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Single-Needle Hemodialysis on Native Fistulae

Guy Rostoker

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<http://dx.doi.org/10.5772/52995>

1. Introduction

Single-needle (SN) dialysis was first described in 1964 by Twiss, who used a time-activated mechanism with a pump and a double clamp to alternate blood through a caval catheter [1]. As a result of this publication, the technique of SN-hemodialysis on catheter has been widely disseminated and reported in publications primarily in the context of acute renal failure especially in post-operative cases [2]. In the 1980's, the work of Belgian authors allowed the development of the chronic hemodialysis technic in unipuncture particularly in the Benelux countries [3-5]. Vanholder and colleagues using a specific canula and a twin pump-head SN system showed that dialysis efficiency was at least as good as with conventional double-needle (DN) hemodialysis, based on Kt/V , the hematocrit and nerve conduction [3-4]. They also showed that the five-year fistula survival rate was 74%, a figure far better than with conventional DN hemodialysis [5]. SN dialysis failed to gain popularity, however, with the exception of the Benelux countries and recently Asia, and has been confined to specific situations such as the use of a single-lumen catheter, and when temporary and reversible problems of vascular access arise [6, 7]. Nevertheless, many nephrologists and dialysis nurses are reluctant to use SN dialysis, even in cases of problematic vascular access for fear of incidents or underdialysis [7]. The technique of SN-dialysis with a double-pump (Figure 1) must be differentiated from the use of an alternating clamp which should be reserved for the exceptional situation of termination of a dialysis session in the event of an incident on the native fistula on a simple-pump generator.

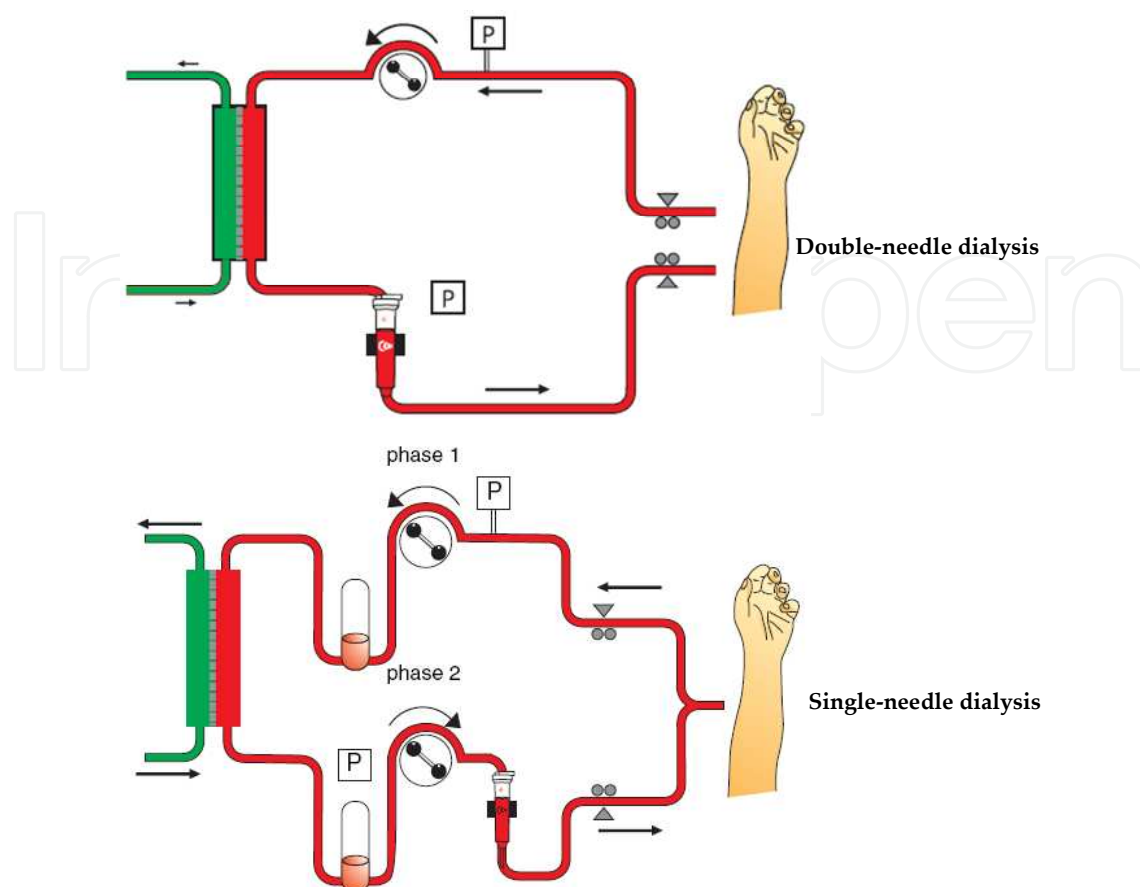


Figure 1. Diagrams of extracorporeal circuits during double-needle hemodialysis and single-needle hemodialysis according to Rostoker G. Short-term single-needle hemodialysis on native fistulae : a general review. *Nephrol Ther* 2010 ; 6(7) : 591-596

