

A systematic review of the effectiveness of intra-cavitary electrocardiographic guidance in improving CVAD tip placement

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Conflict of Interest

The authors have no conflicts of interest that are directly relevant to the content of this study.

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Authors' contributions

All authors have made substantial contributions to the study conception and design, acquisition of data and analysis and interpretation of data. Each author has contributed to drafting and editing the manuscript and approves the final version for publishing as per the ICMJE convention.

Keywords: central venous access device, central venous catheter, electrocardiography

Key phases:

- Five studies involving 729 participants were included in this systematic review.
- ECG-guided insertion was more accurate than surface anatomy guided insertion.
- We found a lack of reporting on complications, patient satisfaction and costs.
- Wide CIs suggest better quality RCTs are required for precise effect.

Abstract

Background:

International standard practice for the correct confirmation of the central venous access device is the chest x-ray. The intra-cavitary electrocardiographic-based insertion method is radiation-free, and allows real-time placement verification, providing immediate treatment and reduced requirement for post-procedural repositioning.

Methods:

Relevant databases were searched for prospective RCTs or quasi RCTs that compared the effectiveness of electrocardiographic-guided catheter tip positioning and confirmation with chest x-ray (CXR) confirmation using surface anatomy guided insertion. The primary outcome was accurate catheter tip placement. Secondary outcomes include complications, patient satisfaction and costs.

Results:

Five studies involving 729 participants were included. Electrocardiographic-guided insertion was more accurate than surface anatomy guided insertion [Odds Ratio: 8.3; [95% CI 1.38; 50.07; p=0.02]]. We found a lack of reporting on complications, patient satisfaction and costs.

Conclusion:

Overall, the evidence suggests that intracavitary electrocardiographic-based positioning is superior to surface anatomy guided positioning of central venous access devices, leading to significantly more successful placements. This technique could potentially remove the requirement for post procedural chest x-ray, especially during PICC line insertion.

Background

Although widely used for central venous access device (CVAD) confirmation, chest x-rays (CXRs) have a number of limitations. CXR interpretation is subjective, with the possibility of errors when interpreting the radiological image depending on clinician level of training and experience. Patients are also exposed to potentially harmful radiation(Pittiruti, La Greca & Scoppettuolo 2011). If incorrect placement of the CVAD tip is detected by CXR, the CVAD is required to be repositioned or even reinserted in some cases. This leads to a delay in patient treatment and further use of practitioner time, with associated increased costs. Furthermore there is potential for more complications, including catheter related bloodstream infection due to the integrity of the dressing being interrupted (Pittiruti et al. 2009, Timsit et al. 2012).

Intracavitary electrocardiogram (ECG) guided catheter placement provides real-time, accurate tip confirmation during the insertion procedure. This removes the need for CXR confirmation entirely. CXR or ultrasound interpretation of pleural visceral integrity is still recommended however for central venous catheters (CVCs) to excluded pneumothorax. Therefore the majority of benefit for ECG guidance is seen during peripherally inserted central catheter (PICC) placement(Oliver, Jones 2013).

If a post-procedural CXR can be avoided when placing a CVAD, line insertion and correct location confirmation can take place in one location. This results in less potential for cross contamination and no exposure to radiation. With ECG-guided technology, operators have immediate confirmation of catheter placement or malposition. As a result, radiographer, nurse and porter time is saved and costs

reduced(Hockley et al. 2007). In many countries, including North America, and in greater Europe, ECG-guidance for confirmation of CVAD placement is accepted as being as effective as a CXR(Pittiruti, La Greca & Scoppettuolo 2011, Gebhard et al. 2007). The gold standard for accurate catheter tip confirmation is transoesophageal echo(Chu et al. 2004), however this cannot be routinely adopted for all patients due to its invasive nature.

Recent technological advances have combined ECG-technology with either electromagnetism - for example the Sherlock 3CG[®] distributed by Bard Medical; or Doppler - such as the ARROW[®] VPS G4 distributed by Teleflex. ECG technology can also be used alone; Vygon has distributed the Nautilus[®] and Romedex have recently developed the Nautilus Delta[®]. The Celerity tip location system is also distributed by Mecom. A number of hospitals both nationally and internationally have used these devices and early data is positive regarding outcomes(Rossetti et al. 2015, Girgenti and Donnellan 2014, Johnston et al. 2014). It is expected that their use will increase in the coming years.

