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ORIGINAL ARTICLE **Open Access**

Reliability of intra-atrial ECG method of insertion of central venous line through right internal jugular vein when compared to formula and radiological landmark method: a prospective randomized study

Manjunatha R. Kamath[1*], Sakshi Tiku[1*], M. Gopalakrishnan[2] and Amith Kiran[3]

Abstract

Background Ideal position of central venous catheter tip should be within 2 cm above and 1 cm below superior vena cava–right atrium (SVC-RA) junction. The objective of the study was to compare intra-atrial ECG method of Central venous catheterization of right internal jugular vein (IJV) with traditional methods. A prospective randomized trial enrolling 90 patients were alternatively allocated to three groups and comparison of intra-atrial electrocardiography, radiological landmark and Pere's formula method for correct positioning of central venous catheter tip were done and tip position were confirmed with post-procedural TEE (transesophageal echocardiography).

Results Catheter tip was present at the ideal position in 100% cases in intra-atrial ECG method compared to only 23.4% in formula method and 93.3% in landmark method (*p* value 0.001). In intra-atrial method group, the central venous catheter tip was placed perfectly in all patients, position of the catheter tip was not acceptable in 71.4% of the patients where formula method is used and not acceptable in 11.1% when landmark method is used (*p* value 0.001). However, we did not encounter any catheter related complications in any of these groups.

Conclusions Intra-atrial ECG method carries the advantage of ideal positioning of the central venous catheter tip by right IJV route in almost all cases when compared to conventional formula and landmark method to some extent. Also, immediate confirmation and real time verification of central venous catheter (CVC) tip is possible, thereby avoids the need for post-procedural chest X-ray and other methods of central venous placement confirmation like arterial blood gas analysis etc., Hence, intra-atrial ECG method is cost effective and safer for confirmation of CVC tip in all the situations.

Keywords Central venous catheter, Electrocardiography, TEE, SVC-RA junction

*Correspondence:
Manjunatha R. Kamath
manjunathrkamath@gmail.com
Sakshi Tiku
sakshitiku9192@gmail.com
[1] Department of Anaesthesiology, KS Hegde Medical Academy, Karnataka State, Mangalore, India
[2] Justice KS Hegde Hospital, Karnataka State, Mangalore, India
[3] Srinivasa Medical College, Karnataka State, Mangalore, India

Background

Central venous cannulation and thereby direct measurement of central venous pressures (CVP) through internal jugular vein (IJV) route are essential in patients undergoing major cardiac surgeries. During surgery, it facilitates administration of various drugs, multiple infusions, monitoring of CVP, transvenous cardiac pacing, pulmonary artery catheterization, aspiration of entrained air and in cases where repeated blood sampling is required. Also, parenteral nutrition can be given postoperatively if needed (Rupp et al. 2012).

Right IJV is preferred as it has relatively identifiable anatomical location and a short straight course to SVC and the apex of left lung is slightly higher making left IJV cannulation prone for pneumothorax (Sulek et al. 2000; Bishop et al. 2007). Left IJV cannulation might also lead to accidental puncture of thoracic duct.

However, the depth of the insertion of catheter tip is of utmost importance because of the complications associated with the over insertion and under insertion. SVC–RA junction is the ideal location for the central venous catheter tip (Fletcher and Bodenham 2000 Aug). So, it is mandatory that catheter tip lies in the correct position. Misplacement of tip can lead to lethal complications such as cardiac tamponade, injury to the major vessels, perforation into pleural space or mediastinum leading to hydrothorax, haemothorax, pneumothorax, and arrhythmia (Booth et al. 2001 March; Askegard-Giesmann et al. 2009).

The various techniques to determine the depth of catheter are radiological landmark method (Yoon et al. 2005; Schuster et al. 2000), Pere's formula method (Peres 1990), and intra-atrial ECG method (Wilson and Gaer 1988; Watters and Grant 1997). This study was conducted to determine accuracy of formula method, landmark method and intra-atrial ECG technique in correct positioning of central venous catheter tip placement through internal jugular vein route and also the complications associated with these techniques.

