

## Hemodialysis in Children: A Simplified Approach.

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**Abstract:** Hemodialysis in children has benefited from major progress over the last 20 years. The morbidity of the sessions has decreased, even disappeared, seizures being exceptional, hypotensive episodes or headaches rare, and pain related to the fistula puncture effectively prevented by xylocaine ointment. The development of urea kinetic modeling enables calculation of the dialysis dose and indirect assessment of protein intake, nPCR. Even if the validity of these values is questioned their combined analysis provides an assessment and therefore is a "good thing". The patient also benefits from the technological revolution. The newer machines enable precise control of ultrafiltration volumetric assessment and continuous blood volume monitoring during the session, buffered bicarbonate has become a standard technique, synthetic more biocompatible membranes and specific material available for babies/infants have been developed. Non invasive intervention, for example blood volume guided ultrafiltration have provided more adequate dialysis sessions and better dry weight assessment. Last, the availability of erythropoietin and of growth hormone and the promising results from enhanced dialysis dose on both growth and cardiac function, all give the dialyzed child a real increased quality of life. In theory, reduction of dialysis prescription to only a urea dialysis dose achieved by three short (3-h) dialysis sessions, should be abandoned for long term dialyzed children and replaced by optimum dialysis obtained with longer (4 and more hours) and/or more frequent (daily: 5 to 6) sessions. But for such a daily dialysis strategy all the costs must be considered. On the one hand the financial cost cannot be neglected.

### INTRODUCTION

Traditionally peritoneal dialysis (PD) has been the preferred modality of dialysis in children. However with advances in technology, hemodialysis (HD) has rapidly gained popularity. During the past two decades there have been many improvements in the technology: bicarbonate used as buffer in the dialysis solution, volumetrically controlled ultrafiltration, smaller dialysis lines and synthetic membranes useful even for babies, modeling of ultrafiltration rate and dialysate composition, on line hemodiafiltration and the concept of ultrapure dialysate, i.e. sterile and pyrogen free. Non invasive technologies to assess patient target dry weight and access flow offer a potential decrease in dialysis morbidity and costs. Recently marketed medications to improve anemia, for example erythropoietin and iron infusion, contribute to the clinical improvement of the hemodialysis session.

### INDICATIONS FOR HD

In some European countries hemodialysis (HD) is often preferred for children over the age of five years. HD is not offered to children less than 5 years old unless there are important contra-indications for PD [1]. For older children HD is applied for drop-outs from the PD program or if there are medical (rare) or psychosocial (more often) reasons for not performing PD. In contrast, peritoneal dialysis (PD) is offered to the younger children especially under the age of two years or weighing less than 10 kg. A multicenter European study has, found that factors ranked as first priority for choice of therapy included age of the child (30%), parent choice (27%), distance from unit (14%), patient choice (11%), social condition (7%), and unable to do one mode (6%). Choosing a mode of dialysis, either HD or PD, for a child requires consideration, among other factors, of the probable impact of either mode of dialysis on the maintenance of residual renal function (RRF), because of its specific impact on patient outcome. Although there is no general consensus, peritoneal dialysis has been associated with less risk of RRF loss. Overall the choice of the mode of dialysis is just a part of the integrated care model, each child should be considered for a combined dialysis-transplantation program.

### IMPORTANT CONSIDERATIONS FOR HD IN CHILDREN

1. Provision of adequate vascular access remains the single greatest

obstacle to successful HD, especially in infants. Unlike in the USA, where patients frequently use a central catheter for vascular access, in Europe an arteriovenous fistula is the most common vascular access for chronic/long term dialysis. According to the K-DOQI guidelines, the percentage of catheters in a dialysis unit for adults should be less than 10%, although many pediatric centers do not meet this standard, because of the difficulty of creating fistulas in smaller children, especially in children less than 2 years of age.

2. Dialysis adequacy quantification by urea kinetic modeling enables a more specific approach to dialysis dosing and indirect assessment of protein intake, despite the limited value of small-solute clearance. Nevertheless, it has been widely accepted that clinical results depend at least in part on the dialysis dose delivered. In fact, a single center experience shows the beneficial impact of longer dialysis duration on clinical outcome in children. In children the hemodialysis prescription should be individualized. Choice of the mode of hemodialysis should take into account the presumed waiting time before kidney transplantation as a "justification" for the use of "the best available" mode having the highest cost and, conversely, being supported by very limited/preliminary studies only.
3. Nutrition and Growth: The importance of the choice of material used for dialysis and its application should not obviate the need for management of the entire child with ESRF, especially regarding optimum nutrition. Because dialysis per se is not able to correct completely the numerous functions of the kidney lost during ESRF, medications and dietary recommendations are needed in children on hemodialysis. Recombinant growth hormone is often needed considering the growth velocity rate of children on chronic dialysis.