Current evidence suggests that the ECG-based method is a safe and simple procedure, with high success rates. It is radiation-free, and allows real-time placement verification. The clinical and cost-effectiveness in comparison with surface anatomy landmarks for determination of correct positioning have yet to be assessed by full systematic review(Gebhard et al. 2007).

Methods

The authors searched the following databases from the articles published between 1988 to February 2015: MEDLINE, CINAHL, Cochrane Central Register of Controlled Trials (CENTRAL), PubMed, The Joanna Briggs database and the Google Scholar Search Engine. The MESH terms used were Electrocardiography, Central Venous Catheters, Catheterisation, Central Venous, Vascular Access Devices and X-rays. Key word searches included: CVC position, ECG CVC, CVC placement, catheter ECG placement, PICC placement, CVAD tip position, CVAD tip placement, CVC tip placement, surface anatomy-guided placement and systematic review. Searches were limited to those published in the English language and focusing on the human population.

Two review authors (GW and RC) independently screened the titles and abstracts of articles identified by the search strategy. The same two authors then assessed the full text of articles independently, according to the inclusion and exclusion criteria. A third author's opinion would have been sought if differences of opinion could not have been resolved by consensus.

All randomised controlled trials (RCTs) or quasi-RCTs that examined the effectiveness of ECG-guided catheter tip insertion vs. surface anatomy guided insertion for confirming successful tip placement, in adults or children receiving a CVAD insertion were included in the final analysis. The decision was made to focus on RCTs as general consensus considers them to carry more weight when considering the effectiveness of an intervention (Greenhalgh 1997). The primary outcome looked at was a successful tip placement, defined as being successful if it met the trial

author's criteria for correct location on post procedural CXR. This varied from being in the lower third of the SVC to the upper part of the atrium, depending on study. Secondary outcomes included complications, patient satisfaction and costs. Complications were defined as any adverse event, including thromboembolism, infection, dysrhythmias, pneumothorax and catheter malfunction. Patient satisfaction and costs could be measured by any method chosen by the trial authors.

Data was extracted using a pre-designed data extraction form (appendix 1) by two authors (GW and RC). Data was checked for accuracy and entered into the Review Manager 5.3 software (RevMan). For each included study, we extracted the study intervention and setting, baseline demographic and clinical characteristics of the groups and primary and secondary end points. Any conflict of interest was noted, as well as details on ethics and patient consent. Finally, we extracted information on any patient exclusion from analysis.

Studies were critically appraised by two review authors independently (GW and RC) using the Cochrane Risk of Bias Assessment Tool (Higgins et al. 2011) for the use of random sequence generation, allocation concealment and blinding of both participants and outcome assessment. The tool also assessed for incomplete outcome data, selective outcome reporting and other possible problems that could put the study at risk of bias. Risk of bias is rated as low, high or unclear for each domain. An attempt was made to contact study authors for additional information.

Statistical heterogeneity was tested using the Chi² test, with significance set at a p-value < 0.1. An I² value was also calculated, to describe the percentage of variability

in effect estimates due to heterogeneity rather than sampling error. When the meta-analysis was carried out, if the results for heterogeneity were significant ($I^2 > 40\%$) a random effect model would be applied to incorporate heterogeneity. Review Manager 5.3(RevMan) was used to perform the meta-analysis of included studies. As the outcome was dichotomous, we calculated odds ratio (OR) with 95% confidence intervals (CI). If evidence of significant heterogeneity was identified ($I^2 > 40\%$), we aimed to explore a potential cause for this.

Results

The initial search returned 523 articles. Our selection process is detailed in Figure 1. A total of 4 RCTs(Chu et al. 2004, Gebhard et al. 2007, McGee et al. 1993, Lee et al. 2009) and 1 quasi RCT(Francis et al. 1992) were identified for inclusion in the systematic review.

The five included studies (table 1) included a total of 729 patients who received CVAD insertion via ECG-guidance. All of the studies were unblinded and carried out with adult patients as single-centre designs. No studies focused on specific vessel insertion therefore insertion into any commonly used vein in the body was deemed as acceptable. All studies used the standard method of ECG-guided insertion only in the intervention arm. Four studies (Francis et al. 1992, Gebhard et al. 2007, Lee et al. 2009, McGee et al. 1993) looked at CVC insertion and one study looked at implantable venous port insertion(Chu et al. 2004).