Methods

We conducted a prospective randomized study on adult patients undergoing elective cardiac surgery for which USG guided CVC placement (Miller 2002; Brass et al. 2015) and TEE (Hilberath et al. 2010) examination were planned to monitor cardiac function and hemodynamic changes. We excluded patients with gross anatomical or pathological deformities of neck and chest, gastric oesophageal reflux disease, altered coagulation parameters, any rhythm disturbances, patients with height < 150 cm or > 180 cm, any contraindication to TEE probe insertion (Hilberath et al. 2010).

After obtaining institutional ethical committee clearance for the study, patients were evaluated during their pre-anesthetic visit. Written informed consent was obtained. Standard NPO guidelines were followed and standard premedication was given on the pre-operative night and 7am on the day of surgery.

Patients were randomly allocated to three different groups of 30 each by closed envelope method (Fig. 1).

After shifting the patient to operation theatre, electrocardiography (ECG), pulse oxymeter, and blood pressure monitoring was established. Standard anaesthesia induction was employed.

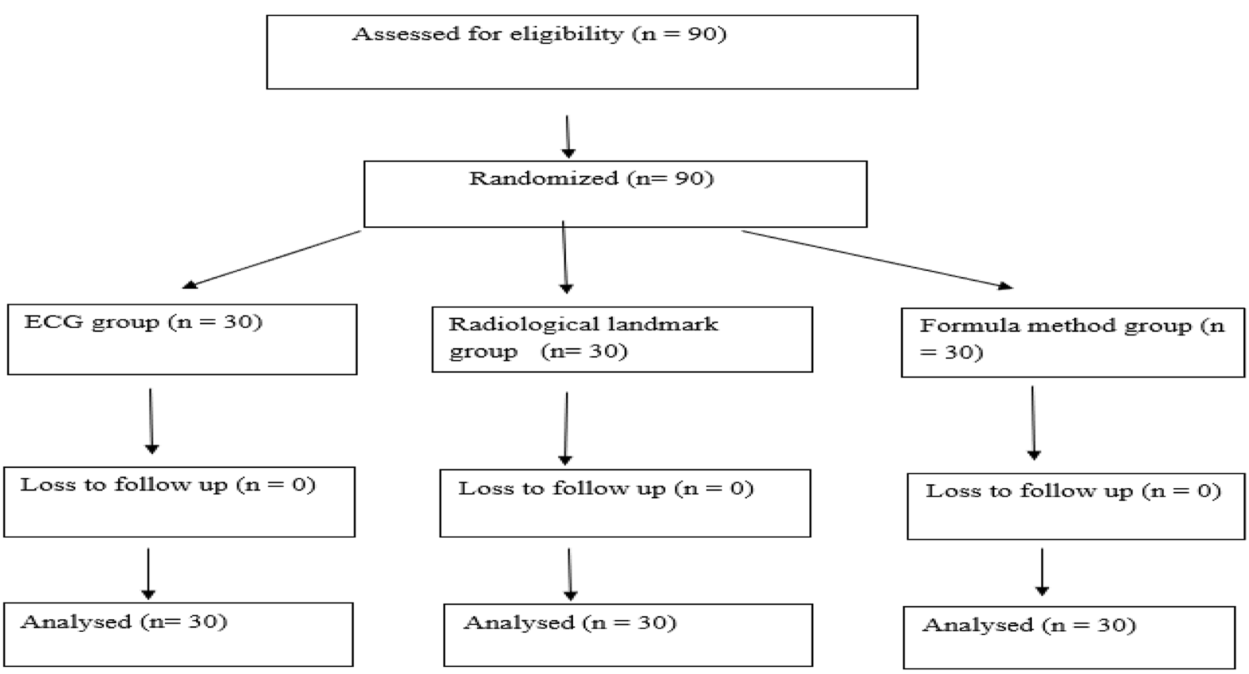

Fig. 1 Consort diagram

- The patient was placed in 15° of Trendelenberg position with head turned slightly to left side, so that the neck is better exposed and chin is kept away.
- Central venous catheterization was done by real-time ultrasound guidance with a portable ultrasound machine equipped with a linear array transducer (13–6 MHz; Sonosite Inc., Bothell, WA, USA) (Miller 2002; Brass et al. 2015).
- 7 Fr 16 cm triple lumen catheter was introduced to a depth which was estimated in different groups as mentioned earlier.

A multiplane TEE probe (8–3 MHz Micromaxx TEE probe; Sonosite Inc.) was inserted into the esophagus, bicaval view (Hilberath et al. 2010) was obtained and position of the catheter tip was noted.

