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The Effect Of Increasing Dialysate Flow Rate In Hemodialysis

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Abstract

Hemodialysis is a technique of removing, or "clearing", solutes from the blood and removal of extra fluid from the body, by using dialyzing machine and a dialyzer which is also known as (artificial kidney). The principle of hemodialysis is, primarily, the diffusion of solutes across a semipermeable membrane and ultrafiltration for removal of extra fluid.
The purpose of this study is to demonstrate the effect of increasing nominal dialysate flow rate from 500 ml/min to 800 ml/min on the amount of the small solutes (urea) removed from the blood and examine its effect on the amount of dialysis delivered.
In this study the in vivo effects of increase in dialysate flow rate on the delivered dose of dialysis studied on 28 maintenance hemodialysis patients.
Hemodialysis was performed at dialysate flow rates 500 and 800 ml/min. The patients treated two times per week for 3 hours. The results show increase in urea clearance and dialysis adequacy, and a significant increase in the urea difference between pre- and post-blood urea concentration by increasing dialysate flow rate from 500 to 800 ml/min.

It can be concluded that hemodialysis with dialysate flow rate 800 ml/min should be considered in selected patients not achieving adequacy despite extended treatment times and optimized blood flow rate. And increasing nominal dialysate flow rate from 500 ml/min to 800 ml/min alters the mass transfer characteristics of hollow fiber hemodialyzer and results in a larger increase in urea clearance.

Keywords: ***Biomechanics, Hemodialysis, kidney, dialysate.***

1. Introduction

Dialysis is a treatment for people who are in late stage of chronic renal insufficiency (kidney failure).
The choice for a patient who reaches the point where renal function is insufficient to sustain life is: (1) Chronic dialysis treatments (either hemodialysis or peritoneal dialysis), (2) Renal transplantation, (3) Death.
Dialysis is a temporary treatment. This treatment requires for removing toxic waste products and excess water from the body, and restoration of body fluid volume and composition toward normal. This can be accomplished by dialysis with an artificial kidney.
There are two forms of dialysis: Hemodialysis and Peritoneal dialysis. In hemodialysis, the blood is passed through an artificial kidney machine to clean it. Peritoneal dialysis uses a filtration process similar to hemodialysis, but the blood is cleaned inside the body rather than in a machine.
Hemodialysis uses a dialyzer, or special filter to clean the blood. During treatment, the blood travels through tubes into the dialyzer. The dialyzer filters out wastes and extra fluids. Then, the newly cleaned blood flows through another set of tubes and back into the body.
The major components of the hemodialytic process are: (1) The artificial kidney or dialyzer, (2) The delivery system, which is the mechanical device that pumps the patient's blood and the dialysate through the dialyzer, (3) The dialysate, the fluid having a defined chemical composition used for solute clearance. The variables of the hemodialysis procedure that may be manipulated by the physician on the basis of the clinical needs of the

patient are: Blood and dialysate flows, which influence solute clearance, Type of dialyzer, which determines solute clearance and ultrafiltration capacity, Hydraulic pressure, which drives ultrafiltration, Dialysate composition, which influence solute clearance, Duration and frequency of the dialysis procedure, which determines the solute clearance, and Intensity of anticoagulation.

Special training is needed for self-care or home hemodialysis. Each type of dialysis has strengths and limitations. The healthcare team can provide information and support to help the patients understand all the options and answer any questions that the patients may have. 1

The dialysis care team will test the patient's blood to establish the adequacy of dialysis by using one of two formulas: Urea reduction ratio (URR) and the single pool urea kinetic model, utilizing (Kt/V); is widely used to help assess the adequacy of hemodialysis. 2

The Kt/V value represents dialyzer clearance (K), distribution volume of urea (V), and dialysis duration (t)3, to see whether the treatments are removing enough wastes. The Kt/V is more accurate than the URR in measuring how much urea removed during dialysis, primarily because the Kt/V also considers the amount of urea removed with excess fluid. All tests look at one specific waste product, called blood urea, as an indicator for the over all level of waste products in the system.4

