Central venous catheters—the inability of ‘intra-atrial ECG’ to prove adequate positioning

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Background. The classic increase in P wave size, known as ‘P-atriale’, is a widely accepted criterion for determination of proper positioning of central venous catheter tips. Recent transoesophageal echocardiography (TOE) studies did not confirm intra-atrial position despite advancing the central venous catheter further than indicated by ECG guidance. We postulate that the pericardial reflection rather than the entry into the right atrium corresponds to the ECG changes. In order to test our hypothesis we sought to determine the anatomical substrate for the electrical changes in an animal study. Subsequently, a modified version of the study was undertaken in man and is also reported.

Methods. In six juvenile pigs the left external jugular vein and right carotid artery were cannulated. A triple-lumen central venous catheter was positioned by ECG guidance using a Seldinger wire as an exploring electrode. The venous and arterial catheters were suture fixed 2 cm beyond the onset of an increase in P wave size. The corresponding anatomical catheter tip position was determined by open exploration of the vessels and the heart. Subsequently the catheter tip position (during advancement) of a pulmonary artery catheter and the corresponding electrical ECG changes were examined in 10 patients during open chest cardiac surgery.

Results. All catheters—arterial and venous, in animals and humans—revealed an increase in size of the P wave as well as the QRS complex. All venous catheters were positioned in the superior vena cava, beyond the pericardial reflection but outside the right atrium. All arterial catheters were positioned in the ascending aorta thus also beyond the pericardial reflection.

Conclusions. The start of an increase in P wave size does not correspond with the entrance of the right atrium. The anatomic equivalent for the electrophysiological changes of the ECG is the pericardial reflection. ECG guidance is unable to distinguish between venous and arterial catheter position.


Keywords: heart, catheterization, central venous; veins, internal jugular; monitoring, electrocardiography

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positioned at the superior vena cava-right atrial (SVC-RA) junction or into the right atrium to ensure optimal blood flow. With regard to temporary or non-tunnelled haemodialysis catheters, the NKF/DOQI recommend positioning the catheter tip at the SVC-RA junction or in the SVC.

In a recent study, we advanced 57 of 110 triple-lumen catheters 1–5 cm beyond the ‘correct’ position as determined by ECG guidance. Only five of these catheter tips were found to be positioned 1 cm distal to the crista terminalis, in the right atrium as confirmed by transoesophageal echocardiography (TOE) (Fig. 1). We hypothesized that the ECG amplitude signal is actually detecting another anatomical structure other than the right atrium. In order to investigate this phenomenon, we positioned 100 triple-lumen CVCs either via the right or the left internal jugular vein by ECG guidance using a fluid column in the middle lumen as a detecting electrode (port opening 2.5 cm from catheter tip). None of these catheters were found to be intra-atrial. Finally, we postulated that the increase in P wave amplitude corresponds to the pericardial reflection. This study was designed to test this hypothesis. Initially, we recorded the course of electrical changes during ECG-guided central venous and arterial catheter insertions in pigs. Then we adapted the study design to a clinical setting where tip position of a pulmonary artery catheter (PAC) and the associated electrical ECG changes were examined in patients during open chest cardiac surgery.

**Materials and methods**

This prospective, observational study was performed at the Institute for Experimental Animal Research and in the Department of Cardiothoracic and Vascular Anaesthesia at the Friedrich-Schiller University of Jena. The study protocols were approved by the local ethics committee.

**Animal study**

Six juvenile female pigs (21–26 kg) received care in compliance with the ‘Guide for the Care and Use of Laboratory Animals’ published by the National Institutes of Health.

Each pig was pre-medicated with an i.m. injection of ketamine 20 mg kg⁻¹, 150 U hyaluronidase, and atropine 0.04 mg kg⁻¹. Anaesthesia was induced with an i.v. injection of propofol 2 mg kg⁻¹ and maintained with a continuous infusion of midazolam 10–16 μg kg⁻¹ min⁻¹, fentanyl 0.2–0.4 μg kg⁻¹ min⁻¹, and pancuronium 6–10 μg kg⁻¹ min⁻¹. After tracheal intubation, all animals were mechanically ventilated by a volume-controlled ventilator (Servo Ventilator 900 C; Siemens AG Medical Solutions, Erlangen, Germany). A triple-lumen polyurethane CVC was introduced (Certofix Trio SB 730, length 30 cm, 7 French) into the left external jugular vein using the Seldinger technique. The cannulation kit included a connection cable with a crocodile clip for connecting the guide wire to a Certodyn universal adapter (both B. Braun Melsungen AG, Melsungen, Germany). The guide wire was used as a unipolar electrode. A black marking on the proximal end of the guide wire indicated the point at which the tip of the wire is just level with the port of the distal catheter lumen. A connection cable was clamped to the guide wire at the marked position in order to connect it with an adapter that allows the operator to switch from a surface to an intravascular ECG. The skin reference electrodes were placed on the left extremities. Using continuous ECG guidance, the catheter was advanced together with the guide wire 2 cm beyond a marked increase in P wave size where the catheter was eventually fixed by sutures. The intravascular baseline ECG and an ECG after the first onset of an increase in P wave size were followed on the ECG-monitor (Cardiocap II, Datex, Helsinki, Finland) and recorded on a paper strip (Sony Model UP-860 CE video graphic printer, Sony Deutschland, Köln, Germany). Markings on the catheter allowed measurement of the depth of insertion. A second catheter was placed intra-arterially through the right carotid artery followed by the same ECG guidance procedure (Fig. 2).