Formula method: (Peres 1990) Depth was determined by applying Pere's formula

$$\text{Required depth of catheter tip} = \text{Height(in cm)}/10$$

Landmark method*:* (Yoon et al. 2005; Schuster et al. 2000) The vertical length from the right sternoclavicular joint to the carina was calculated with the help routine preoperative chest radiograph using an internal measuring tool which is available on the Picture Archiving and Communication system (PACS).

In this group, the right sternoclavicular joint was used as the landmark on the skin surface. The surface distance from the skin insertion point to the right sternoclavicular joint was calculated. The depth is determined by sum of measurements for the surface distance and distance between the right sternoclavicular joint and carina (Fig. 2).

Intra-atrial ECG method: (Wilson and Gaer 1988; Watters and Grant 1997) Depth was determined by observing the change in configuration of P in an indigenously designed adaptor placed between the monitor and CVC.

In this method the right shoulder lead of the ECG (red) is replaced by the tip of the catheter in the venous system. Once the intracavity electrode is connected to the ECG monitor, the P wave in Lead II changes its height and shape according to its position in the venous system of the heart.

The variation in the amplitude of the P wave represents the proximity of the electrode to electric field of the right atrium and closer the tip of the catheter, the higher the amplitude of P wave will be seen. The P wave shows the following features.

- Upper 1/3rd SVC: Almost normal ECG or slight increasing amplitude of P wave (Fig. 3a)
- Near RA (1 cm in SVC): 2/3 of maximal P wave (Fig. 3b)
- Atrium: P wave equals R wave showing a biphasic pattern (Fig. 3c)
- When withdrawn till ECG becomes normal (Fig. 3d)

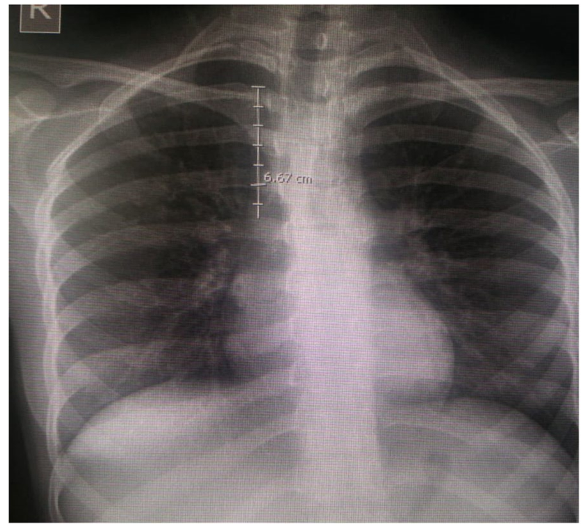

Fig. 2 Chest X-ray showing distance between right sternoclavicular joint and carina

The correct position of the catheter tip was checked by Transesophageal echocardiography. It is a semi-invasive technique which helps us in visualizing structural anatomy of heart and also great vessels. TEE is done in majority of the patients posted for cardiac surgeries as it tells us about the real time assessment and hence the success of surgical outcome (Hilberath et al. 2010). A multiplane TEE probe (8–3 MHz Micromaxx TEE probe; Sonosite Inc., Bothell, WA, USA) is introduced into the oesophagus, and a bicaval view is achieved by rotating the transducer at 80–110° and changing the direction of the probe to the right.

The relationship of the catheter tip with the SVC–RA junction can be quantified precisely in terms of distance in centimeters from the crista terminalis, which is a round-shaped fibromuscular labrum that originates from the interatrial septum and runs anterior to the atrial orifice of the SVC in the atrio-bicaval view (McKay and Thomas 2007). It is present as a hyper echoic spur adjoining the RA at the entry of SVC (Fig. 4).

The region within 2 cm above and 1 cm below the SVC–RA junction is considered to be the target zone (Vesely 2003).