2. Experimental work

Materials, Instruments, and Equipments

1. Blood samples for blood urea measurement must be drawn in a particular manner. Pre-dialysis blood urea samples should be drawn immediately prior to dialysis. Post-dialysis blood urea samples should be drawn using the stop pump technique.
2. Concentrated solutions are Acetate; which are the group of concentrated solutions for HD.
3. Rinsing solutions are 0.9% NaCl for rinsing and priming of the tubing system as well as for washing back the remaining blood in the tubing set at the end of dialysis.
4. The dialyzer used is a capillary dialyzer of type Fresenius Polysulfone® Low-Flux dialysers; UF 4.0.
5. Three types of dialysis machine are used in this study: Fresenius Medical Care 4008B, Gambro AK 10 Ultra, and Altratouch 1000 (Althan), dialysis apparatus. Where Fresenius and Althan are a computerize machine, while Gambro is a manual one.
6. Disposable needles to draw the blood from the patients.
7. Tubes used to collect the blood sample for laboratory tests.

3.Methods

3.1. Patients treatment

The patients were treated with HD for the following parameters: the dialysis session time (t) was unchanged (3 hours, 180 min) from machine start to machine stop; and the blood flow rate ranged from 150, 180, 200, 220, 250, 280, 300 ml/min. The patients were divided into two groups according to the dialysate flow rate: the first group use standard dialysate flow rate (500ml/min) and the second group used dialysate flow rate (800ml/min). 5

A blood samples have been drawn from the patients weekly at the beginning of dialysis session (Pre-dialysis), and at the end of dialysis (Postdialysis) immediately and after the blood pump was stopped 6, (Co) and (Ct) respectively. A standard laboratory processing of blood urea samples used for measuring: Blood Urea, Serium Creatinine, Potassium (K+), Sodium (Na), hemoglobin (HB), and hematocrit (PCV),7 while other data obtained either from the patients or from the machine such as: the age, duration, frequency, patients weight before and after dialysis, the conductivity and the temperature of dialysis fluid, and the transmembrane pressure (TMP), are routine data obtained with any dialysis treatments according to the data sheet.

3.2. Blood sample testing

To see whether the dialysis session was removing enough urea from the blood, we tests a patient's blood was tested to measure the concentration of urea pre- and post-dialysis session; we see that the blood at the end of dialysis will have a lower concentration of waste products (urea) than the blood at the beginning of dialysis session. The levels of urea in the two blood samples are then compared 8, by determined the difference between them (Ud), for the two groups of dialysate flow rate 500 and 800 ml/min. 9

$$Ud = Co - Ct \qquad (1)$$

Where Co and Ct are pre- and post-dialysis urea concentration respectively.

Other calculations, as blood water urea clearance (Kw), the dose of dialysis (Kt/V) and urea reduction ratio (URR), for each patient for both groups are used 8. All tests look at one specific waste product the urea, as an indicator for the overall level of waste products in the system 4.

Clearance is defined as the amount of solute removed from the blood per unit time, divided by the incoming blood concentration represents the volumetric rate of removal multiplied by given blood flow. 10

$$K_w = \frac{Q_{BW} \times (C_o - C_t)}{C_o} \qquad (2)$$

The national kidney foundation's kidney disease outcomes quality initiative (K/DOQI) recommended using the Daugirdas second-generation formula for calculating the delivered dialysis dose Kt/V (both single pool and equilibrated). 6, 7

The value for the single-pool Kt/V (spKt/V) calculated according to the Daugirdas second-generation formula [6, 11, 12]:

$$spKt/V = -\ln(Ct/Co - 0.008 \times T) + (4 - 3.5Ct/Co) \times UF/Wt \qquad (3)$$

Where Co, Ct start and end session urea concentration, T treatment time (hours), UF intradialytic weigh loss (kg), and Wt end session body weight (kg).
The HD dose should be expresses in terms of equilibrated Kt/V (eKt/V) which can be determined by using Daugirdas correction formula, have been developed from a single-pool Kt/V Daugirdas (spKt/V): 6, 12

$$eKt/V = spKt/V(1 - 0.6/T) + 0.03 \quad (4)$$

The reduction in urea as a result of dialysis, or the URR, is one measure of how effectively a dialysis treatment removed waste products from the body. URR stands for urea reduction ratio, but it is commonly expressed as a percentage. 8
The URR is computed as: 8

$$URR = \frac{100 \times (\text{Initial level} - \text{Postdialysis level})}{\text{Initial level}} \quad (5)$$

or

$$URR = \frac{100 \times (Co - Ct)}{Co} \quad (6)$$

Kt/V and urea reduction ratio URR% are generally used to assess dialysis adequacy or dialysis efficiency. 12

3.3. Mathematical calculations

The mathematical calculations for the equations above (Ud, Kw, spKt/V, eKt/V, and URR) have been done by using a personal computer with specific software programs for math work. The first program used was: Mat Lab version 6.5 for the calculation and the second was: Microsoft office Excel 2003, used to express the results as arithmetic mean and standard deviation, and for determined charts for the results obtained.

