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REVIEW

Single needle hemodialysis: is the past the future?

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Abstract

Whereas the usual way to gain access to the vascular bed for hemodialysis is by inserting two needles, an alternative option based on the introduction of only one needle has been available for several decades. Although single needle hemodialysis gradually lost popularity in the early nineties of last century, this option now seems to make a come-back, with the current change in patient mix towards more elderly and cardio-vascular disease and the appearance of more flexible hardware. Single needle hemodialysis offers several advantages, such as the possibility to puncture small or maturing access systems, a decrease in number of punctures with less potential access damage and subsequent complications, the avoidance of central vein catheter use, and an improved quality of life by reducing puncture-related pain, stress and complications. The main drawback is recirculation which however can be overcome (if considered necessary) by making dialysis somewhat longer and in addition has more impact on removal of small water soluble compounds than on clearance of the more toxic difficult to remove solutes (middle molecules and protein bound compounds). Effective dialyzer blood flow with single needle dialysis cannot be much higher than 300 mL/min, which however also offers advantages by making short dialysis sessions less feasible and thus reducing the likelihood of intradialytic blood pressure falls, organ stunning and other negative outcomes of shorter dialysis. Direct outcome comparisons between single and double needle dialysis are not available but indirect data suggest no differences, in as far as efficient enough access perfusion can keep dialyzer blood flow adequate. The single needle method seems especially suited for the elderly and for home hemodialysis. Recent technological improvements have made the system more accessible and adequate, but further studies are needed to assess with modern methodologies the clearance kinetics of these systems, which could emanate in further technological fine-tuning.

Keywords Central vein catheter · Double needle · Hemodialysis · Home hemodialysis · Single needle

Introduction

The advent of arterio-venous grafts and fistulae enabled repeated access to the vascular bed for maintenance hemodialysis, precluding a fatal end of chronic end-stage kidney disease. The traditional approach is by inserting two needles, allowing blood purification by continuous blood flow through the dialyzer. However, from those early days on, some clinicians also considered using only one needle.

In the double needle approach, blood saturated with uremic toxins is extracted via one needle, transferred to the dialyzer, brought into contact with dialysate and/or filtered through a semi-permeable membrane, and after purification returned via a second needle, which, if possible, is inserted at some distance of the first needle. In contrast, in single needle dialysis, blood entering and leaving the system follows a common pathway. During the early inflow phase, purified blood that filled the needle during outflow, is reentering the system to be purified once more, hence decreasing the potential for mass transfer and thus removal (recirculation—see below).

In this publication we will review the history and the advantages and limitations of single needle dialysis. It is acknowledged that direct evidence in favor of the single needle strategy is often missing, so that a number of viewpoints in this publication are extrapolated from indirect evidence. Hopefully, this text will stimulate the nephrological community to study modern day single needle dialysis more intensively with the intention to provide a more solid evidence base and further fine tuning this methodology.

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History

The father of modern hemodialysis, Willem Kolff, was one of the first to develop a single needle system [1]. These early systems were however entirely time controlled, resulting in a too fast alternation between inflow and outflow, high recirculation and a lack of adequacy. Somewhat later, partially or entirely pressure regulated systems (pressure–time or pressure–pressure) were developed which allowed a better control of cycle alternation and thus more adequate dialysis [2].

Although single needle dialysis reached a certain level of popularity, especially in Europe, it largely lost its position in the early eighties of previous century. However, in view of recent innovations [3], the concept might be ready for a revival. In this review we will summarize the advantages, limitations, indications and contraindications of single needle dialysis, with attention to both the older and more recent literature.

Single needle dialysis can be performed via one lumen (single lumen single needle) or with two lumens (double lumen single needle), whereby inflow and outflow tract are divided by a central septum separating two semicircular lumens or are positioned coaxially with an inner and an outer circular lumen. Such systems minimize the effect of recirculation (without entirely eliminating it as inflow and outflow remain close), but this decrease in recirculation is offset by blood flow limitations and an increase in shear stress. In addition, needles are thicker than with single lumen, necessitating too much pressure on the skin for perforation [2], enhancing insertion pain and patient discomfort. Also excessive bleeding upon their removal has been reported [2].

In this publication, we will only discuss single lumen single needle dialysis.