![Fig 1](http://bja.oxfordjournals.org/)

**Fig 1** The echocardiographic junction between SVC and RA was defined as the superior edge (*) of the crista terminalis (white arrow). The catheter tip (black-white arrow) was usually identified as two closely spaced, parallel, bright echodense lines surrounding the darker fluid-filled lumen. Rapid flush of cephalosporin 2 g in 20 ml normal saline was used to identify the distal end of the CVC by TOE. The microbubbles of the solution act as contrast medium. (LA, left atrium; RPA, right pulmonary artery.)

![Fig 2](http://bja.oxfordjournals.org/)

**Fig 2** Intravascular baseline ECG and an ECG after the first onset of an increase in P wave size in one of the pigs (P marked). The upper series belongs to the intra-arterial catheter (RCA, right carotid artery). The lower series was recorded from the i.v. catheter (LEJV, left external jugular vein).
Fig 3 A left-sided thoracotomy was performed followed by opening of the veins, the aorta and the right atrium. Catheter tip positions were documented. This arrow points at the pericardial reflection, the lower catheter tip is positioned in the ascending aorta (AA), the venous catheter tip ends in the SVC (†).

To confirm the corresponding anatomical positions of both catheters the animals were killed by rapid injection of potassium chloride 7.45%. A left-sided thoracotomy was performed followed by opening of the veins, the aorta and the right atrium (Fig. 3). Catheter tip position was documented.

In order to prevent an observer bias, each ECG recording was analysed without knowledge of the corresponding anatomical position by a blinded investigator.

**Human observational study**

From July to September 2003, 10 male patients, undergoing open chest cardiac surgery with the need for a PAC and TOE monitoring, were enrolled into the study. Exclusion criteria were absence of sinus rhythm, previous open heart surgery, contraindication to TOE or missing TOE study after CVC placement, failure of the Alphacard®-system and refusal to sign written consent. Patient characteristics recorded were age (49–69 yr, median 60.5), sex, BMI (23–33.7, median 26.9), and type of surgery.

Following induction of general anaesthesia with i.v. midazolam (0.15–0.2 mg kg⁻¹) and sufentanil (1.5–2 µg kg⁻¹) on inspired oxygen 100%, tracheal intubation was facilitated with pancuronium (0.08–0.1 mg kg⁻¹). Anaesthesia was maintained with sufentanil 25–50 µg h⁻¹, and sevoflurane and oxygen in air (FiO₂=0.4). The right or left innominate vein, were then cannulated. The vein was punctured using a sterile Seldinger technique. The guide wire was advanced and a PAC (CCO/SvO₂, 744H 7.5 F, Edwards Lifescience, Munich, Germany) was inserted through a percutaneous sheath introducer (8.5 F, SI-09875-E, Arrow Lifescience, Munich, Germany) to the PAC. The fibre-optic light channel emits a red light at the catheter tip. Following sternotomy but before the opening of the pericardial sac, the surgeon freed the innominate vein from surrounding connective tissue. Under continuous ECG-guidance the PAC was advanced until the surgeon noted the balloon or the red light at the pericardial reflection. At this site a second intravascular ECG was recorded. The extrathoracic position was confirmed additionally by TOE. The surgeon was blinded with respect to the ECG.

**Statistics**

Statistical analysis was performed using SPSS 11.0 (SPSS GmbH Software, Munich, Germany). Data were expressed as mean and 25th and 75th percentiles. Comparison of the two P wave amplitudes was performed using Wilcoxon Signed Ranks test. P values less than 0.05 were considered significant.