3.4. Statistical analysis:

The statistical methods, which were used to analyze and assess the result, were:

A. Descriptive statistics

- Arithmetic mean.
- Standard deviation.
- Statistical tables.
- Graphical presentation.

B. Inferential statistics

This includes statistical analysis of data by using "Student's t-test" for each patient to determine the comparative significant difference between the two groups that determined in this study. The differences with P value < 0.05 were considered as statistically significant.

4. Results

The results of patients with dialysate flow rate = 500 ml/min and with blood flow rate 150, 180, 200, 220, 250, 280, 300 are shown in table (1).
While the results of patients with dialysate flow rate = 800 ml/min are shown in table. 2
From the results, it is to be noted that there is an increase in the mean with an increase in dialysate flow rate from 500 to 800 ml/min, as shown in figures from (1) to (10).
Statistical analysis of the data of urea difference, by using student t-test, revealed that there was a statistical significant difference in the increment in mean of urea difference values between the patients with dialysate flow rate 500 ml/min and patients with dialysate flow rate 800 ml/min, as shown in table (3).

Table (1) Mean effect of patients with dialysate flow rate = 500 ml/min

Blood flow rate (ml/min)	Test	Mean	SD
150	Urea difference	33	2.8284
	Kw	28.341	3.4429
	URR	21.89	2.509
	spKt/V	0.3152	0.0327
	eKt/V	0.2822	0.0261
180	Urea difference	40.1	2.687
	Kw	49.397	6.1352
	URR	31.903	3.2717
	spKt/V	0.4519	0.0635
	eKt/V	0.3915	0.0508
200	Urea difference	51	1.4142
	Kw	67.731	31.282
	URR	37.872	17.152
	spKt/V	0.5864	0.253
	eKt/V	0.4991	0.2024
220	Urea difference	55.3	1.1314
	Kw	65.898	4.3084
	URR	34.06	2.0145
	spKt/V	0.4899	0.0501
	eKt/V	0.4219	0.0401
250	Urea difference	57.55	0.495
	Kw	70.688	9.5396
	URR	31.74	4.4406
	spKt/V	0.5001	0.1446
	eKt/V	0.4301	0.1157
280	Urea difference	60.3	1.8385
	Kw	88.676	3.6579
	URR	37.357	2.064
	spKt/V	0.5463	0.0198
	eKt/V	0.4671	0.0158
300	Urea difference	65.15	3.0406
	Kw	97.118	4.9243
	URR	37.339	1.8936
	spKt/V	0.5734	0.0628
	eKt/V	0.4887	0.0503

Table (2): Mean effect of patients with dialysate flow rate = 800 ml/min

Blood flow rate (ml/min)	Test	Mean	SD
150	Urea difference	39.25	1.0607
	Kw	47.2	6.9954
	URR	36.245	5.3111
	spKt/V	0.5438	0.0658
	eKt/V	0.4651	0.0526
180	Urea difference	51.62	5.8266
	Kw	54.303	0.9278
	URR	34.833	0.3026
	spKt/V	0.5268	0.0232
	eKt/V	0.4515	0.0185
200	Urea difference	56.3	1.8385
	Kw	69.09	19.144
	URR	39.715	11.717
	spKt/V	0.6319	0.2743
	eKt/V	0.5355	0.2194
220	Urea difference	62.6	2.2627
	Kw	67.999	2.446
	URR	34.3	0.5084
	spKt/V	0.4918	0.0297
	eKt/V	0.4431	0.0153
250	Urea difference	67.3	1.8385
	Kw	80.897	4.5156
	URR	37.506	3.1869
	spKt/V	0.5506	0.0839
	eKt/V	0.4705	0.0672
280	Urea difference	70.9	0.7071
	Kw	114.65	33.896
	URR	47.966	15.133
	spKt/V	0.8177	0.3418
	eKt/V	0.6842	0.2734
300	Urea difference	77	4.2426
	Kw	113.42	8.4429
	URR	44.06	2.2903
	spKt/V	0.712	0.0029
	eKt/V	0.5996	0.0023