### GUIDELINES FOR HD

The following are some of the important guidelines for dialyzing children recommended by the European Pediatric Dialysis Working Group:

#### Guideline 1: The dialysis unit

- hemodialysis should be delivered in a dialysis center with a multidisciplinary support team which supports individualized and integrated therapy
  - nutrition, growth, and educational support are of major importance
- Because of the specific needs of children, hemodialysis should be delivered

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at the best, and in a pediatric dialysis unit. This may not be a viable option financially in developing countries especially when the number of children being dialysed in a centre are very few. In such situations dialysis can be done in a combined facility provided there are nurses and technicians trained in the management of such children. This includes the treatment of adolescents up to the age of 18 years and beyond depending upon their physical and psychological development and transition arrangements to adult units. Taking care of a child with ESRF necessitates an engaged team consisting of doctors, nurses, dietician, psychologist, school teacher, play therapist, and social worker. This "second family or support team" should be multidisciplinary and immediately available to the chronically ill child, both close and distant enough to stimulate normal family life, supporting a proper (school) education, leaving all possibilities open for "full" integration into society in the future. Hemodialysis, in contrast with peritoneal dialysis, is usually performed in an hospital setting, with a frequency of three times per week for most patients. This frequency may be increased to address the specific needs of babies and/or adolescents requiring "more dialysis".

### Guideline 2: Water quality

- adequate in terms of biochemical composition
- free from microbiological contamination

The dialysis machine needs water for dialysate production adequate in terms of biochemical composition and free from microbiological contamination, i.e. germs and endotoxins. The standards are similar for those of adults and the details are mentioned in the chapter on water treatment.

### Guideline 3: The dialysis machine

- volumetric ultrafiltration control
- option for both single and double-needle dialysis

In the last decade numerous innovations in equipment have been developed by different manufacturers. But the relevance to child outcome remains unknown, because of the absence of sufficient controlled study results. Nevertheless the following innovations seem *essential*: dialysate production by double dilution pumps using volumetric ultrafiltration control and blood pumps with double pumps available for single-needle dialysis. Children can be dialysed on the same machine provided the pump settings are modified to fit for the smaller pediatric tubings.

Other significant "high-tech" innovations are individual modeling of the dialysis session with monitoring of ultrafiltration and dialysate solute concentration (i.e. sodium, bicarbonate); polyvalency machine which enables not only conventional dialysis but also hemofiltration and hemodiafiltration providing the highest standard in terms of tolerance and efficiency. Newer dialysis machines provide monitoring of hematocrit variation as a major promising innovation and direct urea kinetic monitoring. All these innovations enable individualized hemodialysis for the children, but their regular application should take into consideration the balance between the expected benefits and the costs as well as the experience of the staff in handling such equipment.

### Guideline 4: Blood lines

- available in infants/babies size
- biocompatible material

A range of blood lines are available for dialysis of babies to dialysis of the largest adolescent. They should be considered for their biocompatibility, type of sterilization (ethylene oxide-free), and most importantly their contribution to the extracorporeal circuit volume.

### Guideline 5: Principles of blood purification

- small solute clearance and more, from diffusion process (urea) to convection (other uremic toxins "middle molecules") mass transport
- hemodiafiltration is an option to consider to obtain "maximum" dialysis

efficiency

Uremic toxin extraction in dialysis is related to a combination of the diffusion process and convection mass transport). In hemodialysis (HD), blood purification depends mostly on a diffusion process secondary to a concentration gradient, which ensures the best elimination of small molecules (urea). HD clearance ( $K_{HD}$ ) correlates directly with blood flow rate. In hemofiltration (HF), uremic toxin extraction is mostly dependent on convection mass transport secondary to a pressure gradient, which optimizes the elimination of both low and middle-molecular-weight compounds. HF clearance ( $K_{HF}$ ) directly correlates with ultrafiltration flow rate which is limited by the blood flow rate. In the post dilution mode, i.e. replacement fluid in the venous line chamber located after the dialyzer membrane, maximum filtrate flow rate is less than half the blood flow rate; it is usually one third, to limit the risks of excessive hemoconcentration. In the predilution mode, i.e. replacement fluid perfusion in the arterial line chamber, which is situated before the dialyzer membrane, maximum filtrate flow rate should be two thirds of or equal to the blood flow rate.