In each study we analysed the primary outcome of successful tip placement within the lower third of the SVC and upper part of the atrium. The exact position regarded as an

appropriate position for each CVAD varied slightly between studies (Lee et al. 2009, Francis et al. 1992, Gebhard et al. 2007, Chu et al. 2004, McGee et al. 1993). Only one study compared complications between the intervention and control groups (Lee et al. 2009). None of the included manuscripts included any comprehensive cost analysis or mention of patient satisfaction between groups.

The risk of bias table and summary are shown in Figure 2 and 3. Three of the five studies allocated patients to groups based on random number generation (McGee et al. 1993, Lee et al. 2009, Gebhard et al. 2007). The study by Chu (Chu et al. 2004) stated that patients were randomly assigned to group but it did not state how this randomisation was carried out. In the quasi-RCT study by Francis (Francis et al. 1992), patients were assigned to group based on hospital number.

Three studies stated that the radiologist determining outcome assessment was blinded to group (Lee et al. 2009, McGee et al. 1993, Gebhard et al. 2007). Chu (Chu et al. 2004) described use of outcome assessor blinding where: ‘Another anaesthesiologist, who was unaware of the surgical procedure, evaluated the IV-ECG signals from another room and determined when the proper catheter position had been achieved’.

Although not stated explicitly, there was no evidence of incomplete outcome data in any of the five studies. No patients were withdrawn post-randomisation. Study protocols were not available for any of the five studies, however expected outcomes for these comparisons were reported. The outcomes described in the methods section and results were consistent in each study. Group sizes between intervention and control were similar in each study.

Baseline patient characteristics are not provided in McGee(McGee et al. 1993) and Francis (Francis et al. 1992)'s studies. In the other 3 studies patient characteristics between groups seem sufficiently matched. Chu (Chu et al. 2004) specifically stated; "Both groups were matched with respect to age, body weight, sex and type of major abdominal malignancy".

One study (Gebhard et al. 2007) reported manufacturer sponsorship in the form of financial support to the research coordinator. However, the trial authors declared that the sponsor had no involvement in the conduct of the study and writing of the report. The remaining studies did not declare any conflict of interest.

Effects of interventions

Successful tip placement (primary outcome)

Primary results from all studies except Lee's (Lee et al. 2009), concluded that ECG-guided positioning of catheter tip was more effective than surface anatomy tip positioning. Lee concluded that the techniques were comparable.

For our meta-analysis, we combined results from four studies (Lee et al. 2009, McGee et al. 1993, Chu et al. 2004, Gebhard et al. 2007). The decision was made to exclude Francis(Francis et al. 1992) from the meta-analysis as it was carried out as a quasi RCT and did not report patient characteristics by group. Further, unlike the other studies, the outcome data were analysed by line insertion rather than by patient. An attempt was made to contact the author to ask for per-patient data however no reply was received.

There was significant heterogeneity when the four remaining studies were combined [$I^2 = 77\%$; $p = 0.004$]. Consequently we used a random effects model for meta-analysis. Meta-analysis reported an effect size of OR 8.3 (95% CI 1.38; 50.07; $p = 0.02$) in favour of the ECG-guided insertion technique (see Figure 4). Number-needed-to-treat (NNT) to avoid one malposition was calculated as 6. The variation in the 95% CIs indicates that the magnitude of effect is relatively uncertain however the low p-value for test of overall effect indicates that there is an overall positive effect of the intervention.

A sensitivity analysis was conducted with a meta-analysis excluding Lee's study (Lee et al. 2009) due to the high heterogeneity detected in the primary meta-analysis (see Figure 5). The overall direction of results and conclusions of the primary analysis were not affected when Lee's results were removed from the analysis (OR = 13.67; 95% CI 5.82; 32.11; $p < 0.001$).

Complications (secondary outcome)

Francis (Francis et al. 1992) reported two incidents of complications, both in the ECG-insertion group. One was an arterial puncture and the other a new arrhythmia. Lee (Lee et al. 2009) reported three complications in the surface anatomy group (two ventricular premature contractions and one arterial puncture); there were six complications in the ECG-group (four ventricular premature contractions and two arterial punctures). Gebhard (Gebhard et al. 2007) reported arterial punctures in 33 patients (11%) and small haematomas, which required no further intervention

developing in eight of these patients. However, the results were not reported by group. Complications were not mentioned by McGee(McGee et al. 1993) or Chu(Chu et al. 2004). None of the complications in any study were seen as being directly attributable to the CVAD confirmation method.