Table (3): Student t-test between the two rates of dialysate flow 500 ml/min and 800ml/min on urea difference values

Blood flow rate (ml/min)	Test	Mean	SD
150	**Urea difference**	**2.93**	*
180	**Urea difference**	**3.01671**	*
200	**Urea difference**	**3.23147**	*
220	**Urea difference**	**4.08**	*
250	**Urea difference**	**7.2421**	*
280	**Urea difference**	**7.61036**	*
300	**Urea difference**	**3.21063**	*

α = 0.05
* = Significant.
t-tab = 2.920

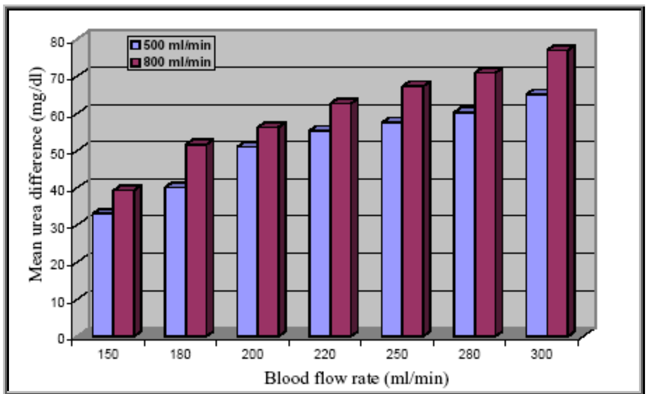

Figure (1) Histogram for the effect of increase in dialysat flow rate from 500–800 ml/min on the mean urea difference

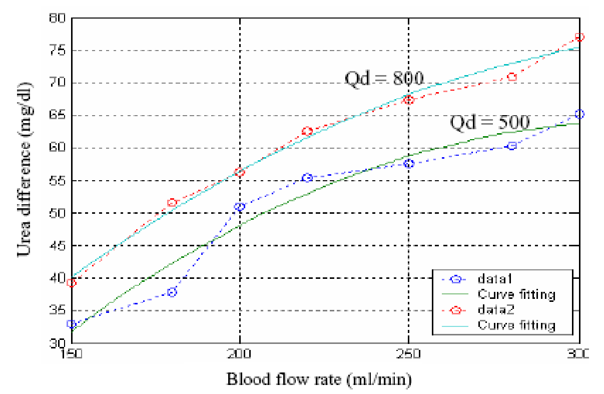

Figure (2) The effect of increase in dialysate flow rate from 500–800 ml/min on the urea difference

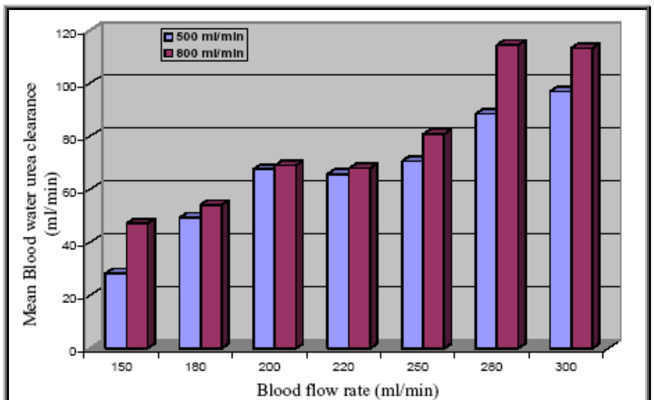

Figure (3) Histogram for the effect of increase in dialysat flow rate from 500–800 ml/min on the mean Blood water urea clearance

