The placement of central venous catheters in hemodialysis: role of the endocavitary electrocardiographic trace. Case reports and literature review

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ABSTRACT: At present, the placement of a central venous catheter is becoming more and more a routine procedure nevertheless it involves different operators in fields such as oncology, nutrition, nephrology, and emergency medicine. It is well known that complications in the placement of CVC may occur in up to 20% of cases. One fifth of the catheters may result to be misplaced either in the internal omolateral jugular vein or in the innominate vein or in the controlateral brachiocephalic veins and usually a chest radiogram is necessary to evaluate its location. On the basis of 10 years of experience including more than 1,000 CVC placements, we now believe that endocavitary electrocardiography EC-ECG, initially studied and applied by Dr. Serafini, constitutes the best technique, more secure and more comfortable for the patient, to verify the position of the tip of a CVC. The technique EC-ECG, very simple and secure, utilizes the CVC as an endocavitary electrode. This is connected to a standard electrocardiograph, the same one to which the patient is connected during the placement of the CVC, and provides, in derivation V_1 or D_3, an electrocardiographic pattern extremely sensitive to the position of the catheter tip.

From December 1991 to December 2000, this technique has been used successfully in our departments of nephrology and applied to 1,139 patients that needed a CVC for hemodialysis. EC-ECG and a standard chest radiogram controlled the first 100 CVC we placed and in the other 1,039 cases, the control was made by EC-ECG alone. Only in 31 patients (2.7% of all cases), due to arrhythmia, the technique EC-ECG was not utilized. According to our experience, the procedure EC-ECG is an extremely reliable technique, sensitive and specific in 100% of cases, easy for the operator to perform, comfortable for patient. It doesn't need additional time to be performed and eliminates the need of taking a chest radiogram that up to now was considered indispensable in order to verify the position of the catheter tip. In this manner serious complications such as pneumothorax, and haemothorax that can complicate the placement of a CVC can also be avoided.

Based on our experience, we now believe that this technique, that today has a large application in nephrology, oncology, clinical nutrition and in various branches of general medicine whenever the placement of a CVC is required, should be considered as a possible new guide line in controlling the placement of a CVC together with a chest X-ray when it is necessary. (The Journal of Vascular Access 2001; 2: 80-88)

KEY WORDS: *Acute renal failure, Endocavitary electrocardiography, Internal jugular vein, Peritoneal dialysis, Subclavian vein, Surgical vascular access*