Statistical analysis

Statistical tests were performed using Statistical Package for Social Science statistical (SPSS) version 20. Quantitative data like age, sex of the patient, height

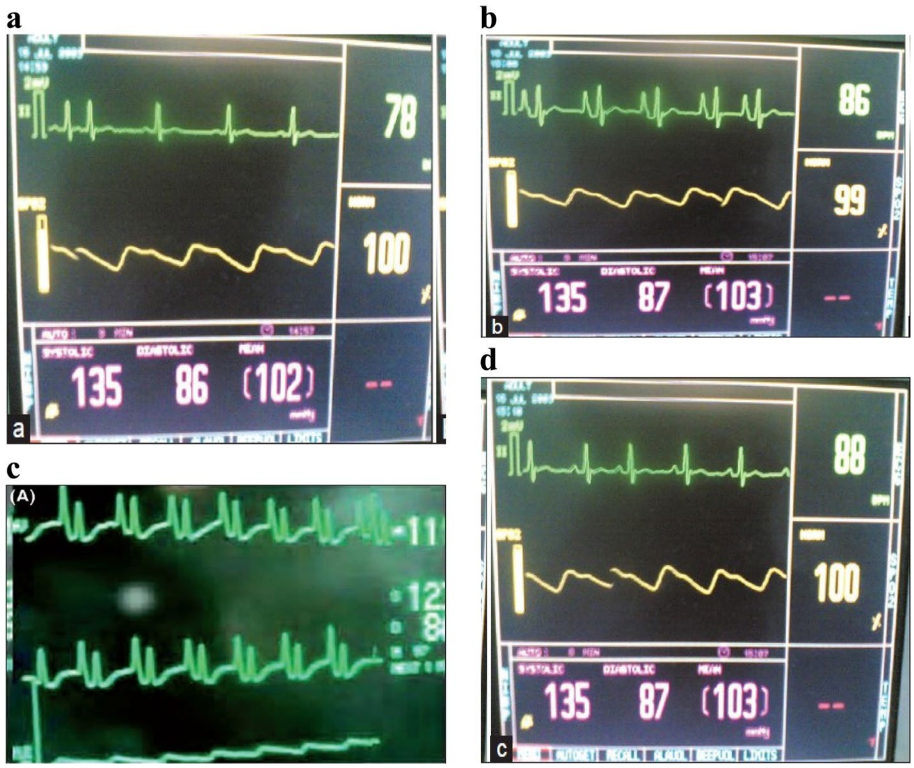

Fig. 3 **a** Normal intra-atrial ECG when catheter tip is in upper third of SVC**. b** P wave increases in amplitude denoting proximity to Sino-Atrial node. **c** P wave equals R wave when catheter tip in right atrium. **d** P wave comes back to normal size once the catheter is retrieved

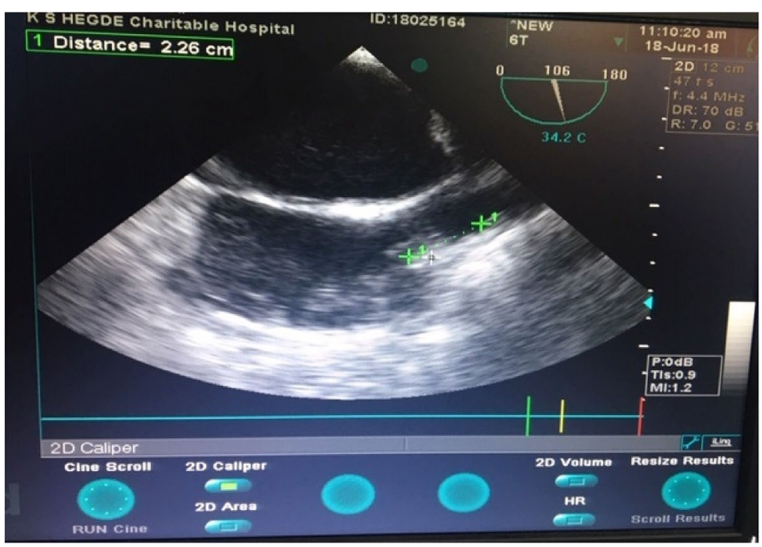

Fig. 4 TEE image of SVC–RA junction-bicaval view showing location of catheter tip from the junction

etc. was presented as mean and standard deviation. Age distribution between the groups were analysed using one-way ANNOVA and gender distribution by chi square test. Qualitative data like malpositioning was presented as percentage and proportion and three groups were compared using Fisher's exact test. Pair-wise comparisons are done to get more recognizable results between the groups. *P* value less than 0.05 were considered significant.