### Guideline 6: Extracorporeal blood access and circulation

- fistula vascular access is preferred for long-term chronic hemodialysis
- in young children, less than 15 kg, the time needed to develop a fistula before it can be used could be some months
- the double-needle technique is the standard, but single needle with double pump system is an alternative
- a single lumen catheter with clamps offers for small children an acceptable compromise between a very low extracorporeal blood volume and valuable dialytic efficacy
- total extracorporeal blood volume (needles, tubing and dialyzer) should, approximately, be less than 10% of patient total blood volume
- anticoagulation in the extracorporeal circuit is achieved either with conventional heparin or with low-molecular-weight heparin
- an extracorporeal blood flow rate ( $Q_B$ ) of 150–200 mL min<sup>-1</sup> m<sup>-2</sup> or 5–7 mL min<sup>-1</sup> kg<sup>-1</sup> is often sufficient

The most critical factor for success of chronic hemodialysis is a good vascular access: internal arteriovenous fistulae (AVF), shunt (AVS), graft (AVG) or central venous catheter. The type of access used is variable depending on factors in different units and countries, for example surgical experience, patient age and size, the time available before dialysis must be started, and the presumed waiting time before transplantation. Patient choice plays a major part, especially with adolescents.

**Catheters:** A catheter is more commonly used in the USA than in Europe. A catheter can be a primary access particularly in acute renal failure or chronic renal failure with acute presentation, in small children and in the case of a presumed short period on chronic hemodialysis. Internal jugular vein catheter access is superior to subclavian vein; it admittedly preserves the future arteriovenous fistula implantation on the arm. Femoral catheter access should be used only for "rescue and transient" access if intensive care is needed: it is easy to perform but with a higher risk of infection and thrombosis. A double lumen cuffed catheter, at least 8 French, is mostly preferred for children and has been reported to have a survival rate as high as 60 to 85% in one year, or as low as 30%. Nevertheless in small infants a single lumen catheter used with the alternative clamps technique offers an acceptable compromise between recirculation and both the amount of extracorporeal blood volume and the achieved blood flow. There are different sizes of catheters for different age groups (table 1). Thrombosis, a major cause of catheter failure, is reported to be between 9 and 46%. Thrombosis causing poor flow can be corrected to salvage the catheter by different methods: catheter replacement over guidewire, systemic oral anticoagulation and local urokinase or tissue plasminogen activator instillation. Loss of catheter access related to infection has decreased during the last decade; the aggressive use of antibiotics and perhaps antibiotic lock therapy, although not universally accepted, account for this lower rate of infection

related catheter loss.

Table – 1: Catheter Size

Patient Size	Catheter Size	Access location
Neonate	UVC – 5.0 F UAC – 3.5, 5.0 F Or 5.0 single lumen	Umbilicus  Femoral vein (s)
3 – 15 kg	6.5, 7.0 F dual lumen Or 6.5, 7.0 F dual lumen	UVC, femoral vein Femoral
16 – 30 kg	7.0, 9/0 F dual lumen	Femoral / Int Jugular
> 30 kg	9.0, 11.5 F dual lumen	Femoral / Int jugular

