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ORIGINAL ARTICLE

The intracavitary ECG method for positioning the tip of central venous access devices in pediatric patients: results of an Italian multicenter study

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ABSTRACT

Purpose: The Italian Group for Venous Access Devices (GAVeCeLT) has carried out a multicenter study investigating the safety and accuracy of intracavitary electrocardiography (IC-ECG) in pediatric patients.

Methods: We enrolled 309 patients (age 1 month-18 years) candidate to different central *venous access devices* (*VAD*) - *56 peripherally inserted central catheters* (*PICC*), *178 short term centrally inserted central catheters* (*CICC*), *65 long term VADs, 10 VADs for dialysis* - in five Italian Hospitals. Three age groups were considered: A (<4 years, n = 157), B (4-11 years, n = 119), and C (12-18 years, n = 31). IC-ECG was applicable in 307 cases. The increase of the P wave on IC-ECG was detected in all cases but two. The tip of the catheter was positioned at the cavo-atrial junction (CAJ) (i.e., at the maximal height of the P wave on IC-ECG) and the position was checked during the procedure by fluoroscopy or chest x-ray, considering the CAJ at 1-2 cm (group A), 1.5-3 cm (group B), or 2-4 cm (group C) below the carina.

Results: There were no complications related to IC-ECG. The overall match between IC-ECG and x-ray was 95.8% (96.2% in group A, 95% in group B, and 96.8% in group C). In 95 cases, the IC-ECG was performed with a dedicated ECG monitor, specifically designed for IC-ECG (Nautilus, Romedex): in this group, the match between IC-ECG and x-ray was 98.8%.

Conclusions: We conclude that the IC-ECG method is safe and accurate in the pediatric patients. The applicability of the method is 99.4% and its feasibility is 99.4%. The accuracy is 95.8% and even higher (98.8%) when using a dedicated ECG monitor.

Keywords: Central venous access, Central venous catheters, Children, Intracavitary ECG, Malposition, Pediatric, PICC, Tip position

Introduction

The correct position of the tip of a central venous access is of paramount importance in all patients and particularly in pediatric patients. Catheters whose tip is placed "too high" [i.e., in the middle third of the superior vena cava (SVC) or higher] are associated with an increased risk of malfunction, fibroblastic sleeve, and venous thrombosis; catheters whose tip is "too low" [i.e., in the lower part of the right atrium (RA) or in the right ventricle] are associated with the risk of arrhythmias.

As in adults, also in children, the ideal zone for placing the tip of a central venous access is soon above or soon below the cavo-atrial junction (CAJ), in the lower third of the SVC or in the upper part of the RA (1). Considering that the position of the tip is deeply affected by the posture of the patient (upright vs. supine), by breathing, by the movements of the arms, and by other factors, it is difficult to obtain that the tip might remain steadily in an "ideal" spot. Also, the ideal position of the tip may be dependent on the use planned for the central venous access: a venous access device (VAD) inserted for the purpose of hemodialysis or for the purpose of hemodynamic monitoring should ideally have the tip in the RA, while a long-term VAD inserted for

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chemotherapy or parenteral nutrition may have the tip in the lower part of the SVC.

In pediatric patients, the estimate or the actual verification of the tip position is more problematic than in adults: surface landmark for estimating the length of the catheter from puncture site to the CAJ is less reliable than in adults; the interpretation of radiological images (both intra-procedural fluoroscopy and post-procedural chest x-ray) is more difficult, as there are no clear-cut criteria for defining where the CAJ is; finally, in small children, the achievement of a correct tip position during the maneuver itself is of great relevance, as any possible malposition diagnosed after the procedure would imply a reposition that might be expensive and invasive, as it will include a novel general anesthesia.

For all these reasons, the use of the method of intracavitary electrocardiography (IC-ECG) for real-time verification of the tip position (2) appears to be particularly appropriate in children. A recent multicenter study conducted by GAVeCeLT (The Italian Group for Venous Access Devices) in eight Italian hospital centers on more than 1,400 patients (3) has already demonstrated the safety and feasibility of IC-ECG in the positioning of short, medium, and long-term central venous accesses in adult patients and has confirmed its accuracy compared with the postoperative chest x-ray.

The scope of this protocol is to verify the safety, feasibility, and accuracy of IC-ECG in the positioning of short, medium, and long-term central venous accesses in pediatric patients.