**Results**

**Animal study**

In all six pigs a significant increase in P wave amplitude was observed in venous (P<0.05) and arterial (P<0.05) catheters (Table 1). All venous catheter tips were found to be placed distal to the pericardial reflection but outside the right atrium. All arterial catheter tips were positioned distal to the pericardial reflection in the ascending aorta.
ment outside the heart in the venous system. The P wave size becomes normal ensures correct placement. It is generally accepted that an increase in P wave amplitude occurs as the catheter enters the right atrium. Therefore, it monitored. It is generally accepted that an increase in P wave amplitude.

For obvious reasons, ECG guidance of arterially placed CVCs has never been studied in humans. A guide wire or catheter serves as the exploring electrode and usually Einthoven lead II is monitored. Observations in humans

In all 10 male patients a significant increase in P wave amplitude was noted at the pericardial reflection (Table 2). TOE examination confirmed the extra-atrial catheter tip position of all 10 catheters at the site of the first increase in P wave amplitude.

Discussion

Right atrial electrocardiography is established as a method to determine catheter tip position, but almost all previous studies are based on right-, not left-sided catheterization, if information on cannulation site is provided at all. For obvious reasons, ECG guidance of arterially placed CVCs has never been studied in humans. A guide wire or a saline-filled catheter serves as the exploring electrocardiographic electrode and usually Einthoven lead II is monitored. It is generally accepted that an increase in P wave size occurs as the catheter enters the right atrium. Therefore, it is said that withdrawing the catheter up to 3 cm from the point where the P wave size becomes normal ensures correct placement outside the heart in the venous system. The manufacturer of the Certodyn® adapter even claims on his teaching link (http://www.cvc-partner.com/en.html?/en/main.html) that the elimination of an elevated P wave is a clear signal of the catheter’s position prior the entrance to the right atrium.

In a previous study we inserted 50 central venous triple-lumen catheters either via the right or left jugular vein. Catheter tip position was ascertained by ECG guidance. Method A: a Seldinger guide wire in the distal lumen served as an exploring electrode, the respective insertion depth was recorded. Method B: the middle lumen (port opening 2.5 cm from catheter tip, thus the catheter was advanced more towards the atrium) filled with a 10% saline fluid column served as the exploring electrode, and the insertion depth was recorded again. On average, the catheters were advanced by the expected 2 (SD 0.3) cm using Method B beyond the initial insertion by Method A. We therefore concluded that both methods detected the same structure. Confirmed by TOE all 100 CVCs were finally correctly positioned in the SVC. On postoperative CXR not a single catheter abutted the lateral wall of the SVC. As catheters placed by Method B did not result in intra-atrial CVC tip position, the first increase in P wave amplitude does correspond to a structure in the SVC. We hypothesized that a second anatomical structure needs to be responsible for the electrocardiographic phenomenon, most likely the pericardial reflection. The adjacent atrial wall tissue is thought to be responsible for the increase in voltage of the ‘P-atriale’.

We postulated that the pericardium might serve as an electrical isolator and is responsible for the phenomenon observed. Three different mechanisms contribute to an increase in P wave amplitude

The far field effect of electromagnetic fields.

- This entails an increase in amplitude inversely related to the source distance (in case of non-dipolar source configurations at even higher order). This at least might explain an obvious rise in amplitude when advancing the catheter tip towards the central vascular compartment.

- Near field effects of electromagnetic fields: these come into action when arriving at the pericardial reflection. Slight manipulations if the catheter tip significantly alter source-to-sensor geometry because of the nearby cranio-caudal right atrial excitation wave front.

- Alteration of volume conductor resistivity at the pericardial reflection: the resistivity of connective tissue is three times greater than that of blood. This bundles isopotential lines at the entrance of the cardiac compartment.

Calculations of isopotential lines accounting for volume conductor effects of pericardial resistivity as well as establishing precise distance-to-amplitude relationships are objectives of our ongoing research in this field. This will clarify the

Table 1

Results from the six pigs studied. P1, baseline intravascular P wave amplitude; P2, increased P wave amplitude at pericardial reflection; SD, standard deviation (**P, Wilcoxon Signed Ranks test)

<table>
<thead>
<tr>
<th>Pig</th>
<th>P1, venous (mV)</th>
<th>P2, venous (mV)</th>
<th>P1, arterial (mV)</th>
<th>P2, arterial (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>0.35</td>
<td>0.18</td>
<td>0.59</td>
</tr>
<tr>
<td>2</td>
<td>0.18</td>
<td>0.55</td>
<td>0.18</td>
<td>0.36</td>
</tr>
<tr>
<td>3</td>
<td>0.18</td>
<td>0.71</td>
<td>0.18</td>
<td>0.59</td>
</tr>
<tr>
<td>4</td>
<td>0.14</td>
<td>0.43</td>
<td>0.14</td>
<td>0.43</td>
</tr>
<tr>
<td>5</td>
<td>0.25</td>
<td>0.63</td>
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<td>0.67</td>
</tr>
<tr>
<td>6</td>
<td>0.17</td>
<td>0.83</td>
<td>0.17</td>
<td>0.67</td>
</tr>
</tbody>
</table>