Table 1 Age distribution (one-way ANOVA)

Age	*N*	Mean	Std. deviation	*P*
ECG	30	56.03	11.568	0.381
Formula	30	59.30	9.256	
Landmark	30	58.90	8.580	

Results

The mean age in ECG group, formula group and radiological landmark group was 56.03 years, 59.3 years, and 58.9 years respectively and no significant difference with respect to age (p value = 0.381) (Table 1).

In ECG group, there were 56.7% males and 43.3% females, landmark group which had 73.3% males and 26.7% females while formula group had 60% males and 40% females. The groups were comparable with respect to sex distribution (p value = 0.366) (Table 2).

As discussed earlier, the correct position of catheter tip was considered acceptable if it was in the target zone, i.e., 2 cm above and 1 cm below SVC–RA junction.

Catheter tip was at the SVC–RA junction, which is the desired location in 23.3% patients in ECG group compared to 10% in landmark group and 6.7% in formula group. The difference between the three groups was found to be highly significant (p value = 0.001). Moreover, it was at the target zone in 100% cases in ECG group compared to 93.3% in landmark group and only 23.4% in formula group (Table 3).

Catheter tip was far below the target zone, i.e., in the right atrium in 23% in commonly used formula method and none in intra-atrial group (P value = 0.001) (Table 4). Intra-atrial method is slightly superior to landmark group as in 6.7% of patients, the catheter tip was not in the target zone P value = 0.188 (Table 5).

Results also showed landmark technique far superior when compared to conventional formula method and statistically significant (P value 0.001) (Table 6).

If the catheter tip is in the target zone, i.e., 2 cm above and 1 cm below SVC–RA junction, it was considered acceptable. In formula method, the position of the catheter tip was not acceptable in 23 out of 30 patients and it was below the junction, i.e., too inside the heart and in 2 patients in landmark method group. (Fig. 5).

However, there were no complications seen with any of the methods studied.

Discussion

Central venous catheterization is one of the most common percutaneously performed invasive procedures in all patients undergoing major cardiac surgeries (Rupp et al. 2012). It helps in administration of vasoactive drugs,

Table 2 Gender distribution

Gender			Group			Total	*P*
			ECG	Formula	Landmark		
	Female	Count	13	12	8	33	0.366
		% within group	43.3%	40.0%	26.7%	36.7%	
	Male	Count	17	18	22	57	
		% within group	56.7%	60.0%	73.3%	63.3%	
Total		Count	30	30	30	90	
		% within group	100.0%	100.0%	100.0%	100.0%	

Table 3 Location of CVC tip at SVC–RA junction

CVC tip position		Group			Total	*P*
		ECG	Formula	Landmark		
Within 2 cm above junction	Count	23	5	25	53	0.001
	% within group	76.7%	16.7%	83.3%	58.9%	
Junction-within 1 cm below junction	Count	7	2	3	12	
	% within group	23.3%	6.7%	10.0%	13.3%	
> 1 below junction	Count	0	23	2	25	
	% within group	0.0%	76.7%	6.7%	27.8%	
Total	Count	30	30	30	90	
	% within group	100.0%	100.0%	100.0%	100.0%	

Table 4 ECG Vs formula (post hoc test)

CVC tip position			Group		Total	*P*
			ECG	Formula		
	Within 2 cm above junction	Count	23	5	28	0.001
		% within group	76.7%	16.7%	46.7%	
	Junction-within 1 cm below junction	Count	7	2	9	
		% within group	23.3%	6.7%	15.0%	
	> 1 cm below junction	Count	0	23	23	
		% within group	0.0%	76.7%	38.3%	
Total		Count	30	30	60	
		% within group	100.0%	100.0%	100.0%	

Table 5 ECG Vs landmark (post hoc test)

CVC tip position			Group		Total	*P*
			ECG	Landmark		
	Within 2 cm above junction	Count	23	25	48	0.188
		% within group	76.7%	83.3%	80.0%	
	Junction-within 1 cm below junction	Count	7	3	10	
		% within group	23.3%	10.0%	16.7%	
	> 1 below junction	Count	0	2	2	
		% within group	0.0%	6.7%	3.3%	
Total		Count	30	30	60	
		% within group	100.0%	100.0%	100.0%	

Table 6 Formula vs landmark (post hoc test)

CVC tip position			Group		Total	*P*
			Formula	Landmark		
	Within 2 cm above junction	Count	5	25	30	0.001
		% within group	16.7%	83.3%	50.0%	
	Junction-within 1 cm below junction	Count	2	3	5	
		% within group	6.7%	10.0%	8.3%	
	> 1 below junction	Count	23	2	25	
		% within group	76.7%	6.7%	41.7%	
Total		Count	30	30	60	
		% within group	100.0%	100.0%	100.0%	

intraoperative central venous pressure monitoring, insertion of pulmonary artery catheter and is a site for aspiration of venous air embolism (Rupp et al. 2012).