Advantages (Table 1)

Needling of small fistulas

Single needle dialysis allows needling of small access systems. Even if in well constructed fistulae flow increases quickly after their creation [4], access problems are frequent in the first 3 months [5, 6]. It may take some time until a segment becomes long enough for double puncture [7], and single needle dialysis allows earlier puncture of maturing fistulae [8, 9].

Likewise, if fistulas remain small because of vascular disease, old age, obesity, or the presence of tortuous veins [10] or if for these reasons an upper arm (brachiocephalic) fistula is installed [11], insertion problems are frequent [7], which can be obviated by a single needle approach. The significance of these difficulties is rising in view of the increasing prevalence of old age and cardio-vascular risk factors among today's dialysis population [12, 13]. Single needle dialysis is however no solution for fistulas without adequate blood flow [2] (see below).

Decreasing the number of fistula punctures

Fistula loss is one of the main factors defining negative outcome of hemodialysis patients [14–16]. Access patency is lost progressively as time since the initiation of dialysis progresses [17] (and the cumulative number of punctures increases). One of the main reasons for fistula failure is their frequent laceration by needling, resulting in stenosis, thrombosis and inadequate flow. Single needle dialysis reduces the number of access punctures by 50%, and concomitantly also decreases the damage to fistula cell layers and the risk of complicated and multiple cannulation procedures [18], which cause pain and stress next to endangering the access system itself [18, 19] (see below).

Table 1 Advantages of single needle dialysis

Characteristics	Remarks
Enables the puncture of small fistulae	Adequate dialysis only possible with sufficient access blood flow
Enables the puncture of maturing fistulae	Adequate dialysis only possible with sufficient access blood flow
Decreases the number of fistula punctures	
Decreases fistula damage and its consequences (thrombosis, stenosis, inadequate flow)	
Decreases the risk of complicated needling procedures (hematoma, infiltration)	
Avoids central vein catheter use	Avoids negative outcomes linked to central vein catheter dialysis
Improves quality of life	
Decreases pain and stress	

Unfortunately, there are no direct comparative fistula survival data between single needle and double needle dialysis, so that we can only rely on indirect arguments.

The daily trial of the Frequent Hemodialysis Network (FHN), primarily compares mortality and left ventricular hypertrophy in standard thrice weekly vs. six times weekly hemodialysis, but one of the secondary analyses assesses the number of access interventions [20]. Although the study was not powered for access problems, a trend for more fistula interventions was observed in the frequent dialysis arm, which by definition implies a double number of access punctures vs. standard, in the same way as double needle vis-à-vis single needle dialysis.

In the dialysis unit of the University Hospital Ghent, all patients without exception were treated with single needle dialysis until the early nineties of last century. In 1987, the experience in this unit was compared to data in other studies on double needle dialysis (hereafter referred to as the Ghent single needle dialysis study) [21], and also contained an assessment of vascular access outcomes compared to contemporaneous studies in double needle dialysis which revealed substantially higher 5-year patency for single needle dialysis [21, 22].

In the probably most direct comparison, fistula complications as illustrated by the need for central vein catheter insertion, investigative access procedures (e.g. fistulagraphy) and missed dialysis sessions, were less frequent with single needle than with double needle dialysis [23].

Avoidance of central vein catheters

When access patency is lost, the only option to continue hemodialysis is via the placement of a central vein catheter. Although this type of analyses does not exclude residual confounding, many observational studies point to an association of catheter dialysis with a negative prognosis as compared to fistula or graft dialysis [14, 15, 24, 25]. In addition, in a group of hemodialysis patients who were all treated by central vein catheters at the beginning of a 6 month observation period, C reactive protein (CRP), a surrogate outcome marker of which an increase of concentration is associated with mortality and cardiovascular events even when in the normal range [26, 27], was high normal [28]. Whereas CRP decreased dramatically in the patients who were switched to a fistula during follow-up, in the subgroup remaining on a catheter CRP even increased slightly, with a significant difference between both study arms at the end of follow-up [28]. Of note, reportedly, none of the catheters in that study was infected during the study course.

