Chronic Dialysis

10

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10.1 PD

10.1.1 Introduction

Peritoneal dialysis (PD) is a versatile renal replacement therapy (RRT) modality for acute kidney injury (AKI) as well as long-term dialysis.

PD works on the principle of equilibration of blood in the peritoneal capillaries and dialysis fluid in the peritoneal cavity. The dialysis takes place by diffusion and convection.

Peritoneal dialysis in AKI has been described in Chap. 8. This chapter deals with PD in endstage renal disease (ESRD).

Milestones that led to the wide acceptance of PD as a modality for chronic RRT were the development of appropriate peritoneal catheters, the introduction of plastic bags containing stable, standardized dialysis solutions, improved connection technology that helped reducing the infection risk, the invention of automated PD (cyclers) and, more recently, the propagation of light, portable cyclers.

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Determining the indication for PD, dialysis prescription, and treatment of PD-associated peritonitis are medical acts performed by the nephrologist. However, many aspects of PD can be managed by qualified nurses in conjunction with a nephrologist or trained pediatrician.

The PD team should further include a social worker and a surgeon/urologist.

This chapter can only give the framework for this dialysis modality. Delegation of the preparation and education of the family and the patient by the PD nurse, and day-to-day technical instructions and recognition of potential problems, requires the creation of a set of clearly outlined protocols for all PD-related procedures and for trouble shooting.

A center offering PD should have a knowledgeable member of the medical team that can be reached 7 days a week and 24 hours a day. The major providers of PD equipment have a help-line and personnel to trouble shoot when technical problems arise, and provide hands-on training and useful educational material.

10.1.2 Definitions

10.1.2.1 Principles of PD

- Physical and physiological principles underlying PD is the exchange of solutes and water between the blood (peritoneal capillaries) and the surrounding tissue, and the dialysis solution across the peritoneal membrane.
- The major mechanisms are *diffusive transport* of solutes (based on the concentration gradient between dialysate and blood), *ultrafiltration* (UF; removal of plasma water) and *convective mass transfer* (when solutes and proteins are "dragged" along with the UF). The UF driving force in PD is determined by the osmotic pressure exerted by the dialysate glucose concentration.
- The permeability of the peritoneal membrane (the tissue between the capillary lumen and the peritoneal space) can be increased by inflammation (peritonitis) and impaired by progressive peritoneal fibrosis.
- The surface area of the peritoneal membrane correlates with the body surface area (BSA): this relationship remains constant across patient age groups. Dialysate volume prescription is therefore scaled to BSA, specifically when determining dialysis adequacy and peritoneal transport properties (see Sect. 10.1.4.9).

10.1.2.2 Types of PD

- Chronic PD can be performed manually or with an automated device (cycler).
- CAPD (chronic ambulatory peritoneal dialysis) is typically performed with four exchanges during the day and a long night-time dwell
- CCPD (continuous cycling peritoneal dialysis), consisting of 5–10 nightly exchanges, is possible using a cycling machine and a long daytime dwell (also termed automated PD, or APD).
- Chronic PD depends on the presence of a surgically placed catheter. To avoid pericatheter leakage and minimize infection (PD peritonitis), the catheter is tunneled

and usually has two subcutaneously buried cuffs. Dialysate, additives, and all catheter manipulations and connections have to be done under aseptic conditions.

- Complications to CAPD/CCPD in children include abdominal hernia, back pain, hydrothorax, obesity, and hyperlipidemia.
- Long-term dialysis modifies the peritoneal membrane characteristics, e.g., due to unphysiological, high glucose concentrations, and may decrease dialysis efficiency.
- Commonly used PD terms and abbreviations are found in Box 10.1.
- The principal differences between various types of PD are depicted in Fig. 10.1.

Box 10.1 Types of PD (the PD Alphabet)

APD	Automated peritoneal dialysis (PD; see also "APD-C")
	PD using a "cycler" to effect dialysate infusion and drainage (conveniently performed over night. Can be combined with manual drain or fill cycle during the day if needed)
APD-A	Adapted peritoneal dialysis (also termed APD)
	Sequential use of short dwell times (and small fill volume) to promote ultrafiltration and longer dwell times (with larger fill volume) to promote removal of uremic toxins (e.g., phosphate)
APD-C	"Conventional" automated peritoneal dialysis
	Automated PD using uniform dialysate volumes and dwell times during a given dialysis period
CAPD	Continuous ambulatory peritoneal dialysis
	"Classical" form of PD; advantages are its simplicity, low-cost, and similar efficiency in most patients
CCPD	Continuous cycling peritoneal dialysis
	Long daytime dwell and several cycles overnight. A minority of patients undergoing CCPD does not have daytime dwell (NIPD) and some patients must also do a midday exchange to meet adequacy or ultrafiltration (UF) targets
CFPD	Continuous flow peritoneal dialysis
	Continuous dialysis technique using two separate catheters or a double lumen PD catheter and high dialysate flow rates. Spent dialysate can be regenerated with hemodialysis technology. Theoretical advantages of CFPD are its very high clearances and improved UF. Impractical in most settings
CPD	Continuous peritoneal dialysis
	No "dry" periods; CPD may also denote "chronic PD" (to distinguish from "acute PD")
IPD	Intermittent peritoneal dialysis
	Alternating periods of "wet" and "dry" peritoneum (e.g., cycler changes during the night followed by complete drainage of the peritoneum in the morning; see NIPD)
IPP	(Hydrostatic) Intraperitoneal pressure
IPV	Intraperitoneal volume
NIPD	Nocturnal (nightly) intermittent peritoneal dialysis
	"Dry" abdomen during daytime