Patient satisfaction and cost (secondary outcome)

No studies reported any data related to patient satisfaction or cost.

Discussion

The results of this systematic review provides evidence that ECG-based positioning of CVADs is more effective than surface anatomy guided insertions in achieving insertion success. The data identifies the ECG-based method as around eight times more effective, with the actual effect likely to be between one and fifty times more effective. For every six patients on whom the technique is used, the ECG-guided insertion method will result in one more correct placement. Therefore ECG-based confirmation appears a suitable replacement for post-procedural CXR confirmation.

When the results of each study related to the primary outcome were combined, there was significant heterogeneity. This appeared to be due to the results of Lee's study(Lee et al. 2009). There was no obvious reason to suggest why the results from this study found equivalence between ECG-guided insertions and surface anatomy guided insertions. A possible explanation could be that the professionals involved in inserting the lines had many years of experience in the CVAD insertion procedure via surface anatomy guidance and were therefore better at performing this procedure. The authors were, however, unavailable for comment to discuss this possibility.

No studies measured time to first use of the inserted CVAD, therefore precluding comparison of the clinical and cost savings that are likely achieved through use of ECG-confirmation. This could be explored in a future research paper. No studies in our review assessed the secondary outcomes; cost and patient satisfaction. However, there is mention of these outcomes in non-RCTs included in the current literature with results generally supporting ECG guided insertion(Moureau et al. 2010, Oliver, Jones 2013). There was a low rate of complications reported across all reviewed studies in both groups. There was a slightly higher rate of complications in the ECG-insertion group in studies by Francis(Francis et al. 1992) and Lee(Lee et al. 2009). However, we propose that this is coincidental. The majority of complications were arterial punctures or haematomas; they are a consequence of needle to vein and ultrasound rather than any guidance method(McGee, Gould 2003). Almost all patients were suitable for the procedure except those suffering from clinical conditions such as atrial fibrillation and atrial flutter. The prevalence of atrial fibrillation increases with age, rising from 0.7% in people aged 55- 59 years to 18% in those older than 85 years(Heeringa et al. 2006). It results in an absent P-wave on the standard “surface” ECG.

All studies included in this review were conducted with adult patients but other non-RCT results suggest the technique is as effective in children(Hoffman et al. 1988, Rossetti et al. 2015, Simon et al. 1999, Weber, Buitenhuis & Lequin 2013). These results require confirmation using well designed randomised trials.

Francis(Francis et al. 1992) randomised patients using their hospital number. This is a potential source of bias since it is not truly random (eg. allocated sequentially to each

new patient admitted, or corresponding to patient year of birth or other demographic factor). The method for allocation concealment was not reported in any studies, so risk of bias for this domain remained ‘unclear’.

The review results could have been influenced by the experience and skill level of the health professional inserting the catheter and interpreting tip termination in both treatment groups. A number of different professionals were involved in each study, including anaesthetists, medical and surgical residents and ICU fellows. A clear description of patient baseline characteristics in the two oldest studies was missing (McGee et al. 1993, Francis et al. 1992), so the representativeness of the population compared with current patients needing CVADs today is unclear.

Electrocardiographic guidance is quick and easy to perform, and prevents delays, workload and costs incurred by post-procedural CXR (Pittiruti, La Greca & Scoppettuolo 2011). Although not yet interrogated by randomised trials, ECG-guidance technology may be the most efficient method for the insertion of PICCs. At present, many clinicians still wish to view a CXR, post CVC insertion, to exclude pneumothorax (Pirotte 2008). Ultrasound interpretation of pleural viscera integrity could be a useful alternative to CXR for pneumothorax exclusion (Goodman et al. 1999). For PICC line insertion however, pneumothorax is not a common complication.

Recent international guidelines have advocated the ECG method as a valid alternative to radiologic verification of CVC tip placement (Pittiruti et al. 2009). Previous reviews have estimated that the ECG method is suitable for 93% of patients (Pittiruti, La Greca & Scoppettuolo 2011). The results of our larger scale review confirm this

figure. The main limitation of the technology is the inability for accurate use in patients who suffer from clinical conditions where the p-wave is absent on the standard “surface” ECG (eg. atrial fibrillation). Therefore in such cases, radiological verification should still be used.