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INTRODUCTION

Hemodialysis is more and more necessary as an emergency procedure. The patient, in the majority of cases, has a severe clinical picture and needs the rapid preparation of a vascular access for hemodialysis.
Very often, in 50% of cases, as results from the case histories presented here, the patient is affected by acute renal failure (ARF) and needs a quick solution for a vascular access that, however, can be utilized over a long period.
The catheterization of central veins was used for the first time in hemodialysis by Erben in 1969 (1). Later, this technique became well known especially thanks to Uldall (2), and at present is the principal temporary vascular access having supplanted the external artero-venous shunt of Quinton-Scribner (3) in emergency conditions. Furthermore, in an increasing number of patients it constitutes a long-term or even permanent vascular access in substitution of the artero-venous fistula (FAV) native or prothesic. Hemodialysis catheters may be inserted in jugular, subclavian or femoral veins. Because of its superficial position, just medial to the femoral artery in the groin, the femoral vein is easy to cannulate. The femoral vein site, being difficult to care for and limiting ambulation, is usually reserved for temporary catheters. Moreover, due to the high prevalence of infections (4) and phlebothrombosis (5), it was almost completely abandoned and only recently reconsidered.
Compared to the femoral approach, the subclavian access is more comfortable for patients who may then easily ambulate, and the catheter has an extended functional life. On the other hand, subclavian vein cannulation is associated, even in skilled hands, with more insertion complications than a femoral access.
Subclavian vein stenosis or thrombosis is common in patients who have undergone temporary catheterization for hemodialysis and might be difficult to diagnose clinically (6). Some time ago, we abandoned the use of external arterovenous shunt in the intent to save the peripheral veins in order to construct a definitive vascular access; the catheterization of the subclavian vein was also abandoned because of a high risk of thrombosis and stenosis of the vein itself that often compromised definitively the creation of an homolateral FAV.
Percutaneous jugular vein cannulation is technically more difficult because the anatomical landmarks are less prominent than with subclavian vein catheterization. By contrast, jugular vein cannulation does not damage the proximal venous drainage of the arms.
With standard insertion procedures, percutaneous puncture of the jugular vein rarely entails life-threatening complications, but the failure rate ranges from 11.7 to 17.6% (7). In addition to the skill of the operator, the successful placement of catheters using landmark localization depends upon multiple factors, including the normal anatomic location of the vein, venous patency and venous caliber. It is often very difficult to have access to the internal jugular veins using landmark technique in patients who are obese or have swelling of the neck, or who have had surgery or multiple prior placements of venous catheters in the neck, which may have distorted the anatomy of the target vein.
Ultrasound has been used to guide cannulation of central veins for over a decade (8). The use of real time ultrasound for insertion of temporary and long-term hemodialysis catheters has been reported in multiple studies and its usefulness compared with the traditional landmark technique (9-11). Ultrasound permits visualization of the vessels and can be used to directly guide venous cannulation. Since Denys (12) and colleagues in 1993 reported a 100% success rate with ultrasound guidance of jugular vein catheterization, we have, as a matter of routine, used for venous catheter placement real-time ultrasound guidance.
Recently, we have also performed the cannulation of the jugular vein previous a simple echotomographic control of the vessels of the neck to verify the total patency of the vein and the absence of anomalies in the big vessels of the neck, in accordance with literature (12, 13).
In order to verify the correct position of the catheters, normally a fluoroscopic control is advisable during the placement itself and a chest X-ray at the end of the procedure.
We now believe that a better way of detecting the exact position of the catheter tip is by using the technique of right atrial electrocardiography (EC-ECG), first described by Serafini in 1985 (14, 15).
The aim of this study is to present our results obtained applying the EC-ECG tecnique in the positioning of semi-rigid, un-cuffed catheters and soft-cuffed catheters for acute and chronic patients in hemodialysis treatment.
This method has been used in a significant number of uremic patients. Furthermore, in literature, there are no other publications reporting this technique applied with success in a large number of cases, if not in pediatrics (16).
Moreover, considering that this technique has not yet been validated as a method in compliance with the new guide lines, the second aim of this paper is to describe this method in the intent that it will in

