cvc-partner

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Controlling the placement of Central Venous Catheters

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The handbook series "cvc-partner" deals with the use and application for central venous catheters. Arterial or pulmonary catheters, hemodialysis catheters, tunneled or implanted catheters are not classified as central venous catheters in this series.

Issue No. 1: Guide for Central Venous Catheterization 04/2002
Issue No. 2: Controlling the placement of Central Venous Catheters 11/2002

All information is consistent with the current state of scientific knowledge.

The lack of brand name labeling does not permit any statements about the free use of product names.

This series has been prepared in consultation with many users to whom we wish to express our heartful gratitude for their various contributions.

It is the intention of this series to support all users. We therefore rely on the feedback from our readers. We welcome any suggestions and critique which will be forwarded to the editorial team if you write to **info@cvc-partner.com** or if you send an mail message placed at the homepage **www.cvc-partner.com**.

Controlling the placement of Central Venous Catheters

Preface

When inserting a central venous catheter by percutaneous venipuncture, the main concern of most physicians is to locate and incannulate rapidly and safely the vein, avoiding accidental arterial puncture and acute pleuropulmonary complications (such as pneumothorax): correct positioning of the catheter tip is often regarded as a secondary or marginal goal.

Though, increasing evidence from the medical literature shows that the correct position of the tip is of paramount importance for a safe and effective use of the central line. This appears obvious for long term central venous access (for prolonged parenteral nutrition or chemotherapy) but it is highly relevant also for short term access (in critically ill or postoperative patients).

The least incidence of complications appears to be associated with the position of the tip of the catheter in the lower third of the superior vena cava.
Nonetheless, correct positioning of the catheter tip is not easy, and malpositions are a frequent complication of central venous cannulation (ranging from 2 to 30 %, depending upon the venous route we consider and upon the criteria by which we define tip malposition).

Different methods have been advocated as a guidance for correct positioning of the catheter tip (1):
- appropriate choice of the venous route (catheters placed via the infraclavicular route to the subclavian vein are more likely to be malpositioned than those placed via the internal jugular route or via the supraclavicular route to the sublcavian vein);
- accurate planning of the length of the catheter to be inserted, by anatomic landmarks or by ready-to-use algorhythms
- radiological methods: intraoperative fluoroscopy or postoperative chest radiography
- electrocardiographic methods (of which a detailed explanation is offered in this handbook)
- echocardiographic methods (standard or transesophageal echocardiography).

The radiological methods have often been regarded as the 'golden standard', but still they have some clear disadvantages:
- radiation exposure for the patient and the staff
- high cost
- possible mistakes due to difficult interpretation of the radiological imaging
- variability of the tip site secondary to patient position (supine vs. standing; normal supine vs. Trendelenburg position), particularly in the pediatric patient.

The main advantage advocated for x-ray is its additional usefulness in excluding the presence of pneumothorax or acute pleuropulmonary complications. Nonetheless, two important points are to be stressed:
1) the intraoperative or immediate postoperative x-ray does not absolutely exclude a pneumothorax, since an increasing occurrence of 'delayed' pneumothorax (12-24 hrs after central venipuncture) has been recently described in the literature.
2) An intra- or post-operative x-ray for ruling out pneumothorax is mandatory only when the physician has adopted a technique of venipuncture potentially associated with pneumothorax (such as subclavian venipuncture).

It is interesting to note that in two very recent and authorative guidelines dealing with central venous cannulation for parenteral nutrition (guidelines from ASPEN, American Society of Parenteral and Enteral Nutrition, and from SINPE, Società Italiana di Nutrizione Parenterale ed Enterale, both published in 2002) (2-3) the x-ray control during/after central venous cannulation is considered to be necessary only (a) if a technique associated with pneumothorax risk has been used, AND (b) if the tip position has not been checked by other methods.

The electrocardiographic method for correct positioning of the catheter tip is thoroughly described and discussed in this handbook. It may be surprising that such a simple, unexpensive, and safe method has not become the standard for correct tip positioning; the possible reasons may be:
- the lack of an adequate standardization of the technique of electrocardiographic positioning
- the widespread use of cannulation via the subclavian route, which has compelled the physicians to use x-ray methods, which can rule out both malposition and pneumothorax.

Analyzing the current literature, it is evident the increasing awareness of the risks associated with subclavian venipuncture (4): in recent years, many papers has been published about the use of ultrasound guidance for minimization of the risk of pneumothorax during subclavian cannulation; safer and easier routes for central venous access has been advocated (such as the so-called 'low lateral' route for internal jugular venipuncture, which appears to be simpler and safer than standard techniques of internal jugular or subclavian cannulation) (5).

Thus, the problem of monitoring the position of the tip of the catheter is not simple, since many factors should be taken into account (cost-effectiveness, safety of the patient, type of venous access, expected duration and use of the central catheter, and so on). Also, reviewing the literature, there are few reliable statistical data (such as prospective randomized

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clinical trials), so that evidence-based recommendations and guidelines are hard to define.

Overviewing this complex field, the present handbook – simple, clear and practice-oriented – will offer to the reader an accurate review of the different methods which may help us to achieve a correct position of the catheter tip: though an 'ideal' method is yet to be defined, the physician which perform a central venous cannulation should be aware of the importance of correct positioning of the tip, and he should know advantages and disadvantages of each method, so to choose the best procedure in terms of patient's safety and cost-effectiveness.

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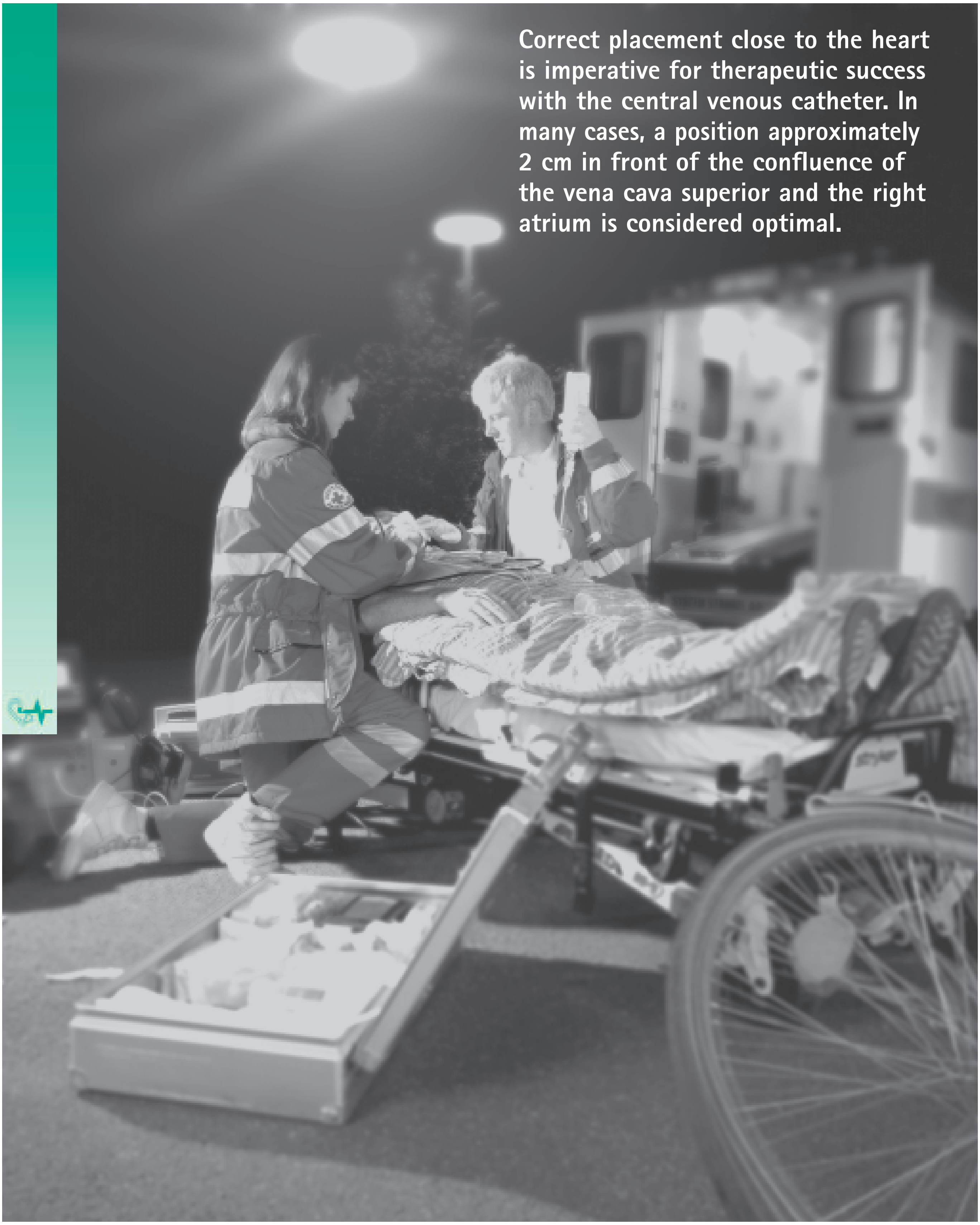
Positioning the catheter tip

Correct placement close to the heart is imperative for therapeutic success with the central venous catheter. In many cases, a position approximately 2 cm in front of the confluence of the vena cava superior and the right atrium is considered optimal.



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The central venous catheter allows the rapid administration of medications and solutions, when necessary in high concentrations, through large caliber veins close to the heart. The peripheral blood vessels are unsuitable for this purpose because their small diameter produces a lower blood flow rate and because the vessel can rapidly occlude when irritant medications are infused.
However, if the catheter is not optimally positioned in the vein close to the heart, there is an increased risk of damage to the vessel wall and associated structures. Correct positioning of the central venous catheter is therefore required to avoid undesired complications with short and long term indwelling catheters.
In Issue No. 2 of the handbook series "cvc-partner", a catheter is regarded incorrectly positioned when:

- the catheter tip is not located in the superior or inferior vena cava (central venous catheters advanced as "midline" catheters into the subclavian vein are not considered in this issue),
- the catheter forms a loop, e.g. in the vessel close to the heart or in the vena cava which can impede catheter removal,
- the catheter tip is advanced too far into the heart, inducing arrhythmias, damaging the right heart valve or even precipitating cardiac tamponade,
- the catheter tip is positioned too close to the vein wall, preventing infusion/aspiration.

As the list shows, correct positioning of the catheter is a critical factor for a successful outcome of clinical therapy, and misplacement might even put the patient's life at risk. The fundamental question, "Where is the optimal position of the catheter, and especially of the catheter tip" remains a subject of scientific debate despite much intensive research (1–4).

There is a consensus that the catheter tip must be located outside the right atrium to avoid damaging the heart (1, 4).
If access via the superior vena cava is chosen, the catheter tip should come to rest about 2 cm before the confluence of the vena cava superior with the right atrium (see figure 1, position A and 1,2). If the catheter is advanced through the lower vena cava, a route often preferred in the pediatric setting, a high position of the catheter tip in the inferior vena cava at the level of the diaphragm or above should be chosen (see figure 1, position B and 5).

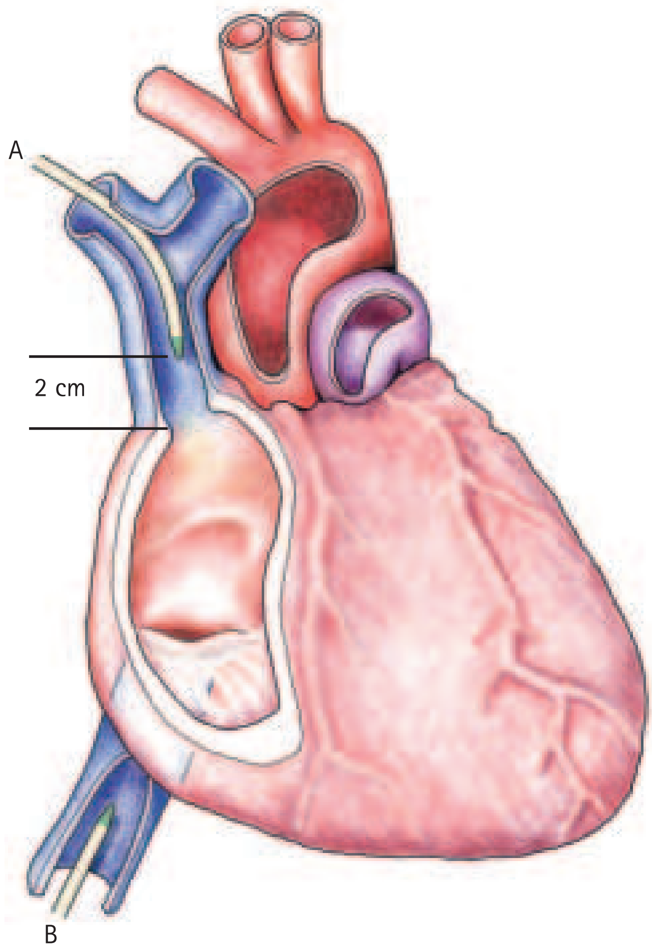


Figure 1: Recommended position of catheter tip in the superior (A) or inferior vena cava (B).