In view of this negative outcome potential of central vein lines, single needle dialysis offers several benefits. Not only is it of help to preserve fistula integrity thus allowing safe garding in a preventive way patency and thus avoiding a future need for catheter use when patency would be lost [23] (see above), in addition it may help avoiding catheters during the early maturation process. Moreover, an observational analysis in the context of the Dialysis Outcomes Practice Patterns Study (DOPPS) showed an association between central vein catheter use in the period before first fistula puncture and maturation disturbances [16]. In the recent European Best Practice Guidelines on vascular access, early fistula puncture (after week 2 but before week 4) is suggested as preference if it can help obviating catheter dialysis, and single needle dialysis is proposed as one of the options to make this possible [8, 9].

Improving quality of life

The interest of the nephrological community in patient-centered outcomes and patient empowerment is growing [29]. Quality of life worries related to vascular access mainly are centered on the pain induced by access puncture and fear for painful or disabling complications [30]. Yet, patient-related outcomes were and still are a neglected aspect in clinical hemodialysis access research [31].

Single needle dialysis reduces the number of access punctures by half. Moreover, its impact via reducing puncturing mistakes is likely even more important, as the second puncture usually is more problematic than the first one, especially in small or not yet matured access systems. In addition, the complications generated by these erroneous punctures such as hematoma, infiltration, or thrombosis, as well as the catheter insertion to provide an alternative access and the angioplastic or surgical interventions to correct them or to create a new access system are a source of even more pain and worries. One of the most appreciated vascular access outcomes by hemodialysis patients is a long period without access intervention [30]. Pain reduction is an important bonus point for single needle dialysis. Pain at access puncture is a patient-centered outcome that rarely has been studied. Although access related pain has been identified as highly relevant to patients [32, 33], yet this outcome was studied in only 11% of vascular access trials [31]. In an international survey by Standardized Outcomes in Nephrology (SONG), pain was classified by patients and caregivers as the most frequent access related complication, together with cannulation problems [34] (both 40%). A patient preference for single needle dialysis, because of more comfort and less punctures, has been reported [35].

Limitations (Table 2)

Blood flow

As the direction of blood movement through the access needle is alternated at every cycle, maximum inflow/

outflow for each rotation is about two times higher than the effective flow in the dialyzer. If this maximum flow exceeds or even approaches access flow, this will result in excess recirculation [36], system collapse, interruptions of dialysis due to alarms and/or shear stress related complications (hemolysis, thrombogenicity, dialyzer pore clogging). An effective (mean) flow of ± 300 mL/min is to the best of our knowledge the maximum that has been reached. When in the Ghent single needle dialysis study, effective inlet (arterial) blood flow was measured real time by the bubble method (measuring the volume of displaced blood per time unit from the distance travelled by an air bubble through a long tubing with known dimensions), a value of 284 ± 33 mL/min (n = 76) was found [21]. Of note, this parameter refers to real flow, not peak flow, as the bubble is followed over several pump cycles, progressing each time the pump on its side is rotating, to stop when the alternative pump is activated. In other publications, blood flow rates ranging from 269 to 286 mL/min have been reported [37]. These were mostly obtained with a pressure–pressure regulated system with one motor and two pump heads that was manually calibrated to an optimal stroke volume of about 40 mL per cycle [21]. However, more recent (and more sophisticated) systems seem to reach somewhat lower average blood flows (180–220 mL/min) [3], although this lower value is in some systems compensated by other characteristics that positively affect adequacy (see below).

Single needle dialysis is thus hard to match with very high blood flows. However, the seminal question is whether those high flows are really needed, especially in older patients, who are one of the targeted populations of single needle systems (see below). High blood flows are usually coupled to shorter dialysis sessions, increasing the risk of intradialytic hypotension [38–40] and of vital organ stunning [41, 42], while effective removal is decreased compared to low flow, low efficiency dialysis [43].

In addition, single needle dialysis is no solution for fistulas without adequate blood flow [2], in which case treatment will be inadequate irrespective of the needling system. The problem will be even worse with the single needle option since its high peak flows increase recirculation in case of inadequate access [36].