**AV Fistulas :** Microsurgery enables creation of a functional AVF at the wrist in most children, even small ones. Creation of a fistula at the elbow is a second-choice vascular access. With a non functional cephalic vein, a basilic vein transposition, i.e. superficialization, is possible. Synthetic grafts should be reserved for children who have exhausted autologous veins and should be used in children only very rarely. For all these reasons preoperative evaluation of the vessels to determine the correct choice of vein before the operation is mandatory. The non-dominant arm should be regarded as first choice of fistula implantation. The survival rate for a AVF is higher than the survival rate for a catheter, with more than two thirds of the children having a functioning AVF at four years. With a basilic vein superficialization the fistula should not be used before full healing (2 to 6 weeks) to avoid a dissecting hematoma. Otherwise the time needed for venous development before use depends on the age of the patient and the place of the AVF (distal or proximal). In small children this period of time is often a delay of months. Before surgery it is essential to avoid venopuncture of the selected arm in the weeks before AVF creation. It is of interest to protect the dominant arm from the beginning of taking care of a child with “chronic dialysis risk” to enable, if necessary, implantation of a fistula. Such venoprotection should not be forgotten for peritoneal dialysis children, even babies/infants. For a period of time before surgery, especially for small children, dilatation of the veins by immersion of the forearm in hot water is advantageous, a maneuver enhanced by placement of a tourniquet. A proximal AVF with a high blood flow, usually close to  $1000 \text{ mL min}^{-1} \text{ m}^{-2}$ , is a risk factor for cardiac failure. Nevertheless, the major complication is thrombosis, consequent to local stenosis. Therefore, follow up of the access flow is essential, on the one hand clinically: auscultation (the sound of the AVF is maximum at the surgical site and decreases with distance from the fistulae), observation (elevation of the forearm should induce emptying of the previous dilated veins, and on the other hand by Doppler ultrasound or vascular access flow monitoring. Application of regular access flow monitoring can be used to detect vascular stenosis before complete AVF thrombosis [9]. But it should be remembered that “Trasonic” access flow monitoring can only be performed with double-pump dialysis and is not available for pediatric-sized blood lines.

The extracorporeal blood flow rate is achieved through venous puncture, most often via two needles, one for blood aspiration called the arterial needle, one for venous reinjection called the venous needle. The distance between the needles should be sufficient to limit recirculation, which is best prevented by opposite orientation of the needles: the arterial one toward the fistula, the venous one in the opposite direction. Usually the needle size is 17-gauge at initiation of dialysis; thereafter considering patient need and fistula development 16 or 14-gauge needles, particularly in adolescents, can be used to achieve a sufficiently high blood flow rate. Pain related to the puncture should be prevented by anesthetic cream (Emla or Amelop); this advance is important for both the children and nurses.

**Blood Flows :** An extracorporeal blood flow rate ( $Q_B$ ) of  $150\text{--}200 \text{ mL min}^{-1} \text{ m}^{-2}$ ,  $5\text{--}7 \text{ mL min}^{-1} \text{ kg}^{-1}$ , is often sufficient to achieve the targeted goals with double needle dialysis; in small children  $Q_B$  is determined using body weight (BW, kg):  $(BW+10) \times 2.5 = Q_B \text{ (mL min}^{-1})$ . The arterial blood aspiration pressure should be monitored if possible and kept between

150–200 mmHg to limit endothelial trauma.

For single-needle dialysis in children the highest blood flow rate is obtained with a double pump system (venous flow higher than arterial flow) monitored by the pressure, system called time pressure regulation. The risk of recirculation is important with the latter; some machines limit this risk more than others, especially with the addition of clamps. Conversely for small infants a single lumen catheter used with the alternative clamps technique is an acceptable compromise between recirculation and both the extracorporeal blood volume and the achieved blood flow.

**Extracorporeal Circuit:** The total extracorporeal blood volume (needles, tubing, and dialyzer) should preferably be less than 10 % of patient total blood volume. This is essential for small children; however, the relative normal hemoglobin level obtained with erythropoietin therapy enables this volume to be exceeded slightly without significant hypotension at the end of dialysis session when the patient reaches dry body weight. Nevertheless, it should be kept in mind that the higher the extracorporeal blood volume, the higher the volume of returned fluid, which will load the patient with fluid at the end of the dialysis session. (In very small children the substitution by air may be necessary to limit blood loss on one side and high substitution volume on the other side, but is very dangerous and should be strictly monitored.) System priming with saline, albumin, and sometimes blood should be applied in the first dialysis sessions with babies or small infants.

**Anticoagulation :**Anticoagulation of the extracorporeal blood volume is performed either by use of conventional, heparin with continuous infusion of 20 to 30 IU  $\text{kg}^{-1} \text{ h}^{-1}$ , or with low-molecular-weight heparin at 1 mg  $\text{kg}^{-1}$  as a bolus at the beginning of the dialysis session. If the hematocrit is over 35%, the risk of clotting is increased. Regional citrate anticoagulation is sometimes used especially when acute dialysis is needed. Predilution treatment, feasible in either hemofiltration or hemodiafiltration, reduces the risk of clotting and even enables dialysis without anticoagulation in some circumstances. In the presence of thrombopenia heparin-toxicity is to be suspected.