2. Complications of single-needle hemodialysis

The main potential hazards of SN dialysis are the same as those of conventional hemodialysis, but also include hemolysis from shear stresses between red cells and narrow needles, a higher risk of backfiltration, blood recirculation and underdialysis.

2.1. Hemolysis

The classical drama of mechanical or chemical hemolysis with violent abdominal pain and hypotension has become a very rare event in DN and SN dialysis with the current lines and pumps of generators as well as with the chemical quality of current dialysates. While subclinical hemolysis is very rare during DN-hemodialysis [8], a purely biological hemolysis can be observed in SN-hemodialysis when a high blood flow is used on a single needle of low diameter and high length, particularly when using Wallace catheters (to be avoided at all costs when unipuncture is scheduled) [8-9]. Dhaene and coworkers us-

ing plasma lactico deshydrogenase (LDH), as a marker of mechanical hemolysis observed a significant increase in LDH during 41.6 % of the 245 SN-dialysis sessions (among 52 patients) using a 14 Gauge Wallace's catheter, as compared with 25% of the 112 SN-dialysis sessions performed with 14 Gauge metal needles [8]. Hemolysis intensity was also increased twofold with the use of Wallace's catheters [8]. In an "in vitro" hemodialysis system using calf's blood, Wachter and coworkers have also demonstrated by measuring the rate of free hemoglobin released into the plasma that mechanical hemolysis is inversely proportional to the internal diameter of the Wallace's catheters [9].

2.2. Backfiltration

The backfiltration of the dialysate to the blood compartment occurs when the pressure in the dialysate compartment is higher than the pressure of the blood compartment of the dialyzer [10]. It is a phenomenon frequently encountered in conventional DN hemodialysis ; with the use of non ultrapure dialysate, this retrofiltration of the dialysate may favor the entry of bacterial endotoxins into blood, and aggravate the micro-inflammatory state of the dialysis patients through the activation of circulating monocytes [7]. The risk of back filtration is higher with SN than with conventional DN hemodialysis due to increased pressure fluctuations resulting in lower pressure in the blood compartment [10]. This means that SN dialysis should be performed with an ultrapure dialysate [7].

2.3. Blood recirculation

Blood recirculation is defined as the reflux of dialysed blood of the venous line into the arterial line and the contamination of the arterial blood by blood which has been already dialysed thus leading to a reduction in dialysis efficiency [11]. The study of the recirculation in the central venous catheters has been widely covered in the literature [summarized in reference 11]: with double lumen catheters recirculation is estimated to average approximately 5% (with a variation of 2% to 12% depending on the type of catheter) [11]. With single lumen short femoral catheters (13.5 cm) a recirculation as high as 22% is observed; recirculation is lower (12.6 %) with longer catheters of 19.5 cm [11]. In 1993, Hoenich and coworkers observed recirculation rates with SN hemodialysis ranging from 8.8 % to 18% [12]. With modern systems of unipuncture dialysis such as the Fresenius generator 4008, Trakarnvanich and coworkers recently found an average recirculation rate ranging between 10.7 % and 12% [6]. Three factors are involved in the blood recirculation phenomenon in SN dialysis [13]: - a low flow rate in the native fistula, - a substantial dead space in the needle and the connectors, - the compliance of the lines of the dialysis circuit located between the needle and the blood pumps [13]. Blumenthal and coworkers elegantly demonstrated that a significant reduction in the rate of recirculation of single lumen catheters (from 23% to 7%) could be obtained by increasing gradually the time of blood impulse rate up to four seconds [14]. However, with the old systems of unipuncture, there was an inverse relationship between blood inflow time and the speed of pumps which limited the gain in recirculation. These works have led the dialysis industry to optimize the blood inflow time in parallel with the flow of the two blood pumps [14].