Table 2 Limitations of single needle dialysis

Characteristics	Remarks
Effective dialyzer blood flow cannot be much higher than 300 mL/min and is often lower	Makes short dialysis sessions difficult *Longer dialysis sessions improve solute removal and are less prone to hypotension and stunning*[a]
Recirculation	Decreases mass transfer and clearance *May occur to a certain extent also in double needle dialysis* *Relative impact of recirculation on clearance is only a fraction of its percent value* *Can if needed be compensated by increasing dialysis length* *Recirculation mainly impacts removal of small water soluble solutes but much less that of "difficult to remove solutes" (middle molecules or protein bound solutes)* *Impact is most important for short dialyses at high efficiency but less on slow low flow extended dialysis (SLED)*
Difficulty to reach recommended Kt/V values	*Can be compensated by increasing dialysis length* *Acceptable values have been reported, especially with the more recent systems*
Frequent alarms	*Can be overcome with appropriate hardware* *Possibly related to dialysis* via *inadequate access systems* *May be limited by experienced personnel*
Hemolysis	*Mainly with older systems* *Partly linked to factors not related to single needle as such (e.g. incorrect tubing insertion in roller pumps)*
Blood flow in the dialyzer is irregular	*Can be overcome with appropriate hardware and system design*
Backfiltration	*Can be avoided by appropriate hardware* *Is no problem with ultrapure dialysate* *May increase dialysis adequacy*
Hemodiafiltration not possible	Essentially a problem with the current dialysis machines *Hemodiafiltration may have less added value for the target population of single needle dialysis*
High venous return pressure	Potentially damaging to the vascular access wall *Not corroborated by (indirect) literature data*
Outcomes are less beneficial	*Reasoning in part based on negative experience with use with inadequate access* *Not corroborated by (indirect) data* Direct comparison with two needle dialysis is missing

[a]Arguments in italics are positive elements partially or entirely counterbalancing the limitations

Recirculation

In view of the common pathway for inflow and outflow blood, recirculation and the ensuing decrease in mass transfer and clearance are unavoidable drawbacks.

The degree of recirculation is lower for double pump systems as compared to the older single pump systems [2]. In addition, also the number of cycles per time unit has a substantial impact: recirculation diminishes as the time taken by one cycle becomes longer [44]. With the older pressure–pressure regulated systems, the number of alternating inflow and outflow cycles was manually calibrated by dialysis personnel. The optimum number was defined as 7–8/min, which combined with a stroke volume of 40 mL resulted in the blood flow of approximately 280 mL/min mentioned above [2]. With appropriate modern software, similar values could presumably be obtained by mimicking electronically the empirical reasoning held previously by the dialysis nurse.

Percent recirculation values with pressure–pressure systems range between 9 and 15% for fistula needles and 14–25% for central vein catheters [2, 21, 45, 46].

However, even double needle dialysis is not free of recirculation, especially if the position of the two needles is close to each other, access flow is not high enough for the flow in the dialysis system or in the presence of downstream access outflow stenosis.

The relative impact of recirculation on clearance is only a fraction of percent recirculation, with a maximum decrease of clearance that should always be lower than the percent value of recirculation per se (Table 3), unless the unlikely possibility would occur that clearance would equal dialyzer blood flow. The clearance decline by recirculation can easily be overcome, if needed, by prolonging dialysis (Table 3).

Recirculation has the most important impact on small and easy to remove molecules like urea, because their clearance is high, so that returned blood for outflow is almost devoid of those solutes, resulting in a maximal negative effect on mass transfer (Table 3A). The loss of removal becomes less important as percentage removal over the dialyzer is less pronounced (Table 3B), with as hypothetical lowest extreme a removal of 0%, whereby the impact of recirculation by definition will also be 0.

This implies that recirculation has less impact on clearance of molecules that are difficult to remove by dialysis (Fig. 1), such as the middle molecules and protein bound solutes, or small water soluble compounds with complex kinetics (Table 3B). In a recent in depth review these solutes composed the majority of uremic solutes with strongly evidenced toxicity [47] (Table 4). Unfortunately, there are not many data corroborating the thesis that single needle dialysis has a low impact on removal of middle molecules as most studies on toxin removal with single needle dialysis go back to an era when only urea and creatinine removal were analysed. However a cross-over study by Rostoker et al. in patients with adequate fistulae assessed predialysis concentration of β_2-microglobulin, a middle molecule, and phosphate, a cardio-vascular and bone toxin with complex kinetics [48, 49], after 1 week of single needle vs. double needle dialysis [50]. No differences for β_2-microglobulin and phosphate between both needling approaches were found, in contrast with urea and creatinine removal and dialyzer ionic dialysance that were lower with single needle dialysis [50]. Nevertheless, one should be careful in comparing predialysis concentrations to clearances and in analyzing an impact on solute concentration already 1 week after system shift, hence this issue needs further study.