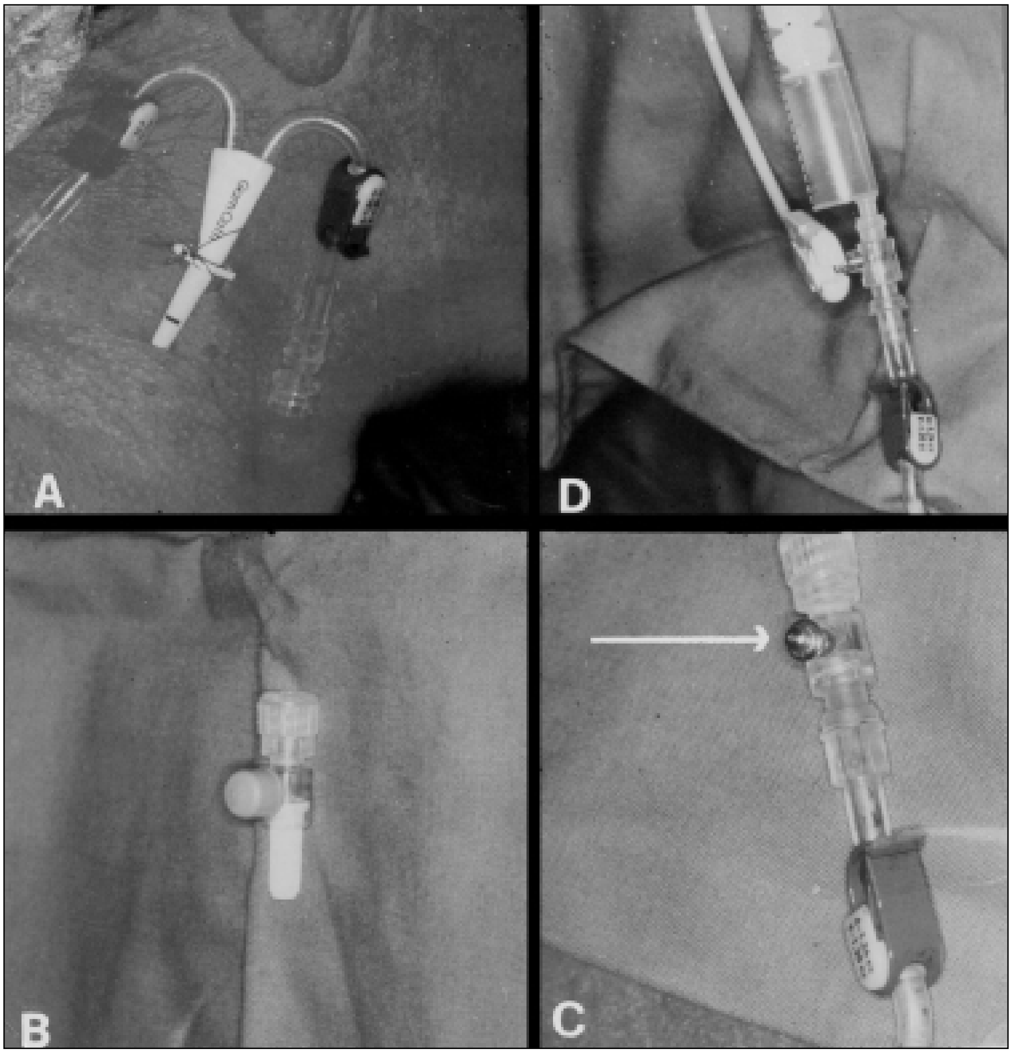

Fig. 1 - ***In this photograph is represented the whole procedure of electrocardiographic control of the tip of the central venous catheter for hemodialysis (CVC). In photogram A, top left, is shown a CVC for hemodialysis just placed at the level of the right jugular vein. In photogram B, bottom left, can be seen the disposable device (made by Arrow) that consents an easy connection between CVC and the electrocardiograph connected beforehand to the patient in position V_1 or D_3. Photogram C, bottom right, shows the connection between the disposable device and the venous branch of the catheter. The disposable device has a metallic tip (see arrow) that easily permits the conjunction with the electrocardiograph. Photogram D, top right, shows the connection between CVC, disposable device joined to the precordial electrode and the syringe filled with a physiological solution. In absence of the disposable system, which is more expensive, the connection can be easily made with the use of a syringe joined to a needle that perforates the little top that closes the venous branch of the cannula.***

future be considered as a possible, new guide line for vascular access, temporary, long-term or permanent, in hemodialysis.

PATIENTS AND METHODS

From 1991 to December 2000 we have successfully adopted this technique in 1,139 patients, 672 M and 467 F, with average age of 67.71±15.57 yrs. In 975 (85.60%) pts, hygroscopic polyurethane, 15-20 cm long, 11F, dual-lumen catheter has been used and in 164 cases (14.39%), a tunnelled permanent catheter of various lengths has been used. In 578 pts out of 1,139 (50.76%) the catheter was used for acute renal failure; in 290 (25.46%) for clotting of the surgical vascular access and in 107 pts (9.39%) for temporary or definitive dropout from peritoneal dialysis. In 164 cases (14.39%) a permanent catheter for exhaustion of vessels has been used. The central vascular access was obtained by transcutaneous puncture of the right IJV in the Sedillot triangle. After transcutaneous puncture of the vessel, the catheter was pushed to its proximal end and washed with isotonic solution. In order to establish promptly the exact position of the catheter tip, an EC-ECG registration was performed. The catheter itself, filled with an isotonic solution, NaCl 0.9%, and connected to the precordial lead (V_1 or D_3) of an electrocardiograph applied to the patient, was used as an endocavitary electrode. The catheter can be attached to the precordial electrode by means of a syringe filled with a physiological solution that perforates the rubber tap of the venous access of the cannula. In alternative it is possible to use a special disposable device (Arrow, International Inc., Bernville - USA) that allows the connection of the venous access to the syringe filled with physiologic solution. This device has a special tip that permits an easy and simple connection with the precordial electrode. Figure 1 shows in detail the whole procedure. In the last 2 years we have applied the tech-