(continued)

Box 10.1 (continued)

PD	Peritoneal dialysis
PET	Peritoneal equilibration test
TPD	Tidal peritoneal dialysis
	Exchanges where the peritoneum always contains at least some dialysate (usually at least one-half full). It is used to improve comfort and drainage. TPD may or may not include a daytime dwell
UF	Ultrafiltrate
	Net UF = Total effluent volume – Total fill volume (usually overnight or a 24-h period)

10.1.3 When to Use PD and HD?

10.1.3.1 Advantages of Peritoneal Dialysis

- Ease of procedure (expertise).
- Can be performed with simple equipment and infrastructure.
- Suitable in challenging circumstances: newborns and small infants, hemodynamically unstable patients, peripheral centers where expertise may not be available.
- No systemic anticoagulation
- Compared with conventional hemodialysis (HD), PD is more physiological with lower risk of disequilibrium syndrome.
- Better control of hypertension and anemia with reduced or no need for blood transfusions.
- Residual renal functions may be preserved better than with chronic hemodialysis.
- PD allows a more liberal diet than HD.

10.1.3.2 Challenges of PD

- Abdominal adhesions following previous abdominal surgeries
- Recent abdominal surgery or inflammation
- Occasionally inferior to blood borne dialysis techniques when large ultrafiltration is required within a short time, as in pulmonary edema
- Limitations in hypercatabolic states such as sepsis, burns, heat stroke, or crush injuries
- Risk of peritonitis if strict asepsis is not followed

10.1.3.3 Contraindications to PD

Absolute contraindications

- Omphalocele
- Gastroschisis
- Bladder exstrophy
- Diaphragmatic hernia
- Severe adhesions
- Peritoneal membrane failure

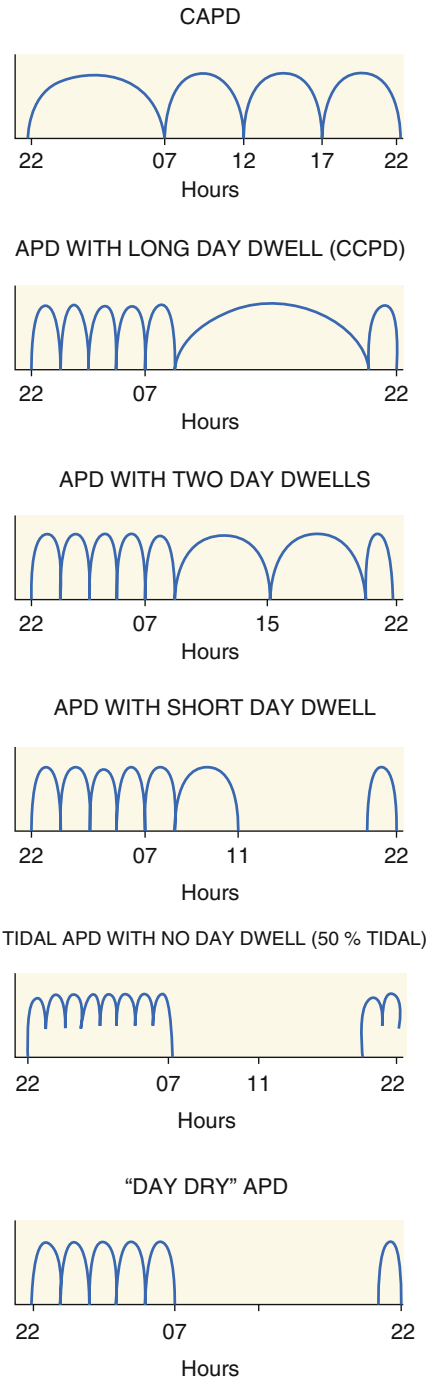

Fig. 10.1 Peritoneal dialysis treatment modalities. For abbreviation see Box 10.1 (From Brenner & Rector's The Kidney, 9th edition; with permission)

Relative contraindications
- Planned or recent major abdominal surgery
- Poor psychosocial condition
- Single caregiver with no support
- Unhygienic home conditions

10.1.4 Initiation of PD

10.1.4.1 When to Start Dialysis
- Indications are based on the individualized combination of clinical, biochemical, and psychosocial assessments
- When the glomerular filtration rate (GFR) reaches 15–10 ml/min/1.73 m^2 and the child is unwell, despite optimal conservative measures, or when the GFR is <10 ml/min per 1.73 m^2
- When signs such as nausea, vomiting, lethargy, restricted daily activities, and diminished height velocity become apparent in a child with advanced CKD
- Uncontrolled hypertension, loss of residual renal functions, hyperkalemia, hyperphosphatemia, and acidosis are factors to be considered in the decision to initiate dialysis

10.1.4.2 Education
- Diligent training of the patient (if applicable) and at least two family members is essential for the success of the treatment and for the PD program.
- A curriculum outline is shown in Box 10.2.
- As similar approach can be used for training new nurses (with adjustments).
- The training is best conducted by a dedicated (PD/dialysis) nurse.