2.4. Underdialysis

Few data are available on short-term SN dialysis and especially on the dialysis dose measured using a reliable method. Four publications have clearly shown that the technique of hemodialysis in unipuncture delivered an insufficient dose of dialysis [15-18], which fell below the recommendations of the EDTA and KDOQI [19-20]. These four publications quantified the dose of dialysis by the single-pool Kt/V [15-18] and the most recent also studied the ionic dialysance and the Kt/V provided by the dialysis monitor [18]. Wright and coworkers in the year 2000, were the first to draw attention to the importance of the method of blood sampling in relation to the circuit of unipuncture for the determination of post-dialysis urea in the single-pool method and the risk of a "dramatically optimistic" overestimation of the single-pool Kt/V (due to the contamination of the arterial blood by the recently dialysed venous blood) : among their five patients in SN dialysis, the mean Kt/V taken without precautions measured 1.7 instead of a real value of 1 [15, 21]. Vlassopoulos and coworkers have studied in 17 patients, by means of the double-pool Kt/V measured 20 minutes after the dialysis session, the influence of haemoglobin level and dialysate flow on the dose of dialysis delivered in SN and DN dialysis : with a standard dialysate flow at 500 ml/min and a mean hemoglobin of 11.9 g/dl, the Kt/V dropped from 1.26 in bipuncture to 0.82 in unipuncture [16]. Despite the increase in the dialysate flow to 800 ml/min, the increase of the hemoglobin level with Erythropoiesis Stimulating Agent at 12.8 g/dl, led to a significant reduction in the double-pool Kt/V to 1.09 in bipuncture and to 0.74 in unipuncture [16]. Toussaint and Beuret studied six patients for two periods of 15 days (six dialysis sessions) and found a decrease in the single-pool Kt/V from 1.20 in bipuncture to 0.93 in unipuncture [17]. We recently reported the results of the evaluation of the dose of dialysis delivered by SN dialysis compared to DN conventional hemodialysis in eight patients studied in a prospective four-period design lasting four weeks [18]. The dialysis dose was measured by single-pool Kt/V with careful blood sampling according to Wright [15], ionic dialysance recorded 45 minutes after the beginning of the dialysis session and 30 minutes before the end of the session and Dialysis monitor-recorded Kt/V [18]. Ionic dialysance is a variable measured online by several dialysis monitors and reflects small-solute clearance during a dialysis session; it is based on conductivity measurements in the inlet and outlet dialysates and is not affected by the use of one versus two needles [22]. Ionic dialysance is as reliable as effective clearance taking into account cardiopulmonary and vascular access recirculation, and has become the preferred quality assurance parameter of dialysis efficiency [22]. The technique of ionic dialysance is also used to determine and optimize the dialysis dose delivered by double and single lumen catheters [23-26]. In unipuncture period on generator Integra, with the blood flow of 180 ml/min as recommended by the manufacturer, the ionic dialysance was measured at 130ml/min in unipuncture, 45 minutes after the beginning of the dialysis session compared to 181ml/min in bipuncture ; the ionic dialysance 30 minutes before the end of the dialysis session was measured at 122 ml/min in unipuncture compared to 171 ml/min in bipuncture ; the monitor-recorded Kt/V was also statistically reduced in unipuncture to 0.74 (versus 1.05 in bipuncture) as the single-pool Kt/V (unipuncture 0.90 versus in 1.35 in bipuncture) [18] (Figures 2, 3, 4, 5).