The venous blood line has a pediatric size air-trap chamber to limit extracorporeal blood volume. The dialysis membrane is protected by an arterial chamber of expansion which in small children is often not incorporated in the line to reduce the extracorporeal blood volume. Prevention or treatment of ethylene oxide allergy is possible by using steam sterilization of needles, lines, and membranes.

**Guideline 7: Which dialyzer membrane to “choose”**

- synthetic membrane, low flux, capillary configuration
- high-flux membrane use requires use of ultrapure dialysate
- removal of urea and other uremic toxins dialytic should be considered, especially in chronic, long-term dialysis

Three general types of membrane are available at present: unmodified cellulose (low flux and so-called bioincompatible membranes), modified/regenerated cellulose (low flux or high flux; so-called relatively biocompatible), synthetic (low flux or high flux; so called relatively biocompatible).

The choice of a dialyzer membrane should take into account the following (Table 2):

Table-2: Hemofilters Appropriate for Pediatric Use

Hemofilter	Priming volume (mL)	Surface area(m <sup>2</sup> )	Ultra filtration rate (mL/min, QB = 100)	Membrane	Manufacture
Minifilter, Minifilter Plus	8, 15	0.2, 0.8	0.5-1.5, 1-8	Polysulfone	Renal systems
HF 400, 700	28, 53	0.3, 0.7	20-35, 35-45	Polysulfone	Renal systems
Multiflow 60	47	0.6	14-29	AN 69	Hospal
PAN-03, 06	33, 63	0.3, 0.6	15-28, 28-43	PAN	Asahi
Freseneui F40	45	0.4	14 – 29	Polysulfone	Fresenius

- the biocompatibility of the material towards leucocytes and complement activation

- the blood volume priming requirement, which is membrane area-related
- the permeability, determined in the most simple way by two characteristics
- Hydraulic permeability ( $C_{UF}$ ) measured in mL per mmHg of transmembrane pressure achieved per hour, i.e. either low permeability,  $C_{UF}$  under 5 mL mmHg<sup>-1</sup> h<sup>-1</sup> (low-flux membrane), and high permeability,  $C_{UF}$  over 15 to 20 mL mmHg<sup>-1</sup> h<sup>-1</sup> (high-flux membrane)
- molecular permeability determined at least by the molecular weight of the molecule considered, usually between 0.8 and 0.9 for urea and lower for the other uremic toxins with a cut off of zero for albumin. In practice this cut off is often under a molecular weight of 20,000 Daltons. The profile of this molecular permeability is a specific characteristic of each manufactured dialysis membrane. Highly permeable membranes give the theoretical potential for middle-molecular-weight (Babb theory; 500 to 2,000 Daltons) uremic toxins being removed during dialysis. In adult dialysis patients the clinical benefits of improved removal of middle molecules by high flux, large pore, biocompatible membranes, more or less established, are: reduction of uremia related amyloidosis, maintenance or residual renal function, and reduction of inflammation, malnutrition, anemia, dyslipidemia, and mortality.

For conventional dialysis low-flux membranes are suitable, but to achieve hemofiltration or hemodiafiltration high-flux membranes are necessary. The higher the hydraulic permeability, the higher is the backfiltration risk; this process could be limited both by permanent convective flow from the blood compartment to the dialysate compartment, as ultrafiltration (HF, HDF, or at least weight loss) and by use of ultrapure dialysate. Synthetic membranes seem the best theoretical choice but clinical justification of the relatively higher cost is uncertain. Justification for use of high-flux synthetic membranes, as used in on-line HDF, remains a matter of debate for children on dialysis for short periods only while waiting for their kidney transplant.

Reuse of the membrane is not recommended in children. However in developing countries like ours one may have to reuse dialysers because of cost considerations.

#### **Guideline 8: The Dialysate**

- bicarbonate buffered,
- low calcium level (1.25 mmol L<sup>-1</sup>) becomes the standard,
- glucose concentration at physiological level,
- dialysate quality control (germs and endotoxins) is required

The dialysate is prepared as a dilution of concentrate with water, ideally with ultrapure water. The composition of the dialysate is similar to that used in adults and will be dealt with in another chapter. The current use of oral calcium carbonate as a phosphate binder has mandated the need to decrease the calcium concentration of the dialysate, usually at a low rate, 1.25 mmol L<sup>-1</sup> Ca<sup>2+</sup>, less often at a normal rate, 1.5 mmol L<sup>-1</sup>, avoiding the "historically" high level of 1.75 mmol L<sup>-1</sup> Ca<sup>2+</sup>. The need for glucose in the dialysate is of importance and should be near the physiological concentration. Higher glucose concentrations or the introduction of parenteral feeding during dialysis will drive the potassium into the cells, leading to ineffective potassium-extraction.