In parallel with the impact on molecules with low dialysis clearance, recirculation also can be hypothesized to have less influence in dialysis strategies with low clearance such as low flow extended hemodialysis (Fig. 1). Also this hypothesis is not corroborated by data, though.

Table 3 Impact of recirculation on dialyzer clearance

Recirculation (%)	Decrease clearance (%)	Increase dialysis length (min)[a]
(A) Easy to remove solute ($K/Q_B = 0.7$)		
5	3.6	8.9
7.5	5.4	13.6
10	7.2	18.7
15	11.0	29.7
(B) Difficult to remove solute ($K/Q_B = 0.3$)		
5	1.6	3.8
7.5	2.4	5.8
10	3.2	8.0
15	5.0	12.7

% decrease of clearance was calculated as described in [2] by the formula $[1 - K_R/K].100$ whereby K is dialyzer clearance and K_R a correction factor that is calculated as $K(1 - R)/[1 - R(1 - K/Q_B)]$ whereby R is percent recirculation (as a fraction of 1) and Q_B dialyzer blood flow. Increase in dialysis length was calculated as $240[(1 - DC]$ where DC is the % decrease in clearance (as a fraction of 1)

[a]For 240 min of dialysis to compensate loss of clearance

Kt/V and clearance

Dialyzer urea clearance (K) multiplied by dialysis time (t) and divided by urea distribution volume (V) or Kt/V_{urea}, hereafter named Kt/V, is a universally used but debated indicator of dialysis adequacy [51–55]. Urea dialyzer clearance being one of its main determinants, Kt/V is strongly dependent on dialyzer blood flow and prone to be decreased by recirculation. Hence, the question arises whether appropriate Kt/V values can be obtained with single needle dialysis.

