; 110: 131–136.
33. Gebhard RE, Szmuk P, Pivalizza EG, et al. The accuracy of electrocardiogram-controlled central line placement. *Anesth Analg* 2007; 104(1): 65–70.
34. Pittiruti M, Scoppettuolo G, La Greca A, et al. The EKG method for positioning the tip of PICCs: results from two preliminary studies. *J Assoc Vasc Access* 2008; 13(4): 179–186.
35. Moureau NL, Dennis GL, Ames E, et al. Electrocardiogram (EKG) guided peripherally inserted central catheter placement and tip position: results of a trial to replace radiological confirmation. *J Assoc Vasc Access* 2010; 15(1): 8–14.
36. Pittiruti M, la Greca A and Scoppettuolo G. The electrocardiographic method for positioning the tip of central venous catheters. *J Vasc Access* 2011; 12(4): 280–291.
37. Pelagatti C, Villa G, Casini A, et al. Endovascular electrocardiography to guide placement of totally implantable central venous catheters in oncologic patients. *J Vasc Access* 2011; 12(4): 348–353.
38. Pittiruti M, Bertollo D, Briglia E, et al. The intracavitary ECG method for positioning the tip of central venous catheters: results of an Italian multicenter study. *J Vasc Access* 2012; 13(3): 357–365.
39. Capozzoli G, Accinelli G, Fabbro L, et al. Intra-cavitary ECG is an effective method for correct positioning of the tip of tunneled Groshong catheters. *J Vasc Access* 2012; 13(3): 393–396.
40. Baldinelli F, Capozzoli G, Pedrazzoli R, et al. Evaluation of the correct position of peripherally inserted central catheters: anatomical landmark vs. electrocardiographic technique. *J Vasc Access* 2015; 16(5): 394–398.
41. Ortiz-Miluy G and Sánchez-Guerra C. Intracavitary electrocardiogram during the insertion of peripherally inserted central catheters. *Enferm Clin* 2013; 23(4): 148–153.
42. Santacruz E, Mateo-Lobo R, Vega-Piñero B, et al. Colocación de catéteres centrales de inserción periférica (PICC) mediante control electrocardiográfico intracavitario (ECG-IC) de la punta del catéter. *Nutr Hosp* 2018; 35(5): 1005.
43. Walker G, Chan RJ, Alexandrou E, et al. Effectiveness of electrocardiographic guidance in CVAD tip placement. *Br J Nurs* 2015; 24: S4–S12.
44. Bloemen A, Daniels AM, Samyn MG, et al. Electrocardiographic-guided tip positioning technique for peripherally inserted central catheters in a Dutch teaching hospital: feasibility and cost-effectiveness analysis in a prospective cohort study. *J Vasc Access* 2018; 19(6): 578–584.
45. Cales YK, Rheingans J, Steves J, et al. Electrocardiogram-guided peripherally inserted central catheter tip confirmation using a standard electrocardiogram machine and a wide-mouth electrocardiogram clip compared with traditional chest radiograph. *J Assoc Vasc Access* 2016; 21(1): 44–54.
46. Wuerz L, Cooke J, Hentel K, et al. Successful implementation of electrocardiogram-placed peripherally inserted central catheters at a major academic medical teaching organization. *J Assoc Vasc Access* 2016; 21(4): 223–229.
47. Wang G, Guo L, Jiang B, et al. Factors influencing intracavitary electrocardiographic P-wave changes during central venous catheter placement. *PLoS ONE* 2015; 10(4): e0124846.
48. Yuan L, Li R, Meng A, et al. Superior success rate of intracavitary electrocardiogram guidance for peripherally inserted central catheter placement in patients with cancer: a randomized openlabel controlled multicenter study. *PLoS ONE* 2017; 12(3): e0171630.
49. Li W, Xu R and Fan D. Clinical application of electrocardiogram-guided tip positioning in peripheral inserted central catheters placement. *J Cancer Res Ther* 2018; 14(4): 887–891.
50. Yin YX, Gao W, Li XY, et al. Insertion of peripherally inserted central catheters with intracavitary electrocardiogram guidance: a randomized multicenter study in China. *J Vasc Access* 2019; 20(5): 524–529.
51. Liu G, Hou W, Zhou C, et al. Meta-analysis of intracavitary electrocardiogram guidance for peripherally inserted central catheter placement. *J Vasc Access* 2019; 20(6): 577–582.
52. Yu T, Wu L, Yuan L, et al. The diagnostic value of intracavitary electrocardiogram for verifying tip position of peripherally inserted central catheters in cancer patients: a retrospective multicenter study. *J Vasc Access* 2019; 20(6): 636–645.
53. Ling G, Zhiwen W, Guorong W, et al. Guide wire electrode versus liquid electrode for intravascular electrocardiography–guided central venous catheterization in adults: a systematic review and meta-analysis. *J Vasc Access*. Epub ahead of print 17 August 2019. DOI: 10.1177/1129729819868044.
54. Stabletskiĭ AD and Marochkov AV. Electrometric control of the position of a venous catheter in children. *Vestn Khir Im I I Grek* 1983; 130(5): 118–121.