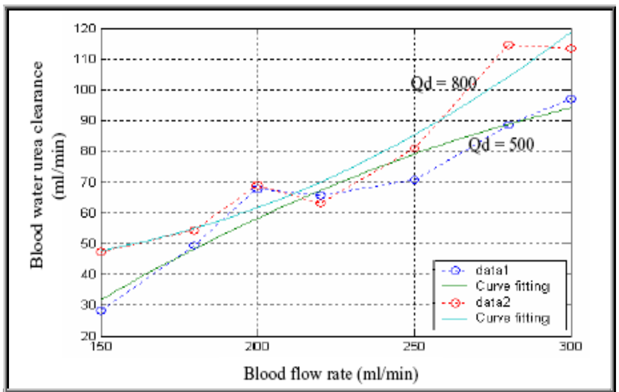

Figure (4) The effect of increase in dialysate flow rate from 500–800 ml/min on the Blood water urea clearance

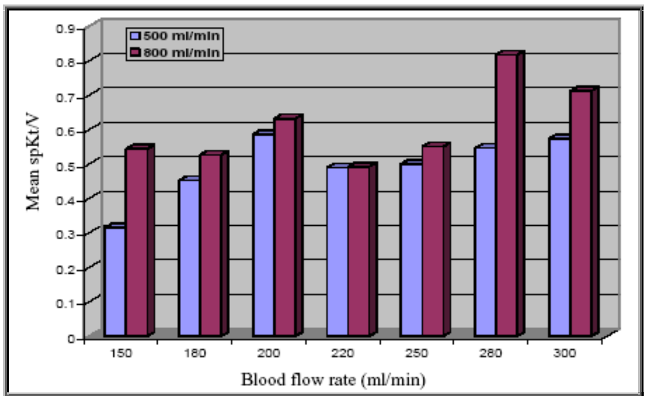

Figure (7) Histogram for the effect of increase in dialysat flow rate from 500–800 ml/min on the mean spKt/V

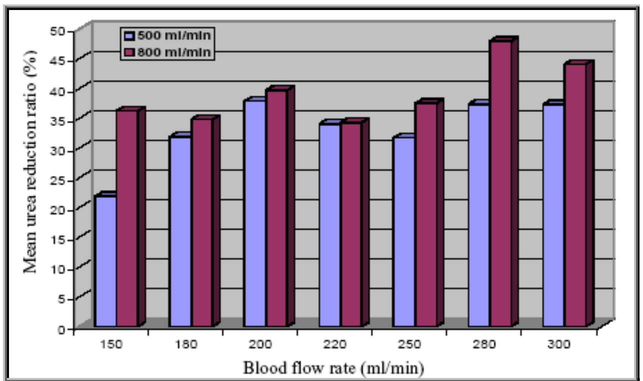

Figure (5) Histogram for the effect of increase in dialysat flow rate from 500–800 ml/min on the mean urea reduction ratio

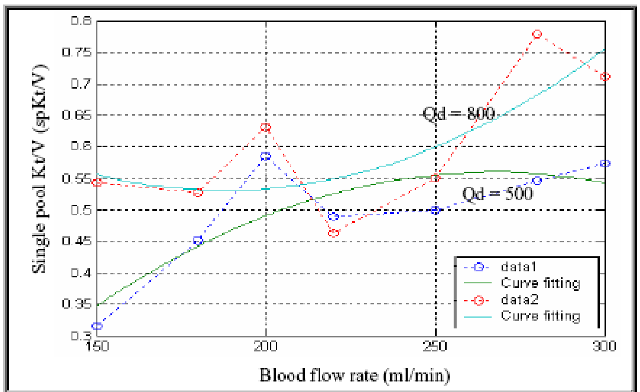

Figure (8) The effect of increase in dialysate flow rate from 500–800 ml/min on the spKt/V

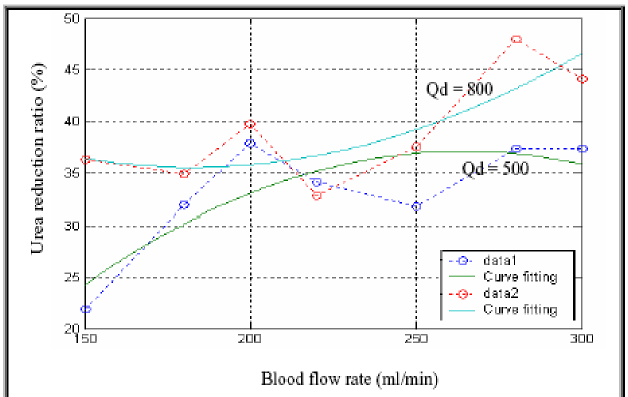

Figure (6) The effect of increase in dialysate flow rate from 500–800 ml/min on the urea reduction ratio