1

Positioning the catheter tip

The increased incidence of cardiac tamponade associated with access through the left side of the body prompted Fletcher and Bodenham to recommend positioning the catheter tip in the brachiocephalic vein and not lower (1).

With access through the right jugular vein, both authors consider a tip position close to the atrium acceptable in cases where advancing the catheter tip to an even lower position is ruled out (1). Numerous studies have shown, however, that when access through the brachial or subclavian vein is chosen, the catheter tip is advanced or withdrawn over considerable distances by movements of the arm or upper part of the body (3). A distance of about 2 cm from the right atrium should be maintained, since this leaves enough space for the catheter tip to move without directly damaging the cardiac atrium.

The central venous catheter is generally positioned by estimating the length on the patient, according to one of the following published rules of thumb (6):

Right subclavian or jugular vein: 13–16 cm
Left subclavian or jugular vein: 15–20 cm
No corresponding recommendations are available for the basilic vein.

Peres and coworkers published catheterization guidelines for adult patients (7) and the working group of Andropoulos designed a formula for predicting correct CVC positioning in pediatric patients (2). Both groups followed similar methods, comparing the radiographically identifiable position of the catheter tip with the chosen catheter length.

Peres devised the formula for access through the subclavian and jugular vein, while there was insufficient data available for other puncture sites.
The following relationship was established between patient height (H in cm) and catheter length (L in cm).

Entrance	Formula
Right side: Subclavian vein: External and internal jugular vein:	L = H/10 – 2 L = H/10
Left side: External jugular vein:	L = H/10 + 4

Andropolous and coworkers performed a similar study in children and juveniles, but considered only access through the right subclavian and internal jugular vein.

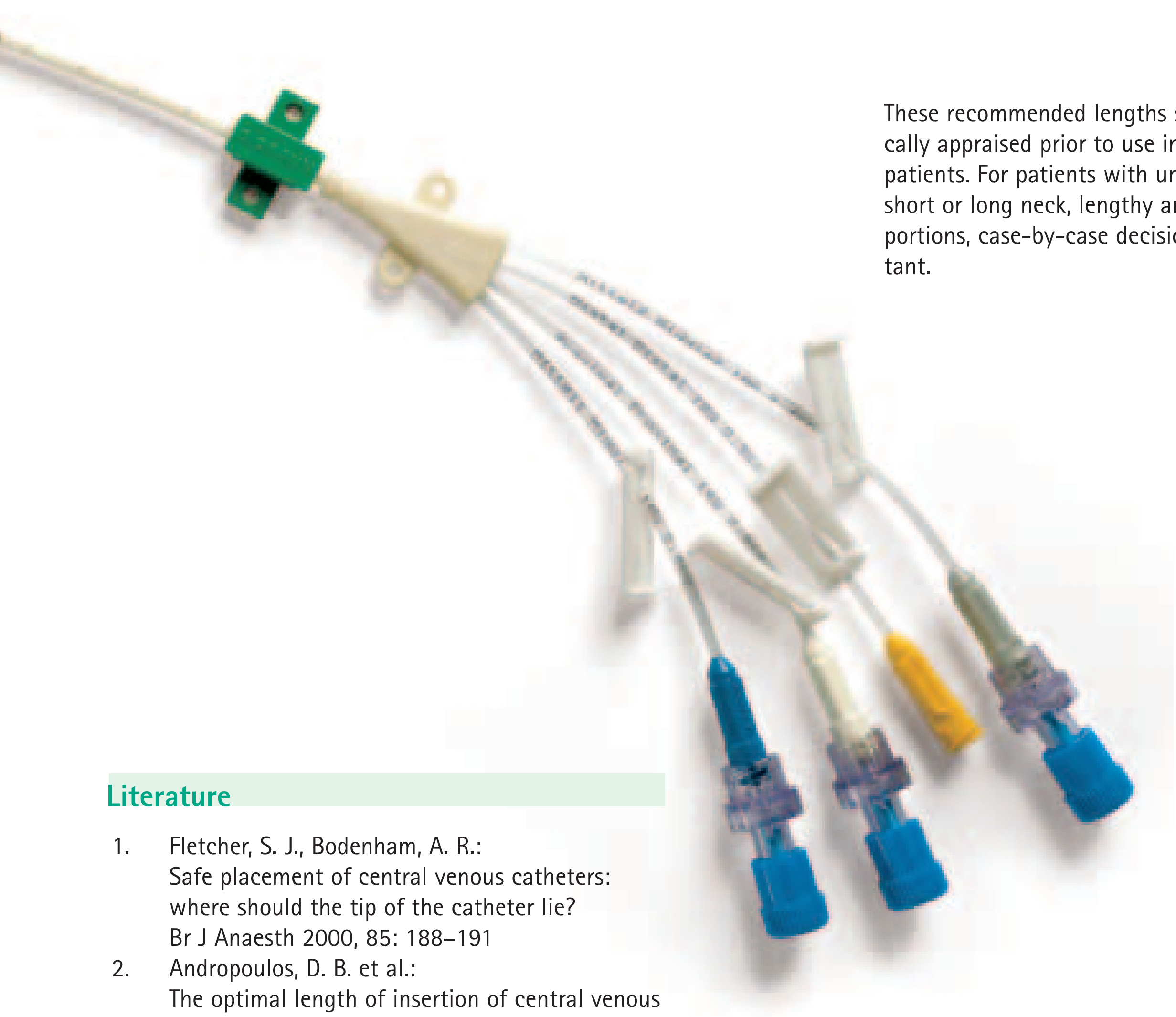
Height	Formula
Right subclavain external and internal jugular vein:	
H ≤ 100 cm	L = H/10 – 1
H > 100 cm	L = H/10 – 2

The values obtained using the Andropolous formula contradict those of the Peres formula in patients taller than 100 cm and when access through the jugular vein is used. This discrepancy merits further investigation.

1

Table1 shows the catheter length calculated according to Peres and Andropoulos in cm as a function of access route and patient height.

		Height (cm)	50	60	70	80	90	100	150	160	170	180	190
Access route	Right	Subclavian vein	4	5	6	7	8	9	13	14	15	16	17
		External and internal jugular vein	4	5	6	7	8	9	15	16	17	18	19
	Left	External jugular vein							19	20	21	22	23



These recommended lengths should always be critically appraised prior to use in the individual patients. For patients with unusual proportions, e.g. short or long neck, lengthy arm or upper body proportions, case-by-case decision-making is important.

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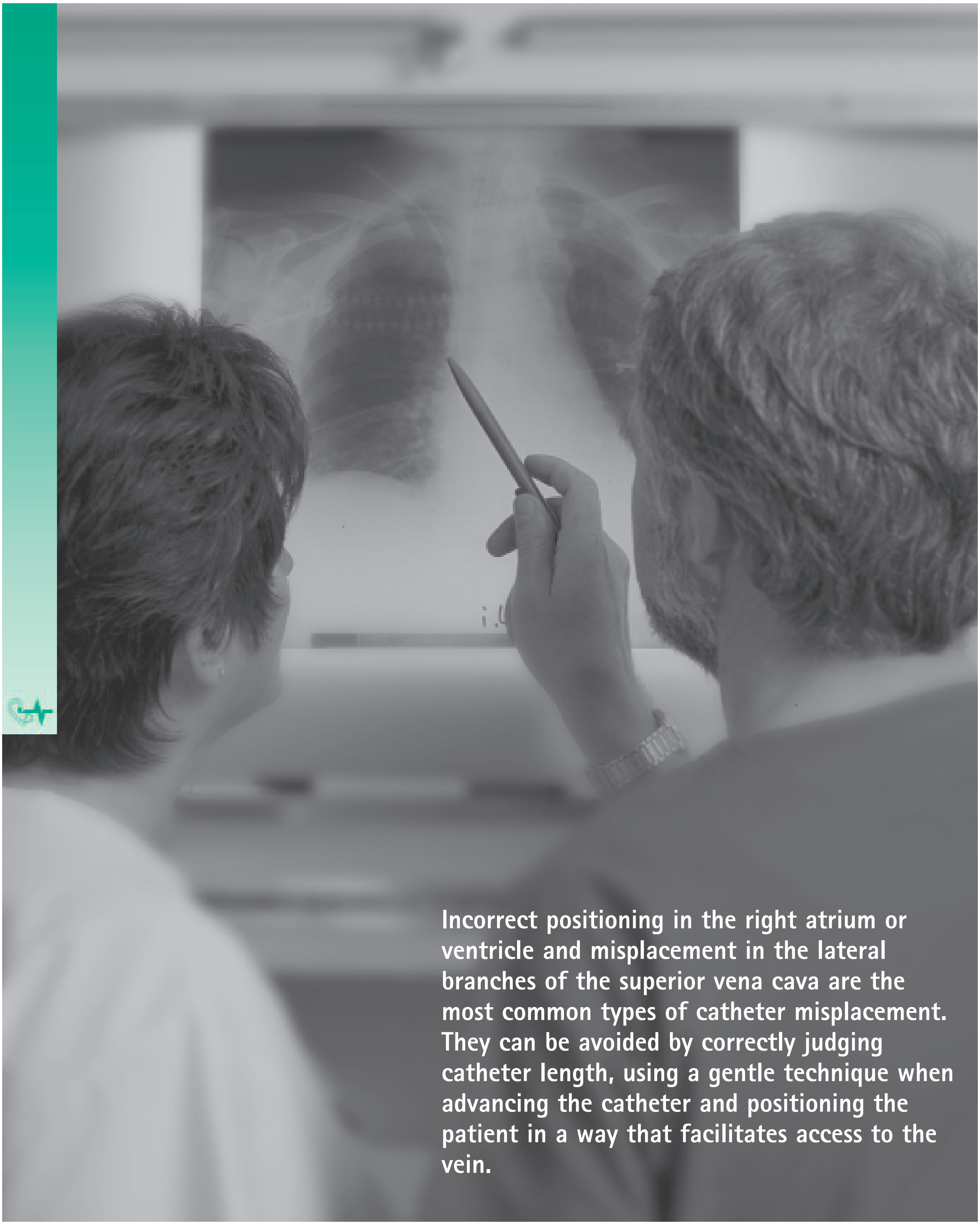
2 The misplaced catheter



Incorrect positioning in the right atrium or ventricle and misplacement in the lateral branches of the superior vena cava are the most common types of catheter misplacement. They can be avoided by correctly judging catheter length, using a gentle technique when advancing the catheter and positioning the patient in a way that facilitates access to the vein.

2

The central venous catheter is usually introduced "blindly" and demands a high level of manual dexterity from the user to reliably bypass anatomical constrictions or branching sites. If you encounter elastic resistance when advancing the guidewire or catheter, never change the position by making jerky movements or exerting too much force (1,3).

Increased resistance during advancement may, for example, be caused by the catheter tip impinging against a venous valve (see figure 2).
If the tip becomes lodged in a small collateral vessel, advancement is also perceptibly more difficult. In many such cases it will still be possible to continue advancing the catheter, however, radiographic monitoring will subsequently reveal misplacement like looping of the catheter.

One can occasionally overcome the obstruction by briefly advancing and retracting the catheter while simultaneously rotating it, or the catheter/guidewire must be removed if further advancement proves impossible (caution: do not push the catheter back through the metal cannula – risk of shearing part of the catheter off!). If resistance is felt during advancement, check the catheter position immediately after the placement.

Numerous study reports show that catheter misplacement occurs in 20 %–30 % of cases even when performed by experienced physicians (1–3). The incorrect position often remains initially undetected since there are no clinical symptoms.

The anatomical variability of the most commonly utilized access routes (basilic vein, subclavian vein, internal or external jugular vein) critically influences the potential misplacement of the catheter tip. The patient's body and head position during catheter advancement can also negatively affect the success rate for placement (3). Issue number 1 of the handbook series gives some tips how to circumvent misplacement depending on the access route.

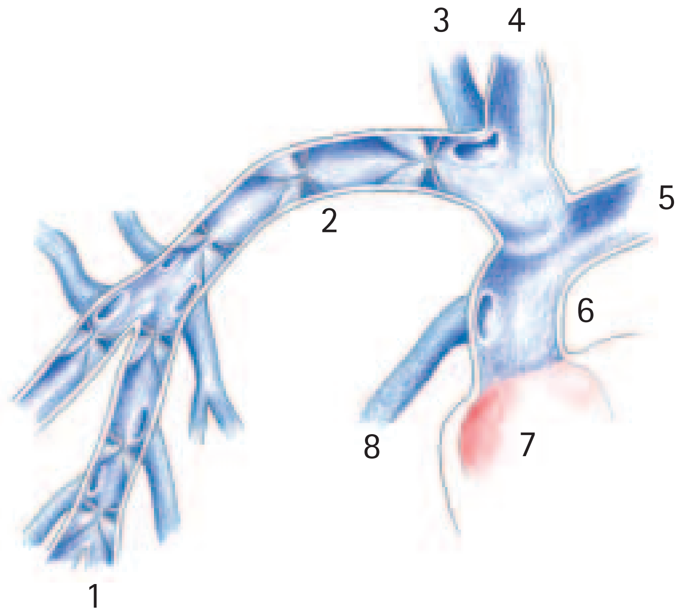


Figure 2: Scheme of veins used for central venous access with position of venous valves and veins close to the right atrium.