55. Serafini G, Pietrobono P and Cornara G. Location of central venous catheters in children by endocavitary ECG: a new technique. *Clin Nutr* 1985; 4(4): 201–202.
56. Parigi GB and Verga G. Accurate placement of central venous catheters in pediatric patients using endocavitary electrocardiography: reassessment of a personal technique. *J Pediatr Surg* 1997; 32(8): 1226–1228.
57. Hoffman MA, Langer JC, Pearl RH, et al. Central venous catheters-No X-rays needed: a prospective study in 50

consecutive infants and children. *J Pediatr Surg* 1988; 23(12): 1201–1203.
58. Neubauer AP. Die zentralvenoüse Plazierung des Silastik-katheters durch Ableitung eines intravasalen EKG. *Klin Padiatr* 1991; 203(3): 146–148.
59. Neubauer A-P. Percutaneous central iv access in the neonate: experience with 535 silastic catheters. *Acta Pædiatrica* 1995; 84(7): 756–760.
60. Zachariou Z and Daum R. Intra-atrial ECG recording: a new and safe method for implantation of Broviac catheters in children. *Pediatr Surg Int* 1994; 9(5–6): 457–458.
61. Redo SF and Dinner MH. Placement of central venous catheters by cut-down with electrocardiogram positioning. *Surg Gynecol Obstet* 1993; 177(1): 49–53.
62. Giraldo Lozano L and Barjau Capdevila M. Silastic catheters: pinpointing the end tip of the catheter by means of electrocardiographic monitoring. *Rev Enferm* 1997; 20(230): 50–52.
63. Simon L, Teboul A, Gwinner N, et al. Central venous catheter placement in children: evaluation of electrocardiography using J-wire. *Paediatr Anaesth* 1999; 9(6): 501–504.
64. Tierney SN, Katke J and Langer JC. Cost comparison of electrocardiogprahy versus fluoroscopy for central venous line positioning in children. *J Am Coll Surg* 2000; 191(2): 209–211.
65. Weber F, Buitenhuis M and Lequin MH. Determination of the optimal length of insertion of central venous catheters in pediatric patients by endovascular ECG. *Minerva Anestesiol* 2013; 79(4): 379–384.
66. Mastroianni R, Capasso A and Ausanio G. The intracavitary electrocardiography method for tip location of jugular internal vein access device in infants of less than 5 kg: a pilot study. *J Vasc Access* 2018; 19(6): 639–643.
67. Rosche N and Stehr W. Evaluation of a magnetic tracking and electrocardiogram-based tip confirmation system for peripherally inserted central catheters in pediatric patients. *J Infus Nurs* 2018; 41(5): 301–308.
68. Weber MD, Himebauch AS and Conlon T. Repositioning of malpositioned peripherally inserted central catheter lines with the use of intracavitary electrocardiogram: a pediatric case series. *J Vasc Access* 2019; 21: 259–264.
69. Biban P, Cavalli C, Santuz P, et al. Positioning of umbilical vein catheter with ECG-guided technique: randomized study. *Acta Biomed Ateneo Parmense* 2000; 71: 647–650.
70. Zhou LJ, Xua HZ, Xu MF, et al. An accuracy study of the Intracavitary Electrocardiogram (IC-ECG) guided peripherally inserted central catheter tip placement among neonates. *Open Med* 2017; 12(1): 125–130.
71. Capasso A, Mastroianni R, Passariello A, et al. The intracavitary electrocardiography method for positioning the tip of epicutaneous cava catheter in neonates: pilot study. *J Vasc Access* 2018; 19(6): 542–547.
72. Ling Q, Chen H, Tang M, et al. Accuracy and safety study of intracavitary electrocardiographic guidance for peripherally inserted central catheter placement in neonates. *J Perinat Neonatal Nurs* 2019; 33(1): 89–95.
73. Rossetti F, Pittiruti M, Lamperti M, et al. The intracavitary ECG method for positioning the tip of central venous access devices in pediatric patients: results of an Italian multicenter study. *J Vasc Access* 2015; 16(2): 137–143.
74. Barone G and Pittiruti M. Epicutaneo-caval catheters in neonates: new insights and new suggestions from the recent literature. *J Vasc Access*. Epub ahead of print 5 December 2019. DOI: 10.1177/1129729819891546.
75. Galli F, Efficace E, Villa G, et al. Endocavitary electrocardiography (EC-ECG) in monitoring central venous cannulation for vascular access in haemodialysis. *Nephrol Dial Transplant* 1993; 8(5): 480–481.
76. Dionisio P, Valenti M and Bajardi P. Monitoring of central dual-lumen catheter placement in haemodialysis by endocavitary electrocardiography: a simple and safe technique for the clinical nephrologist. *J Vasc Access* 2000; 1(3): 88–92.
77. Dionisio P, Cavatorta F, Zollo A, et al. The placement of central venous catheters in hemodialysis: role of the endocavitary electrocardiographic trace. *J Vasc Access* 2001; 2(2): 80–88.