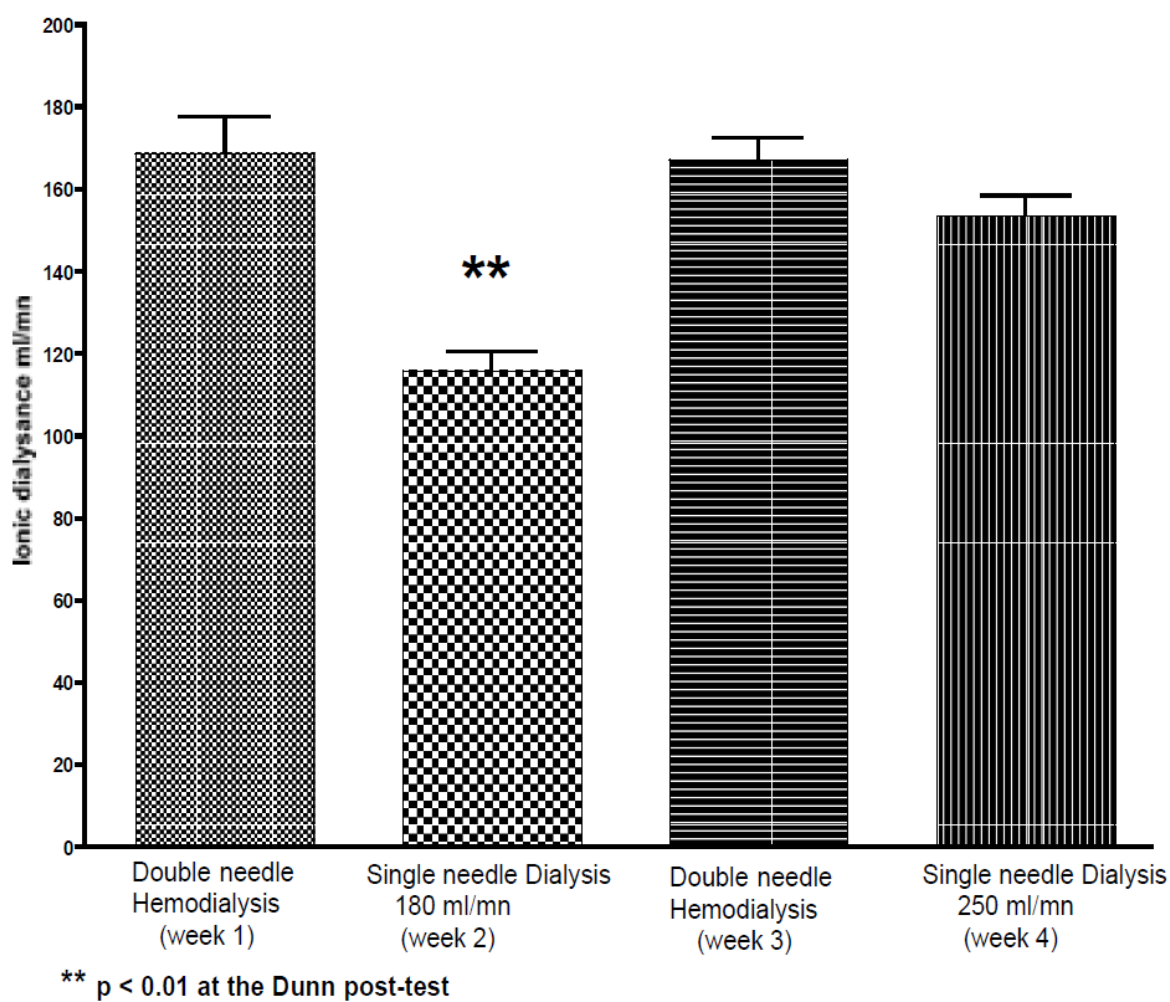


Figure 2. Ionic dialysance 45 minutes after the beginning of the dialysis session in SN and DN Dialysis according to Rostoker G et al. Improving the efficiency of short-term single-needle hemodialysis. Renal Failure 2009 ; 31 : 261-266. This figure shows the reduced ionic dialysance in SN dialysis performed according to the manufacturer's recommendations (at 180ml/min) and the improvement of this parameter by increasing the blood flow rate to 250 ml/min.