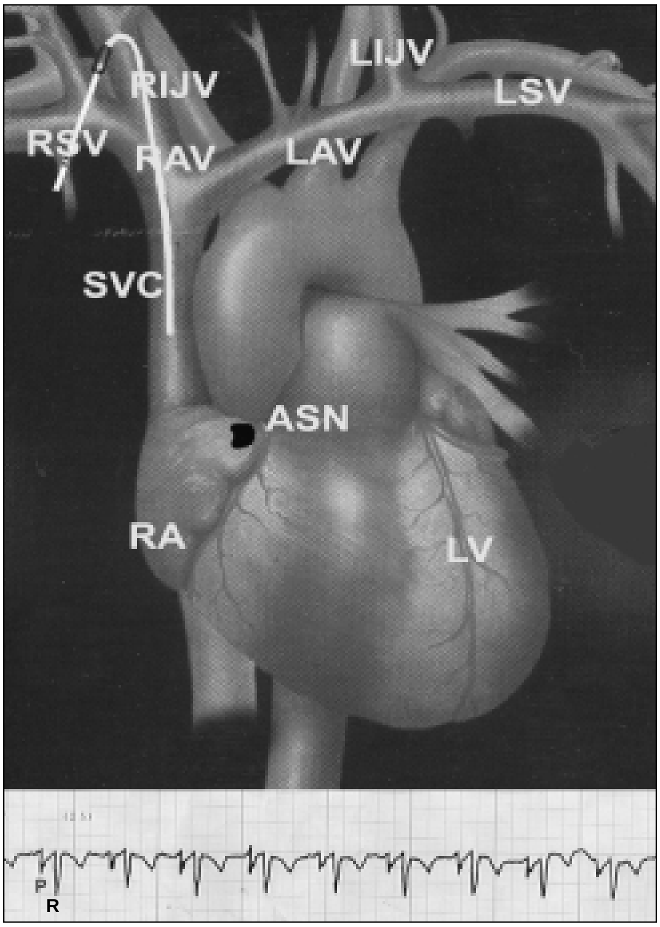

Fig. 2 - ***Schematic image representing the right atrium (RA), the sinoatrial node (ASN), the left ventricle (LV), the superior vena cava (SVC), the right subclavian vein (RSV) and the left subclavian vein (LSV), the right internal jugular vein (RIJV) and the left one (LIJV), the right innominate vein (RIV) and the left one (LIV). The CVC shown in the photograph is placed in the SVC above the ASN, as demonstrated by a small deflection of the "P" wave in the electrocardiographic trace performed during the control of the position of the tip of the catheter.***

