Blood flowrate and dialysis adequacy in patients with permanent central venous catheters

S. MANDOLFO[1], F. GALLI[2], V. PIAZZA[2], E. IMBASCIATI[1]

[1] Nephrology and Dialysis Unit, Ospedale Maggiore, Lodi - Italy
[2] Nephrology and Hemodialysis Division, Fondazione Maugeri, Pavia - Italy

ABSTRACT: **Vascular access efficiency is a major determinant of an adequate dialytic treatment and reports from literature indicates a growing interest in the field of central venous catheterisation as permanent vascular access for hemodialysis. The main reasons are the continuous improvement in design and biomaterials along with the increased number of patients with failure of their vascular beds. In this paper it is presented and commented a series of negative crucial factors which can reduce the quality of the hemodialysis treatment: the problem of recirculation and the catheter related (and the patient related) causes of inadequate flowrate. Finally the Authors conclude with a short presentation of their clinical experience in the field.**

KEY WORDS: *Hemodialysis, Vascular access, Central venous catheters*

INTRODUCTION

Over recent years central venous catheters (CVCs) have increasingly been proposed for permanent vascular access in uremic patients on maintenance hemodialysis. The placement of permanent CVCs in hemodialysis patients is growing, as outlined by reports from the United States, where CVCs for vascular access have risen from 2% to 20% over the last seven years (1). Widespread scientific interest is highlighted by over one thousand references, five hundred in the last four years alone, quoted in the Medline search for the last ten years (Fig. 1). Moreover the American DOQI guidelines on vascular access have issued nine recommendations on the proper use of CVCs (2). With regard to Europe, data from the Catalan renal registry showed that 5.6% of the patients were dialyzed with permanent CVCs (3). An Italian national survey pointed out that the prevalence of permanent CVCs in dialysis patients was in the 6-10% range in 16% of the centers, but increased up to the 16-20% range in some of the units (4). A regional questionnaire in Lombardy has recently found that 173 permanent CVCs were placed in chronic hemodialysis patients over a one-year period (7.8% of 2200 overall vascular access procedures) (5).
The reasons for the increased use of CVCs for permanent access may be partly due to the great improvements made by industry both in terms of materials (better biocompatibility) and performance (increased flow rates and lower recirculation), but also to the exhaustion of vascular endowment by many patients on chronic hemodialysis (owing to various circumstances such as aging and/or underlying vasculopathy).

CATHETERS AND DIALYSIS ADEQUACY

The need to prescribe an adequate dialytic dose in patients on maintenance treatment has lately been stressed by several scientific societies through updated guidelines. Hemodialysis adequacy is usually evaluated by KT/V and URR, obtained from urea kinetics and it is commonly agreed that the mini-

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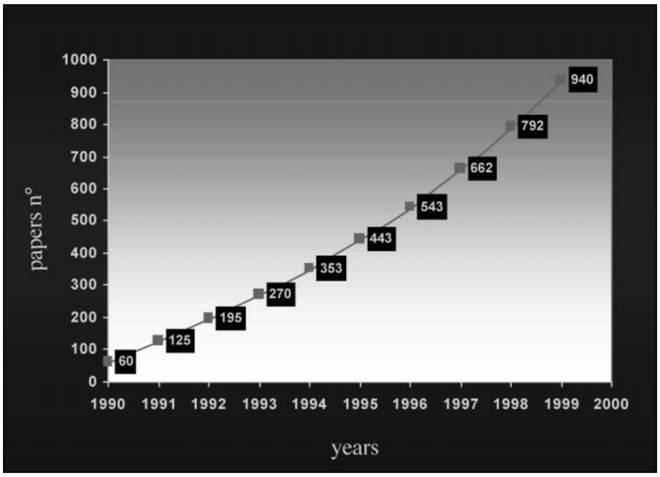

Fig. 1 - ***Scientific interest in hemodialysis venous catheters (from Medline, April 1999).***