Box 10.2 Outline of Training for Peritoneal Dialysis (Training Curriculum)

1. Background and theory
   - (a) Renal functions
   - (b) Principles of peritoneal membrane transport and dialysis (PD)
   - (c) Effects of fluid and water balance on weight, blood pressure, and survival
   - (d) Composition of dialysis solutions: glucose, electrolytes, lactate, and bicarbonate
   - (e) Purpose of using different dialysis solutions
   - (f) Infection risk, organisms, principles of asepsis/techniques
2. Practical training
   - (a) Training in aseptic techniques
     - (i) Handwashing
     - (ii) Connections
     - (iii) Exit site infections and exit site care
     - (iv) What to do in case of (possible) breaks of sterility (contamination)

Box 10.2 (continued)

(b) Set-up for dialysis: manual PD and cycler (if applicable)
  (i) Step-by-step procedure guide (preferably with visual material)
  (ii) Documentation (charting)
(c) Problem-solving
  (i) Manual PD (CAPD)
  (ii) Cycler alarms and malfunction
(d) Daily measurements
  (i) Body weight
  (ii) Blood pressure and heart rate
  (iii) Recoding and understanding implications
(e) Others: Obtaining a dialysate specimen; administering of intraperitoneal (IP) medications

3. Complications of PD
(a) Peritonitis
  (i) Signs, symptoms, laboratory diagnostic
  (ii) Steps to follow when peritonitis is suspected
  (iii) Treatment of peritonitis and long-term risks
  (iv) IP antibiotics and their administration
(b) Exit site and tunnel infection
(c) Dialysate drain problems
  (i) Constipation
  (ii) Fibrin
  (iii) PD catheter position
(d) Hyper- and hypotension
(e) Changes in the amount of ultrafiltrate (UF)
(f) Dialysate leaks
(g) Pain related to dialysis
(h) Bloody or cloudy dialysate effluent

4. Life with PD
(a) Ordering and managing PD supply
(b) Record keeping, important phone numbers
(c) How and when to contact hospital/dialysis center/dialysis team
(d) Medications and prescriptions
(e) Clinic appointments
(f) Home visits
(g) School, sports, vacation, and travel

The training curriculum has to be adjusted to the needs of the caregiver and patient (family) and nurses in training, respectively. Concrete material is available from the major suppliers (manufacturers) of dialysis equipment, textbooks, and the Internet

- PD training is started before the initiation of therapy or during the healing phase after PD catheter placement.
- "Refresher" sessions and review of caregiver's (patient) performance should be planned and are advisable after each episode of peritonitis or after a prolonged break of PD.

10.1.4.3 PD Catheter Placement and Choice of Catheter

- While trained nephrologists place chronic PD catheters in many (adult) centers, it is usually a dedicated (pediatric) surgeon, who inserts pediatric catheters, generally laparoscopically.
- PD catheters come in a variety of flavors, but all models may not be available in a given center.
- All but neonatal catheters should have 2 cuffs to anchor the catheter in the abdominal wall and reduce the peritonitis risk due to microbial infections.
- The catheter should have a downward or lateral subcutaneous tunnel configuration.
- Perioperative antibiotic prophylaxis to be given within 1 h before the incision for PD catheter placement to reduce the risk of early-onset peritonitis.
- The catheter can be used immediately; however, delayed PD initiation is preferred to allow the catheter to heal in and reduce the risk of pericatheter leaks.

10.1.4.4 Post Catheter Insertion Break-In Protocol

Management immediately after PD catheter insertion

Details see Table 10.1

Management during the healing phase (break-in period)