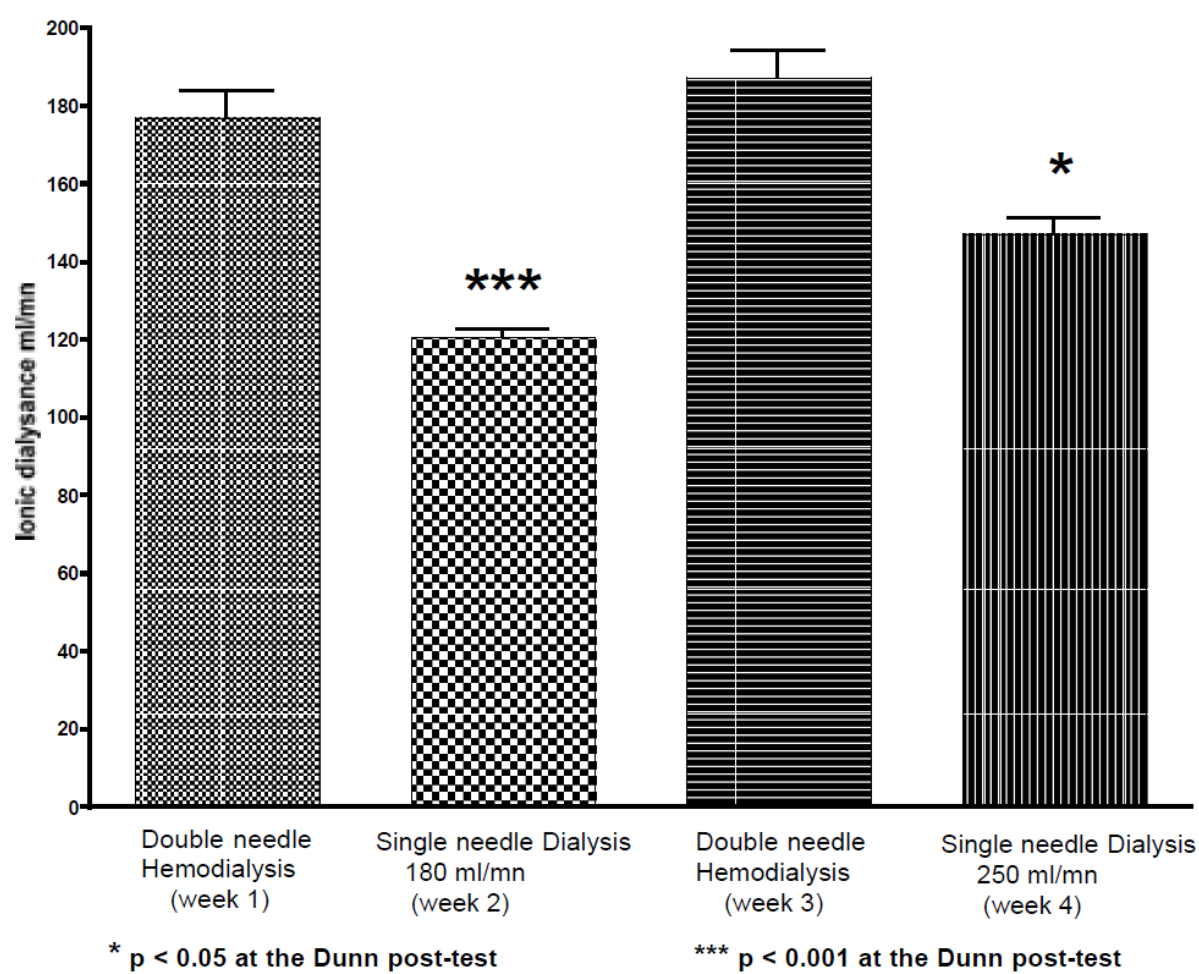


Figure 3. Ionic dialysance 30 minutes before the end of the dialysis session in SN and DN Dialysis according to Rostoker G et al. Improving the efficiency of short-term single-needle hemodialysis. Renal Failure 2009 ; 31 : 261-266. This figure shows the reduced ionic dialysance in SN dialysis performed according to the manufacturer's recommendations (at 180 ml/min) and the improvement of this parameter by increasing the blood flow rate to 250 ml/min