Methods

The study was developed by GAVeCeLT and designed as a prospective, multicenter, noncontrolled study. Anesthesiologists, surgeons, and nurses from five Italian hospitals participated in the study: Bolzano City Hospital (OB), "Besta" Institute, Milan (BM), "Santobono" Children's hospital, Naples (SN), "Meyer" Children's Hospital, Florence (MF) and "Gemelli" Catholic Hospital, Rome (GR). The study was coordinated by the center located in Florence. Each center had at least 1 year of experience with IC-ECG in children. The study protocol was examined and approved by the Ethics Committee for the coordinating center, and approved by all other local Ethics Committees.

The objective of the study was to verify the clinical efficacy of IC-ECG in ensuring the proper positioning of the tip of central venous catheters in pediatric patients. In particular, we decided to evaluate:

1. The applicability of the method; as the IC-ECG is based on the variations of the shape of the P wave, we defined applicability as the percentage of children who had a visible P wave on the surface ECG and thus were eligible for the IC-ECG.
2. The feasibility of the method in technical and operational terms, referring to a specific proposal for standardization (see below). "Feasibility" was defined as the possibility of successfully bringing the procedure described below to conclusion, that is the proper identification of the "peak" P wave corresponding to the passage between the SVC and the RA.
3. The safety of the method, in terms of potential arrhythmogenic risk or other types of risk (including electrical hazard) for the patient or for the operator. The evaluation of safety was based on the detection and reporting of any possible adverse event directly or indirectly linked to the execution of IC-ECG according to the procedure described below.
4. The accuracy of the method was defined in comparison with a method widely used in clinical practice, though of limited accuracy (if compared with highly accurate methods such as trans-thoracic or trans-esophageal echocardiography): the radiological verification of the tip position at the end of the procedure. Accuracy was calculated as the match or mismatch between the position of the tip as assessed by IC-ECG during the procedure and the position of the tip assessed at the end of the procedure by chest-x-ray. As the radiography has a wide margin of variability in detecting the actual tip position, it was absolutely important to define precise criteria for the interpretation of the radiological image (see below). Furthermore, as the posture of the patient affects the position of the tip, we chose to have the post-procedural radiological control consistently in supine position (i.e., in the same position of the VAD insertion).

Patients

All pediatric patients requiring central VADs (short-term VADs; medium-term VADs, such as Hohn catheters or PICCs; long-term VADs, such as tunneled/cuffed catheters or totally implantable systems) were candidates to this study.

Inclusion criteria were age between 1 month and 18 years, and parental informed consent for positioning the VAD using IC-ECG.

Exclusion criteria were neonatal age or age greater than 18 years; VAD positioned in the district of the inferior vena cava (by saphenous or femoral cannulation) or in a non-central position (peripheral VADs); surgically placed catheters (by "venous cutdown"); VAD inserted as an emergency procedure; and VAD with caliber less than 3Fr.

Venous access devices

The VAD was chosen according to the protocols of each individual center. Different VADs were considered: short-term or medium-term central venous catheters, inserted through direct central venipuncture (puncture at the chest/cervical level); central venous catheters with peripheral insertion (PICC) inserted through peripheral venipuncture (puncture at the arm level); long-term central venous accesses, tunneled/cuffed or completely implantable (port). Dialysis catheters were also included, as long as they were positioned in the district of the SVC. Epicutaneo-caval catheters were excluded, as they are appropriate only in neonates (which were excluded by the protocol) and because their caliber is so small (<3Fr) that the IC-ECG might be difficult.

The technique of VAD placement was chosen in accordance with the protocols of each individual center, but necessarily including either an ultrasound-guided central venipuncture—supraclavicular (brachio-cephalic vein, subclavian vein, internal

jugular vein, external jugular vein) or infraclavicular (axillary vein, cephalic vein)—or an ultrasound- guided peripheral venipuncture at the arm (basilic vein, brachial vein, cephalic vein, axillary vein). Depending on the type of VAD and on the age of the child, the procedures were performed under mild sedation, local anesthesia, or general anesthesia.

For the purposes of this study, all VADs whose tips were within a target zone corresponding to the lower third of the SVC, or at the CAJ, or in the upper area of the RA (see below for the definition of this area with electrocardiographic and radiological criteria) were considered as correctly positioned, unless a specific different position had been planned by the operator.