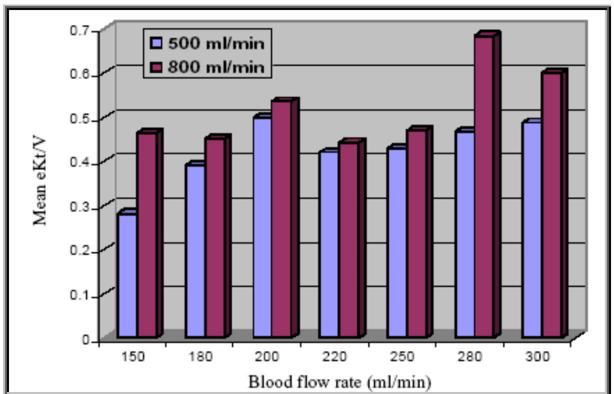

Figure (9) Histogram for the effect of increase in dialysat flow rate from 500–800 ml/min on the mean eKt/V

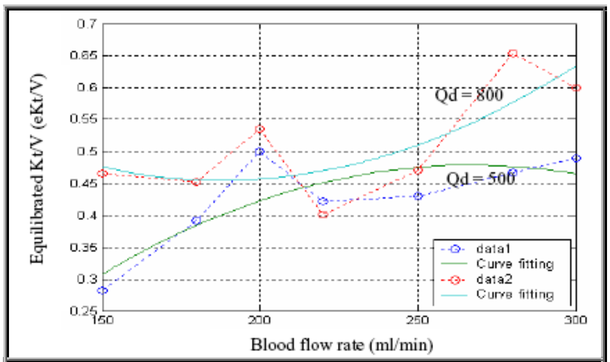

Figure (10) The effect of increase in dialysate flow rate from 500–800 ml/min on the eKt/V

5. Discussion

The principle of hemodialysis is the same as other methods of dialysis, in that it involves diffusion of solutes across a semipermeable membrane. Hemodialysis utilizes counter-current flow, where the dialysate is flowing in the opposite direction to blood flow in the extra-corporeal circuit, a maximal concentration gradient is achieved in this manner. This maintains the concentration gradient across the membrane at a maximum, allowing the dialysis to be very efficient. Fluid removal (ultrafiltration) is achieved by altering the hydrostatic pressure of the blood compartment, causing free water to move across the membrane along a pressure gradient. 13

Solutes are transported across this membrane by two different mechanisms: either diffusion or convective flux. In diffusive solute transport, solutes move across the dialysis membrane in a direction dictated by the concentration gradient established across the membrane of the hemodialyzer, from a higher plasma concentration (Cp) to a lower dialysate concentration (Cd). During hemodialysis water moves from blood to dialysate driven by a hydrostatic pressure gradient between blood and dialysate compartments (the pressure in the blood compartment of the dialyzer is positive and the pressure in the dialysate compartment is usually negative and can be reduced as low as possible,14 by generation of negative hydraulic pressure on the dialysate side of the dialyzer, 13 a process referred to as ultrafiltration. Movement of water tends to drag solute across the membrane, a process referred to as convective transport. 15

We also discuss the effect of increase the dialysate flow rate on the clearance of urea. The diffusive clearance of a solute is directly proportional to the dialysate flow. This relationship is linear for dialysate rate up to 500 ml/min; faster flows cause more turbulence in the dialysate compartment. So dialysate flows up to 800 ml/min will enhance diffusive clearance.

A faster dialysis solution flow rate increases the efficiency of diffusion of urea from blood to dialysate. The usual dialysis solution flow rate is 500 ml/min and a faster flow rate is 800ml/min.