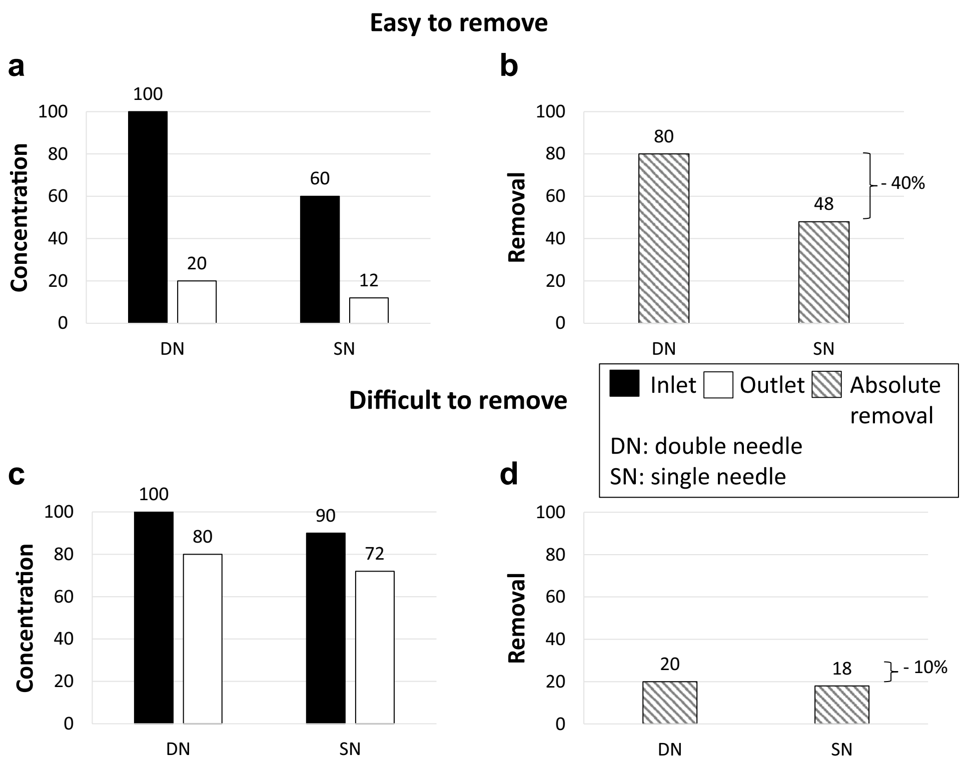

Fig. 1 Effect of double (DN) vs. single needle dialysis (SN) on solute removal. An extreme example with very high (50%) recirculation is shown to highlight differences. Concentration (vertical axis of left panels) and removal (vertical axis of right panels) arbitrarily set at a maximum of 100 (unspecified) units. Upper parts **a**, **b** easy to remove molecules. **a** If inlet concentration (black column) would be at 100 units and dialyzer removal at 80%, outlet concentration (white bar) with double needle (DN) dialysis would be 20. In single needle dialysis (SN) the mixture of both would result in an inlet concentration of 60 (average of 100 + 20). With 80% removal this would give an outlet concentration of 12 units. **b** (Absolute decrease in concentration—hatched bars): this would be 80 (100–20) units with double needle and 48 (60–12) units with single needle. Thus the loss of removal would be by − 40%. Lower parts **c**, **d** difficult to remove molecules. **c** Here removal would be only 20 (100–80) with double needle dialysis and 18 (90–72) with single needle. **d** Absolute removal only shifts from 20 to 18, thus here the difference is only − 10%. As in reality recirculation will be less than 50%, the changes will be less extreme but the proportional differences between easy and difficult to remove molecules will remain the same

Calculation of Kt/V in the Ghent single needle study showed a value of 0.98 (single pool) [21, 35] conform with the threshold that was applicable at that time [56] but lower than the standards proposed nowadays [57]. Apart from the discussion whether Kt/V is a valid parameter of dialysis adequacy [54], those relatively low values compared to today's standards should be seen in the context of the dialysis principles applicable at that time, with relatively short dialysis sessions and small surface area dialyzers containing less efficient membranes than today. In the Ghent single needle study, average dialyzer surface was only 1.17 m^2 for a dialysis length of 3 h and 48 min [21].

In a study comparing double needle dialysis at a blood flow of 250–300 mL/min to two single needle settings (one at effective blood flow of 180 mL/min, and one at 250 mL/min), Kt/V was lower for both single needle approaches (− 33% and − 19% for the respective blood flow strata) [50]. In another study, where mean effective blood flow was 273 mL/min, Kt/V did not differ (1.30 double needle vs. 1.29–1.34 for single needle) [58]. In a cross-over study, a small decrease in weekly Kt/V when switching 4 h double needle dialysis to single needle for the same time length, was turned around into an increase by prolonging dialysis by 30 min (from 1.69 to 1.94) [59]. In another study from the same group, there were no differences in Kt/V irrespective of the needling approach or dialysis length, if thrice weekly dialysis was applied [60]. Finally, in a study with a novel single needle system equilibrated Kt/V (eKt/V) was 1.26 ± 0.29 (see below) [3].

Hence, Kt/V values with single needle dialysis are in general satisfactory, especially with the more recent hardware, or decreases can easily be overcome by minor increases in dialysis length, if desired.

Alarms

Single needle systems are often considered to be difficult to handle because of frequent alarms. This problem can partly

Table 4 Ranking and removal possibilities by dialysis of the uremic toxins with the highest level of toxicity

Molecule	Easy to remove	Difficult to remove	Reasons for difficult removal	Score
P-cresyl sulfate		X	PB, CK	4/7
β_2-Microglobulin		X	MM, CK	4/6
ADMA		X	CK	4/5
Kynurenines		X	PB, CK	4/5
AGEs		X	MM, PB, CK	3/7
Indoxyl sulfate		X	PB, CK	3/6
Uric acid	X			3/6
Ghrelin		X	MM, CK	3/5
Indole acetic acid		X	PB, CK	3/5
Parathyroid hormone		X	MM, CK	3/5
Phenylacetic acid		X	PB, CK	3/5
TMAO	X			3/5