Intra-procedural verification of tip position by IC-ECG

In the electrocardiographic method for the positioning of the tip (IC-ECG), the catheter itself is used as an intracavitary electrode and this can be obtained by two different techniques: either the intracavitary electrode is a metallic guide inserted inside the catheter or the intracavitary electrode is a liquid column (saline solution) contained in the catheter. Within this study, only the technique of the liquid column was considered, as it is safer with regard to possible arrhythmias that can be triggered by the J-wire that comes out of the catheter and may come in contact with the atrial walls.

The methodology described below was performed using devices specifically designed for the IC-ECG and easily available on the market: transducers (Alphacard, BBraun; Vygocard, Vygon; Arrow-Johans adapter, Teleflex; Saline Adapter, Romedex) and switches for easy shifting from surface ECG tracing to intracavitary ECG tracing, (Certodyn, BBraun; Pajunk, Teleflex). As an ECG monitor, a dedicated system (Nautilus, Romedex) or a standard ECG monitor was indifferently used.

The ECG needs at least three surface electrodes (red—right shoulder; yellow—left shoulder; green—left flank). The IC-ECG focuses on lead II (red to green), which is ideal for the visualization of the P wave. The system will allow two possible readings, the "surface" lead II (when the electrode is connected to the skin of the right shoulder) or the "intracavitary" lead II (when the electrode is connected with the saline-filled catheter, via the transducer).

Whenever the P wave is evident on surface ECG on lead II, the IC-ECG is applicable.

When the vein has been punctured and cannulated, the catheter is advanced over a guide ("catheter over guidewire": direct Seldinger technique) or within an introducer ("catheter through introducer": indirect or modified Seldinger technique). After the removal of the guidewire (direct Seldinger) and/or removal of the introducer (indirect Seldinger), the catheter is filled with saline and attached to the connector of the transducer. The catheter is threaded further on into the venous system. When it approaches the target area, the surface ECG is switched to the intracavitary ECG. Watching the variations of the shape of the P wave on the intracavitary lead II, it is possible to infer the position of the catheter tip. In the case of Groshong-valved catheters, in order to read these signals, a continuous infusion of saline solution through the catheter is necessary.

As the catheter proceeds into the SVC, the P wave gets higher and reach its peak at the CAJ; proceeding further, a progressive reduction of the P wave amplitude and/or the appearance of an initial negative component in the P wave occurs; deeper on, the P wave becomes diphasic. To be absolutely sure that the "peak" of the P has been reached, it is appropriate to insert the catheter until the P becomes diphasic and then pull it back until the P has just a small negative component (position that will correspond to the upper portion of the RA), or until the P is at its peak (position that will correspond to the CAJ) or even higher, when the peak starts to decrease (about half to one-third of the maximum amplitude; this will correspond to the lower third of the SVC).

On this basis, each operator of each center was left free to decide the ideal position of the catheter tip based on the type of VAD and/or on local policies, but always taking into consideration that the tip should nonetheless be in the target area defined by the study at the level of the CAJ, or in the upper third of the SVC or in the upper portion of the atrium.

It is assumed that the verification of the tip position by IC-ECG should be done when the patient is in a neutral supine position (no Trendelenburg).

The proper reading of the variations of the P wave may be influenced by many technical factors, such as the position of the electrodes (the green electrode should be placed in an appropriately low position, e.g., at the level of the left flank); the choice of the voltage most appropriate for the display of the monitor (the amplitude must be set so to visualize comfortably the variations of P); the choice of the monitoring mode (the "diagnostic" mode is preferred, if this option is available on the monitor); and the interference from other electro-medical devices operating in proximity to the patient (non-essential devices should be deactivated, possibly unplugging them or switching, when possible, to battery powered mode). In the pediatric setting, also passive warmers may significantly interfere with the reading of the IC-ECG trace.

Post-procedural radiologic control of tip position

The radiological control at the end of the procedure was carried out through a standard chest x-ray (in one or two projections) or through fluoroscopy, depending on the protocol of each center. All patients were studied in a neutral supine position, arms along the body and with no forced breathing (normal breathing or controlled mechanical ventilation), considering that tip position may significantly change moving from the supine to upright position, or adducting vs. abducing the arm, or changing the mode of breathing (forced inspiration vs. normal or controlled breathing). In particular, upright position and forced inspiration make the tip move upwards (4). This observation further justifies the preferential choice of positioning the tip at the CAJ, as it gives us a wider margin of safety, considering that even when the patient will be standing or in forced breathing, the tip might rise to the level of the lower third of the SVC and still be in a "safe" area.