In addition, low in dialysate flow rate result in nearly complete saturation of the effluent dialysate with respect to urea. So higher dialysate flow 800 ml/min maintains a higher concentration gradient for diffusion of urea, and therefore, the urea clearance rate is higher. 16 The urea clearance increase with increase in dialysate flow rate up to 800 ml/min, thus the net rate of transfer of a given solute (urea) from the blood side to the dialysate side will be greatest when the concentration gradient between the two solutions for that particular solute is highest. Secondary, there was a reduction in the overall mass transfer resistance with an increasing dialysate flow rate. This reduction is attributed to the presence of turbulence in the dialysate pathway at higher flow rate 16. The presence of such turbulence produces rapid variation of pressure, thus the small solutes moves from the blood to dialysate in the dialyzer as a result of a hydrostatic pressure gradient between the blood and dialysate compartments. The rate of ultrafiltration will depend on the total pressure across the membrane 17. The results in table (3) shown significant difference in amount of urea removed from the blood and these data demonstrate that increasing nominal dialysate flow rate 500 to 800 ml/min alters the mass transfer characteristics of hollow fiber hemodialyzer and results in a larger increase in urea removed (clearance). 6

6. Conclusions

The conclusions that can be drawn from this study are: the diffusive clearance of a solute is directly proportional to the dialysate flow, and the mean increasing rate of dialysate flow allows faster removal of the toxins that are being cleared.

An understanding of the importance of the increase in dialysate flow rate should assist clinicians as they try to reach adequacy dialysis, particularly in those patients in whom this adequacy is difficult to attain.

Also it can be concluded that dialysis membrane permeability (or flux) is a dialyzer property that influences the dependence of small-solute clearance on dialysate flow rate.

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تأثير زيادة معدل جريان سائل التحليل في عملية الغسل الكلوي الدموي (الديلزة)

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الخلاصة

الديلزة هي إحدى التقنيات لإزالة أو تنظيف المواد المذابة في الدم، وأيضاً إزالة السوائل الزائدة من الجسم، باستخدام جهاز التحليل والمحلل والذي يعرف أيضاً بـ(الكلية الصناعية). إن مبدأ الديلزة يعتمد في الأساس على انتشار المواد المذابة عبر غشاء ذو نصف نفاذية والترشيح الفائق لإزالة السوائل الزائدة.

عند الغسل الكلوي الدموي (الديلزة)، يُضخ الدم من الجسم إلى مرشح خاص (المحلل) مكون من أنابيب شعرية بلاستيكية صغيرة جداً. يتم تنقية الدم عند انتشار المكونات المهملة من الدم عبر غشاء الأنابيب الشعرية إلى سائل الديلزة. ويعاد الدم المنقى ثانية إلى الجسم والسائل المستهلك يتم صرفه.

تهدف هذه الدراسة لبيان تأثير زيادة معدل تدفق سائل الديلزة من ٥٠٠ مليلتر/دقيقة إلى ٨٠٠ مليلتر/دقيقة على مقدار المواد المذابة الصغيرة (اليوريا) التي أزيلت من الدم، وفحص ودراسة هذا التأثير على كمية الغسل الكلوي (الديلزة) الموفرة للمريض.

تم في هذا البحث دراسة التأثيرات داخل الجسم عند زيادة معدل تدفق السائل على كمية الغسل الممنوحة لثمانية وعشرين مريضاً معتمدين على الكلية الصناعية، حيث تم التحليل لمعدلات تدفق ٥٠٠ و ٨٠٠ مليلتر/دقيقة. أظهرت النتائج زيادة في إزالة اليوريا وعلى كمية الديلزة المستفادة من قبل المريض. ووجود زيادة ملحوظة في فرق التركيز لليوريا في الدم قبل وبعد الغسل الكلوي الدموي عند زيادة معدل تدفق سائل الديلزة من ٥٠٠ إلى ٨٠٠ مليلتر/دقيقة.

يستنتج من ذلك، ان عملية الغسل الكلوي الدموي (الديلزة) بمعدل تدفق سائل الديلزة ٨٠٠ مليلتر/دقيقة يجب اعتباره في المرضى الذين لم يحصلوا على الغسل الكلوي الكافي بالرغم من علاج زمني مستمر ذو معدلات تدفق دم فضلى، وأن زيادة معدل تدفق سائل الديلزة من ٥٠٠ إلى ٨٠٠ مليلتر/دقيقة يغير خصائص إنتقال المواد في جهاز التحليل (المحلل) وينتج زيادة أكبر في التخلص من اليوريا.