Table 10.1 Break-in protocol: immediate post-insertion period

Step	Procedure	Instructions
1	X-Ray (plain film)	In operating or recovery room Initiate catheter/peritoneal flushes as soon as patient is back in the ward
2a	Rapid in-out exchanges until clear (about three exchanges)	Peritoneal infusion volume 10 ml/kg Heparin 1,000 units/l in dialysate bag (for the first week) Cefazolin 250 mg/l for the first 12–16 h. Stop the morning after catheter insertion. Alternative antibiotic, if patient allergic
2b	When dialysate is clear, begin hourly exchanges	50 min dwell (including filling time) 10 min drain (depending on fill volume)
2c	Repeat cycles hourly for 12–16 h or less	Individualize according to patient's status
2d	Repeat steps 2a–c for eight more hours	After 16 h if dialysate (effluent) *un*clear or color*ed* and/or *in*appropriate draining Reassess
2e	Proceed to the maintenance phase	After 16 h dialysate clear and colorless, with appropriate draining
3	Prescribe antiemetic PRN for nausea/ vomiting and for pain	Antiemetics are used to avoid high intra-abdominal pressures Dimenhydrinate: 5 mg/kg/day q 6 h (IV, IM, PO)
4	Pain management	Morphine: 0.05–0.1 mg/kg/dose PRN q 2–4 h (IV, IM, PO) Antidote: naloxone (IV, IM, PO) <20 kg 0.01–0.1 mg/ml/kg per dose q 3–5 min >20 kg 2 mg per dose q 3–5 min
5	Use stool softeners	Locally available preparations (example, docusate-Na 5 mg/kg/day divided twice daily)

- The break-in period refers to the time immediately following catheter insertion Routinely, dialysis is initiated 2–4 weeks post catheter insertion to allow adequate healing.
- Some centers report no difference in post-insertion complications (esp. pericatheter leak) when the catheter is used earlier. However, there are no prospective, controlled studies comparing different break-in protocols for CAPD and for CCPD/NIPD.
- Risks for PD catheter complications depend on catheter placement technique, (early) initiation of daytime fill, resumption of physical activity, and age.
- The purpose of the break-in procedure is to clear intra-peritoneal blood and fibrin from the catheter, minimize immediate omental adhesion, and reduce the incidence of pericatheter leak by maintaining low intra-abdominal pressure.
  - Pericatheter leakage delays the in-growth of fibrous tissue into the catheter cuff which provides a medium for bacterial growth which may lead to peritonitis or an exit site infection.
  - Intra-abdominal pressure is minimized by the restriction of dialysate volume and of patient activity.
- Dialysis can be initiated in the immediate post-insertion period if there is urgent need for dialysis.
  Starting exchange volumes are 10–20 ml/kg. For details, see Table 10.2.
- Ambulation and sitting position are not permitted when the abdomen is filled with increased volume for the first 6 weeks. Mobilization is permitted if the patient is filled with a small volume as "last fill."
- Heparin: during the first week of dialysis, add 1,000 units/l to the dialysis solution. Decrease to 500 units/l during the second week, if no fibrin or blood clots are seen in the effluent. Then stop heparin.

10.1.4.5 Healing of the PD Exit Site

- Healing of the exit site may take 6–12 weeks.
- Exit site is cleaned and dressed weekly by experienced PD nurse or physician.
- More frequent dressing changes are not warranted (and should be avoided), unless drainage is excessive or dressing becomes soiled or wet.
- Continue 1-weekly dressing changes until exit site is well healed.
- No shower or bath tub during the healing phase.
- Aseptic techniques for dressing changes and cleaning of exit site using sterile gloves and face mask.

Table 10.2 Maintenance phase for patients in need of immediate dialysis

Procedure	Instructions	
Infuse dextrose dialysate containing 1,000 units/l of heparin as follows:	*Time period*	*Volume (ml/kg)*
	1st 24 h	10 ml/kg
	2nd 24 h	15 ml/kg
	3rd 24 h	20 ml/kg for 4 weeks, then 25 ml/kg for 1 week, and then, 30 ml/kg for 4–8 weeks
	To be reassessed after 8 weeks	

- For detailed guidelines of exit site care, see "Consensus Guidelines for the Prevention and Treatment of Catheter-Related Infections and Peritonitis in Pediatric Patients Receiving Peritoneal Dialysis: 2012 Update."

10.1.4.6 Maintenance Dialysis Prescription

- Typical CAPD consists of four daily exchanges with low-strength dextrose concentrations.
- In contrast to typical adult PD prescriptions, pediatric fill volumes have to be adjusted to body size (1,100–1,200 ml/m^2 surface area or 30–40 ml/kg body weight).
- Measurement of hydrostatic intraperitoneal pressure (IPP) helps to evaluate fill volume tolerance in the individual patients. Fill volume exceeding a pressure of 18 cm H_2O in supine position is associated with abdominal pain and decreased respiratory vital capacity.
- Slightly higher fill volume may be tolerated in supine position (NIPD or CCPD).
- The pricing of appropriate sized bags of dialysis solutions and pediatric tubing may be limiting in some countries or settings.
- Protocols for the use of cycler technology are easily available from the major manufactures or suppliers.

10.1.4.7 Choice of PD Solutions

- The choice of dialysate fluid is tailored to the individual patient's clinical needs considering fluid balance, blood pressure, and peritoneal membrane characteristics (see Sect. 10.1.4.9).
- If a cycler is used, solutions of different dextrose concentrations can be mixed to optimize ultrafiltration and solute removal.
- Traditional PD solutions are lactate-based (which is metabolized to bicarbonate, once absorbed, but confers a relatively acidic pH of 5.5) and have a high (ionized) calcium concentration (1.75 mmol/l; see Table 10.3).