As one of the main problems with the radiological verification of tip position is the subjective interpretation by the radiologists, we tried to find the best possible criteria for defining the position of the tip. In a previous GAVeCeLT

multicenter study on adults (3), the Authors adopted the criteria of the distance from the tracheal carina.

In pediatrics, the reliability of the carina as a radiological landmark is still controversial, due to the variability and unpredictability of the relationships between pericardium, carina and SVC in patients of ages below 6 years. The carina—based on the available literature—is nonetheless one of the most accurate points of reference for the evaluation of the position of the central VADs, even in children (5-12).

A radiological landmark often cited in the pediatric literature is the radiologic image of the vertebral bodies; specifically, the CAJ lies two vertebral bodies below the carina (indicating as a "vertebral body" the distance between the inferior margin of one vertebra and the inferior one of the next, including the superior intervertebral body), at the level of T5-T6. These criteria are poorly reliable due to a parallax effect, as the vertebral bodies and the SVC are quite distant inside the mediastinum.

To rely on the interpretation of the right cardiac silhouette is even worse, as the real anatomy is poorly represented by such projection image: in 38% of patients, the radiological right cardiac profile is a compound of the opacity of the left atrium that spills over onto the image of the right one on its cranial-lateral portion, with the result that the tip of a well positioned catheter appears on the projected radiogram inside of the cardiac shadow; the SVC enters posteriorly and not cranially into the RA, so that a tip well positioned at the CAJ usually appears within the cardiac shadow. A further problem with this landmark in pediatric patients is represented by the fact that the right cardiac margin may be covered by the thymus.

On the contrary, the use of the carina as a radiological landmark has several advantages: it is not affected by most pathological changes of the lungs, consistently remaining cephalic to the CAJ; it is located in the anterior mediastinum, at a small distance from the RA, so that the parallax effect is minimal; it can be easily identified even in x-ray films of low technical quality.

Thus, in this study, we have decided to use the criteria of the carina for the radiological verification of the position of the tip. Considering the data available in the pediatric literature, we have divided the patients into three groups, based on their age:

1. GROUP A: patients from 1 month to 3 years old; CAJ = 1-2 cm below the tracheal carina
2. GROUP B: patients from 4 years to 11 years old; CAJ = 1.5-3 cm below the tracheal carina
3. GROUP C: patients from 12 years to 18 years old; CAJ = 2-4 cm below the tracheal carina

However, when the carina could not be identified easily, or when there was some doubt in interpretation, we have additionally considered other radiological indications and other reference landmarks suggested in the literature.

Collection and analysis of the data

For each insertion, we considered the following data:

1. Patient's data: age, weight, height, sex, basic pathology and/or originating department, and presence of any alterations of the surface ECG before the insertion;
2. VAD's data: definition of the VAD as short, medium or long term (according to the classification indicated above), with further information on the specific model, its brand, the number of lumens, external diameter (Fr), type of material (polyurethane vs. silicone), total length, and so on, as well as the tip position considered most appropriate for the optimal function of the VAD.
3. Insertion data: vein punctured and cannulated (according to the classifications indicated above); side of insertion (right or left); possible puncture-related complications (accidental arterial puncture, pneumothorax, and so on);
4. IC-ECG data: identification of the peak of the P wave during the maneuver; final position of the tip (lower third of the SVC = P wave at about half to one-third of his maximum amplitude; CAJ = peak of the P; upper portion of the RA = P wave decreasing in amplitude and/or with an initial negative component); intraoperative complications potentially related to IC-ECG (arrhythmias and so on); type of monitor used (Nautilus vs. standard ECG monitor).
5. Radiological data: type of radiological exam (chest radiography in one or two projections vs. fluoroscopy); modality of execution (if different from what that described in the protocol, i.e., supine position, arms along the body, no forced breathing, no Trendelenburg); classification of the tip position as follows: mismatch between IC-ECG and x-ray: tip not within the target zone (specifying where and/or the distance from the carina); and a good match between IC-ECG and x-ray: tip within the target zone (specify the distance in cm from the carina).