In adult population, various types of catheters can be used for cannulation, however we have selected most preferred 7 Fr 16 cm triple lumen catheters.

The right internal vein is a commonly used site for venous cannulation due to its comparatively straight course, predictable anatomy, avoidance of thoracic duct puncture, and manual compression can be given in case of bleeding (Sulek et al. 2000; Bishop et al. 2007).

USG-guided central venous cannulation was done as it helps in real time verification and improves the success rate (Miller 2002; Brass et al. 2015).

The correct position of CVC tip is of utmost importance. Over insertion can lead to various complications (Booth et al. 2001 March; Askegard-Giesmann et al. 2009). It can also lead to overestimation of central

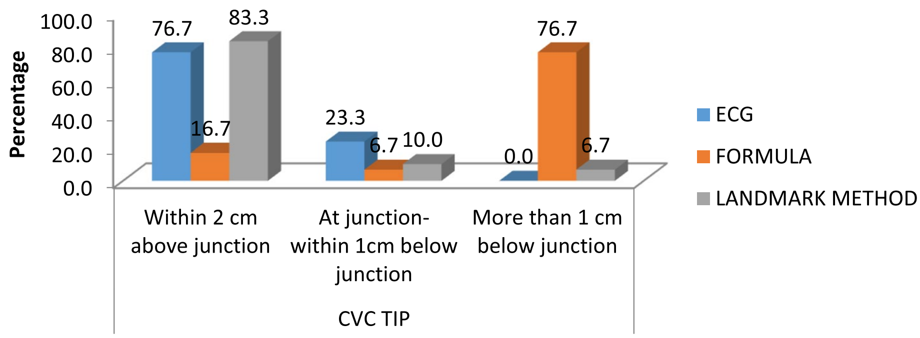

Fig. 5 Analysis of catheter tip position

venous pressure. Under insertion of the tip can lead to incorrect measurement of the central venous pressure and local complications can occur due to veno-irritant drugs (Kusminsky 2007).

So, we compared the depth of central venous catheter tip after formula, radiological landmark and intra-atrial ECG methods of CVC placement. Post-insertion of CVC, we have confirmed the position of tip with the help of TEE.

Age and gender did not differ significantly between the three groups.

Pere's formula method is the most commonly used method routinely. However, in our study, the tip of the catheter was too much inside the heart in 76.7% in Pere's formula group and was not in the target zone. Our observations were similar to a study conducted by Sharma and his co-workers (Sharma et al. 2013) in 2013. They demonstrated appreciable increase in the length of CVC inserted in formula method in comparison to ECG and anatomical landmark technique of CVC placement. Pere's formula may not be appropriate for our Indian population and leads to over insertion of catheter into the cardiac chamber which can lead to perforation, arrhythmias etc., However, we did not encounter any problems.

In landmark group, in 83.3% patients, the tip was above the junction and exactly at the junction in 10% of the study population. Only in 6.7% of study population, over insertion of the catheter was there. Ezri et al. (Ezri et al. 2007) did a prospective randomized study in 2007 on role of external landmarks as the guide to determine the depth of insertion of right IJV CVCs correctly. They concluded that topographic method is accurate in deciding CVC placement with right IJV approach. Only drawback is the exposure of the patients to the pre-procedural radiological examination. This may be a concern in non-cardiac procedures in which routine preoperative X-ray is not indicated. Ahn et al. (Ahn et al. 2017) in 2017 and Manudeep et al. (Manudeep et al. 2020) in 2020 in their studies also concluded that radiological landmark formula is superior to Peres' formula for measuring optimal depth of insertion of right internal jugular venous catheter.

In intra-atrial ECG method, our results showed that tip of the catheter was accurately placed at SVC-RA junction when compared to other groups and it was at the target zone in 100% of the study population. Our findings were similar to a study conducted in 2008 by Joshi et al. (Joshi et al. 2008) who opined that intra-atrial ECG guided technique helps in accurate placement is of right internal jugular vein CVC. The procedure is more accurate than the commonly used formula method derived by height but requires universal adaptor.