Newer machine capabilities enable dialysate profiles to change during a dialysis with respect to sodium and ultrafiltrate profiles to increase tolerated weight loss; and bicarbonate profiles, to enhance phosphate removal. Intermittent ultrafiltration rates, enabling better plasma refilling is the most common profile used. Similarly, the dialysate flow rate can be adapted to need, usually in the range 300 to 800 mL min<sup>-1</sup>. In general practice, 500 mL min<sup>-1</sup> is used. The dialysate flow is usually in the opposite direction of the blood flow, separated by the membrane of the dialyzer. Dialytic thermal exchanges seem of importance especially for babies and/or high-flow dialysate use, leading to a risk of patient hypothermia. Control of thermal exchanges during a dialysis session is

therefore available on a new machine.

#### **Guideline 9: Post-dialytic dry weight assessment and adjustment**

- particularly difficult to define in growing children
- no "unique" optimum method, importance of a clinical "pediatric" experience
- need for regular assessment in a growing child
- close collaboration with pediatric renal dietician

Patient dry weight is defined as the weight at the termination of a regular dialysis session, below which the patient will become symptomatically hypotensive. Incorrect estimation of dry weight will lead either to chronic fluid overload or chronic dehydration. Estimation of dry weight is particularly difficult in children for many reasons. First, the hypotensive tendency during a dialysis session is multifactorial and not only related to the ultrafiltration rate but also to the plasma refilling rate capacity. Second, body composition, i.e. total body water ratio to total body mass, is variable with age, especially during infancy and puberty. In infants and in adolescents dry weight must be assessed almost monthly to follow rapid body composition changes during a rapid growth period. This is also important under anabolic conditions such as with growth hormone treatment, and conversely under catabolic conditions such as the ill child with intercurrent infections or reduced food intake.

Clinical criteria used to assess hydration status are important but not always reliable. Measurement of the diameter of the IVC (IVCD) by ultrasound, expressed as an index to body surface-area in mm m<sup>2</sup>, and the decrease on deep inspiration, called the collapse index, expressed as a percentage (%) seems to be an accurate non-invasive method easily performed serially. An IVCD between 8.0 and 11.5 mm m<sup>2</sup> and a collapse index between 40 and 75 % is considered as representing normovolemia. However, unlike body impedance, interstitial volume and sodium balance are not reflected by IVCD. In fact all these approaches have to be balanced by clinical judgment and experience and combined with nutritional support. Achievement of dry weight during ultrafiltration is associated with a drop of the hematocrite level. Ultrafiltration is well tolerated until a certain level of decrease of initial hematocrite, called "crash hematocrite" a patient individual characteristic, usually over 10% blood volume reduction over a 3-h session. If the hematocrite curve is flat over time during a dialysis session, the patient could be considered as being over his optimum dry weight. In practice, monitoring of hematocrit (or blood volume) and guided ultrafiltration should avoid both fluid overload and hypotensive "crash hematocrit" and consequently approach more precisely the patient dry weight.

#### **Guideline 10: Urea dialytic kinetic, dialysis dose, and protein intake assessment (nutrition)**

Urea kinetic modeling (UKM) has been widely accepted as a method for dialysis dose assessment despite its limited value as a unique measure of dialysis adequacy. UKM facilitates identification of underdialyzed patients and recognition of dietary compliance. The measures most widely used to gauge dialyzer treatment are  $Kt/V$ , that is dialyzer urea clearance ( $K$ ) multiplied by duration ( $t$ ) of the dialysis session and divided by urea volume ( $V$ ) of distribution, and the normalized protein catabolic rate (nPCR). Urea dialytic reduction rate (URR) is derived from the pre and post-dialysis serum urea values and quantitates urea removal by dialysis. URR when expressed as the difference between pre and post-urea, divided by the predialysis value, should at least equal to or higher than 0.60. URR is proportional to dialysis efficiency, and thus to urea dialytic clearance. URR is inversely proportional to the urea refilling rate of the blood compartment and the extracellular space (EC) from the intracellular space (IC), called the transcellular urea mass transfer coefficient ( $K_{ie}$ ). Usually urea dialytic clearance in children is low in comparison with the high  $K_{ie}$  which is between 200 to 1000 mL min<sup>-1</sup> (6 to 12 mL min<sup>-1</sup> kg<sup>-1</sup> BW).