All data were inserted in a software-based database for proper storing and for statistical analysis. Quantitative variables (age, weight, height, and so on) were described in terms of means and standard deviations, while qualitative variables (type of central venous access, insertion modality, and so on) were described in terms of percentages. A Chi-square test was carried out when indicated, for example, to evaluate any association between the insertion modality or the type of VAD and the incidence of malposition.

The size of the sample was calculated by assuming strict concordance between IC-ECG and x-ray (or, that the non-concordance between the two methods—due to the effect of sampling variability and non-controllable factors—would not exceed 1%).

Results

A total of 309 VAD insertion were recruited for the study: 157 in children less than 4 years old, 119 in children 4-11 years old, and 31 in children 12-18 years old. More than half of the VADs (178) were short-term central VADs, 56 were PICCs, 65 were long-term VADs, and 10 were catheters for dialysis or apheresis. Table I summarizes the distribution of the VADs in the five different hospitals participating to the multicenter study.

In two children (one infant 2 months old and one child 5 years old) out of 309, the P wave was not evident on the surface ECG, so that IC-ECG could not be performed. This corresponded to an applicability of 99.4%.

TABLE I - VADs in the different centers

	OB	BM	SN	MF	GR	
PICC	11	3	2	4	36	56
Short term	7	53	18	-	100	178
Long term	1	-	19	7	38	65
Dialysis	-	-	8	-	2	10

TABLE II - Patients distribution in the different centers

	OB	BM	SN	MF	GR	
Total	19	56	47	11	176	309
Not app.	1	-	-	-	1	2 (0.6%)
Gr. A	5	39	28	2	83	157
Gr. B	3	16	13	7	80	119
Gr. C	10	1	6	2	12	31
Not feas.	-	-	-	-	2	2 (0.6%)

TABLE III - Preferred location for the tip

	OB	BM	SN	MF	GR	
CAJ	14	54	38	9	173	288
SVC	4	-	4	1	-	9
RA	-	2	5	1	-	8

IC-ECG was performed in 307 children, though in two cases (one infant 1 month old and one child 2 years old), no elevation of the P could be detected on the intracavitary ECG (so, overall feasibility was 99.4%).

Table II shows the distribution of the patients in the five different centers.

In the vast majority of cases, the planned position for the tip was at the CAJ; in few cases, for clinical reasons, the operator planned to have the tip in the lower third of SVC or inside the RA (see Tab. III). The choice of the tip position in the SVC was often justified by the need for a long-term access for parenteral nutrition; the choice of the tip in the RA was associated with the use of the VAD for dialysis or for hemodynamic monitoring.

The IC-ECG was performed via a standard ECG monitor in the majority of patients; in less than one-third of patients, a dedicated monitor specifically designed for the IC-ECG (Nautilus, Romedex) was used (Tab. IV).

In most cases, the radiological control was performed via a chest x-ray; fluoroscopy was adopted only in selected cases (Tab. V).

The concordance between the tip verification by the IC-ECG method and by the radiological methods was very high: the overall match—that is, tip correctly located both according to IC-ECG and according to X-ray—was 95.8% (no significant differences between the age groups: 96.2% in group A,

TABLE IV - Type of ECG monitor

	OB	BM	SN	MF	GR	
Nautilus	-	-	15	-	80	95
Standard	18	56	32	11	94	212

TABLE V - Type of radiological control

	OB	BM	SN	MF	GR	
Chest X-ray	17	56	21	1	173	268
Fluoro	1	-	26	10	-	37

TABLE VI - Mismatch between IC-ECG and x-ray

	OB	BM	SN	MF	GR	
Mismatch Gr. A N = 157	-	-	3	1	2	6 (3.8%)
Mismatch Gr. B N = 119	-	-	1	2	3	6 (5%)
Mismatch Gr. C N = 31	1	-	-	-	-	1 (3.2%)

95% in group B, and 96.8% in group C). The 13 cases of mismatch are shown in Table VI: in 12 cases out of 13, the tip position as estimated by IC-ECG was too low according to the radiologic criteria (from 1 to 5 cm too low). There was no correlation between the incidence and mismatch and the type of VAD, and no statistical differences between the centers. As the only interesting difference, the concordance between IC-ECG and X-ray was higher (98.8%) when a dedicated ECG monitor had been used.

With regard to the safety of the maneuver, it was 100%, as no adverse event directly or indirectly related to the IC-ECG occurs during the whole study.