Solutes are ranked in order of evidence of their toxicity, based on [47]. Scoring system based on a maximum score of 4, corresponding to 2 points for experimental evidence and 2 for clinical evidence. Only solutes with a score of 4 and 3 are listed and per score they are further ranked based on the number of organ systems that are toxically affected. Score: total evidence (maximum: 4)/total number of affected organ systems (maximum: 10) [47].Twelve toxins out of 69 reviewed were considered highly toxic, of which 10 (83%) are difficult to remove, either because they are middle molecules (MM), protein bound (PB) or have complex kinetics (CK). Phosphate is not mentioned as the analysis [47] considered only anorganic toxins. However, phosphate could also be classified as toxic and with complex kinetics [48, 49]

AGEs advanced glycation end products, *ADMA* asymmetric dimethyl arginine, *TMAO* trimethylamine-*N*-oxide

be related to the use of this strategy with inadequate access systems and partly to limitations in the possibilities for the personnel to acquire sufficient expertise because these systems are often used only sporadically. Modern software may enable to overcome such problems [3].

Hemolysis

Hemolysis with single needle dialysis has essentially been reported in older studies and is attributed to the peak blood flow rates inducing shear stress in the needles, but also to incorrect adjustment of the tubings in the blood pumps, which is not specific for single needle dialysis [2, 61]. The fact that hemolysis occurred in only some of the studied dialysis sessions or not at all, suggests that hemolytic episodes were not related to single needle dialysis per se but to occasional factors. Not all single needle systems gave the same degree of hemolysis [61]. In a study with one of the earliest time regulated systems, no differences in free hemoglobin in plasma were found before and after hemodialysis with single needle vs. double needle dialysis, in spite of the high number of alternating cycles per unit of time [1].

More recent studies report no clinical hemolysis [3, 6], no differences in LDH between single needle and double needle dialysis [59, 60], and no differences in serum haptoglobin [50]. However, as some of these studies were not undertaken with up to date equipment and all of them contained no comprehensive assessment of hemolysis markers, and in view of the toxicity and pro-inflammatory effect of free hemoglobin and heme [62, 63], this issue warrants further study.

Backfiltration

The push–pull of the classical single-needle systems resulting in alternating positive and negative pressures in the dialyzer also induces an alternation of positive ultrafiltration and backfiltration. This might result in filter clogging but also in increased adequacy due to compulsory hemodiafiltration, and in spilling of dialysate content into the blood stream. The latter is however only a problem with contaminated and not with ultrapure dialysate.

Hemodiafiltration

It is generally not possible to combine single needle dialysis with hemodiafiltration with the current dialysis machines, which usually contain two pumps, whereby the second pump is used either for infusion of substitution fluid in hemodiafiltration or for the single needle approach. This does not preclude that both strategies can be combined as it was possible to perform hemodiafiltration with the old pressure–pressure modulated devices [21]. Irrespective of this technical discussion and the contradictory outcomes of controlled studies assessing survival outcomes with hemodiafiltration [64–67], one may wonder whether hemodiafiltration would be of much added value or even possible in the populations that according to this paper have most benefit from single needle dialysis, i.e. the elderly, those with cardio-vascular problems, patients with small and/or developing access systems, and home hemodialysis patients.

High venous return pressure

In view of the higher maximum blood flows than with two needle dialysis, return pressures in the access system might also be higher, which has the potential to damage the access system. This drawback might neutralize the positive potential of a more limited number of punctures (see above). However, the historic literature data we have available comparing access outcomes with single needle versus two needle dialysis do not point into this direction [21, 22] (see above).

Outcomes

There are virtually no data directly comparing outcomes with single needle dialysis to alternative strategies.

Before Kt/V was conceptualized, the time averaged urea concentration (TAC) over 1 week was used as a marker for dialysis adequacy. The relation of this parameter with outcome had been assessed in the first randomized controlled trial (RCT) in dialysis, the USA National Collaborative Dialysis Study (NCDS), in which it was shown that the groups targeted to a lower TAC of urea had a better primary outcome which was hospitalization rate [68]. The study was insufficiently powered to find differences in mortality. Hospitalization rate in the Ghent population on single needle dialysis, was similar as in the low TAC_{urea} groups of the NCDS study [21]. Also TAC_{urea} values were equivalent to the target values imposed by the NCDS in the low TAC $_{urea}$ groups with better outcomes [68]. Favorable outcomes with low TAC_{urea} however necessitate a sufficient urea generation (equivalent to protein intake), as patients with low TAC_{urea} with low protein intake had worse outcomes [68]. In the Ghent single needle population, urea generation was assessed by two independent methods, and again appeared conform the thresholds suggested by the NCDS [21, 68].