(1) Basilic vein
(2) Subclavian vein
(3) External jugular vein
(4) Internal jugular vein
(5) Brachiocephalic vein (innominate vein)
(6) Superior vena cava
(7) Atrium
(8) Azygos vein

2 The misplaced catheter

Positioning the catheter too low in the right atrium is commonly reported in clinical studies (see figure 3). A tip located deep inside the atrium usually induces electrocardiographically identifiable arrhythmias. If it is not immediately recognized that the catheter has been inserted too deeply, cardiac function can be compromised by impairment of the right atrioventricular valve. Permanent frictional contact between the catheter tip and the myocardium can lead to erosion of the muscle and subsequent cardiac tamponade, which has a fatal outcome in more than 50 % of cases (4).

With access through the left side of the body, the anatomy of the brachiocephalic vein opens up several possibilities of misplacement (see figure 4). The brachiocephalic vein almost impinges upon the superior vena cava at the right angle, which facilitates the advance of the catheter into the contralateral subclavian or jugular vein (upper arrow) or into the small azygos vein (lower arrow). If the catheter has not been moved far enough to reach the atrium the tip of the catheter might contact the superior vena cava at the right angle (middle arrow). Especially in patients with long-term therapy, this tip placement can lead to erosion of the vein wall (5). The position of the catheter tip should thus always be carefully verified when utilizing a left-sided access through the subclavian or jugular vein.

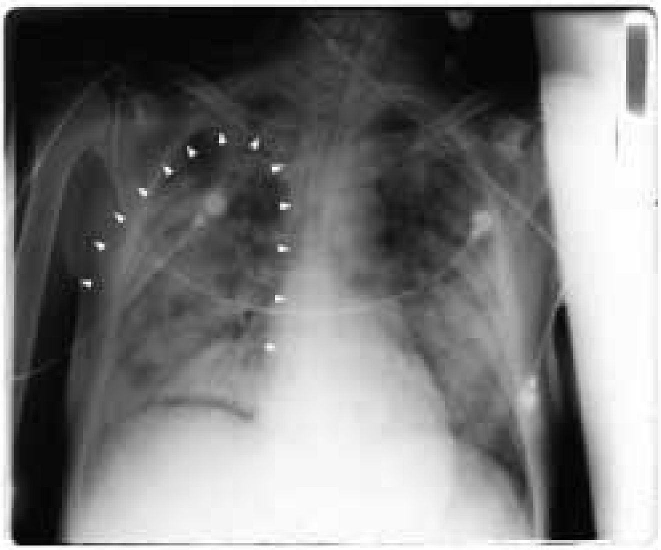


Figure 3: Chest x-ray showing a deeply in the atrium placed central venous catheter which has been advanced from the right basilic vein

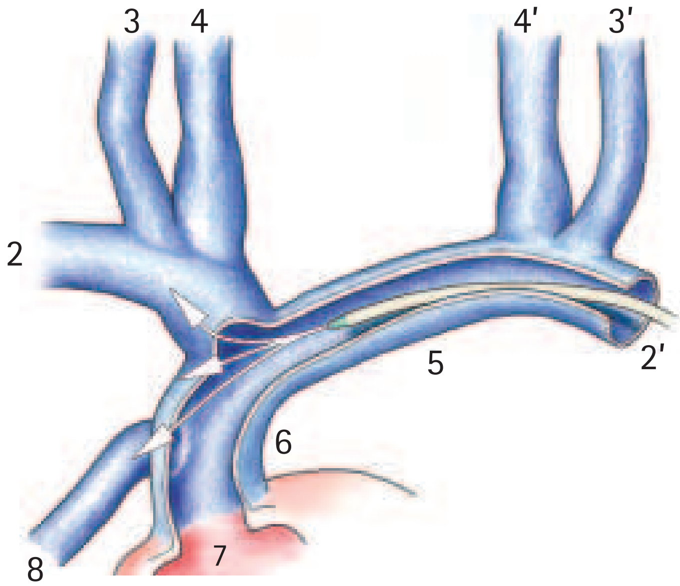


Figure 4: Possibilities of catheter tip misplacement with access from the left side. Arrow: possible ways for advancement; 2, 3, 4 and 2' 3' 4': right and left side respectively Explanation of veins see figure 3.

Choosing an incorrect catheter length, paying insufficient attention to resistances encountered during advancement and threading the catheter without length control will increase the risk of such serious complications. The recommendations presented in Chapter 1 should be followed when selecting the catheter length. Clinical symptoms such as hypotension, chest tightness and shortness of breath are signs that the catheter tip has been inserted too deeply.

The most frequent complication associated with central venous catheterisation is misplacement of the catheter tip outside the vena cava. This could happen by looping of the catheter or by erroneously advancing the catheter into wrong vessels. In the first case (see figure 5 and 8) the catheter tip normally will not reach the correct terminal position before the atrium. In the latter the catheter and the tip will be positioned far away from the heart (see figure 6 and 7).

Figure 5: X-ray image demonstrating tip misplacement in the brachiocephalic vein due to looping of catheter in the left subclavian vein.

Figure 6: Fluorographic chest image showing a catheter which was erroneously advanced through the internal jugular vein into the subclavian vein.

A catheter positioned outside the superior vena cava in a relatively small vessel represents a considerable risk for clinical therapy. The risk of thrombus formation and thus of venous occlusion is much higher in small vessels. There is also a risk of perforating the thin vein wall with extravasation of the infused solutions into the mediastinum manifesting as hydrothorax.

Figure 7: AP fluorographic image of a misplaced catheter which was advanced from the internal into the external jugular vein.

2 The misplaced catheter

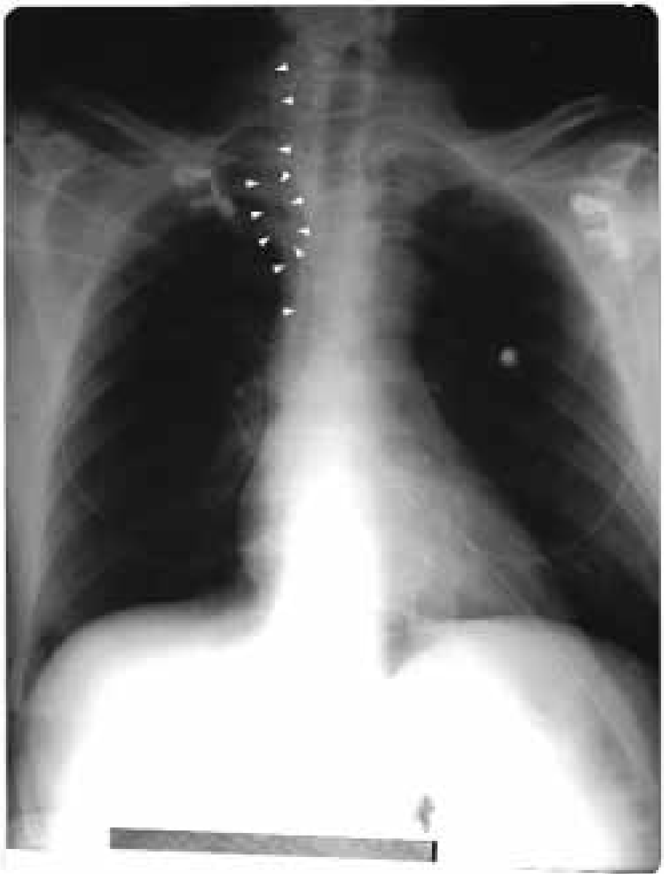


Figure 8: X-ray image showing looped catheter with access from the jugular vein.

Catheter position monitoring is always necessary when a central venous catheter is positioned "blindly". A misplaced catheter represents a substantial risk and only about 80 % of catheter tips terminate correctly above the right atrium.

If the central venous catheter has become looped as shown in figure 8, flow through the lumen is usually greatly impaired. The catheter is then useless since medications or solutions can no longer be administered rapidly through a looped line. Reliable diagnostic measures, such as measuring central venous pressure, are also impossible to carry out in such cases.

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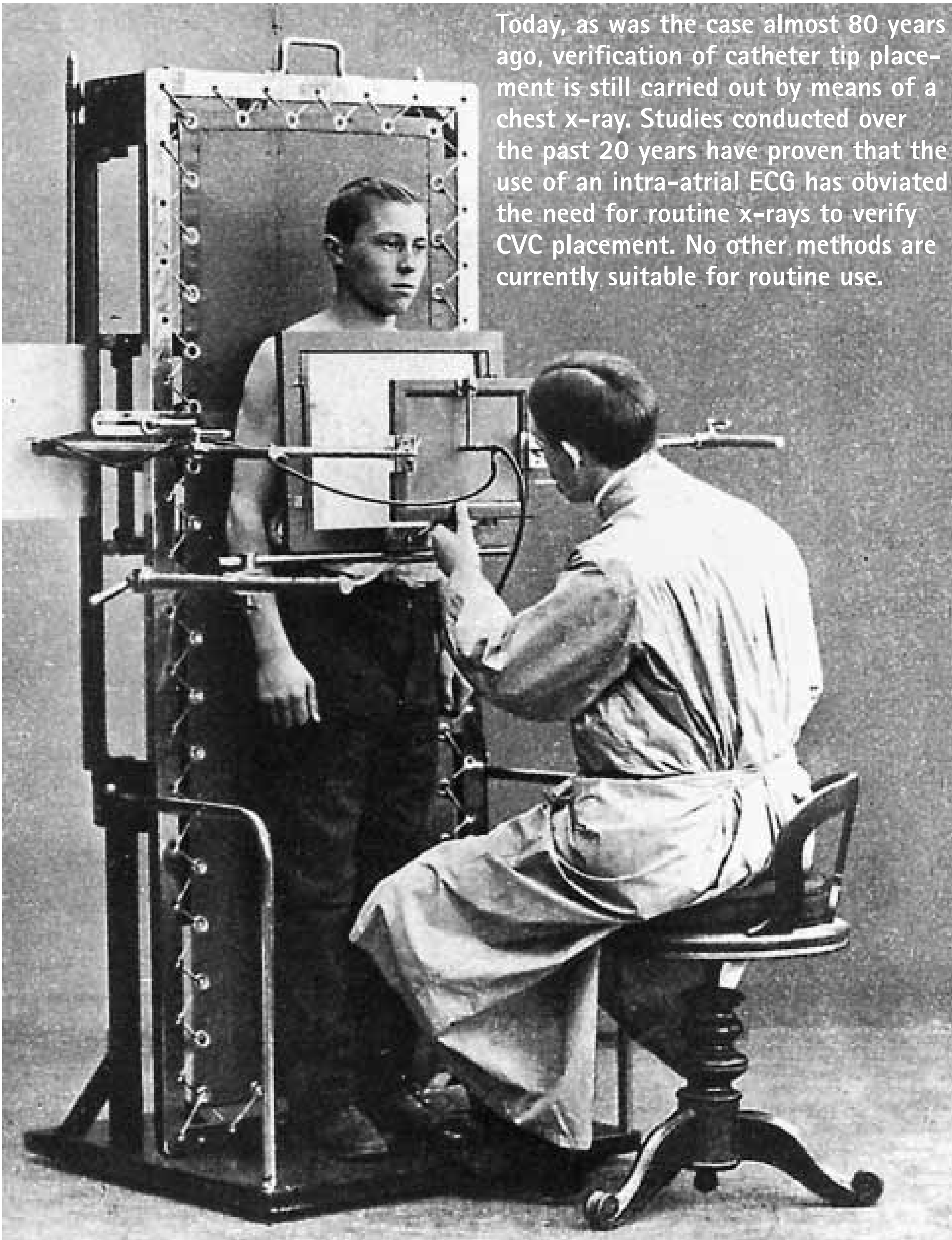
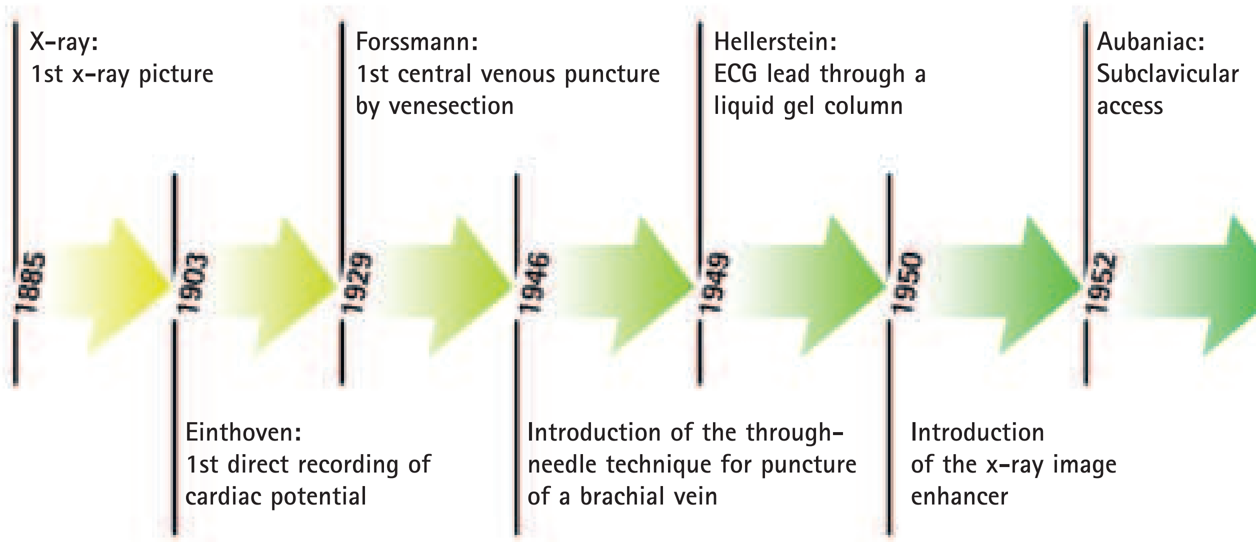
The history of catheter placement control

3



Today, as was the case almost 80 years ago, verification of catheter tip placement is still carried out by means of a chest x-ray. Studies conducted over the past 20 years have proven that the use of an intra-atrial ECG has obviated the need for routine x-rays to verify CVC placement. No other methods are currently suitable for routine use.