Discussion

To our knowledge, this is the first multicenter study investigating the IC-ECG method in pediatric patients.

The idea of using the IC-ECG in children is not new, as from 1985 to 2002, almost a dozen of clinical studies from Europe have reported the possibility of use IC-ECG in pediatric patients, both in neonates and in children, with different VADs (including epicutaneo-caval, Broviac, and umbilical catheters). Most of these studies, though pioneering in this field, did not use standardized methods or reported limited number of cases and had a little impact on the clinical practice (13-24).

More important has been a recent study from Rotterdam (25): in 44 children out of 50, there was a concordance between the IC-ECG and the post-procedural chest X-ray; one patient had serious anatomic abnormalities of his vasculature;

in five patients, the IC-ECG failed because the catheter was too short and did not reach the target or because the anesthesiologist did not trust the IC-ECG. The Authors also reported a potential shorter duration of the procedure by using IC-ECG. The results of this Dutch study do not differ substantially from our finding, though the strength of our study lies in the adoption of very precise, standardized, and repeatable criteria for the radiological interpretation of the position of the tip (i.e., based on the distance from the carina).

In our study, the overall applicability of the method was more than 99%, in contrast with the common finding that in adult population, a significant percentage of patients (7-9%) may not show a clear P on the surface ECG (because of atrial fibrillation or other acquired cardiac diseases). Also, the feasibility was very high (>99%), similarly to what reported by the previous GAVeCeLT multicenter study on adults (3).

The accuracy of IC-ECG was very high (95.8%). When dealing with tip location, we can consider two different types of accuracy, a "real" accuracy—which should consist in comparing the tip verification by IC-ECG vs. the only method that we can consider absolutely accurate, which is trans-esophageal echocardiography (TEE)—and a "relative" accuracy, which means the comparison between the IC-ECG and the radiological methods, which notoriously are less accurate than TEE. As TEE is particularly invasive and expensive, it can be adopted only in very selected cases (e.g., during general anesthesia for cardiac surgery) and a trial comparing TEE and IC-ECG might be logistically or ethically difficult to carry out. Trans-thoracic echocardiography (TTE) is also highly accurate, especially in neonates, but it may not be feasible in some categories of children or it may require a "CEUS" methodology (contrast-enhanced ultrasonography). In our study, as for the previous multicenter study in adults, we have decided to compare the IC-ECG to X-ray, considering that the radiological methods are still the most used worldwide for tip verification in children. The problem with the radiological methods is that most often the criteria are quite subjective and non-standardized. We tried to overcome this problem by choosing the criteria of the distance from the carina, which currently seem to be the most convincing, the easiest, and the most repeatable of the criteria.

Thus, rather than accuracy, we have tested the concordance between the IC-ECG and the radiological method. The result (95.8%) was very close to the result obtained in the adult multicenter study (95.4%). In that study, the main reason for mismatch between the two methods was the fact that in many cases, the radiological control had been performed with the patient in standing position and/or in forced inspiration. In our study, all radiological verifications of the tip position were performed in supine posture, so that this was not an issue. On the contrary, there were some difficulties in the interpretation of the intracavitary ECG tracing, which is not surprising considering that in children, the variations of the P wave have lower voltages and occur in a short distance (in infants, the P may start to rise, reach its peak and become diphasic in the span of 2 cm only). Interestingly, the so-called "accuracy" was definitely higher (98.8%) when IC-ECG was performed with a dedicated ECG monitor (Nautilus), which is likely to reduce the human error, facilitating the interpretation of the intracavitary ECG tracing.

With regard to the safety, our study confirmed that the IC-ECG is absolutely safe: no arrhythmia—and no other complication potentially related to IC-ECG—was reported. Also, the IC-ECG method is particularly safe, as—as the catheter approaches and enters the RA—the operator is able to recognize the position of the tip of the catheter at any moment and thus can avoid to get too close to the tricuspid plane, which is the area most arrhythmogenic of the RA.

Conclusion

The IC-ECG method is safe and accurate in the pediatric patient as much as in adults. Its applicability and feasibility are more than 99%. The concordance with the radiological methods is high (95.8%) and even higher (98.8%) when using a dedicated ECG monitor. If compared with X-ray, IC-ECG has the obvious advantages of allowing an accurate verification of the tip position that is intra-procedural, and without X-ray exposure.

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