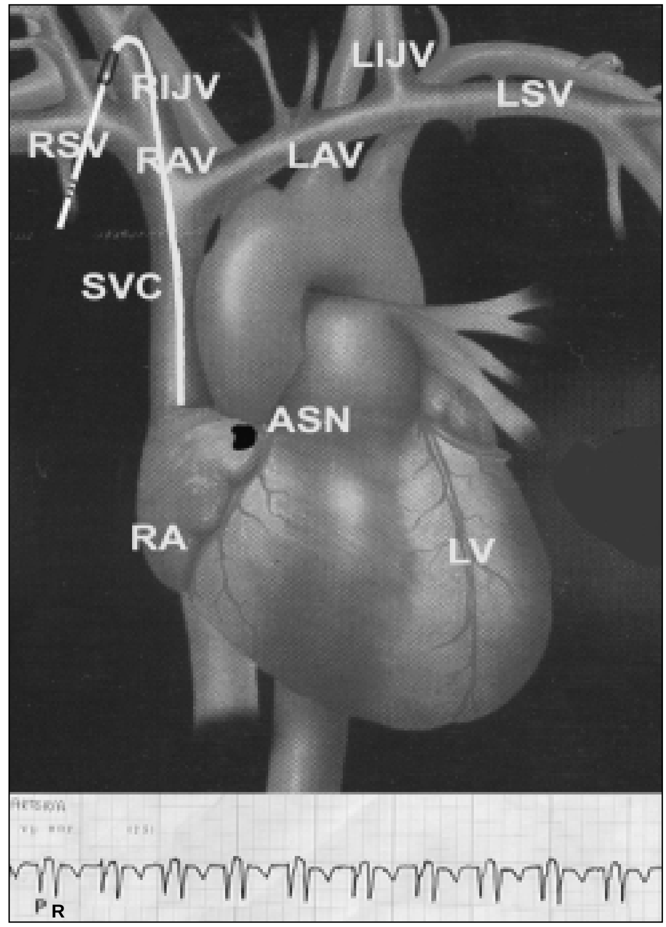

Fig. 3 - ***The photograph shows the CVC placed at the level of the ASN. The bottom part of the image pictures the electrocardiographic trace obtained putting the catheter at the level of the ASN with a deep deflection of the "P" wave in respect to the "R" wave.***

nique of endocavitary electrocardiography using a guide-wire inserted according to the technique of Seldinger. In this case, the guide-wire itself is used as an endocavitary electrode that permits obtaining immediately after the puncture of the vein an electrocardiographic trace that rapidly informs us of the exact position of the guide in vein. Successively, the method was repeated using the catheter itself, filled with a physiological solution, as an endocavitary electrode. This double endocavitary registration has been adopted in 150 placements of jugular catheters during the last 2 years. The guide-wire and the vascular catheter, filled with physiological solution, attached to the precordial lead of an electrocardiograph standard (V_1-D_3) consent the registration of a typical electrocardiogram linked to the morphology and the morphometric of the "P" wave.

It is well known that, during the endocavitary electrocardiography, the pattern of the "P" wave depends on the electrical activity of the atrium and on the position of the endocavitary electrode in respect to the sinoatrial node. It is also known that the "P" wave during the endocavitary electrocardiography shows a negative deflection (Fig. 2) and that its amplitude increases as it approaches the sinoatrial node (Fig. 3). When the tip of the catheter overpasses the node, the "P" wave shows a two-phase course (Fig. 4). This tecnique has not been used in cases of atrial fibrillation or arrythmia as the "P" wave is absent or unreadable. After the electrocardiographic valuation, the catheter, just

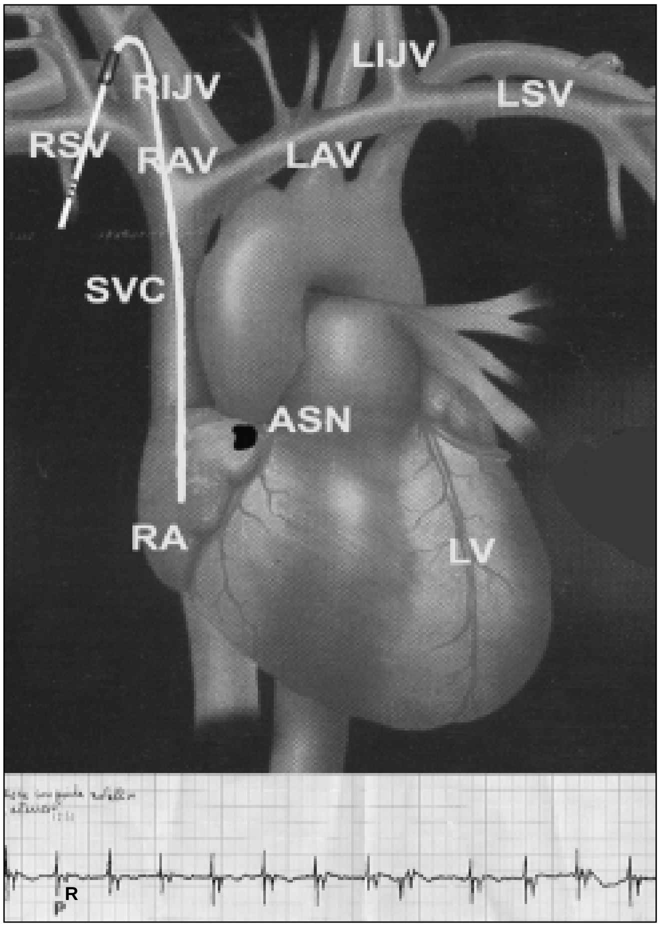

Fig. 4 - *The photograph shows the CVC placed at the level of the entrance of the right atrium below the ASN. At the bottom can be seen the electrocardiographic trace obtained leaving the catheter under the level of the ASN: in this manner, a two-phased deflection of the "P" wave in respect to the "R" wave is readable.*