25th Percentile: 0.16, 0.41, 0.16, 0.34
Median: 0.18, 0.59, 0.18, 0.51
75th Percentile: 0.20, 0.74, 0.22, 0.67

Table 2

Results from the ten patients studied. P1, baseline intravascular P wave amplitude; P2, increased P wave amplitude at pericardial reflection. All catheter tips were seen in the SVC by TOE (**P, Wilcoxon Signed Ranks test)

<table>
<thead>
<tr>
<th>Patient</th>
<th>P1, venous (mV)</th>
<th>P2, venous (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.18</td>
<td>0.27</td>
</tr>
<tr>
<td>2</td>
<td>0.36</td>
<td>0.55</td>
</tr>
<tr>
<td>3</td>
<td>0.36</td>
<td>0.91</td>
</tr>
<tr>
<td>4</td>
<td>0.36</td>
<td>0.91</td>
</tr>
<tr>
<td>5</td>
<td>0.14</td>
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</tr>
<tr>
<td>6</td>
<td>0.18</td>
<td>0.73</td>
</tr>
<tr>
<td>7</td>
<td>0.18</td>
<td>0.55</td>
</tr>
<tr>
<td>8</td>
<td>0.27</td>
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<tr>
<td>9</td>
<td>0.18</td>
<td>0.45</td>
</tr>
<tr>
<td>10</td>
<td>0.18</td>
<td>0.55</td>
</tr>
</tbody>
</table>

25th Percentile: 0.18, 0.41
Median: 0.18, 0.55
75th Percentile: 0.36, 0.77

*P < 0.028

*P < 0.005
different contributions of these mechanisms to the observed P wave phenomenon.

In all animals the P wave amplitude started to increase significantly outside the heart at the pericardial reflection. Interestingly, this phenomenon was observed in venous as well as arterial intravascular ECGs.

This phenomenon was also confirmed for the SVC in all humans studied. Therefore, we conclude that traditionally ECG-guided catheter tips are located outside the pericardial sac. The site of the pericardial reflection is not identical with the entrance of the right atrium, but crosses the SVC more cephalad.17

Hence, cardiac tamponade caused by perforation of the atrial wall or the SVC below the pericardial reflection can be prevented by ECG guidance, provided catheter migration is averted. Except for cubital CVCs,18 it is more common for CVCs to move back into the great veins than forward into the atrium, if displaced.19

The potential risk of vessel perforation might be minimized by positioning the catheter with its tip parallel to the SVC.20 most easily accomplished with right-sided placements. Because the innominate vein meets the SVC at an angle of almost 90° left-sided catheters passing from the innominate vein into the SVC may impinge on the SVC at an acute angle.21

A review of reported cases and in vitro data suggest, that catheter tips with an impingement angle to the SVC of higher than 40° require repositioning.22 We believe that an unsatisfactory tip position above the heart should not be accepted purely to satisfy FDA guidelines.4 Whenever the catheter negotiates a sharp bend, the catheter must be passed a reasonable distance beyond the bend such that the axes of the catheter and vein are aligned. The low SVC-upper RA is a suitable tip site from any access point in the upper body. Unlike some authors, we believe that the left innominate vein is not a suitable site for the tip of left-sided catheters, especially in patients depending on vasoactive substances and patients with high-flow catheters such as those for haemodialysis.20

In left-sided CVCs X-ray control is strongly recommended because ECG guidance is unable to give any information on the impingement angle.6

To avoid withdrawal of an impinging catheter into the left innominate vein, associated with an increased rate of thrombosis, in our opinion left-sided catheters should always be inserted deeper than indicated by P wave size alteration.7 23

A further incorrect assumption is that a ‘P-atriale’ is only associated with i.v./right atrial positioning. To clear up with this misconception, we recorded the ECG in the ascending aorta of six pigs. Again the P wave amplitude increased significantly below the site of pericardial reflection crossing the ascending aorta. For obvious reasons, this experiment could not be transferred to humans. However, the results are in keeping with our own observations during inadvertent carotid artery cannulations. Indeed, inadvertent arterial catheterization and advancement of the catheter caused a ‘normal’ increase in P wave size not suggestive of arterial misplacement.

References

8 National Institutes of Health. Guide for the Care and Use of Laboratory Animals. 1985; 85: 23