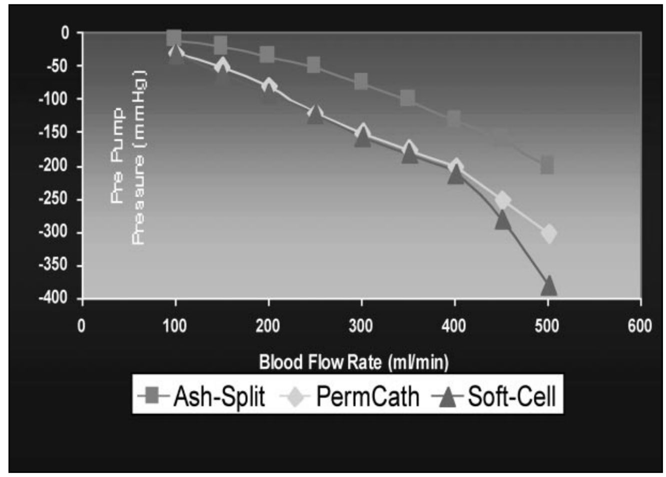

Fig. 2 - ***Central venous catheters on the market:*** **in vitro** ***blood flowrate (data from manufacturer's specification sheet).***

mum KT/V value to be delivered should not be less than 1.2 (6, 7). The KT/V index derives from dialyzer urea clearance (K) times duration of dialysis (T), divided by the patient urea distribution volume (V). The dialyzer clearance is closely related to blood flowrate; for example, in a patient of medium build (60-70 kg), whose treatment time is about 4 hours, an adequate KT/V requires a blood flowrate of not less than 250 ml/min.

Nowadays the technical performance of several double-lumen catheters results in a theoretical blood flowrate of 400 ml/min or more, thus they can deliver an adequate dialysis dose as confirmed by Atherikul et al, in a study group of 64 patients treated with 3 types of CVCs (8).

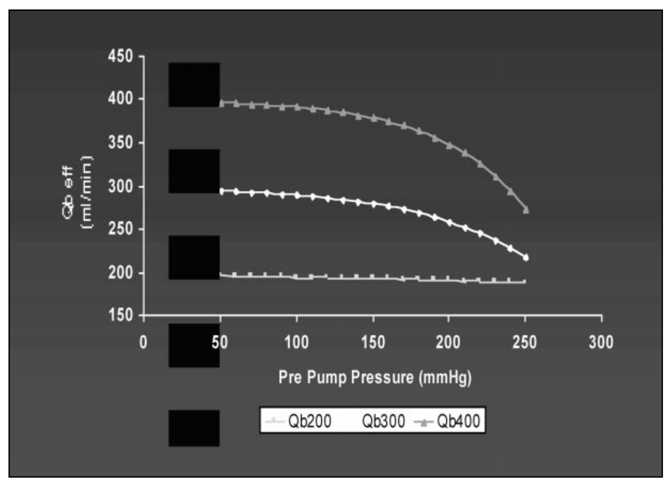

Fig. 3 - ***Blood flowrate and pre-pump negative pressure in vascular access (experimental data in 8 patients on maintenance hemodialysis).***

THE IMPORTANCE OF BLOOD FLOWRATE

The difference between the prescribed and delivered dialysis dose is the chief problem when dealing with dialysis adequacy (9). The efficiency of the dialytic treatment can be affected by many factors (Tab. I), above all the difference between true blood flowrate (Qbt) and the value displayed by the blood pump flowmeter (Qb). Qbt is directly related to access flowrate and inversely related to recirculation rate and to pre-pump negative pressure (10).

The problem already observed in arteriovenous fistulas (AVF) becomes much greater in CVCs, which provide lower blood flowrate values than AVF, so that they require a more elevated pre-pump pressure in order to obtain a blood flowrate of around 300 ml/min. The relationship between Qbt and pre-pump pressure in hemodialysis vascular access is shown in Figure 3. Experimental data were record-