placed, was anchored to the cutis by 2 silk stitches. In our clinical trial the placement of the first 100 catheters was carried out using endocavitary electrocardiography and later confirmed by a radiogram of the chest. The remaining 1,039 patients were treated with hemodialysis immediately after the placement of the catheter and an electrocardiographic control. A radiogram of the chest was necessary in all patients affected with arrythmia.
In every case, the central vascular access was obtained by the puncture of the right jugular vein in the site of Sedillot triangle (Fig. 4). The right internal jugular vein is, in fact, larger than the left one; measuring 9-12 mm it continues directly into the innominate vein, only 3 cm long and almost co-axial to the descending cava. On the other hand, the innominate left vein is twice as long, measuring 6 cm. Furthermore, it is placed almost horizontally, making the access to the descending vena cava very difficult. For this reason the left IJV has been used only in a very few cases.

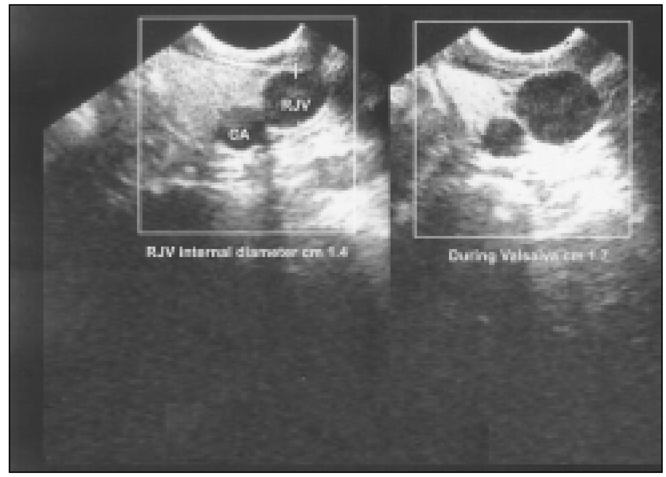

Fig. 5 - *The photograph shows the ecographic image of the big vessels of the neck obtained at the level of the right Sedillot triangle. The scan shows the perfect patency of the right internal jugular vein (RJV) and of the common carotid artery (CA): The anatomical relationship of the vessels is regular. The RJV demonstrates the calibre of 1.4 cm in basal conditions and of 1.7 cm after Valsalva maneuver (top right). (Echotomograph B and K Medical Diagnostic Ultrasound System, 7.5 MHz had-scan).*

RESULTS

The technique EC-ECG allows the registration of a typical pattern due to the electrical atrial activity expressed by the deflection of the "P" wave. The "P" wave is negative during the EC-ECG and its amplitude increases more and more as it approaches the sinoatrial node. A chest X-ray to ensure the accuracy of the EC-ECG validated the first 100 CVC placements. The remaining 1,039 pts were submitted only to EC-ECG and to hemodialysis treatment as soon as possible. The EC-ECG was successful in 100% of cases. Only in 31 pts (2.7%), because of atrial fibrillation, it was not possible to obtain an EC-ECG trace with a readable "P" wave. Our results confirm the reliability of the EC-ECG technique in the placement of CVC in uremic pts requiring hemodialysis. Its use is only impaired by the absence of a "P" wave or an unreadable "P" wave due to cardiac arrhythmia. The extreme accuracy of the technique, shown by 100% of sensitivity and specificity, eliminates the need of chest X-ray and avoids the risks due to repeated thoracic radiographs. However we agree that chest X-ray is necessary in cases of multiple passes or attempts at CVC placement. In our clinical trial, having used only in about one half of our patients an echographic real-time control, in those cases in which a percutaneous puncture has been repeated, we have systematically performed a chest X-ray. Chest X-ray is mandatory when an EC-ECG trace is completely absent, although this situation has never occurred in our practice.