In a comparison of survival of patients in the Ghent single needle study versus contemporaneous data from the registry of the European Renal Association-European Dialysis and Transplant Association (ERA-EDTA) which supposedly contained a large majority of patients treated with double needle dialysis, outcomes of single needle dialysis were at least as good (and in fact better) [21]. However, even if the positive result was striking, one should be careful when comparing a single center with dedicated personnel to registry data where all kinds of centers in various countries with different policies and philosophies are included. However, in the comparison with the NCDS discussed above [21, 68], the comparator was a population enrolled in an RCT, which are in general also patients subjected to careful follow-up.

Overall, these data suggests that if single needle dialysis is carefully performed and not based on a selection of patients with insufficient access blood flows, outcomes can be similar to classical double needle dialysis.

Technical alternatives

Most modern hemodialysis machines contain an option allowing single needle dialysis. Such systems are usually conceived with pressure–pressure or pressure–time regulated switch systems. Conceptually they are not different from those used several decades ago, only they are steered by software more than by human skills. Mostly the inherent software makes such systems easy to apply and removes the pressure upon the nurses to manually seek optimal adequacy, although this might come at the expense of somewhat lower dialyzer blood flows.

For several decades, the systems remained conceptually the same. Only recently, a modified alternative became available [3], using a switch system, arterial and venous expansion chambers, automatic regulation of blood flow and one single pump. This allows to keep flow through the dialyzer constant and to avoid the clearance time loss of the traditional systems, with which flow has to build up from stand still to a maximum, each time an alternating pump starts turning. This technical modification allowed a gain in blood volume crossing the dialyzer by 35.8% and in dialyzer blood flow by 21.9% compared to the usual single needle systems [3]. As flow within the dialyzer is continuous instead of tidal, this could possibly impose less shear stress, and decrease the risk of hemolysis, thrombogenicity, and membrane pore clogging by protein and cellular debris. Although the latter probably results in better removal capacity, data on removal of middle molecules and protein bound solutes with this novel system are unfortunately not available. Avoiding tidal flow may also prevent backfiltration.

Conclusions

Single needle hemodialysis has for several decades been neglected as an alternative hemodialysis strategy but is making its reappearance, due to the recent introduction of alternative technical options next to a clinical necessity due to a gradual change in the epidemiological mix of the dialysis population. It offers a possibility for tailored, personalized dialysis and is especially suited for patients with small or maturing fistulae at the prerequisite that access flow is sufficient, for those with pain at puncturing or fear for it, or as an option to avoid central vein catheter dialysis. Basically, however, this method is a valid option for every dialysis patient, as long as fistula flow is well enough, with as additional benefits less damage to the access system and better patient quality of life. Single needle dialysis seems especially suited for geriatric patients, in whom fistulae may be smaller and maturation slower than in the rest of the dialysis population and quality of life as a concern largely prevails on other aspects like hard outcomes. Another condition for which this technique seems specifically suited is home hemodialysis, where length of dialysis is less of a constraint, while easier and less strenuous access punctures may offer an extra benefit for the patient or his/her partner.

Two potential drawbacks are that dialyzer blood flow cannot exceed a certain maximum and that Kt/V according to some may remain below threshold. Whereas the limited blood flow may also turn into an advantage as it optimally will result in a slower and more extended dialysis, Kt/V can easily be corrected by slightly increasing dialysis length, if needed. The question should however be raised whether a non-evidenced outcome marker such as Kt/V [54] should prevail over the duty to provide personal comfort, access survival and regular dialysis delivery.

A consideration for the future may be that software and system design could be further modified, so as to reach by automated means what was possible at the time by manual adjustment and expertise. In addition, more research is needed to analyze the currently available systems more in depth and to conform available knowledge with the current views on uremic toxicity and toxin removal, with a special need for direct data showing the impact on middle molecule and protein bound solute concentration. Other interesting research topics are the mechanistics of toxin removal by imposing different conditions of flow and stroke volume, which might emanate in a further finetuning of removal capacity.

Compliance with ethical standards

Conflict of interest Raymond Vanholder received travel support and speakers honoraria from BBraun.

Ethical approval This article does not contain any studies with human participants performed by any of the authors.

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