Table 10.3 Composition of commonly used Dianeal peritoneal dialysis solution

			PD1[a]			PD4[b]		
	Dextrose ⇒	0.5 %	1.5 %	2.5 %	4.25 %	1.5 %	2.5 %	4.25 %
	Glucose ⇒		1.36 % Iso	2.27 % Medium	3.86 % Hyper	1.36 % Iso	2.27 % Medium	3.86 % Hyper
Dextrose anhydrate	g/l	5.0	13.6	22.7	38.6	13.6	22.7	38.6
Glucose	mmol/l		75.6	126.1	214.4	75.6	126.1	214.4
Sodium [Na^+]	mmol/l	132	132	132	132	132	132	132
Calcium [Ca^{++}]	mmol/l	1.62	1.75	1.75	1.75	1.25	1.25	1.25
Magnesium [Mg^{++}]	mmol/l	0.75	0.75	0.75	0.75	0.25	0.25	0.25
Chloride [Cl^-]	mmol/l	101	102	102	102	95	95	95
Lactate	mmol/l	35	35	35	35	40	40	40
Osmolality	mOsm/kg	295	340	390	480	340	390	480
pH		5.2	5.5	5.5	5.5	5.5	5.5	5.5

[a]PD1 normal calcium solution
[b]PD4 low calcium solution

Table 10.4 Composition of "second generation" peritoneal dialysis solutions

		Bicarbonate-based ("physiological") solutions			Amino acid-based solution	Icodextrin-based solution
	Glucose ⇒	1.36 %	2.27 %	3.86 %	1.10 %	7.50 %
Dextrose anhydrate	G/l	13.6	22.7	38.6	–	–
Glucose in mmol/l	mmol/l	75.6	126.1	214.4	–	–
Sodium [Na^+]	mmol/l	133	133	133	132	133
Calcium [Ca^{++}]	mmol/l	1.25	1.25	1.25	1.25	1.75
Magnesium [Mg^{++}]	mmol/l	0.25	0.25	0.25	0.25	0.25
Chloride [Cl^-]	mmol/l	96	96	96	96	96
Lactate	mmol/l	15	15	15	40	40
Bicarbonate	mmol/l	25	25	25	–	–
Osmolarity (approx)	mOsm/kg	340	390	480	340	282
pH		7.4	7.4	7.4	6.7	5.5

- Relatively low pH (5.5) and high glucose concentration (exceeding physiological blood sugar concentration by about 15 [1.35 % glucose] to 40-fold [3.86 % glucose]) are believed to be toxic to (peritoneal) mesothelial cells.
- "Second generation" PD solutions have physiological calcium concentrations (1.25 mmol/l) to avoid hypercalcemia and elevated Ca x P product, and a close to physiological pH (e.g., physioneal; see Table 10.4 and a recent overview by García-López E et al. *Nat Rev Nephrol* 2012).
- Supra-physiological glucose concentrations, low pH, and glucose degradation products in PD solution can contribute to peritoneal fibrosis by epithelial-mesenchymal transition or increased fibroblast proliferation leading eventually to peritoneal (UF) failure. Glucose degradation products are also thought to inhibit cell proliferation, retard wound healing, induce apoptosis, downregulate cytokines, and stimulate growth factors (TGF-beta, VEGF).
- Icodextrin-based solutions (e.g., extraneal) can be used to circumvent the rapid dissipation of the osmotic pressure of the dialysis solution needed to achieve the water removal (ultrafiltration) and effective solute clearance.
- Icodextrin is a starch-derived, branched, water-soluble glucose polymer with an average molecular weight between 13,000 and 19,000 that acts as a colloid-osmotic agent. It is slowly absorbed into the blood stream (40 % over 12 h) and metabolized to maltose and other oligosaccharides.
- Problems may arise when blood glucose measuring devices are used that do not differentiate glucose from maltose.
- Icodextrin solutions prolong UF to up to 16 h with improved solute and water clearance compared to glucose-based solutions. Use for long day (CCPD) or overnight dwells (CAPD).
- Use of icodextrin reduces unwarranted weight gain that can be seen with glucose-based solution.
- Some patients may develop eczematous skin reactions.

- Amino acid-based dialysate solutions (Table 10.4) can be used in patients with malnutrition (1 or 2 cycles per day).