TABLE I - CAUSES OF REDUCED DIALYSIS EFFICIENCY

- Blood flowrate reduced by clinical events (hypotensive episodes)
- Blood flowrate impaired in failing access
- Dialysate and blood flowrates in parallel
- Reduced performance of the hemofilter (KoA, membrane surface area) for partial clotting
- Technical problems in the dialysis machine
- Duration of delivered treatment less than that prescribed (clinical events, early patient dischange)

ed in 8 patients with CVCs and AVF during dialysis sessions performed using a monitor (Fresenius 4008E™) to estimate Qbt by means of a mathematical model taking into account pre-pump pressure. Figure 3 shows that, when Qb is 300 ml/min and the pre-pump pressure is 150 mmHg, Qbt is only 265 ml/min. The gap between the two blood-flowrate measurements is enhanced with high blood flowrates (400 ml/min or more) whereas it is negligible when the blood flowrate is around 200 ml/min. In a recently-published paper Kapoian et al showed that in patients with CVCs, a Qb of 450 ml/min resulted in a 12.3% reduction in Qbt, the latter evaluated by ultrasound technique. The reduction in Qbt was similar in CVCs and AVF, when the pre-pump pressures values were the same (11).

THE PROBLEM OF RECIRCULATION

Blood returning to the patient from the dialyzer venous line can find its way back into the dialyzer arterial line under certain circumstances. In permanent CVCs such conditions depend on the proximity of the two lumens. This phenomenon is defined as recirculation and its clinical consequence is impaired solute removal with reduced dialysis efficiency. According to our experience and some literature data, if the double-lumen permanent CVCs (PermCath, Ash-Split, VasCath) are well-placed and correctly performing, the recirculation rates are less than 4%, i.e. negligible in terms of dialytic efficiency (15). In Tesio catheters the distance between tips is extremely important. The manufacturer states that it should not be less than 2 cm, but some authors suggest that there should be at least 4 cm between the venous tips (12).

Recirculation becomes important in CVCs if the lumens are reversed when connected to the monitor lines, either because of operator's error in hooking up well-functioning catheters or because of clinical decision, when the inflow lumen gives poor blood flowrate. Twardowski studied 18 patients with upper CVCs (subclavian and internal jugular) and observed that the recirculation rate is 12% in reversed, but well-functioning catheters whereas it is 7% when lumens are reversed owing to inflow failure (13). Whenever a lower approach is used, i.e. the femoral vein, we should bear in mind Leblanc's claim that in 38 patients undergoing either upper (subclavian) or lower (femoral) catheterization, the recirculation rate was fourfold in the femoral approach, when the length of the catheter was the same (14). In the same paper, the author also pointed out that in the femoral vein shorter catheters (less than 15 cm) produce a recirculation rate double that of the longer ones, i.e. over 19 cm (14).

INADEQUATE BLOOD FLOWRATE: CATHETER-RELATED CAUSES

Poor blood flowrate can occur at an early or late stage after catheter insertion. Early causes (within 2 weeks) of catheter malfunctioning are inadequate placement of the tip, partial displacement or kinking of the catheter in the subcutaneous tunnel and early thrombosis. Chest radiograph can easily detect kinking of the catheter and displacement of the tip, which should be positioned at the caval atrial junction (or according to French authors (16) within the atrium) in order to achieve optimal flowrates. An attempt to correctly position the catheter with simple movements should be made before considering replacement. An important cause of poor blood flowrate at a later stage is thrombosis, which develops in the lumen, in the tip or around the catheter (as a fibrin sleeve), but can also affect the vein where the catheter is inserted. In most instances partially obstructed catheters are successfully managed with lock and infusion techniques of urokinase and/or heparin (17).

INADEQUATE BLOOD FLOWRATE: PATIENT-RELATED CAUSES

During hemodialysis blood flowrate can be moderately reduced (i.e. less than 250 ml/min) even if the catheter does not show displacement or thrombosis. This may be explained by several patient-related factors. In fact, according to Poiseuille's Law, flow through any tubular structure is directly dependent on the product between the inlet-outlet