78. Cavatorta F, Zollo A, Galli S, et al. Central venous catheter placement in hemodialysis: evaluation of electrocardiography using a guide-wire. *J Vasc Access* 2001; 2(2): 45–50.
79. Onorato L, Digiandomenico W, Russo F, et al. Evaluation of central venous catheters by endocavitary ECG. *G Ital Nefrol* 2005; 22: S145–S147.
80. Calabria M, Zamboli P, D'Amelio A, et al. Use of ECG-EC in the positioning of central venous catheters. *G Ital Nefrol* 2012; 29(1): 49–57.
81. Beigi AA, Parvizian F and Masoudpour H. Application of intravenous electrocardiography for insertion of central veins dialysis catheters. *Saudi J Kidney Dis Transpl* 2009; 20(5): 794–797.
82. Cho S, Lee YJ and Kim SR. The intracavitary ECG method for insertion of a tunneled dialysis catheter without using fluoroscopy. *J Vasc Access* 2015; 16(4): 285–288.
83. Girgenti C and Donnellan E. Successfully eliminating chest radiography by replacing it with dual vector technology and an algorithm for PICC placement. *J Assoc Vasc Access* 2014; 19(2): 71–74.
84. Ramirez C, Roy L and Foster G. Dual vector biosensor catheter tip positioning system: a 3-year retrospective analysis. *J Assoc Vasc Access* 2015; 20(3): 151–156.
85. Smith L, Brown CM and Mendoza J. Novel catheter positioning system for intravenous central lines: a report of 1 hospital's experience. *J Assoc Vasc Access* 2014; 19(3): 167–171.
86. Ramirez C, Miranda S and Sager E. Hemodialysis catheter insertion without chest X-ray: review of a 24-month study. *J Assoc Vasc Access* 2018; 23(4): 216–220.
87. Johnston AJ, Holder A, Bishop SM, et al. Evaluation of the Sherlock 3CG tip confirmation system on peripherally inserted central catheter malposition rates. *Anaesthesia* 2014; 69(12): 1322–1330.

88. Dale M, Higgins A and Carolan-Rees G. Sherlock 3CG® tip confirmation system for placement of peripherally inserted central catheters: a NICE medical technology guidance. *Appl Health Econ Health Policy* 2016; 14(1): 41–49.
89. Tomaszewski KJ, Ferko N, Hollmann SS, et al. Time and resources of peripherally inserted central catheter insertion procedures: a comparison between blind insertion/chest X-ray and a real time tip navigation and confirmation system. *Clin Outcomes Res* 2017; 9: 115–125.
90. Keller EJ, Aragona E, Molina H, et al. Cost-effectiveness of a guided peripherally inserted central catheter placement system: a single-center cohort study. *J Vasc Interv Radiol* 2019; 30(5): 709–714.
91. Monard C, Lefèvre M, Subtil F, et al. Peripherally inserted central catheter with intracavitary electrocardiogram guidance: malposition risk factors and indications for post-procedural control. *J Vasc Access* 2019; 20(2): 128–133.
92. Pittiruti M, Scoppettuolo G, Dolcetti L, et al. Clinical use of Sherlock-3CG® for positioning peripherally inserted central catheters. *J Vasc Access* 2019; 20(4): 356–361.
93. Go AS, Hylek EM, Phillips KA, et al. Prevalence of diagnosed atrial fibrillation in adults: national implications for rhythm management and stroke prevention: the anticoagulation and risk factors in atrial fibrillation (ATRIA) study. *J Am Med Assoc* 2001; 285(18): 2370–2375.
94. Chow GV, Marine JE and Fleg JL. Epidemiology of arrhythmias and conduction disorders in older adults. *Clin Geriatr Med* 2012; 28(4): 539–553.
95. Patel NJ, Deshmukh A, Pant S, et al. Contemporary trends of hospitalization for atrial fibrillation in the united states, 2000 through 2010 implications for healthcare planning. *Circulation* 2014; 129(23): 2371–2379.
96. Engelhardt W, Sold M and Helzel MV. ECG-monitored placement of central venous catheters in patients with atrial fibrillation. *Anaesthesist* 1989; 38(9): 476–479.
97. Steinhagen F, Kanthak M, Kukuk G, et al. Electrocardiography-controlled central venous catheter tip positioning in patients with atrial fibrillation. *J Vasc Access* 2018; 19(6): 528–534.
98. Pittiruti M, La Greca A and Biasucci D. Intracavitary ECG for tip location in atrial fibrillation patients. *J Assoc Vasc Access* 2016; 21(4): 252–253.
99. Calabrese M, Montini L, Arlotta G, et al. A modified intracavitary electrocardiographic method for detecting the location of the tip of central venous catheters in atrial fibrillation patients. *J Vasc Access* 2019; 20(5): 516–523.
100. Iacobone E, Elisei D, Gattari D, et al. Transthoracic echocardiography as bedside technique to verify tip location of central venous catheters in patients with atrial arrhythmia. *J Vasc Access*. Epub ahead of pint 4 March 2020. DOI: 10.1177/1129729820905200.