Gebhard et al. (Gebhard et al. 2007) in 2007 compared ECG and no ECG technique for placement of central venous catheter tip and concluded that ECG guidance allows for more precise CVC placement, reduces the costs related with repositioning and is safer for the patients.

Lee et al. (Lee et al. 2009) in 2009 comparing landmark technique with ECG-guided method for placement of bedside central venous catheter tip, concluded that landmark technique was comparable to ECG technique for right jugular vein catheterization with regard to CVC tip positioning in SVC.

Intra-atrial ECG method can be used safely in all the cases except in patients with cardiac dysrhythmias. It helps in easy localization of the junction and surrounding structures by change in the shape and height of the "P" wave which can be documented on the monitor (Wilson and Gaer 1988; Watters and Grant 1997).

Jeon et al. (Jeon et al. 2006) did an observational study in 2006and observed that tallest P wave can be used to place the CVC tip at the SVC–RA junction during ECG-guided central venous catheterization, the normally shaped P wave corresponds to the mid to upper SVC, and a biphasic pattern of the P wave helps to locate the RA. It is safe, accurate, and can be used in clinical scenarios where radiological confirmation is contraindicated like pregnancy.

It is inexpensive and prevents the need for post-procedural chest X-ray unlike in landmark method, rendering its use in critical care setting as well as non-cardiac surgeries. It can be used safely in case of emergency situation, in the setup where USG is not available. There is no need of any gas analysis post-procedure for confirmation.

However, as observed by Schummer et al. (Schummer et al. 2003). intra atrial ECG does not detect the junction between the superior vena cava and right atrium. It is not a reliable method for confirming position of left-sided CVCs. They recommended post-procedural CXRs left-sided, but not right-sided CVCs.

As a gold standard, TEE probe is routinely introduced in all major cardiac surgeries as a part of protocol and it is preferred over other radiological imaging for confirmation of the position of CVC tip. It is the most accurate tool and helps in direct visualization of the CVC tip and any manipulation which needs to be done immediately to facilitate correct placement of the tip can be carried out (Hilberath et al. 2010). Also, need for post-procedural chest X-ray is avoided.

Conclusions

Intra-atrial ECG method is superior to radiological landmark method and conventional Pere's formula method as it helps in appreciable reduction in malpositioning of CVC tip, hence preventing the complications associated with over insertion or under insertion. It can also be used outside the operating room such as intensive care units, casualty, and minor OT, as it helps in real time verification which also be documented on the monitor hence preventing the legal issues and reduces the mental stress of the person doing the procedure. Confirming the accurate placement of the catheter tip during the procedure is better and early corrective manipulation can be attempted. Various methods of post-procedural confirmation of the catheter placement like chest X-ray, arterial blood gas analysis can be avoided. Hence, it is cost effective, easy to use, and is reusable.

Abbreviations

CVC	Central venous catheter
CVP	Central venous pressure
ECG	Electrocardiography
Fr	French
G	Gauge
ICA	Internal carotid artery
IJV	Internal jugular vein
INR	International normalized ratio
PT	Prothrombin time
RA	Right atrium
SVC	Superior vena cava
TEE	Transoesophageal echocardiography
USG	Ultrasound guided

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Authors' contributions

MRK and ST: Concepts, Design, Definition of intellectual content, Literature search, Clinical studies, Experimental studies, Data acquisition, Data analysis, Statistical analysis, Manuscript preparation, Manuscript editing, Manuscript review and Guarantor. MG: Design, Definition of intellectual content and Manuscript editing. Ak: Design and Definition of intellectual content

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Availability of data and materials

It is available and all data are with the corresponding author. Accessible if needed.

Declarations

Ethics approval and consent to participate

Approved by institutional ethics committee certificate is enclosed in the supplementary material section. No animals were involved in the study Taken from institutional ethics committee clearance (IEC No. – INST.EC/EC/117/2017-18), KS Hegde Medical Academy, Mangalore, India. No animals were involved in the study. Consent for participation: Informed consent for study participation is taken from all participants in writing.

Consent for publication

Informed consent for study publication is taken from all participants in writing.

Competing interests

The authors declare that they have no competing interests.

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