10.1.4.8 Adequacy of Dialysis

- Adequate control of body fluid volume and management of hypertension are essential goals in PD.
- Preservation of residual renal function (RRF) as *renal* clearance is as important as *peritoneal* clearance.
- RRF provides a better clearance of middle and large molecules and helps maintenance of euvolemia.
- Creatinine clearance: It is calculated from a 24 h collection of dialysate and urine and normalized to 1.73 m^2 body surface area. A plasma sample is obtained for measurement of creatinine at the midpoint of the timed dialysate and urine collection. The target value is >60 l/week per 1.73 m^2.
- Determination of Kt/V tells us how much dialysis is delivered, but not whether it is adequate.
- Total KT/V should be at least 1.7. Lower values have been linked to poorer outcomes.
- Optimal PD dosing includes small solute and middle molecule clearance, and UF.
  - Small solute clearance is determined by frequency of cycles and volume of fluid per cycle.
  - Middle molecule clearance is determined by duration of contact of dialysate to peritoneum (dwell time).
  - UF is influenced by osmotic pressure (glucose concentration) and peritoneal membrane transport characteristics (see below).
- UF can be increased by higher-strength glucose and shorter dwell times. Some patients will do better with icodextrin than with glucose-containing solutions for longest cycle.
- Dialysis targets do not differ across age groups and body size, or for patients with diabetes.
- Residual renal function should be measured every 3 months.
- Urine volume and ultrafiltration volume should be closely monitored and reviewed by the Nephrology team at each clinic visit, usually once a month.

10.1.4.9 Peritoneal Equilibration Test (PET) Protocol

- The PET enables clinician to individualize the dialysis prescription according to the patient's specific requirements.
- The PET is performed 4-8 weeks post PD initiation and may be repeated yearly. It is also indicated following an episode of peritonitis or when clinical findings suggest altered membrane transport characteristics (e.g., poorly explained fluid overload, worsening hypertension, or rising serum creatinine and urea concentrations and/or uremic symptoms).

Test Procedure

- Under aseptic precautions, prepare two dialysis setups – one to drain the patient, the second to fill the peritoneum and obtain the test samples.

- To improve test reproducibility, the pediatric PET uses a standardized fill volume of 1,100 ml/m^2 of 2.5 % dextrose or 2.27 % anhydrous glucose-containing PD solution.
- On the evening before the test date, infuse 1,100 ml/m^2 of dialysis 2.5 % (2.27 %) solution for single, overnight dwell of 8–12 h.
- Connect and drain abdomen over 20 min. Record volume and send samples for cell count, culture, and protein.
- Prime and connect the second dialysis system and infuse 1,100 ml/m^2 of fresh 2.5 % dialysate over 10 min. Ask the patient to roll intermittently from side to side.
- "Zero dwell time" is the time the infusion is complete.
- Send dialysate samples at 0 and 2 h for glucose and creatinine.
- Draw a single blood sample at midpoint of the test period (+2 h) for sodium, glucose, creatinine, urea, and protein.
- After 4 h, drain the patient completely over 20 min, record the volume and send a third dialysate sample from the drained volume (4 h sample) and resume regular PD.
- Dialysate to plasma (D/P) ratio of creatinine and urea, and dialysate glucose concentrations at the measured points to time 0 (D/D_0) are calculated and plotted as shown in Fig. 10.2.
- Based on the statistical distribution of a representative group of pediatric PD patients (Warady et al. 1996), the peritoneal membrane is characterized as "low," "low average," "high average," or "high" transporter.
- The lines represent the maximal, mean +1 SD, mean, mean −1 SD, and minimal values.
- "High transporters" produce a low ultrafiltrate (due to the rapid transport of glucose from the dialysate) with adequate clearance. Increasing the number of cycles of PD with or without volume adjustments overcomes the problem.
- "Low transporters" demonstrate satisfactory ultrafiltration, but poor clearances. Increased dwell times with minor volume adjustments can rectify the deficit.
- No dietary restrictions are required for the test.
- An abbreviated version over 2 h ("Short PET") appears to vie identical results to the conventional 4-h PET (Warady et al. 2007).

Phosphate removal

- Dialytic phosphate clearance contributes to serum phosphate control. It depends on total dialysate turnover and the prescribed number of cycles, and is more adequately predicted by phosphate than by creatinine equilibration characteristics.
- Given its importance as cardiovascular risk factor in uremia, dialytic phosphate removal should be monitored routinely (Schmitt et al. 2009).
- Future modifications of the PET should include phosphate serum and dialysate measurements.

10.1.4.10 Chronic Exit Site Care

- The goal is to maintain a clean catheter exit site and minimize risk of tunnel infection and/or peritonitis during the dressing change.
- The dressing should be changed at least three times per week, and when the dressing is moist, soiled, or after taking a shower.