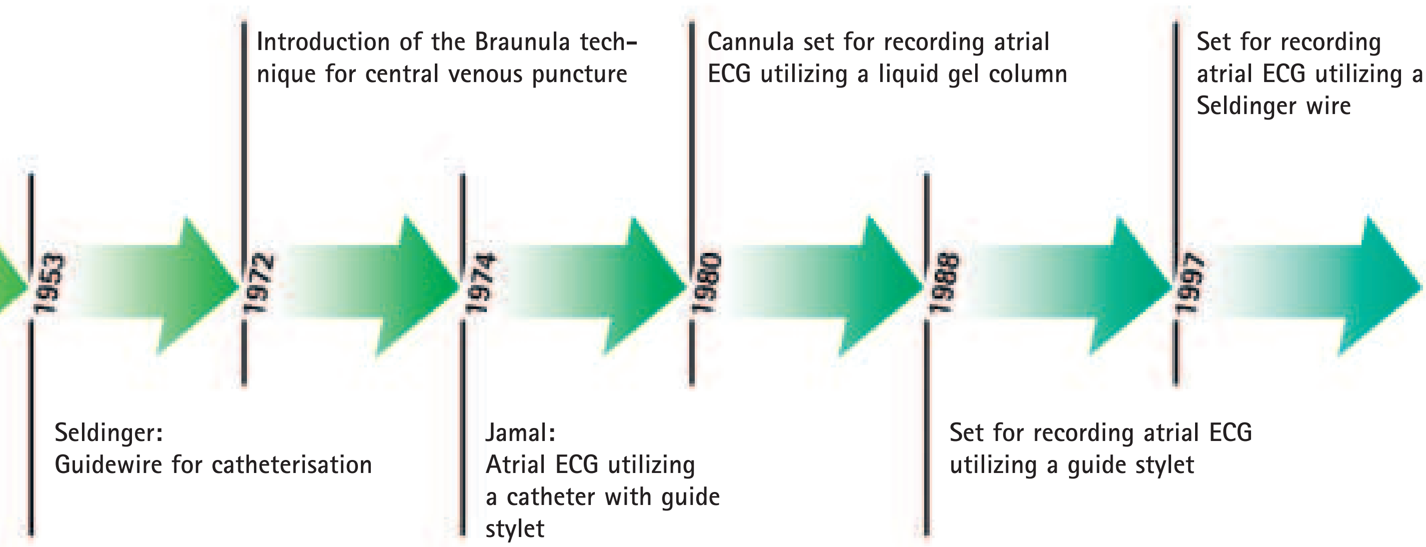
3 The history of catheter placement control



Since the German physician Werner Forssmann described central venous puncture for the first time in 1929 (1), chest x-rays have been used to verify the position of the central venous catheter and involved x-ray imaging of the upper torso in the anterior-posterior direction. Hospitals usually possess the technical equipment and staff to carry out x-ray procedure. This method for confirming placement of the catheter became therefore established as the gold standard.

In the nascent phases of x-ray monitoring, there were only attenuated fluorescent screens that produced poor quality images despite the high radiation dose. It was possible to make fluorographic images of healthy persons which can stand upright but not of critical care patients laying in the bed. The introduction of the x-ray image amplifier in the 50's led to marked improvements in image quality and versatility, thereby paving the way for the chest x-ray to become the standard diagnostic method. Yet, the continuous monitoring of the catheter position during placement under image converter control has not managed to establish itself in clinical practice. One of the main reasons for this is the increased radiation exposure for the patient and hospital staff.

At the beginning of the 20th century the Dutch physician Einthoven constructed a device which for the first time was able to measure the electric current on the skin of an human during heart beats. This opened up new opportunities to understand the heart function. For examination of arrhythmia the patients had to be connected to the bulky and sensitive measure device by about 50 m of wire. Soon technical improvements allowed to shrink the device size and use it for continuous monitoring of the heart function at the patient bed side.



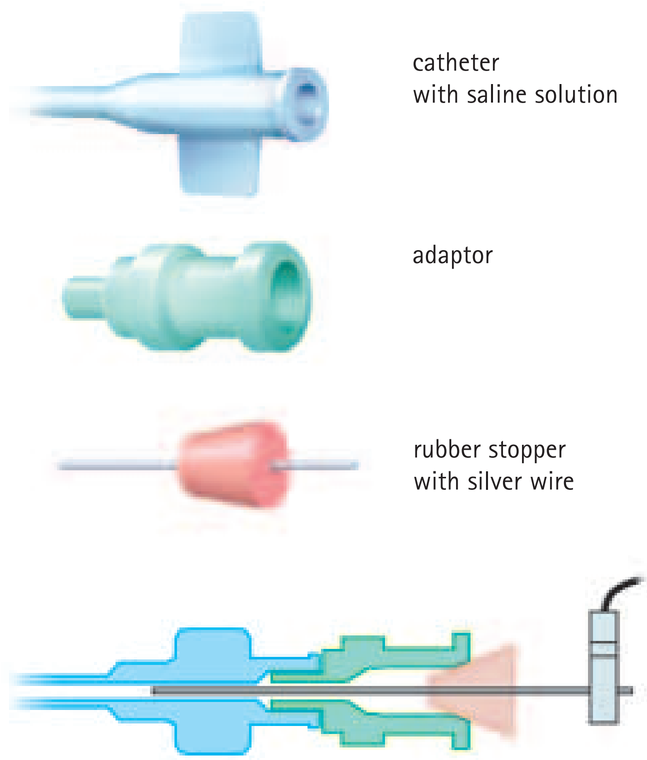


Figure 9: Components used by Hellerstein for intra-atrial ECG using saline solution.

In 1949 Hellerstein took his previous experience with ECG leads and applied them in a unique way for directly recording atrial potentials (2). Hellerstein's method differed from that of his colleagues who used metal wires for recording the signals, whilst he used a central venous catheter filled with saline solution. The signal was captured at the catheter hub through a self-made adaptor and transferred to an ECG monitor. In his landmark publication he examined the recording of both the saline solution and through a metal wire.
Both leads produced a typical change in P-wave contours when the central venous catheter was advanced past the sinoatrial node (for details on ECG monitoring, please refer to Chapter 5 "The principle of atrial ECG for tip monitoring"). The authors noted with foresight "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 …".

3 The history of catheter placement control

Most doctors wanting to monitor the position of a central venous catheter were not exactly thrilled with Hellerstein's work – at the time. Instead advances in x-ray technology helped to establish the chest x-ray as the method of choice. Not until around 25 years after Hellerstein's work did publications by Jamal and by Hufnagel turn the spotlight back on his method. In parallel, industry started developing commercial systems that, like Hellerstein's, used saline solution for recording the atrial ECG (e.g. the Arrows-Johans adaptor, Alpha-

card, Certodyn Cor). In the late 80's, catheter systems were introduced that used metallic guide stylets for ECG lead (e.g. Cavafix Certodyn, Certofix) – recognised today as a standard method (see Chapter 6).

A number of studies were conducted which were able to prove that the use of intra-atrial ECG is a reliable alternative to x-ray monitoring of the catheter tip position (Overview in 3 and Chapter 7). A comprehensive study carried out by McGee et al. in 1993 concluded that the use of the intra-atrial ECG lead fulfils requirements of the Federal Drug Administration (FDA) (4). This body has reminded physicians in 1989 to safely place central venous catheter outside the atrium and control the tip position (5).

Identification of the catheter tip in the vena cava has been attempted using other non-invasive diagnostic methods like ultrasound (6), Doppler sonography (7) and transesophageal echocardiology (8). The success of these methods varies, but none of them has become established. The technological expenditure and time it takes to learn how to correlate the images obtained with the position of the catheter have been detracting factors. Used alone, none of these three methods produces findings that are conclusive enough and they should therefore not be used for routine checks of catheter position.

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Fluoroscopic monitoring – The gold standard?

4

X-ray monitoring has become a standardized element of central venous puncture. Numerous studies have proven, however, that when alternative monitoring methods are used obligatory radiographic monitoring does not produce a clinical advantage, whereas it does increase costs unnecessarily.

4 Fluoroscopic monitoring – The gold standard?

The need to verify the position of the central venous catheter is undisputed in order to rule out hazards to the patient. The established method is the anterior-posterior x-ray image (AP image) that is taken after placement of the catheter.

At first glance, the advantages of fluoroscopic monitoring appear convincing:

- Immediate verification of the catheter position
- Exclusion of pneumothorax
- Conclusive imaging confirmation about the position of the catheter tip
- X-ray is easy to carry out

Many of the arguments favouring radiographic monitoring, however, only apply to a limited degree in routine practice.

- In normal clinical practice, immediate verification really means that the x-ray is taken within the first 4–24 hours. "On-line" monitoring while the catheter is being placed with the aid of an image converter is rarely practised because of the high radiation exposure for the patient and staff. During that 24-hour window, the anaesthesiologist remains in the uncertainty as to whether the tip has been placed in the correct position or not. If the patient's clinical reaction to the administration of the drugs cannot be interpreted clearly, then it must be considered that the placement of the catheter is incorrect.
- The chest x-ray is taken 24 hours after placement of the catheter at the latest in order to rule out the presence of pneumothorax and, at the same time, to document the position of the catheter. The radiographic technique, including intensity and duration, must be optimized so that any shadows in the lung can be discerned (1). A chest x-ray that clearly reveals the presence of pneumothorax is rarely suited for unequivocally establishing catheter tip position. A second x-ray at a changed imaging setting is frequently required to confirm the catheter position.
  If an x-ray is taken shortly (up to 4 hours) after placement of the catheter, this radiograph can only be used to determine the catheter position, nothing more. If the aim is to rule out pneumothorax, then the AP x-ray must be repeated at the latest 24 hours later.

In other words, you will seldom find that the use of radiographic monitoring saves time or money in normal clinical practice.

Figure 10 left: Chest x-ray image of a misplaced catheter

- When checking the catheter position by fluoroscopy, the x-ray image that is produced can only be correctly interpreted by someone with experience. Figure 10 shows an AP image on the left and, on the right, a diagrammatic rendering of the same view that shows the radiodense anatomical structures.

Figure 10 right: Scheme corresponding to AP-image showing x-ray dense structures

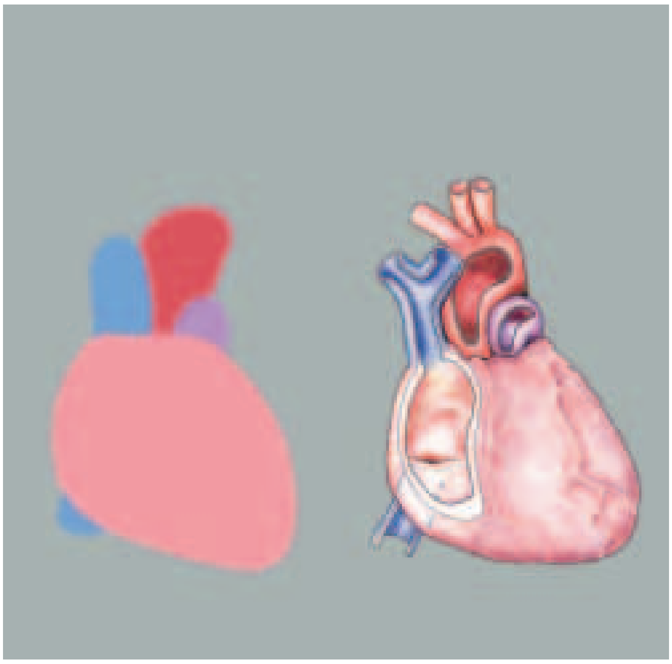

Figure 11: Scheme of x-ray image (left) and anatomical view of the heart (right)

Depending on the strength of the catheter signal the course of the catheter can hardly be followed sometimes. The radiographic image of the heart make the identification of the tip position and a statement about its correct placement before the atrium difficult.