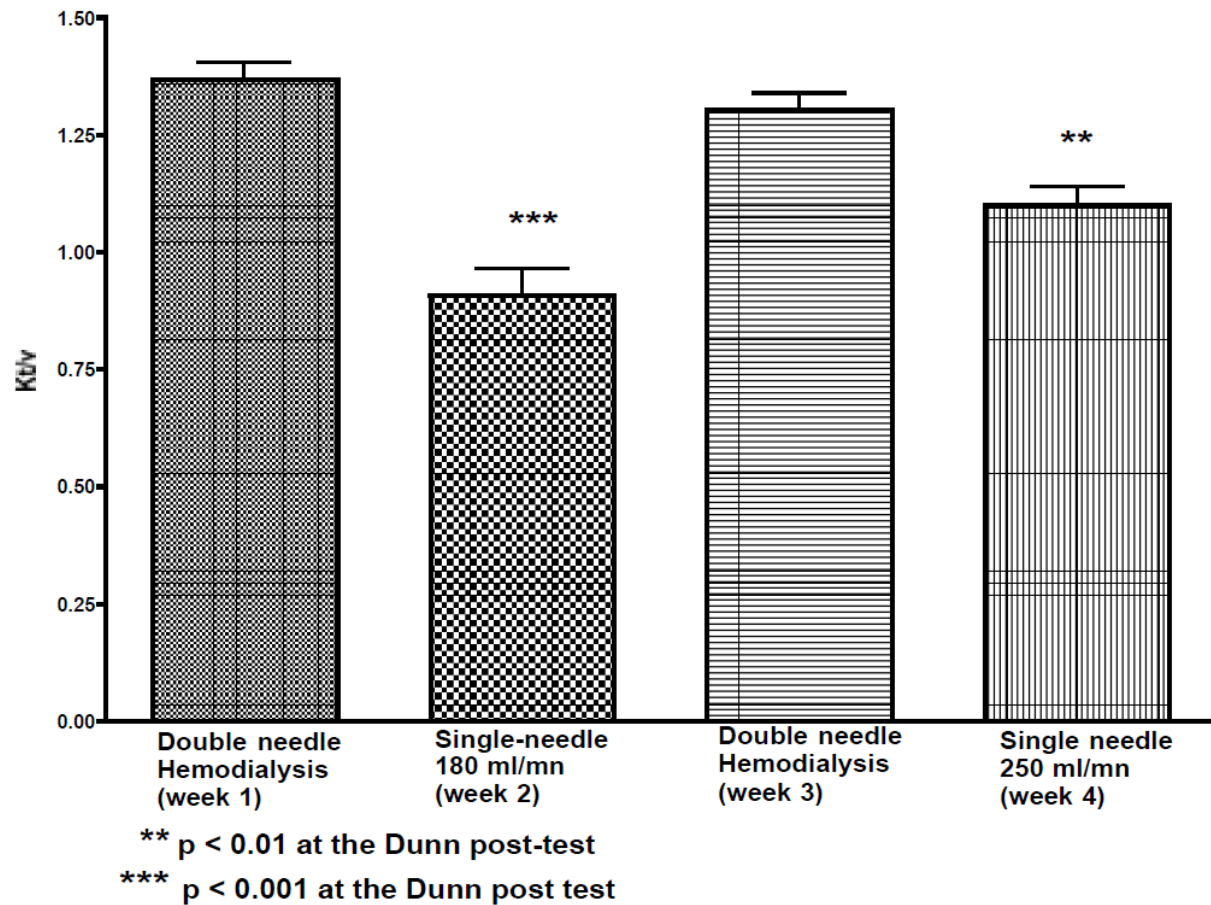


Figure 4. Single pool Kt/V in SN and DN Dialysis according to Rostoker G et al. Improving the efficiency of short-term single-needle hemodialysis. Renal Failure 2009 ; 31 : 261-266. This figure shows the reduced Single pool Kt/V in SN dialysis performed according to the manufacturer's recommendations (at 180 ml/min) and the improvement of this parameter by increasing the blood flow rate to 250 ml/min.

2.5. Increase coagulation in the dialyser

Although not formally studied, several authors have raised the problem of an increase in the coagulation in the fibers of the dialyser linked to the rheological changes induced by the technique of unipuncture and its intermittent flow and the activation of the coagulation cascade following the mechanical fragmentation of red blood cells [7, 14]. This increased coagulation may reduce the performance of the dialyzer and contribute to the reduction of the delivered dose of dialysis. The appearance of hollow fibers at the end of the dialysis session must therefore be the subject of careful consideration by nurses in the event of SN dialysis. In such circumstances, in particular when programming a transitional period of single-needle