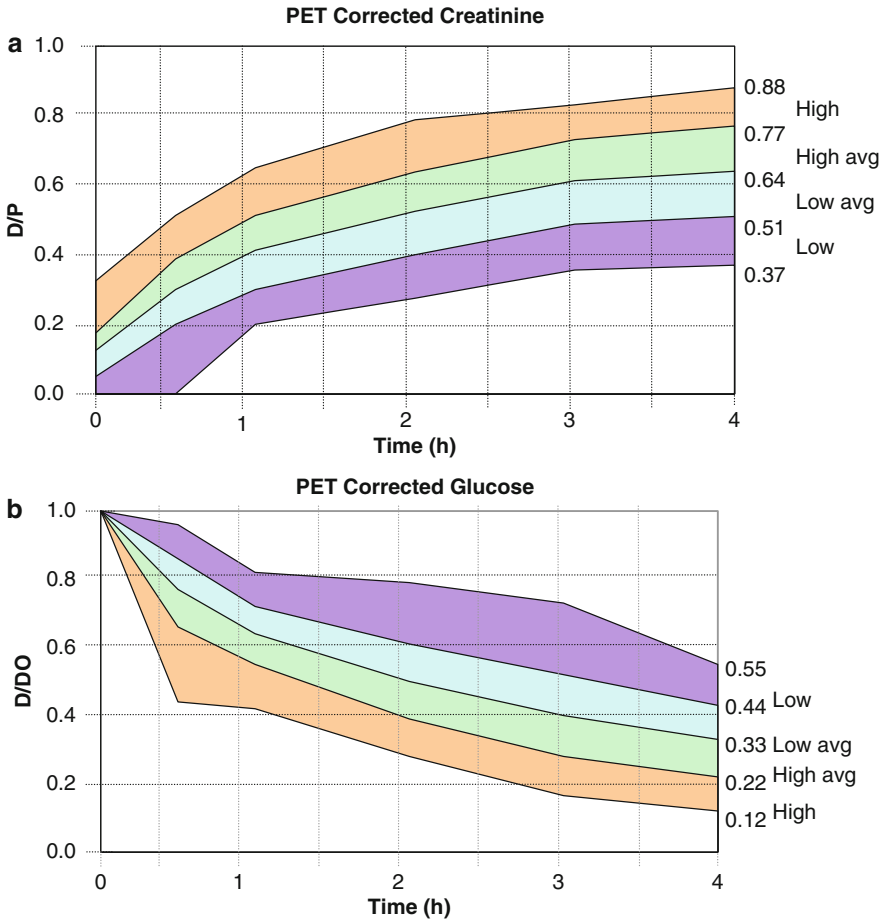

Fig. 10.2 Pediatric PET curves for creatinine (**a**) and glucose (**b**). The original study by Warady et al. 1996 comprised 95 pediatric patients; dialysate test samples were drawn at 0, 0.5,1, 2, 3, and 4 h dwell time, and blood samples at 0 and 4 h

- The exit site is cleaned with sterile antiseptic solution (chlorhexidine, sodium hypochlorite, or octenidine) and sterile gauze.
- A topical antibiotic is applied to the exit site (e.g., gentamicin, mupirocin).
- Excellent hand hygiene before examination of the exit site by patient, caregivers, and health care professionals. This includes handwashing and thorough drying.
- Prophylactic use of mupirocin intranasally or at the exit site reduces the incidence of exit site infection and peritonitis by *S. aureus.*
- A multicenter randomized trial is underway to determine whether daily honey (Medihoney antibacterial wound gel) in nasal staphylococcal carriers reduces the risk of catheter-associated infections in PD patients.

10.1.4.11 Practical Advice (Rules)

Shower and bath

- Shower is allowed with PD exit site exposed to air when the site is well healed (usually after 6 weeks), intact, and after being assessed by PD nurse.
- It is preferred that the PD exit site be covered during the shower.
- When the PD exit site is not intact (erythema, trauma), it should be covered with a medical dressing (e.g., Tegaderm) when showering or bathing.
- A bath is allowed, but PD exit site has to be covered with a gauze and a medical dressing at all times.
- Water must be shallow and not cover the PD exit site.

Activities and Sports

- Avoid contact sports, weight lifting, gymnastics, parachuting, and bungee jumping.
- Swimming is permitted in the ocean or a private swimming pool (after approval by treating nephrologist). PD catheter and exit site must be covered with waterproof dressing (e.g., colostomy bag, Tegaderm).
- Amusement rides are permitted only when exit site is healed.

10.1.5 Complications of PD

10.1.5.1 Mechanical Complications

- Pericatheter leaks (see Table 10.5)
- Positional blockage
- Catheter dislocation

10.1.5.2 Accidental Disconnection Protocol

- Close windows, doors, and ventilation.
- Wash working surface area with alcohol-based disinfectant and wash hands with chlorhexidine 4 % for 2 min, dry hands well.

Table 10.5 Protocol for management of peri-catheter leak

Signs and symptoms	Confirm diagnosis	Corrective measures
Overt fluid leakage at the skin exit site	Confirm leak with glucose dipstick	Discontinue dialysis for 7–10 days
Subcutaneous swelling, local or generalized edema and/or local pallor Weight gain Diminished outflow volume or outflow failure	Nuclear scan or CT scan for suspected peritoneal injury	If discontinuation is not possible due to the patient's condition, return to the break-in schedule (15–20 ml\kg) for 2–3 weeks Perform dialysis only in the supine position, to minimize intra-abdominal pressure If leakage persists, stop PD and switch to hemodialysis for 3–6 weeks If the leakage remains refractory, the PD catheter must be replaced Surgical repair needs to be considered in some situations

- Clamp the PD catheter with a gauze and yellow clamp.
- With aseptic precautions, clean the junction of catheter with chlorhexidine 2 % for 2 min and air dry.
- Repeat the step with alcohol 70 %.
- Replace the old PD transfer set with the new transfer set.
- Unclamp the yellow clamp and drain the patient to flush the bacterial contamination.
- Dialysate culture if contamination is suspected.
- Initiate antibiotic treatment with cefazolin 250 mg/l for 3 days. If cell count shows WBC <100/mm^3, treat for 3 days and stop treatment. If WBC >100/mm^3, continue treatment and change transfer set again when WBC <100/mm^3.