DISCUSSION

The method EC-ECG was described for the first time by Dr. Serafini, chief anaesthetist of the University of Pavia in 1985 (14, 15), adapting and perfecting a technique that had earlier been described in the positioning of ventricular-atrial shunts for draining hydrocephalus (17). The technique was used in pediatric surgery to avoid the risk in small children of repeated radiograms of the chest necessary to verify the exact position of the catheter tip. Since then his method has been used in an ever-increasing number of young patients and Dr. Serafini can count today some 1,500 case histories of catheter placements by EC-ECG (personal unpublished remarks). From the time of his first studies concerning this technique, he has not again performed radiological controls of the chest in his young patients, with the exclusion, obviously, of particularly complicated cases. Recently, in 1997, Drs. Gian Battista Parigi e Giovanni Verga, pediatric surgeons of the University of Pavia (16) published their experience regarding the placement of 807 CVC, used in pediatric patients for parenteral nutrition, chemotherapy and surgery. Their experience over ten years, regarding the use of the method EC-ECG, is today the most extensive study in pediatrics published in literature: in 17 cases (2.1% of the total) in which it was not possible to observe the typical deflection of the "P" wave, the radiological control demonstrated the misplacement of the catheter (almost always in the controlateral subclavian vein). The Authors pointed out that they had never again used a radiological control of the chest in their young patients excluding the above-mentioned cases.

This technique, however, had never been used in patients affected with chronic and acute renal failure that more and more often necessitate a rapid preparation of a central vascular access for hemodialysis. Dr. Galli (18) of the G. Maugeri Foundation of Pavia, in Italy, was the first among Italian nephrologists to use the method EC-ECG in a small number of uremic patients in dialysis. His experience, continued afterwards, at that moment was limited to only 7 uremic patients to whom he applied the method EC-ECG. In all cases it was possible to confirm the exact position of the tip of the catheter by standard chest X-ray.

Successively in 1995, Dr. Dionisio (19) published the results of this technique applied to a larger number of uremic patients obtaining excellent results. Dr. Dionisio's experience over a period of 13 months demonstrated the usefulness of EC-ECG in 81 uremic patients that needed a quick preparation of a CVC. The first 100 placements were controlled by EC-ECG and also by a standard radiogram; in the remaining 21 cases the positioning of the tip of the catheter was controlled only by EC-ECG and the patients were immediately submitted to dialysis. In all of the cases in this report in which the position of the catheter tip was controlled by only EC-ECG, the whole procedure of dialysis was performed without any clinical problems.

The results presented in this work, regarding a vast number of case reports, furthermore confirm the absolute reliability of the technique EC-ECG used in the positioning of a central venous catheter every time a uremic patient needs hemodialysis. This fact is based on the principles of electro-physiology on which endocavitary electrocardiography is founded and it is sensitive and specific in 100% of cases (20-22).

In accordance with literature (23) and in the attempt of making the positioning of a central venous catheter more secure for the patient and the surgeon, we have applied the technique EC-ECG to the metallic guide placed immediately after the puncture of the vein and before positioning the catheter. Even in this case, the sensitiveness and the specificity of the trace made it always possible for us to be quickly informed of the position of the catheter in the vein. Furthermore, changing the position of the guide, according to the electrocardiographic signal, it was possible to define the exact length of the catheter descending in the vein. Using the guide as an endocavitary electrode, the whole QRS complex results to be smaller because of lower voltage. This reduction of voltage is probably due to a loss of the electric signal along the metallic guide, which, however, is not always constant anyway.

In all of our cases, we have placed the catheter tip at the opening of the right atrium, corresponding to the electrocavitary pattern of Figure 3. Our present experience has permitted us to verify that the problem, described in previous literature, regarding the depth of the "P" wave (i.e. spike negative not inferior to 1/3 of the "R" wave) so as not to induce arrhythmia, is to be considered overcome. In fact, our technique differs substantially from that applied by Dr. Robertson (17) in placing a ventricle-atrial shunt in his young patients affected with hydrocephalus. He believed, according to his experience, that the tip of the shunt should be positioned in the midatrium, position identified by an electrocardiographic trace with a two-phased "P" wave, as shown in Figure 4. Today we believe that the most suitable position for catheters in hemodialysis is the entrance of the atrium at the level of the confluence of the superior vena cava in atrium, as we have illustrated in this article in Figure 3, where the "P" wave has a deep, negative deflection that is equal to the negative spike of the "R" wave. In this way, the technique we are presenting here results to be more secure and precise than a chest radiogram in defining the exact position of the catheter tip. Furthermore, this position of the catheter tip significantly reduces the risk of thrombosis if one considers that during our experience, we have had to resort to a pharmacological de-clotting with urokinasi in only one case of a permanent catheter presenting a fibrin sleeve that involved extensively the tip and greatly reduced blood flow. However, it was only a matter of one case out of a vast study where the permanence in site of the catheters was a medium of 35 days within a range of 1 to 242 days (this last figure pertains to only one case of a very critical patient in an intensive care unit in our hospital). Furthermore, in all cases in which a permanent catheter has been adopted, no antiplatelets drug has ever been used.