The shadow of the heart is primarily determined by the right atrium, the right chamber and the aortic arch, as shown in Figure 11. The confluence of the superior vena cava and the right atrium is covered over by the aortic arch. Unequivocal verification of positioning of the catheter tip in front of the right atrium is not always possible on the AP image.

4 Fluoroscopic monitoring – The gold standard?

Figures 12 shows a chest x-ray image depicting a catheter tip that has been advanced to far into the atrium. The catheter which has been advanced from the basilic vein can hardly be recognized along the basilic and subclavian vein. At the point of entrance of the superior vena cava into the atrium the fine line of the catheter could not clearly be distinguished from the heart shadow. Profound knowledge of anatomical landmarks and fluoroscopic imaging techniques are necessary to come to a firm conclusion on the catheter position.

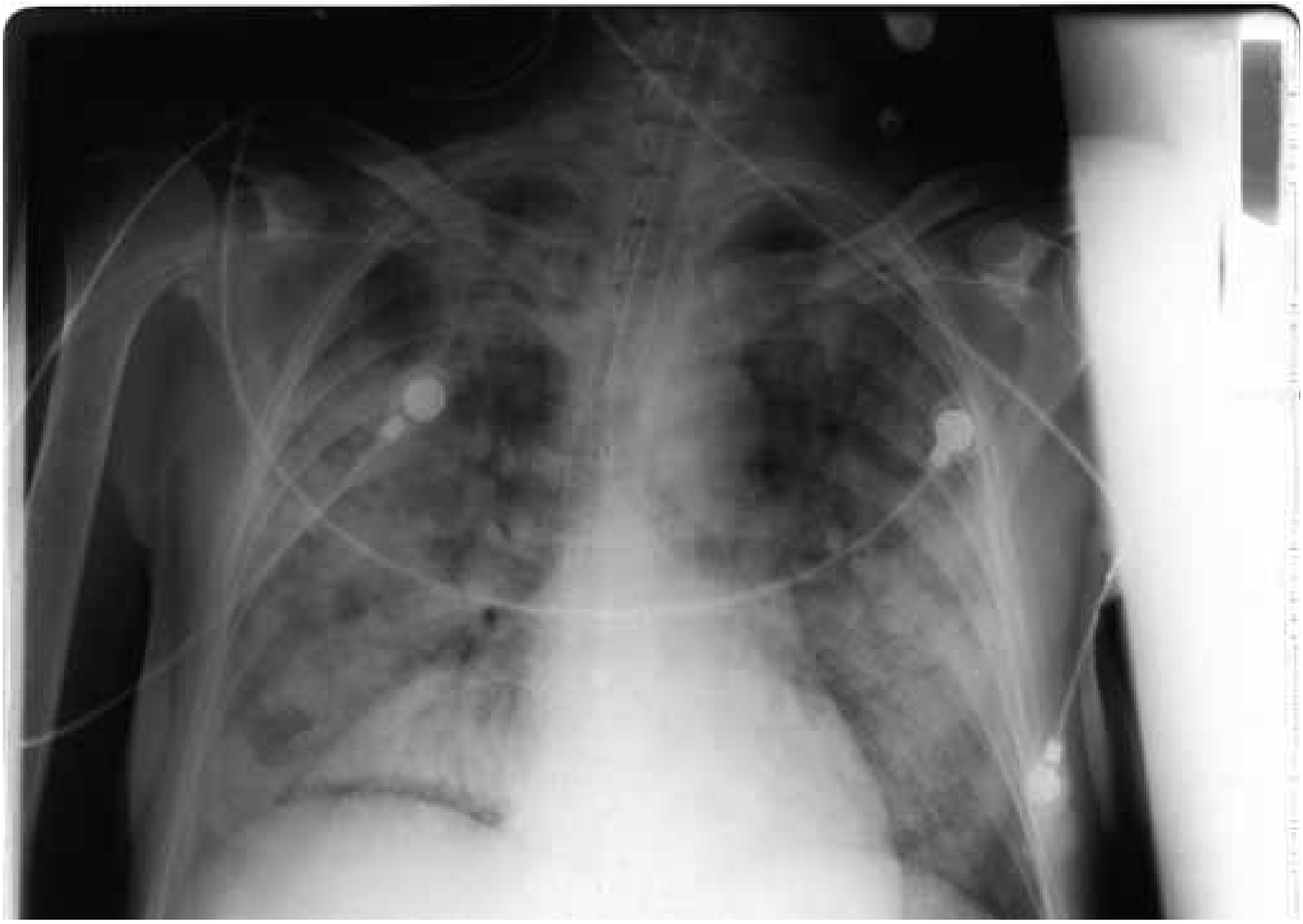

Figure 12: X-ray image showing central venous catheter advanced from the basilic vein with tip lying deeply in the right atrium

4

In the past 20 years, the atrial ECG recording has emerged as an alternative to radiographic monitoring of catheter placement. In comparison to routine chest x-ray monitoring, the intra-atrial electrocardiogramm has an higher accuracy rate for positioning the catheter tip before the point of entry into the atrium (2, Details see Chapters 5 and 7).
Another benefit of switching to the atrial ECG method is that the radiation exposure for the patient and staff is markedly reduced. Particularly in pregnant women and children, the chest x-ray is contraindicated for verification of catheter position.

When used with the appropriate catheter, the intra-atrial ECG can be recorded while the catheter is being advanced. If misplacement occurs, the physician can correct the position right then and there. By contrast, when a chest x-ray is the only method used to check the position, it is often impossible to go back and correct a misplaced catheter.

The economic pressure that hospitals are under these days has led to critical reflection about the routine use of x-rays after placement of a CVC. In Europe, a chest x-ray costs about 40 Euros and, in the USA, up to as much as US$ 150 (3).
Three studies were conducted to investigate whether immediate radiographic monitoring after CVC placement can be obviated by clinical findings or abnormalities noted during CVC placement (3-5). In two publications (3,4) it was found that routine fluoroscopic monitoring is indispensable due to about 15 % misplaced catheters which have been overlooked. The third study conducted by Bailey (5) produced an opposite result and recommend refraining from immediate radiographic monitoring when experienced physicians can place the central venous catheter in a "straightforward" manner (5).

All three studies did show, however, that the clinical findings on their own are not conclusive enough to rule out catheter misplacement.

Constant position monitoring is required to instantly identify problems that might arise during puncture or advancement. The atrial ECG recording is therefore recommendable not only for economical reasons, but because of its high success rate (6).

When weighing the benefits obtained by avoiding catheter misplacement against the health risks of radiation exposure, it is obvious that chest x-rays should be used selectively, and only unless other monitoring methods, such as the intra-atrial ECG, have produced inconclusive findings. When careful procedure is applied or an intra-atrial ECG lead is used, it is no longer necessary to x-ray the patient as a standard procedure for verifying central venous catheter placement.

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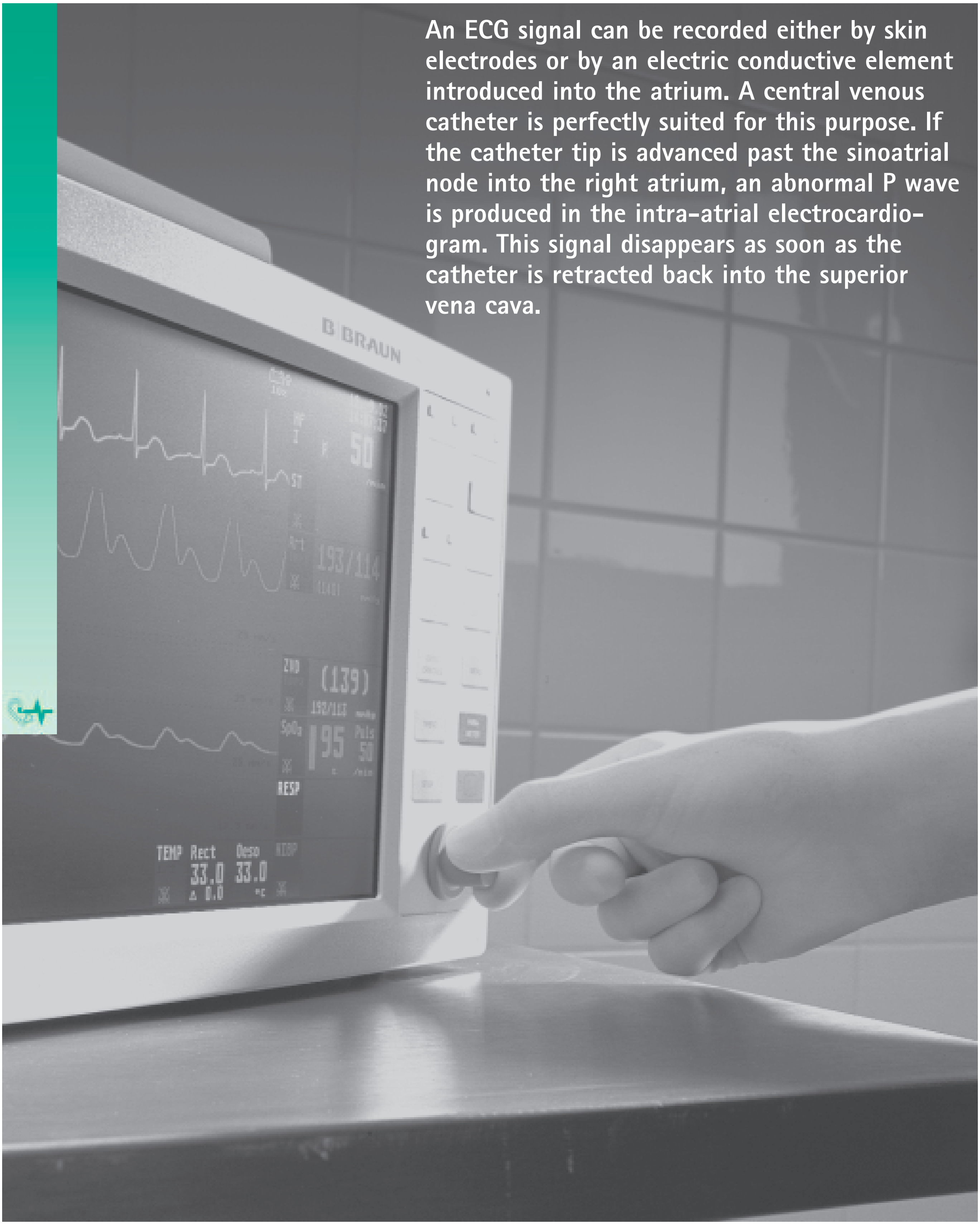
The principle of atrial ECG for tip monitoring

5

An ECG signal can be recorded either by skin electrodes or by an electric conductive element introduced into the atrium. A central venous catheter is perfectly suited for this purpose. If the catheter tip is advanced past the sinoatrial node into the right atrium, an abnormal P wave is produced in the intra-atrial electrocardiogram. This signal disappears as soon as the catheter is retracted back into the superior vena cava.



5

At the turn of the 20th century, the Dutch physician and Nobel laureate, Willem Einthoven developed an instrument that was able to measure the changes in the electrical potential during heart contractions at a higher resolution than was previously possible (1). He used electrodes that were attached to the extremities (right and left arm, left leg) and recorded potential differentials on the skin (see Figure 13). These recordings were called electrocardiograms and produced a characteristic curve comprised of a P wave, QRS complex and a T wave (Figure 14). Each phase corresponds to the conduction of an impulse through the heart. Starting from the sinoatrial node, the electrical impulse that initiates contraction of the heart is conducted from the atria to the ventricles (P wave, approx. 0.1 mV). After it has passed the transition between atrium and ventricle, rapid conduction occurs through both ventricles (QRS complex, brief drop – 0.1 mV, marked rise 0.9 mV, mild drop – 0.3 mV). The T wave represents ventricular repolarisation following the QRS complex; (slow rise and drop 0.3 mV).

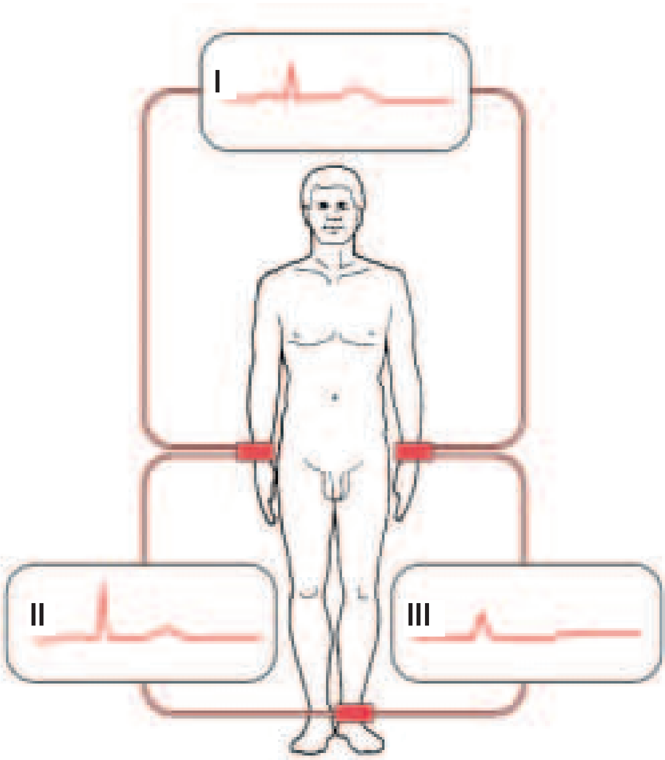


Figure 13: First, second and third lead ECG recording according to Einthoven

Today, the most commonly used skin electrodes for monitoring surgery are in the colours red, black (green) and yellow. They are attached to the right shoulder (red), the left shoulder (black/green) and below the apex of the heart (yellow) (see figure 17 on page 32). The second lead between red and yellow is used for intra-atrial ECG lead.