Cost implications or patient satisfaction were not assessed in detail in any of the RCTs reviewed. Although a number of non-randomized studies appear to show support in favour of ECG-guided insertion related to these outcomes(Moureau et al. 2010, Oliver, Jones 2013), these results should be confirmed with larger scale RCTs. The purchase of (newer) ECG guidance systems can be a significant investment for many health care organisations. The lack of formal cost analysis in the included studies failed to justify fiscal benefits of the technology (such as the reduction in radiology costs) and may limit implementation of the intervention(Haines, Jones 1994). In their 2001 comparative study, Tierney et al concluded that ECG based insertion was \$700 cheaper per procedure in comparison to fluoroscopy(Tierney, Katke & Langer 2000). However, no RCTs focusing on the cost-effectiveness of ECG-based insertion compared to traditional insertion of CVADs in adults were found.

In the majority of studies where multiple insertion sites were used, the procedure tended to be more successful with insertion into the right internal jugular vein (IJV) instead of other sites. A RCT might be useful to compare success rates using the different access routes available. It would also be useful in future studies to focus on the recent technological advances and to compare the relative effectiveness of new

technologies such as; electromagnetism, Doppler, or ECG alone. Such work would help guide hospital policy makers and managers to make investment decisions.

The most recent RCT in this review was published in 2009 and a more contemporary assessment of the technology is warranted. Finally, none of the RCTs reviewed included PICC lines, although there are a number of non-RCT studies in the literature which have also shown positive results for PICC line insertion(Oliver, Jones 2013, Moureau et al. 2010). ECG-guidance technology is potentially the most useful for PICC line insertion and consequently, PICC lines should be included in any future RCTs.

Conclusion

Results from this systematic review of five randomised trials totalling 729 patients, suggests ECG-guided insertion provides a significantly higher rate of insertion success, compared to traditional surface anatomy-guided insertion with CXR confirmation. We found a lack of reporting on complications, patient satisfaction and costs. Further research into the technology in a PICC cohort and a rigorous cost-effectiveness comparison including patient preference are also needed. However, our results suggest that ECG-based confirmation appears a suitable replacement for post-procedural CXR confirmation.

References

- Chu, K., Hsu, J., Wang, S., Tang, C., Cheng, K., Wang, C. & Wu, J. 2004, "Accurate central venous port-A catheter placement: intravenous electrocardiography and surface landmark techniques compared by using transesophageal echocardiography", *Anesthesia & Analgesia*, vol. 98, no. 4, pp. 910-914.
- Francis, K.R., Picard, D.L., Fajardo, M.A. & Pizzi, W.F. 1992, "Avoiding complications and decreasing costs of central venous catheter placement utilizing electrocardiographic guidance", *Surgery, gynecology & obstetrics*, vol. 175, no. 3, pp. 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", *Anesthesia and Analgesia*, vol. 104, no. 1, pp. 65-70.
- Girgenti, C. & Donnellan, E. 2014, "Successfully Eliminating Chest Radiography by Replacing It With Dual Vector Technology and an Algorithm for PICC Placement", *Journal of the Association for Vascular Access*, vol. 19, no. 2, pp. 71-74.
- Goodman, T., Traill, Z., Phillips, A., Berger, J. & Gleeson, F. 1999, "Ultrasound detection of pneumothorax", *Clinical radiology*, vol. 54, no. 11, pp. 736-739.
- Greenhalgh, T. 1997, "How to read a paper. Getting your bearings (deciding what the paper is about)", *BMJ (Clinical research ed.)*, vol. 315, no. 7102, pp. 243-246.
- Haines, A. & Jones, R. 1994, "Implementing findings of research", *BMJ (Clinical research ed.)*, vol. 308, no. 6942, pp. 1488-1492.