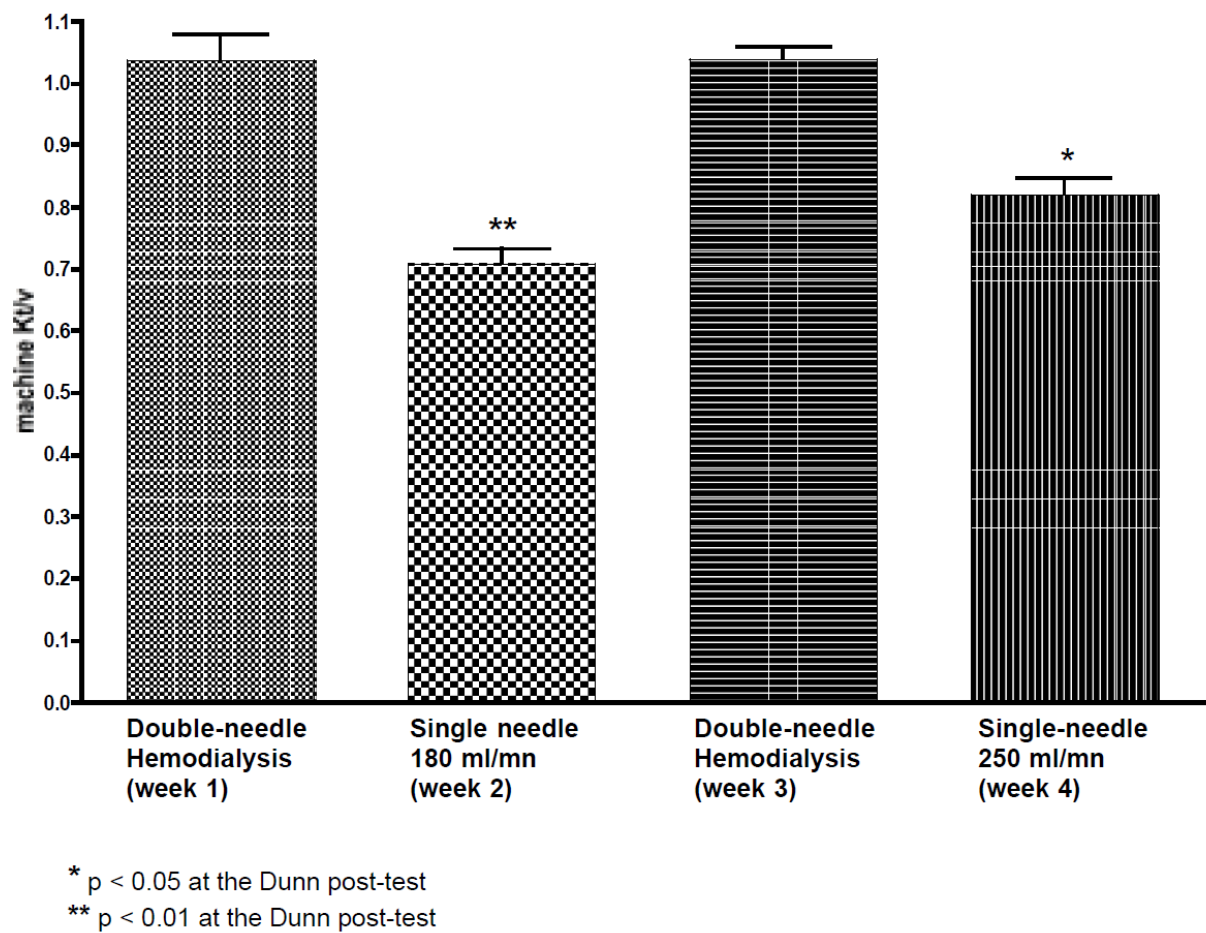


Figure 5. Kt/V provided by the integra monitor in SN and DN Dialysis according to Rostoker G et al. Improving the efficiency of short-term single-needle hemodialysis. Renal Failure 2009 ; 31 : 261-266. This figure shows the reduced Kt/V provided by the dialysis monitor in SN dialysis performed according to the manufacturer’s recommendations (at 180 ml/min) and the improvement of this parameter by increasing the blood flow rate to 250 ml/min.

dialysis, it may be necessary to increase the dose of anticoagulation of the dialysis circuit or to use either dialysis membranes coated with heparin or vitamin E or a dialysate enriched in citrate. [7].

3. Optimization of dialysis dose delivered in transient single-needle hemodialysis

In 2002, Lafon showed that it was possible to significantly improve the ionic dialysance of patients treated by SN dialysis on generator Integra during the same dialysis session by increasing the flow of the two blood pumps with a vacuum threshold of -180 mmHg for the arterial pump and + 250 mmHg for the venous pump ; the ionic dialysance increased from 110ml/min in the first part of the dialysis session to 140 ml/min at the last hour of the session

[27]. We have recently demonstrated in 8 patients (studied on generator Integra during four weeks, depending on four modalities of dialysis), that the increase of the effective blood flow at 250 ml/min (with a venous pressure < 200 mmHg and using a short 15-Gauge stainless steel needle) improved significantly the amount of dialysis delivered by the unipuncture technique and increased the ionic dialysance by approximately 20 %, the monitor-recorded Kt/V and the single-pool Kt/V by approximately 15% (Figures 2, 3, 4, 5)[18]. Trakarnvanich and coworkers have also recently shown in 10 patients, that it was possible to obtain Kt/V identical to those obtained in bipuncture by increasing the time of dialysis from four hours three times per week to 4h30 or five hours (x3/week) and by using in parallel dialysis membranes of a surface area equal to or larger than two square meter [6].

4. Indications of transient single-needle hemodialysis

4.1. Accidents of cannulation of native fistulae

The primary indication of SN dialysis is represented by cannulation-related complications of native fistula or synthetic grafts [7]. In a Dutch study, conducted in 10 dialysis centers in the Maastricht area, 120 patients newly dialysed patients were followed prospectively for the first six months after initiation of hemodialysis to evaluate the frequency of complications caused by cannulation, the frequency of use of transitional venous catheterization or the number of transient SN dialyses ; 74% of the patients had a native fistula and 26% a synthetic graft [28]. The first cannulation of the vascular access using two needles was performed on average 119 days after the creation of native fistulae and 70 days after installation of the synthetic grafts [28]. During the follow up period, only 9% of patients had not presented any accident of cannulation ; a transitional central venous catheterization was necessary in 16% of patients for an average period of 11 days for those with native fistulae and 1.5 days for those with a synthetic graft ; 24% of patients benefited from a transitional SN dialysis [28]. In multivariate analysis, the only predictive factor for successful puncture of the vascular access was the length of the cannulation route [28].