Figure 14: Typical second lead ECG signal. P, Q, R, S, T denotes distinct phases of the ECG recording.

Back as early as the 40's, doctors working in cardiology were aware of the fact that the recording of the electrical signals direct from the atrium of the heart improved the diagnosis of cardiological diseases such as atrial flutter. For recording the intra-atrial ECG, the doctors used a metallic wire within a catheter. In 1949, Hellerstein and his colleagues reported for the first time that an electrolyte solution within a central venous catheter was suitable for use as an intra-atrial ECG lead (2). In their pioneering research, the authors noted a characteristic change in the P wave when the catheter was advanced over the superior vena cava into the right atrium. In the 70's and 80's years, these reports were given renewed attention and changes in the electrocardiogram were systematically investigated as a function of catheter position (for review see 3).

5 The principle of atrial ECG for tip monitoring

Figure 15 summarizes the different ECG-signals obtained when the catheter is advanced through the superior vena cava into the atrium and backward. When the central venous catheter is advanced from the subclavian vein or jugular vein into the superior vena cava, the intra-atrial lead produces a normal P wave (position ①). As soon as the catheter tip reaches the sinoatrial node, there is an abrupt increase in height of the P wave (position ②). When the tip enters into the right atrium, a height of the P wave potential is reached that is at least half of the subsequent Q peak (position ③). If the tip is advanced further into the atrium, the P wave declines again and becomes slightly negative (position ④). A negative P wave will be noticeable if the catheter tip is inadvertently advanced into the inferior vena cava (position ⑤). The height of the potential and displacement of the P wave give an unmistakable indication of the position of the catheter tip.

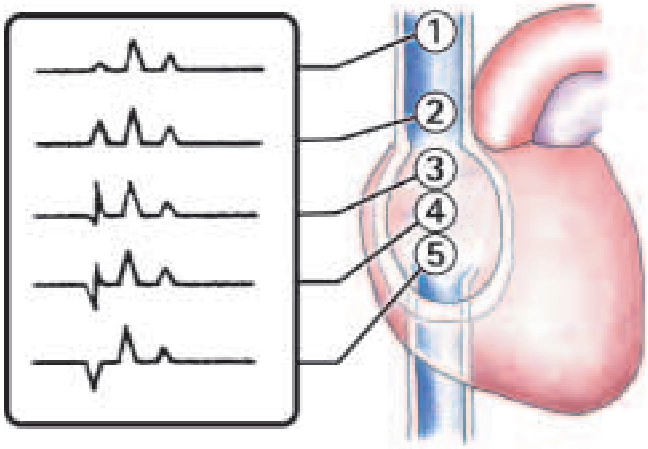
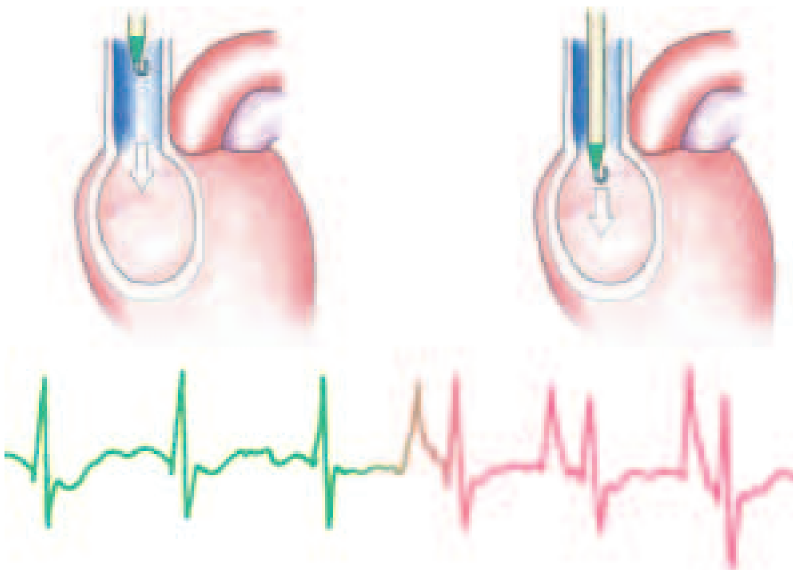
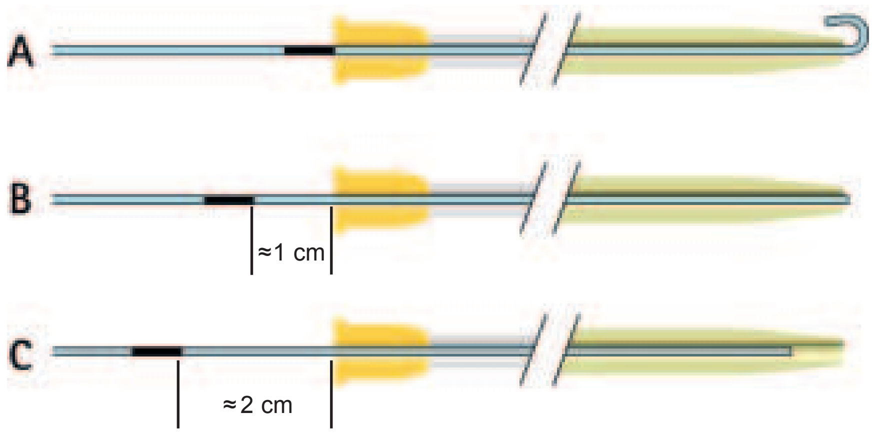


Figure 15: Intra-atrial ECG signal at different catheter tip positions

The catheters used in clinical practice are either filled with electrolyte solution or contain a metallic guidewire in the form of a stylet or a Seldinger wire while it is being advanced. The catheter is advanced up to the right atrium until an elevated P wave is signalled on the intra-atrial lead. Afterwards, the catheter is slowly retracted until the P wave flattens markedly and normalises. When this point is reached, the catheter is retracted another 2 cm to ensure that that the tip is placed in a reliably safe position in the superior vena cava. (For a discussion about correct placement, see Chapter 1). If the access site is on the left side of the patient's body and the targeted catheter position is in the brachiocephalic vein, then the tip must be retracted even further.





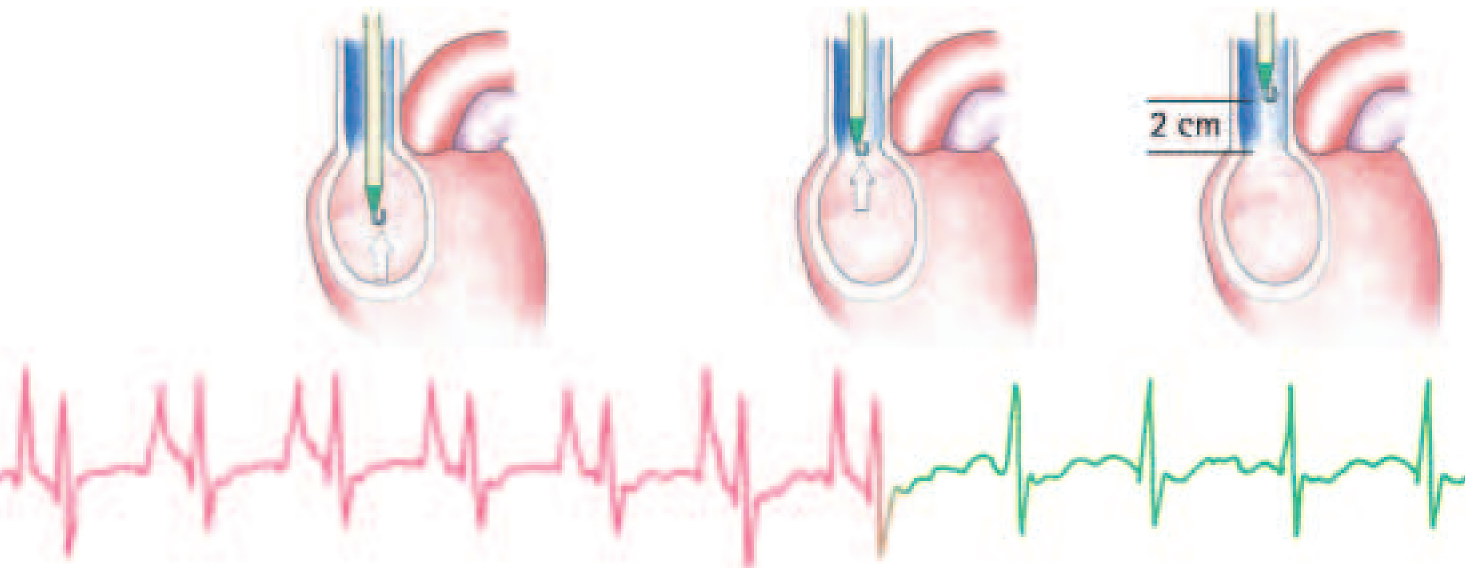
J-tip of guidewire slightly protrudes catheter

Guidewire and catheter tip fits to each other

J-tip of guidewire slightly retracted into catheter

Figure 16: Three acceptable positions of guidewire inside the catheter for sucessful intra-atrial ECG lead.

The catheter sets of B. Braun Melsungen AG are technically fine-tuned to each other so that it does not matter in intra-atrial ECG recording whether the metallic guidewire with J-tip protrudes a little beyond the catheter, is even with it or located slightly behind the catheter tip (Figure 16 A–C). All three configurations will produce an electrocardiogram with an elevated P wave that can be interpreted reliably and accurately as demonstrated by Hansen and colleagues (4). They used the marking on the proximal end of the Seldinger wire to estimate the relation of J-tip and catheter tip and simultaneously recorded the intra-atrial ECG. There was no change of the P-wave height or form visible when the J-tip was advanced beyond or pulled back for about 1 cm into the catheter. When the catheter is advanced over the Seldinger wire and the marking is just barely visible, then the tip of the wire is slightly protruding the catheter tip. The intra-atrial ECG should be recorded when the wire and catheter are in this position. (Figure 16 A)



5 The principle of atrial ECG for tip monitoring

The P wave is triggered when the catheter tip enters into the right atrium. This can be evaluated as arrhythmia, since the normal distribution of the conduction front is changed. Studies have reported that advancing the catheter beyond the sinoatrial node can trigger extrasystoles, sinus tachycardia or atrial flutter, particularly in patients with pre-existing cardiological diseases (5). In all studies that used the technique of placing the intra-atrial lead over the catheter, no patients were adversely affected by arrhythmias. Intra-atrial ECG does not lead to any injury or endangerment of the patient.

To verify the position of the catheter tip by means of intra-atrial ECG is a reliable method, it is easy to learn and can be conducted at minimal cost. Manufacturers like B. Braun Melsungen AG include an electrode cable into their catheter sets, so that the signal can be recorded directly from the metallic guidewire. This electrode cable is connected to a universal adaptor that allows the user to continuously switch back and forth between skin and intra-arterial lead (see following Chapter 6). If a metallic guidewire is not used, devices using electrolyte solution to conduct the ECG signal are available.

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ECG monitoring techniques

6

Recording and transmitting the potential from the right atrium can be accomplished either through a electrolyte solution or a metallic conductor such as a guidewire. The two methods can be regarded as virtually equivalent. The use of a guidewire is technically more simple and thus to be preferred.

It allows immediate detection and correction of catheter misplacement, since the ECG signal is recorded continuously while the catheter is being advanced.

6 ECG monitoring techniques

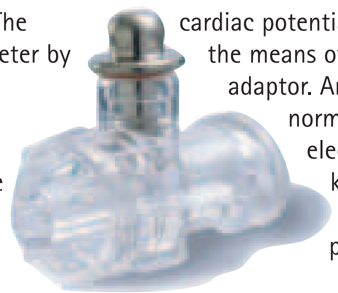
When the central venous catheter is advanced through the vein to the heart, the electrolyte solution in the catheter or a metallic guide stylet can be used to conduct the ECG signal. The commercially available systems, shown in parentheses below, can be divided into two groups:

- Systems using electrolyte solution:
  - Adaptor between infusion line and catheter (Arrow-Johans adaptor)
  - Electrolyte solution-filled syringe with lead cable (B. Braun Alphacard System)

- Sytems using stylet lead:
  - Braunula-type catheter set with J-wire as stylet and lead cable (B. Braun Cavafix Certodyn)
  - Seldinger-type catheter set with Seldinger wire and lead cable (B. Braun Certofix)

An electrical switching device for alternating between the skin lead and intra-atrial lead is required for both the electrolyte-filled and stylet guided lead (exception: Arrow-Johans adaptor). This switching unit is supplied by various manufacturers (B. Braun Certodyn universal adaptor, Tyco/Arbo VIDM-P73 complete cable).