- Heeringa, J., van der Kuip, D.A., Hofman, A., Kors, J.A., van Herpen, G., Stricker, B.H., Stijnen, T., Lip, G.Y. & Wittteman, J.C. 2006, "Prevalence, incidence and lifetime risk of atrial fibrillation: the Rotterdam study", *European heart journal*, vol. 27, no. 8, pp. 949-953.
- Higgins, J.P., Altman, D.G., Gotzsche, P.C., Juni, P., Moher, D., Oxman, A.D., Savovic, J., Schulz, K.F., Weeks, L., Sterne, J.A., Cochrane Bias Methods Group & Cochrane Statistical Methods Group 2011, "The Cochrane Collaboration's tool for assessing risk of bias in randomised trials", *BMJ (Clinical research ed.)*, vol. 343, pp. d5928.
- Hockley, S., Hamilton, V., Young, R., Chapman, M., Taylor, J., Creed, S., Chorley, D., Williams, D.B. & Tippett, M.D.M. 2007, "Efficacy of the CathRite system to guide bedside placement of peripherally inserted central venous catheters in critically ill patients: a pilot study", *Crit Care Resusc*, vol. 9, no. 3, pp. 251-255.
- Hoffman, M., Langer, J., Pearl, R., Superina, R., Wesson, D., Ein, S., Shandling, B. & Filler, R. 1988, "Central venous catheters—no X-rays needed: a prospective study in 50 consecutive infants and children", *Journal of pediatric surgery*, vol. 23, no. 12, pp. 1201-1203.
- Johnston, A., Holder, A., Bishop, S., See, T. & Streater, C. 2014, "Evaluation of the Sherlock 3CG Tip Confirmation System on peripherally inserted central catheter malposition rates", *Anaesthesia*, vol. 69, no. 12, pp. 1322-1330.
- Lee, J.H., Bahk, J.H., Ryu, H.G., Jung, C.W. & Jeon, Y. 2009, "Comparison of the bedside central venous catheter placement techniques: landmark vs electrocardiogram guidance", *British journal of anaesthesia*, vol. 102, no. 5, pp. 662-666.

- McGee, D. & Gould, M. 2003, "Preventing complications of central venous catheterization", *N Engl J Med*, vol. 348, pp. 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*, vol. 21, no. 8, pp. 1118-1123.
- Moureau, N.L., Dennis, G.L., Ames, E. & Severe, R. 2010, "Electrocardiogram (EKG) Guided Peripherally Inserted Central Catheter Placement and Tip Position: Results of a Trial to Replace Radiological Confirmation", *Journal of the Association for Vascular Access*, vol. 15, no. 1, pp. 8-14.
- Oliver, G. & Jones, M. 2013, "Evaluation of an electrocardiograph-based PICC tip verification system", *British Journal of Nursing*, vol. 22, no. Sup9, pp. S24-S28.
- Pirotte, T. 2008, "Ultrasound-guided vascular access in adults and children: beyond the internal jugular vein puncture", *Acta Anaesthesiol Belg*, vol. 59, no. 3, pp. 157-166.
- Pittiruti, M., Hamilton, H., Biffi, R., MacFie, J. & Pertkiewicz, M. 2009, "ESPEN Guidelines on Parenteral Nutrition: central venous catheters (access, care, diagnosis and therapy of complications)", *Clinical Nutrition*, vol. 28, no. 4, pp. 365-377.
- Pittiruti, M., La Greca, A. & Scoppettuolo, G. 2011, "The electrocardiographic method for positioning the tip of central venous catheters", *The journal of vascular access*, vol. 12, no. 4, pp. 280-291.

- RevMan "Review Manager (RevMan) [Computer program]. Version 5.2. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2012.", .
- Rossetti, F., Pittiruti, M., Lamperti, M., Graziano, U., Celentano, D. & Capozzoli, G. 2015, "The intracavitary ECG method for positioning the tip of central venous access devices in pediatric patients: results of an Italian multicenter study", *The journal of vascular access*, vol. 0, no. 0, pp. 0.
- Simon, L., Teboul, A., Gwinner, N., Boulay, G., Cerceau-Delaporte, S. & Hamza, J. 1999, "Central venous catheter placement in children: evaluation of electrocardiography using J-wire", *Pediatric Anesthesia*, vol. 9, no. 6, pp. 501-504.
- Tierney, S.N., Katke, J. & Langer, J.C. 2000, "Cost comparison of electrocardiography versus fluoroscopy for central venous line positioning in children", *Journal of the American College of Surgeons*, vol. 191, no. 2, pp. 209-211.
- Timsit, J.F., Bouadma, L., Ruckly, S., Schwebel, C., Garrouste-Orgeas, M., Bronchard, R., Calvino-Gunther, S., Laupland, K., Adrie, C., Thuong, M., Herault, M.C., Pease, S., Arrault, X. & Lucet, J.C. 2012, "Dressing disruption is a major risk factor for catheter-related infections", *Critical Care Medicine*, vol. 40, no. 6, pp. 1707-1714.
- Weber, F., Buitenhuis, M. & Lequin, M.H. 2013, "Determination of the optimal length of insertion of central venous catheters in pediatric patients by endovascular ECG", *Minerva anesthesiologica*, vol. 79, no. 4, pp. 379-384.