TABLE II - CATHETER-RELATED DATA

Blood flowrate (ml/min)	272 ± 30
Dialyzer negative pressure (mmHg)	175 ± 21
Dialyzer venous pressure (mmHg)	147 ± 21
Dialysis adequacy data	
Duration (min)	236 ± 23
KT/V	1.16 ± 0.25
Recirculation (%)	4.2 ± 2.1

difference in pressure and the diameter raised to the fourth power and inversely related to eight times the length and viscosity of the product (18). Thus increase in patient blood viscosity can reduce catheter flow, as it happens when the hematocrit and plasma protein concentrations rise (19). Circulating paraproteins can also increase blood viscosity. How the hematocrit affects the relationship between pre-pump negative pressure and flow through a catheter is shown in Figure 4, where theoretical data were calculated according to Poiseuille's Law for a 15 cm long, 11 French diameter catheter. As shown in the figure, when the hematocrit is 25%, a blood flowrate of 300 ml/min requires a pre-pump pressure of 80 mmHg, but when the hematocrit reaches 40%, higher (260 mmHg) pre-pump pressure is needed to obtain the same flowrate. Furthermore, the volemic state of the patient directly affects blood flowrate in CVCs, as reported by Jean et al (16). Best blood flowrate values were associated with a central venous pressure >5 mmHg and to a reduced number of intradialytic hypotensive episodes.

OUR CLINICAL EXPERIENCE

We recorded 37 hemodialysis patients (14% of all patients on maintenance dialysis in our units) with permanent CVCs, 26 of which placed in the internal jugular vein (Tesio twin catheters), 3 in the subclavian vein (2 PermCath and 1 Ash-split) and 2 in the femoral vein (Tesio twin catheters), which were tunnelled in the abdomen. Patient mean age was 70±12 years and the mean survival time of the catheters was 15±11 months. CVCs were chosen for vascular access either because of poor venous endowment (72%) or because the venous system was exhausted by previous AV grafts in the upper limbs (20%), whereas in 8% CVCs were a first choice access (2 at the patients' request and 1 in a severely ill patient). Observations over a one-month period are reported in Table II, as mean values of catheter performance (blood flowrate, venous pressure, pre-pump pressure) and of dialysis adequacy (Kt/V, treatment time, recirculation rate). All patients underwent dialytic treatment with medium-high efficiency hemodialyzers (KoA >600 ml/min). The analysis of the dialytic sessions showed that 38% of the studied patients had blood flowrates <250 ml/min, in 70% of them the duration of treatment had to be increased to achieve a KT/V=1.2, while in 3 patients (8%), weighting over 75 kg, KT/V was inadequate in spite of the five-hour sessions.

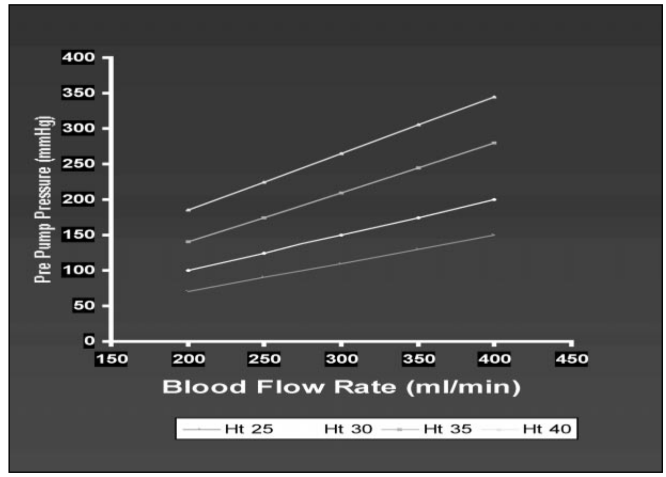

Fig. 4 - ***Changes in blood flowrates induced by hematocrit variations (theoretical data derived from mathematical modeling of Poiseuille's Law).***

CONCLUSION

Vascular access efficiency is a major determinant of an adequate dialytic treatment. Literature reports emphasise how nephrologists are showing a growing interest in central venous catheters for permanent vascular access for hemodialysis. The main reasons are the continuing improvement in catheters (materials, design, technical performance) and the growing number of uremic patients with failed vascular bed and poor health. As far as dialysis adequacy is concerned, the permanent catheters available on the market show negligible recirculation rates and make it possible to achieve an adequate dialysis dose. However, careful attention should be paid to the blood flowrate problem, since the obtained flowrates are often insufficient in preventing underdialysis in patients of medium-large body proportions.

Reprint requests to:
S. Mandolfo, M.D.
Nephrology and Dialysis Unit
Ospedale Maggiore
Viale Savoia, 9
20075 Lodi, Italy

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