The **Arrow-Johans adaptor** is a small adaptor with a metallic knob which is interposed between an infusion line containing electrolyte solution (usually 0.9 % NaCl) and the hub of the distal catheter lumen. The infused solution creates an electrically conductive connection between the heart and the catheter hub. The cardiac potential spreads along the catheter by the means of the electrolyte solution to the adaptor. An ECG wire with clip which is normally attached to the skin electrode will be clamped to the knob of the adaptor to record the atrial ECG impulses.



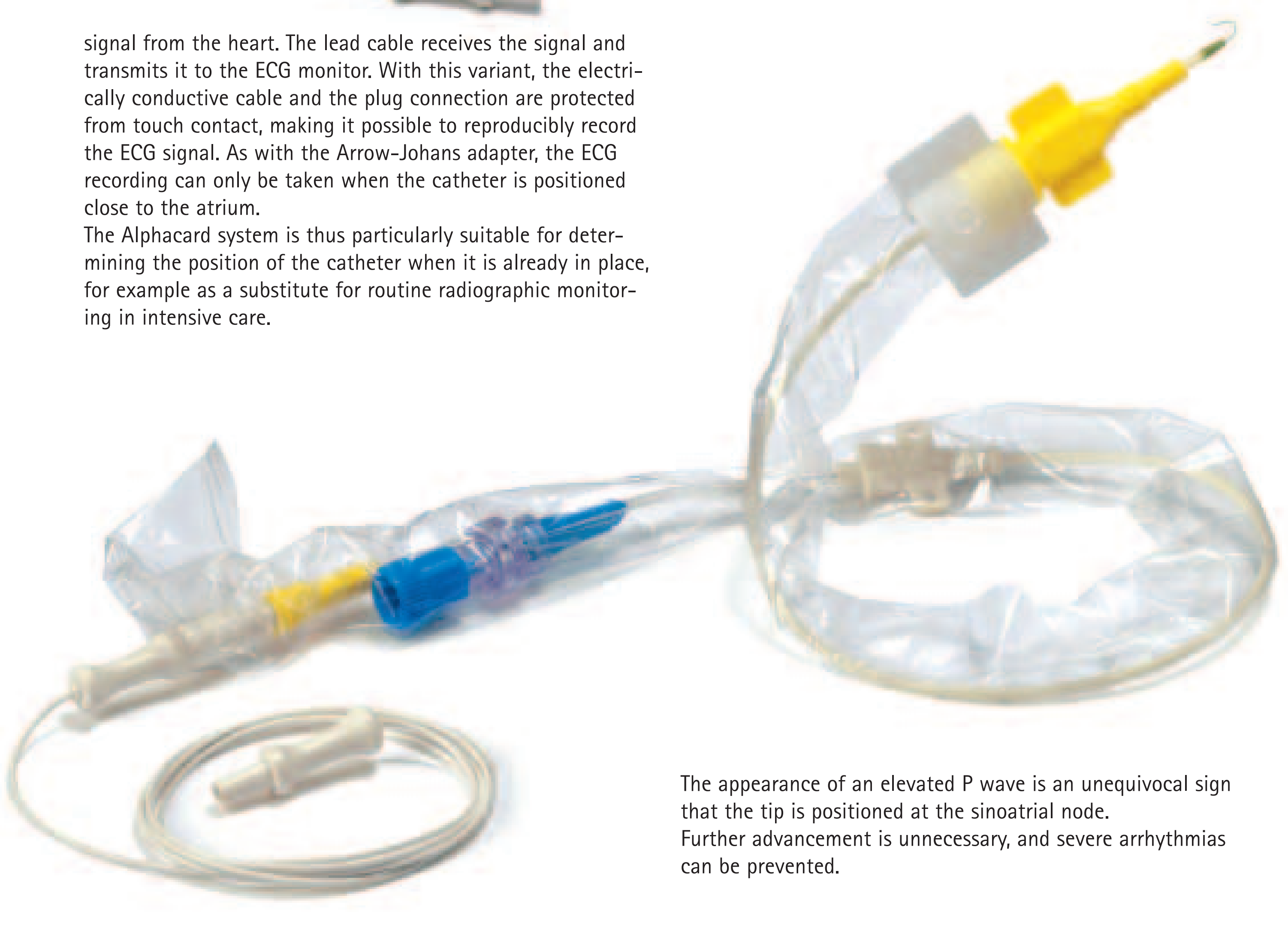
A serious disadvantage of this system is the fact that one can easily touch the knob, which means that if a potential is discharged between the physician and patient it may flow unimpeded into the patient.
It is also important to ensure that there is no electrically conductive connection, e.g. due to moist drapes, between the knob and the patient's skin, since otherwise interference with the atrial ECG will result. Re-plugging of the electrode clip cancels the separation between the sterile puncture area and the patient's unsterile skin and should therefore be viewed critically.
A further drawback of this procedure is that the ECG recording can only be made when the guide stylet (mandrel or Seldinger wire) has already been removed. The catheter should thus already be positioned close in front of the atrium, since further advancement or correction of the catheter position is difficult without guidance.
This system is not recommended for routine use since it has several serious disadvantages.

6

The **Alphacard** system consists of a disposable syringe fitted at its end with an adaptor with Luer Lock and an electrical lead cable. The syringe is filled with 0.9 % NaCl solution and, similarly to the Arrow-Johans adapter, is connected to the hub of the distal catheter lumen. The injected solution conducts the electrical

signal from the heart. The lead cable receives the signal and transmits it to the ECG monitor. With this variant, the electrically conductive cable and the plug connection are protected from touch contact, making it possible to reproducibly record the ECG signal. As with the Arrow-Johans adapter, the ECG recording can only be taken when the catheter is positioned close to the atrium.
The Alphacard system is thus particularly suitable for determining the position of the catheter when it is already in place, for example as a substitute for routine radiographic monitoring in intensive care.

Catheters with a metallic guide stylet offer the greatest user convenience for intra-atrial ECG recording. In catheter sets with J-wire (Cavafix Certodyn), the proximal end of the stylet is fitted with a plug to which a disposable lead cable can be connected. For catheters with Seldinger wire (Certofix), each set contains a disposable lead cable with crocodile clip which can be attached to the free end of the wire (see figure 17 B). Both the stylet and the Seldinger wire conduct the potential from the atrium and onwards through the lead cable to the ECG monitor without risk of interference.
Recording the atrial ECG through the metallic guide stylet greatly simplifies handling, since all the components are present in sterile versions and are easy to connect. One particular advantage is that the atrial ECG can be recorded while advancing the catheter, avoiding inadvertent insertion of the catheter too deeply.



The appearance of an elevated P wave is an unequivocal sign that the tip is positioned at the sinoatrial node.
Further advancement is unnecessary, and severe arrhythmias can be prevented.

6 ECG monitoring techniques

An electrical switching device is always required if the atrial ECG is transmitted through a lead cable and not – as with the Arrow-Johans adaptor – through the electrode cable which is moved. The use of a switching device offers increased electrical safety over the use of the Arrow-Johans adaptor.

Commercially available switching devices make it possible to record the ECG from the heart independently from the type of ECG monitor. The switching device will be connected in between the second lead from the right shoulder (normally red skin electrode, see figure 17). The lead cable coming from the monitor (A) will be fixed to the Universal adaptor which possesses itself a lead cable with clamp (D) which will be fixed to the red skin electrode. During advancement of the catheter with guide wire the disposable lead cable (B) will be clamped to the wire at one side and plugged into the Universal adaptor at the other side. On the top of the Universal adaptor there is a knob to switch the recording between intra-atrial potential and skin potential (C). During advancement of the catheter both recordings can continously been monitored simply by operating the switch.

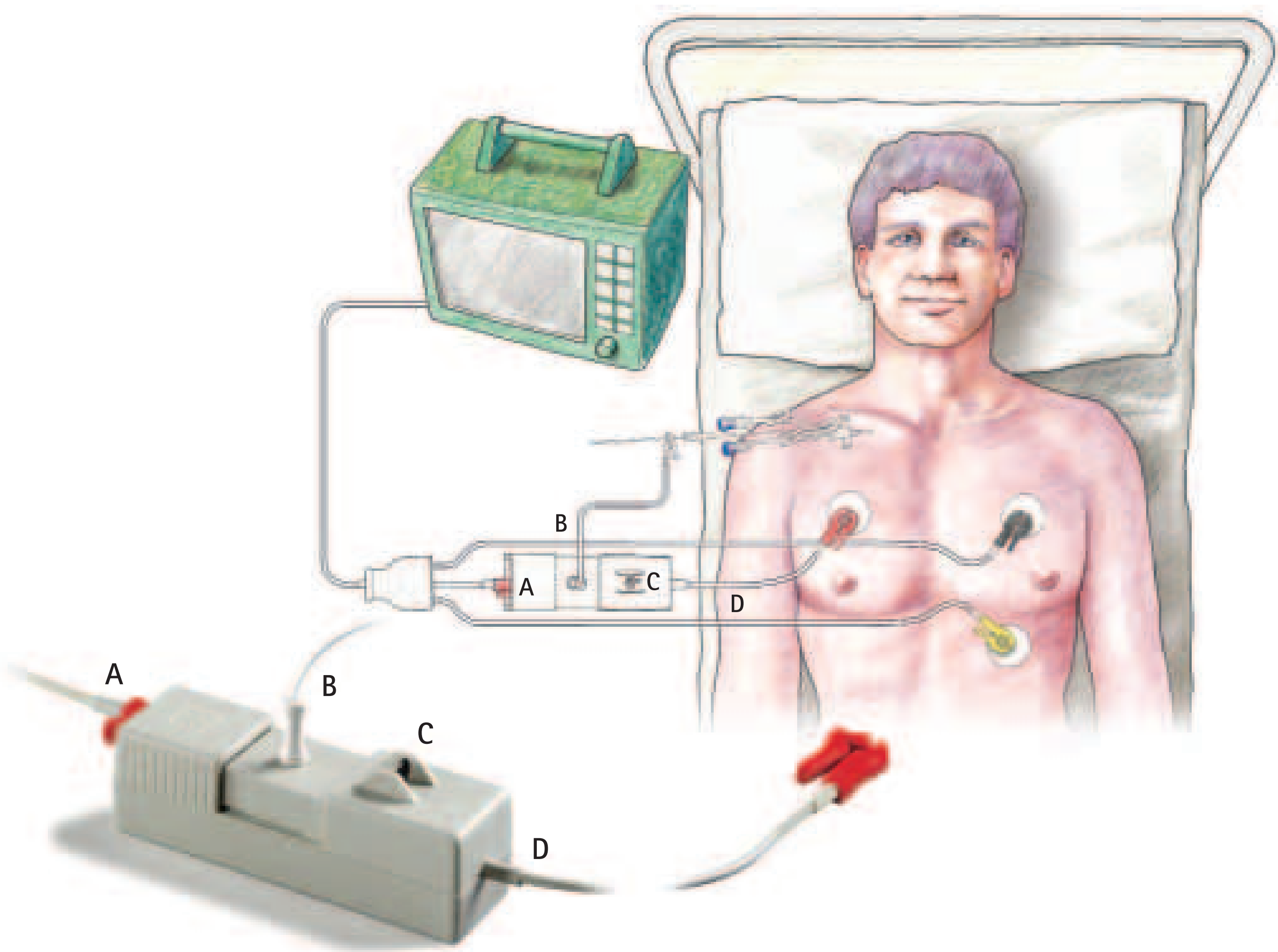


Figure 17: Position of electrodes and cable connections for intra-atrial ECG using a catheter with guide wire and Universal adaptor.

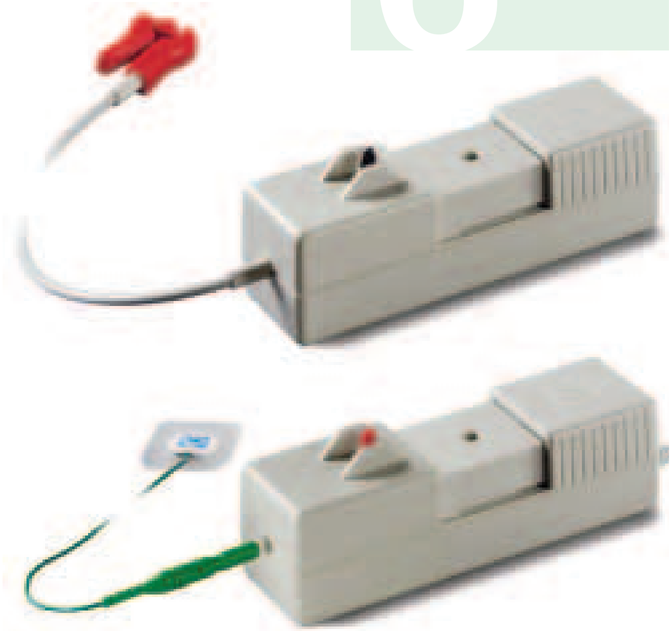


Figure 18: Universal adaptor with lead cable with clamp (adult typ, top) and Universal adaptor with possibility to plug-in disposable skin electrodes (paediatric typ, bottom)

The Certodyn Universal adaptor from B. Braun comes in two versions that differ in their type of lead cable. The first type has a cable with clamp permanently connected to the housing (see figure 18 top), while with the second type offers the possibility to plug-in disposable adhesive electrodes of the kind typically used in the paediatric setting (see figure 18 bottom).