Figure 1: PRISMA Flow Diagram

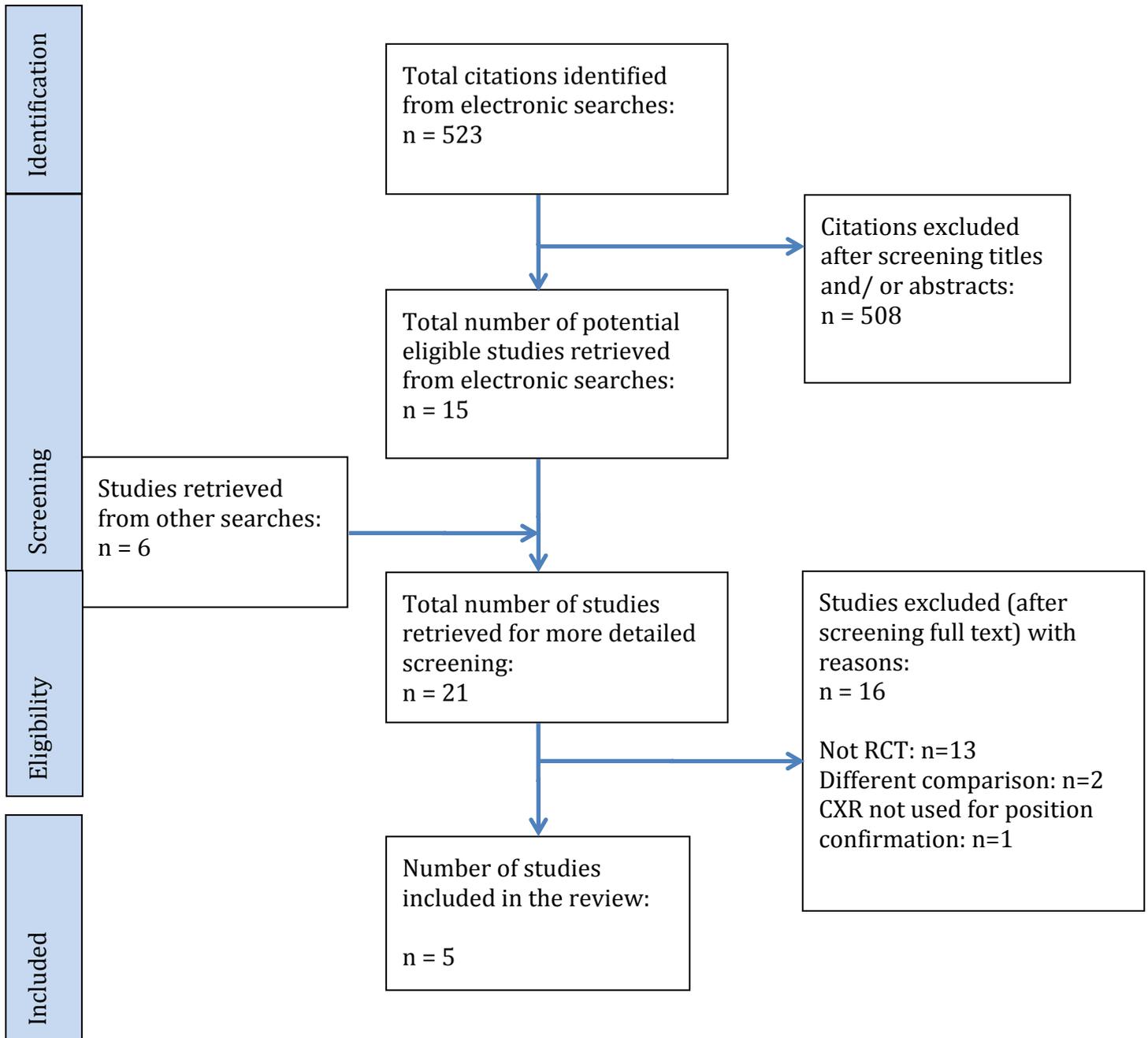


Figure 2: Risk of bias graph: review authors' judgements about each risk of bias item presented as percentages across all included studies