4.2. Native fistulae maturation during initiation of programmed hemodialysis

In the prospective Dutch study carried out in dialysis centers in the region of Maastricht, 51% of the cannulation accidents of native fistulae and synthetic grafts occurred during the first three programmed sessions of DN dialysis [28]. Indeed, in this study, the recommended practice was to perform initiation of hemodialysis straightaway, using the bipuncture technique. These data strongly suggest that too early and too brutal cannulation of native fistulae (and synthetic grafts) by two needles, is a source of later dysfunction of the vascular dialysis access. A Canadian team of dialysis nurses recently conducted a prospective study on the interest of the technique of cannulation by unipuncture at the initiation of hemodialysis [29]. Thirty-three new dialysis patients with native fistulae living in the London area of Ontario were therefore allocated for the first six sessions of dialysis to either SN dialysis (n= 22) or DN dialysis (n= 11) ; the criteria of judgment were the number of transitional venous catheteriza-

tions and angiographic investigations of the fistulae and number of missed dialysis sessions in the first three months after initiation of hemodialysis [29]. The number of transitional venous catheterization was reduced by 50% in the group treated by SN dialysis (9.1 % versus 18.2 % in the bipuncture group); the number of angiographic investigations of fistulae was reduced by more than 60% (13.6 % unipuncture group versus 36.4 % in the bipuncture group) ; the number of missed dialysis sessions because of problems of vascular access was similar in the two groups [29]. These two recent studies provide compelling evidence to recommend the practice of a transitional period of SN dialysis to allow the maturation of native fistulae at initiation of scheduled hemodialysis.

4.3. Other indications of single-needle dialysis

Single-needle dialysis may be proposed in situations of "rescue dialysis" such as regional dialysis with anticoagulation by citrate [30] or when bringing to term a rare pregnancy in dialysis [31]. SN dialysis has been used with success in North America, in patients in daily night dialysis presenting vascular access problems [32]. The prolonged use of SN dialysis has also been proposed for a period of several months in carefully selected patients on conventional hemodialysis with severe vascular access problems [6, 15] ; in such cases the increase in dialysis time, the use of large surface area membranes and the optimization of the blood flow are typically required [7]. In these situations, the monitoring of the dose of dialysis delivered by ionic dialysance should also be currently the rule [7]. Because data on the long-term use of SN dialysis are scarce, physicians should be cautious when using prolonged SN dialysis in selected patients.

5. Conclusions

The primary indication of SN dialysis is represented by cannulation-related complications of native fistulae or synthetic grafts. Recent data strongly suggest that the dialysis dose reliably assessed by ionic dialysance and delivered by transient SN dialysis can be improved by increasing the blood flow rate. Increasing the effective blood flow rate from 180 ml/min to 250 ml/min during SN dialysis is possible in most patients using a short 15-gauge arterial stainless-steel needle, without hemolysis, leading to improved ionic dialysance. This latter regime seems acceptable for short periods of one or two weeks. The use of a larger membrane surface area ($> 2 \text{ m}^2$) and blood flow higher than 250 ml/min, if tolerated by fistulae, can improve the efficiency of SN and increase the dialysis dose to a sufficient level. Nonetheless, careful monitoring of the dialysis dose delivered is required during SN dialysis, as single pool Kt/V, dialysis monitor-recorded Kt/V and ionic dialysance may be far below European Best Practice and KDOQI recommendations. For longer-term SN dialysis, an increase in the dialysis time or a switch to daily dialysis is needed to obtain efficiency similar to that of conventional DN hemodialysis. Since data on the long-term use of SN dialysis are scarce, caution is warranted if SN dialysis is prolonged. Finally, recent studies have also shown that SN dialysis is a valuable option at the start of programmed dialysis on native fistulae allowing their maturation and reducing the risk of stenosis and thrombosis.

Abbreviations

SN dialysis : Single-needle dialysis

DN dialysis : double-needle dialysis

Kt/V: fractional clearance of urea ; this is the normalized dose of dialysis, determined from the clearance of urea and reported to the patient's total water volume.

Dialysis monitor-recorded Kt/V : normalized dose of dialysis determined from the ionic dialysance and reported to the volume of total water of the patient ; the latter parameter is usually calculated using Watson's formula. Because of the overstatement by this formula of urea distribution volume, dialysis monitor-recorded Kt/V underestimate from 20% to 30% the "single pool" Kt/V.

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Conflict of Interest: The author reports no conflict of interest

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