Figure 19: Adult typ Universal adaptor with retracted protection shield to demonstrate the attachment of three different electrode cables

For ECG recording electrode cables with quite different end-pieces are available. To fit to most of these cables the Universal adaptor has different connector sites which are touch protected by a moveable shield which is transparently drawn in figure 19. For example standard cables with clamp (see figure 17 and 19 top) or cables with a end-piece in form of a knob (see figure 19 middle) or even a banana plug (see figure 19 bottom) can be connected to the Universal adaptor.

6 ECG monitoring techniques

From a historical viewpoint, the electrolyte solution and stylet-based systems developed parallel to each other and are generally seen by users as equivalent to intra-atrial ECG recording. So far only few studies have been performed in which recording through the electrolyte solution has been compared with recording by guidewire (1,2). In a clinical study on long-term implanted catheters, the research group of Cheng found no significant differences between the two recording methods. (1). Hansen et al., however, found the ECG signal more interference-free and easier to interpret when the guidewire technique was used as compared to the Arrow-Johans adapter (2). Use of the metallic guidewire to record atrial ECG is recommended for physicians who are still learning the method.

A small study has compared the costs for staff and material of the different procedures for recording atrial ECG (3). Electrolyte solution recording involved 2.9-fold higher costs than the Seldinger wire method. Radiographic chest monitoring even generated 13.6-fold higher costs than the Seldinger wire recording. In summary the ECG lead technology has clear economical and practical benefits in comparison to the fluorographic monitoring of the catheter position.

Verifying the catheter position is an important aspect of central venous catheterisation. The method applied should quickly be performed and technically be simple. ECG recording from the atrium through a metallic guide stylet perfectly meets these demands and should therefore become a routine method in anesthesia.

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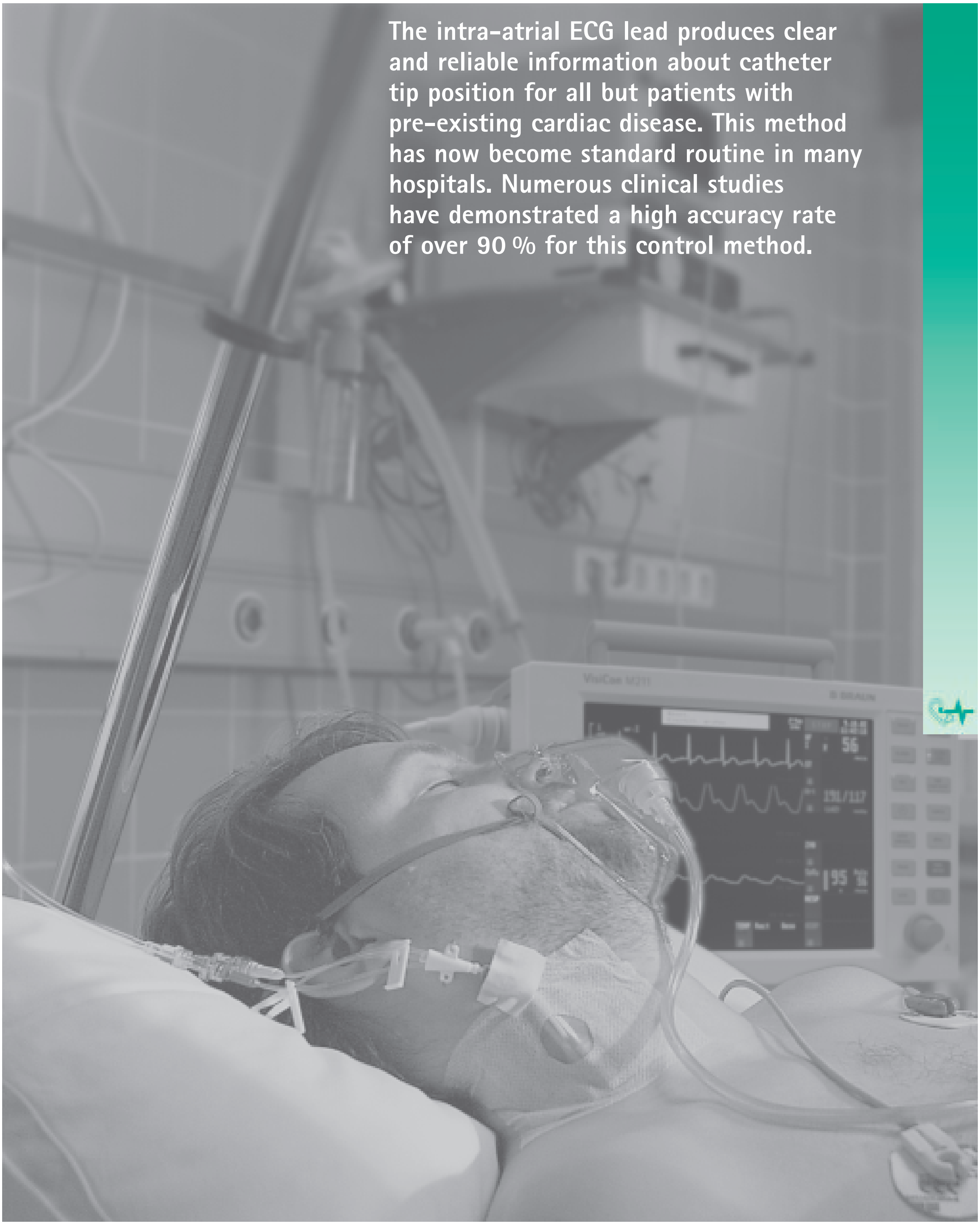
ECG leads – The new standard!

The intra-atrial ECG lead produces clear and reliable information about catheter tip position for all but patients with pre-existing cardiac disease. This method has now become standard routine in many hospitals. Numerous clinical studies have demonstrated a high accuracy rate of over 90 % for this control method.



7 ECG leads – The new standard!

The accuracy of intra-atrial ECG leads in confirming catheter position has been evaluated in numerous studies. In the 1970s, published reports stressed the merits of the method's reproducibility and the conclusiveness of the derived signal (1,2).
In later years, greater importance was placed on the sensitivity of the ECG procedure for detecting incorrect catheter placement. In these studies, intra-atrial ECG was therefore performed parallel to monitoring by chest x-ray and the respective error rates were documented (3–8). Despite the lack of a meta-analysis, it can be concluded that the majority of studies reported correct placement in the vena cava under ECG control. Success rates above 90 % have been reported, distinctly above the 80 % observed with "blind" placement based on anatomical landmarks.

The successful use of intra-atrial ECG lead has been described in adults (3, 5, 6, 8) and children (4, 7). For example Simon and colleagues reported about the clear advantage of this method in comparison to standard x-ray image technique to avoid misplaced catheter in children (4). Figure 20 a shows a typical case of an x-ray image of a central venous catheter which has wrongly been diagnosed to be placed correct. The corresponding intra-atrial ECG recording showed no elevated P wave. At a later time shown in figure 20 b the AP image showed a pleural effusion at the right side due to the misplaced catheter. The authors conclude that the intra-atrial ECG method has a higher sensitivity than fluorographic monitoring.

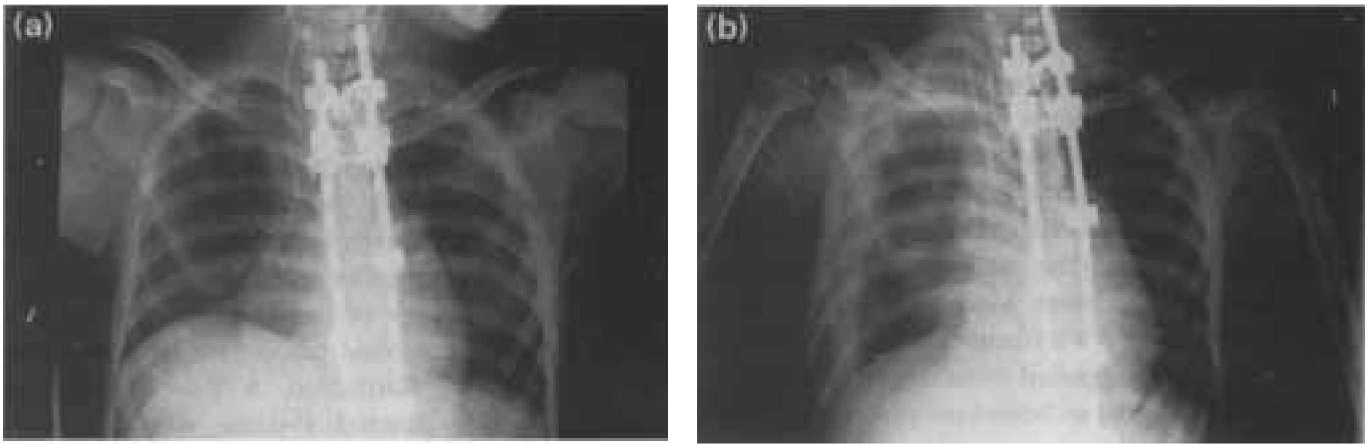


Figure 20: Chest x-ray image of a children with central venous catheter. a) On first image tip position was erroneously diagnosed as correct. b) Second image at a later time shows pleural effusion on right side due to misplaced catheter.

The ECG lead technique is suitable for monitoring the placement of central venous catheters, but also of atrial shunt catheters (5), dialysis catheters (6), tunnelled Broviac catheters (7) and implanted port catheters (8).

For routine use it is important to know the limitations of the intra-atrial ECG method. With the exception of one study by Engelhardt et al. (9), all research in this field suggests that a definite elevation of the P-wave may be absent in patients with pre-existing cardiac diseases. In patients with arrhythmias, atrial fibrillation or implanted pacemakers, the P wave remains unchanged in the intra-arterial ECG lead, even if the catheter is correctly withdrawn from the atrium into the vena cava (10). For such patients without a clear P wave transition, the authors therefore recommend a chest x-ray to verify the catheter position.

So far there is only one single report of catheterisation of the carotid artery with advancement into the right atrium which resulted in the induction of P wave elevation. In this case the ECG signal was interpreted as confirming correct placement although the catheter had been seriously misplaced (11).

7

More frequently described in the literature is the observation that the catheter tip does not reach the sinoatrial node when catheterisation is performed from the left side of the body, and thus no P-wave elevation is induced (10). In these cases, the catheter may be correctly positioned before the atrium, but interpreted as incorrectly positioned because of the absence of any P wave elevation. Choosing the correct catheter length can reliably eliminate these errors. If the height of the P wave does not increase at any time during advancing of the catheter and the catheter length seems to be appropriate according to the recommendations (see Chapter 1) a radiographic control should be performed before any clinical therapy starts.

Results of worldwide research gathered over the last 20 years show that the use of an intra-atrial ECG lead is a reliable and cost-effective method for verifying placement of central venous catheters. Routine chest x-ray after catheter placement is thereby obviated. The use of the ECG lead to verify CVC position has now become a standard technique in anaesthesia and intensive care medicine (12). Physicians who have mastered this technique therefore no longer need to perform chest x-rays to monitor catheter position, since the ECG lead provides sufficiently accurate verification. (12).

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8 Glossary

AP image	X-ray image taken in the anterior-posterior projection
Atrial fibrillation	Rapid irregular twitchings of the cardiac atria
Atrium	Right atrium with connection to the inferior and superior vena cava. Left atrium receiving blood via the Pulmonary vein
Bradycardia	Slowness of the heartbeat, usually defined as a rate under 60 beats per minute
Braunula technique	or Catheter-through-cannula technique: Technique for placement of a central venous catheter utilising a Braunula (needle surrounded by cannula); after retraction of the needle the catheter is advanced through the cannula
Cannula	Short and rigid plastic tube, mainly used as intravenous catheter for short-term use
ECG	Electrocardiogram; electrocardiography
Intra-atrial ECG	Conduction of electrical potential of the heart from inside the right atrium; synonyms: RAECG and IVECG
IVECG	Intravenous electrocardiography: see intra-atrial ECG
Needle	Metal tube with bevel to puncture tissue and blood vessels
RAECG	Right atrial electrocardiography: see intra-atrial ECG
Seldinger technique	or Guidewire technique: Technique for placement of a central venous catheter utilising a metal guidewire which is advanced through the puncture needle or cannula; the central venous catheter is threaded over the wire and after correct placement of the catheter just before the atrium the wire is retracted
Sinoatrial node	The impulse centre at the point of entry to the right atrium
Tachycardia	Rapid beating of the heart with rates over 100 beats per minute
Ventricle	Left and right chamber of the heart
Universal adaptor	Electrical switching device for recording skin and intra-atrial ECG simultaneously

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