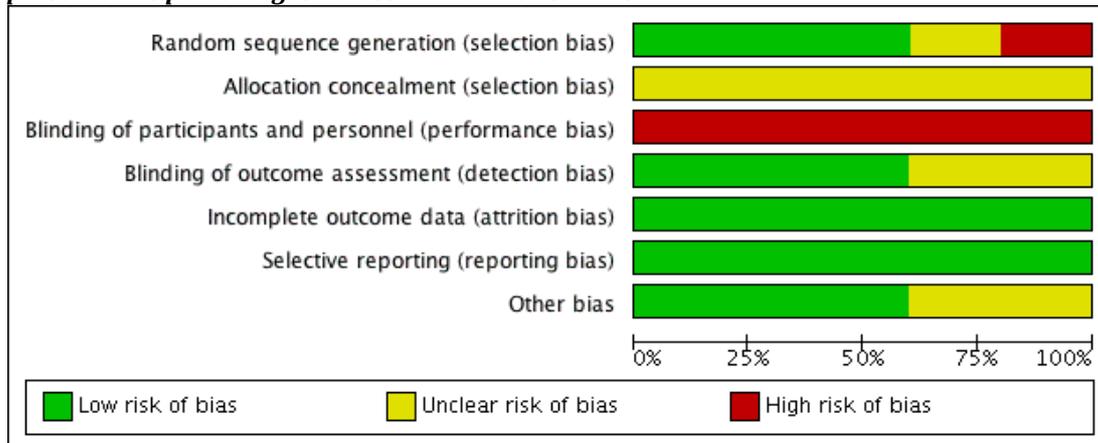


Figure 3: Risk of bias summary: review authors' judgements about each risk of bias item for each included study

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Chu (2004)	?	?	●	?	●	●	●
Francis (1992)	●	?	●	?	●	●	?
Gebhard (2007)	●	?	●	●	●	●	●
Lee (2009)	●	?	●	●	●	●	●
McGee (1993)	●	?	●	●	●	●	?

Figure 4: Forest plot of all studies for confirmed successful tip placement

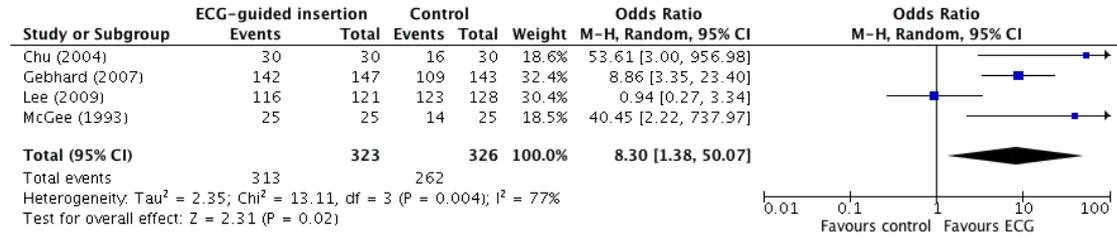


Figure 5: Forest plot excluding study by Lee (2009) for confirmed successful tip placement

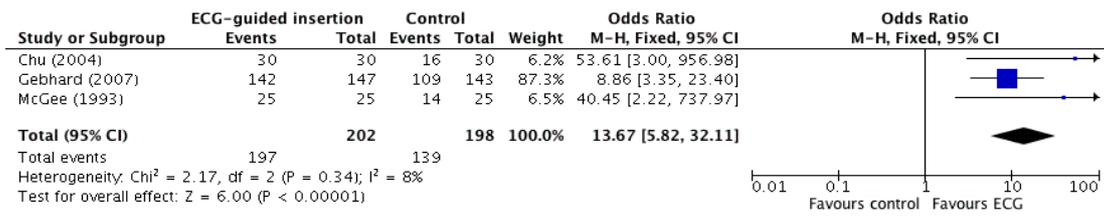


Table 1: Characteristics of included studies (n = 5)

Author/ year/ country	Study type	Trial Size	Patient group	Mean patient age	Device inserted	P C
Chu (2004), Taiwan	RCT	n = 60	adults with malignant diseases	not stated	implantable venous port	
Francis (1992), USA	Quasi RCT	n = 80	receiving percutaneously placed CVC	not stated	CVC	
Gebhard (2007), USA	RCT	n = 290	undergoing elective surgery	50	CVC	
Lee (2009), Republic of Korea	RCT	n = 249	elective thoracic surgery	54	CVC	
McGee (1993), USA	RCT	n = 50	scheduled to receive CVC insertion	58	CVC	