As far as the need of a chest X-ray at the end of the procedure is concerned, it is up to the operator, and him alone, to make the decision. In our experience, as also described by other writers (19), the reliability of this technique has been widely proved in the initial pilot phase of our work in which the placement of the first 100 catheters was controlled by both chest radiogram and EC-ECG.

In almost 10 years of experience, there has been no report of cases of incorrect placement of the catheters, nor major complications such as cardiac perforation with tamponade (24), mediastinal hematoma (25) as reported in literature during the placement of dual-lumen catheters or Tesio catheters, nor the migration of the catheters in the pleura as reported by other authors (26). It is our opinion that a chest radiogram taken only in the projection back-forward is of little use especially if performed immediately after the positioning of the catheter. In literature, cases have been reported in which the tip of the catheter in the projection back-forward resulted adequately well-placed, even though the catheter wasn't functioning at all well: a second radiogram in projection side-to-side showed the presence of an hemorrhagic mediastinal effusion with pleural migration of the catheter tip. In one case in which we were called for a consultation, the catheter did not function correctly and the blood flow was not adequate, but the chest radiogram showed the tip seemingly well placed. Unfortunately, the catheter was left in site and utilized as a line for infusion since the radiogram denoted a correct position. The autopsy of the patient showed that the catheter had punctured the anterior-lateral wall of the vena cava resulting in a grand hydrothorax in which was revealed a high concentration of glucose caused by the glucose solution infused during the night.

In these last cases described, we believe that the application of the technique EC-ECG, which would not have shown an electrocardiographic trace, would have alarmed the operators: in all cases in which the tip of the catheter is out of the vein, the trace is absent, and in all cases in which the pattern of the trace is not that one here described, the operator must realize that the placement is not correct. Furthermore, it must be considered that CVC is being more often adopted in other fields of medicine, such as oncology, parenteral nutrition and pediatrics. The possibility of intervening with a procedure that is rapid, secure and that can be performed by any operator who has some notion of electrocardiography is extremely comfortable and comforting for the patient.

Revision of literature and our own experience consents us to formulate the following conclusions:

- At present, the placement of a central venous catheter in the right internal jugular vein and the control of the position of its tip using the technique EC-ECG seems to constitute the best choice for the preparation of a central vascular access for haemodialysis.
- The technique EC-ECG can be rapidly applied to the patient already in the operating room where the placement of the CVC must anyway be performed under monitoring by electrocardiography. It does not require additional time to be effected. The operator that performs this technique must have some knowledge of the principles of electrocardiography that are more or less those already known and utilized in our clinical and nephrological practice.
- The extreme accuracy of the technique, demonstrated by 100% sensitivity and specificity, eliminates, in our opinion, the need of taking a chest radiogram immediately after the catheter is placed in the vein.
- A chest radiogram must, however, be made when the operator deems it necessary, but this should be done at least 2 hours after the procedure is completed and in 2 projections: back-forward

and side-to-side. Only in this manner, it is possible for the operator to detect small pneumothoraxes that can be noted only after some hours or the incorrect position of the catheter tip.

- A radiogram is always mandatory if, when using EC-ECG, there is no electrocardiographic trace, or when the "P" wave is absent or unreadable.
- According to our experience, the catheter should be positioned where the vena cava joins the opening of the right atrium. This position is easily definable by the electrocardiographic pattern shown in Figure 3.
- In terms of cost, this technique is free of additional expenses and is very secure for the patients, especially for young pediatric ones. We therefore propose that EC-ECG be confirmed as a possible new guide line and be given a place of utmost importance together with a chest X-ray when it is deemed necessary.

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