Nevertheless, after dialysis the concentration of urea in plasma increases rapidly in an initial period, usually until 60 min postdialysis. The predialysis blood sample should be taken from the arterial line, before any rinsing. Because of the practical difficulty in obtaining the postdialysis equilibrated urea sample 60 min after the end of the dialysis, different indices have been proposed to estimate  $C_{eq}$ , for example using a 6 min or a 15 min post treatment sample. The most important rule of the urea end dialysis sample should be the use of the “stop dialysate flow method”, measuring urea 6 min after angio access was removed and cardiopulmonary recirculation completed. The other major cause of error for the  $Kt/V$  calculation is determination of  $V$ . The  $V$ , hence the TBW, could be calculated from a formula or determined by bioimpedance measurements.

### Guideline 11: Dialysis dose and outcome

- only “small solute urea clearance” prescription?
- a minimum  $Kt/V$  urea level of 1.2–1.4 is thought to be desirable; adequacy tests should be performed monthly
- dialysis and residual renal small-solute clearance are not equivalent
- dialysis prescription should be adequate before being optimum, not only a “urea dialysis dose”

Although the optimum level of  $Kt/V$  required is matter of debate, a minimum  $Kt/V$  level of 1.2–1.4 is now thought to be desirable. Overall, this  $Kt/V$  as an index of dialysis dose should only be analyzed in comparison with the nPCR, hence the diet, protein and caloric intake. Increasing dialysis dose seems to have a direct impact on nutrition and the combination of increased dialysis dose and adequate nutrition can promote normal growth in children treated with long-term hemodialysis. Therefore malnutrition should be avoided by using a diet survey and anthropometric measurements..

Dialysis prescription should be adequate before being optimum. In long term chronic dialyzed children the individualized prescription should consider all the available new strategies to fully preserve at the best “the life chances”.

### Guideline 12: The dialysis session, prescription, and monitoring

- individual prescription is required: babies/infants/children specificities
- assessment and adjustment is needed regularly in small/growing children
- psychological preparation of the child and his family is needed, pain prevention is essential

The first dialysis session is of importance to induce child and parent confidence, therefore appropriate preparation is needed. The site of the puncture of the fistula, most often with a double needle, size gauge 17, is carefully chosen and determined so that the needles are sufficiently separated to limit recirculation. Pain prevention is essential by application of a xylocaine ointment (Emla) one hour before needle insertion. Psychological preparation of the child and family is also needed to limit “anxious stress”. An aseptic procedure is essential. The extracorporeal circulation is adapted to the level of arterial aspiration pressure if measurable by the machine to prevent endothelial vascular trauma (not less than “150 mmHg). The venous return pressure should not be more than +200 mmHg to prevent endothelial vascular trauma.

During the first dialysis session, the blood flow rate is maintained at a low level to prevent the dysequilibrium syndrome secondary to too efficient solute removal during this first session. Therefore, the blood flow rate should be approximately  $3 \text{ mL kg}^{-1} \text{ BW}$  (or  $90 \text{ mL m}^{-2}$ ), or even less, so that urea clearance will be less than  $3 \text{ mL min}^{-1} \text{ kg}^{-1} \text{ BW}$ , which is usually well tolerated even in small children and limits the development of the dysequilibrium syndrome. The duration of the first dialysis session should be short, no more than 3 h, or adapted to the ultrafiltration need. If needed, mannitol infusion ( $1 \text{ g kg}^{-1} \text{ BW}$  over 1 to 2 h during dialysis) is effective in preventing the syndrome. Symptoms usually disappear a few hours after the end of the dialysis. The extracorporeal blood flow rate, the duration of the session, and the number of sessions a week is progressively increased

to individual patient need. Usually a blood flow rate of  $150$  to  $200 \text{ mL min}^{-1} \text{ m}^{-2}$  and three sessions per week for 3 to 4 h per session achieve the minimum target prescription of 1.2 to 1.4  $Kt/V$ .

The duration of a dialysis session is often prescribed to reach the anticipated dry weight at the end of the session. The total amount and the rate of ultrafiltration needed must be tolerable. A weight loss per hour of 1.5 to 2% of the BW is standard and most often well tolerated. Intermittent ultrafiltration with bicarbonate buffered dialysate which is not too warm (so called “cooled dialysate”), a normal “high” level of sodium ( $140$  to  $144 \text{ mmol L}^{-1}$ ), which is not more than the normal concentration of sodium per liter plasma water, a normal hematocrit over 30% and optimally near 35% but not higher, and a mode of dialysis based on hemofiltration, i.e. (optimally HDF) are some of the major “tricks” used to enhance ultrafiltration tolerance. Intolerance of weight loss usually becomes symptomatic at the end of the dialysis session, when the patient is near his dry weight. Continuous blood volume monitoring during the session should become a real clinical support to enable optimum ultrafiltration tolerance (notion of crash hematocrit).

## CONCLUSIONS

Hemodialysis in children has benefited from major progress over the last 20 years. The morbidity of the sessions has decreased, even disappeared, seizures being exceptional, hypotensive episodes or headaches rare, and pain related to the fistula puncture effectively prevented by xylocaine ointment. The development of urea kinetic modeling enables calculation of the dialysis dose and indirect assessment of protein intake, nPCR. Even if the validity of these values is questioned their combined analysis provides an assessment and therefore is a “good thing”. The patient also benefits from the technological revolution. The newer machines enable precise control of ultrafiltration volumetric assessment and continuous blood volume monitoring during the session, buffered bicarbonate has become a standard technique, synthetic more biocompatible membranes and specific material available for babies/infants have been developed. Non invasive intervention, for example blood volume guided ultrafiltration have provided more adequate dialysis sessions and better dry weight assessment. Last, the availability of erythropoietin and of growth hormone and the promising results from enhanced dialysis dose on both growth and cardiac function, all give the dialyzed child a real increased quality of life. In theory, reduction of dialysis prescription to only a urea dialysis dose achieved by three short (3-h) dialysis sessions, should be abandoned for long term dialyzed children and replaced by optimum dialysis obtained with longer (4 and more hours) and/or more frequent (daily: 5 to 6) sessions. But for such a daily dialysis strategy all the costs must be considered. On the one hand the financial cost cannot be neglected. For the patient bearing the burden, on the other hand, such an intensive dialysis prescription is acceptable only as.

## BIBLIOGRAPHY

1. Fischbach M, Stefanidis CJ, Watson AR (2002) Guidelines by an ad hoc European committee on adequacy of the pediatric peritoneal dialysis prescription. *Nephrol Dial Transplant* 17:380–385.
2. Strazdins V, Stefanidis V, Watson AR, Harvey B (2004) Renal replacement therapy for acute renal failure in children: European guidelines. *Pediatr Nephrol* 19:199–207
3. Fischbach M, Terzic J, Menouer S, Provot E, Bergere V (2001) Hemodialysis in children: principles and practice. *Semin Nephrol* 21:470–479
4. Watson AR, Thurlby D, Schröder C, Fischbach M, Schaefer F, Edefonti A, Stefanidis CJ, Rönholm K, Zurawska A (2000) Choice of end stage renal failure therapy in eight European centres. *Pediatr Nephrol* 6(5):C38.
5. Bunchman TE (1996) Pediatric hemodialysis: lessons from the past, ideas for the future. *Kidney Int* 53 (Suppl):S64–S67.
6. Goldstein SL (2004) Adequacy of dialysis in children: does small solute clearance really matter? *Pediatr Nephrol* 19:1–5 2360–2367.
7. Coleman JE, Edefonti A, Watson AR on behalf of the European Paediatric Peritoneal Working Group (2001) Guidelines by and ad hoc European committee on the assessment of growth and nutritional status in children on chronic peritoneal dialysis. *Perit Dial Int* 21:323
8. Bouré T, Vanholder R (2004) Which dialyzer membrane to choose? *Nephrol Dial Transplant* 19:293–296
9. Sharma A, Zilleruado G, Abitbol C, Montane B, Strauss J (1999) Survival in children on chronic hemodialysis. *Pediatr Nephrol* 13:245–248.
10. Brittinger WD, Walker G, Twittenhoff WD, Konrad D (1997) Vascular access for hemodialysis in children. *Pediatr Nephrol* 11:87–95