10.1.5.3 Infectious Complication: PD Associated Peritonitis (PDAP)

Diagnosis

- Peritonitis in PD patients is heralded by acute clouding of the dialysate effluent with abdominal pain, vomiting, abdominal distension, UF change, and (rarely) fever, chills and rigor, or (late) shock.
- Conversely, peritonitis should be considered whenever the peritoneal effluent is cloudy.
- Bacterial culture is often positive for coagulase-negative Staphylococci, *S. aureus*, Gram negative organisms (*Escherichia coli*, *Klebsiella* spp., *Pseudomonas aeruginosa*), and *Streptococcus viridans.*

Treatment

- Empiric diagnosis of peritonitis in the presence of effluent WBC count >100/mm^3 with at least 50 % polymorphonuclear leukocytes.
- (Cloudy) dialysate is sent for cell count, differential count, and culture to confirm the diagnosis of peritonitis.
- The differential diagnosis of cloudy effluent is shown in Box 10.3.

10.1.5.4 Empiric Antibiotic Therapy

- In most instances of PD-associated peritonitis, intraperitoneal (IP) treatment is the preferred form of antibiotic administration.

Box 10.3 Differential Diagnosis of Cloudy Effluent

- Infectious peritonitis
- Infectious peritonitis with sterile culture
- Chemical peritonitis
- Eosinophilic effluent
- Hemoperitoneum
- When effluent is taken from a “dry” abdomen
- Malignancy (rare)
- Chylous effluent (rare)

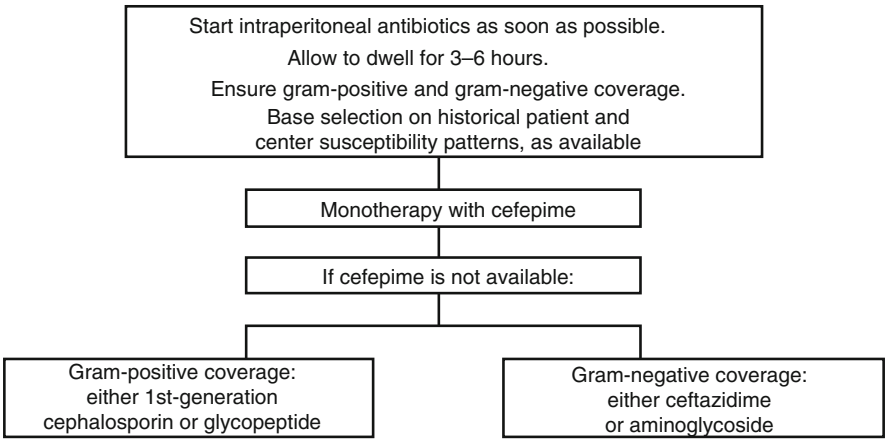

Fig. 10.3 Empiric intraperitoneal antibiotic therapy for PD associated peritonitis (From Warady BA et al. Perit Dial Int 2012; 32:S29–S86)

- Traditionally, treatment is initiated with a first-generation cephalosporin (cefazolin) combined with an aminoglycoside (gentamicin or tobramycin) or ceftazidime.
- Where available and affordable, the International Society for Peritoneal Dialysis (ISPD) Guidelines from 2012 now suggests a fourth-generation cephalosporin (cefepime) as IP monotherapy for empiric treatment.
- Where the center-specific resistance rate of *S. aureus* isolates to methicillin or oxacillin exceeds 10 %, or if the patient has a history of methicillin-resistant *S. aureus* (MRSA) infection or carriage, a combination of a glycopeptide (e.g., vancomycin) with cefepime is suggested (or with a less expensive antibiotic with activity against Gram negative rods, including *P. aeruginosa*) (Fig. 10.3).
- Continuation of antibiotic therapy is directed by the microbiological findings.
- When a Gram positive bacterium is isolated, stop the antibiotics targeting Gram negative organisms (and vice versa). Treatment duration is usually 2 weeks.
- Isolation of *Pseudomonas* spp. calls for treatment with cefepime (or another *Pseudomonas*-active antibiotic, such as piperacilin or ceftazidime) with an aminoglycoside or fluoroquinolone for 3 weeks (Warady et al. 2012).
- For IP antibiotic dosing refer to Table 10.6.

10.1.5.5 Relapsing Peritonitis

- Diagnose "relapsing peritonitis" if peritonitis recurs with the identical organism as in the preceding episode within 4 weeks of completion of antibiotic therapy, based on antibiotic susceptibility and molecular techniques, if available (for the terminology of PD-associated peritonitis see Table 10.7).
- Empiric therapy is reinitiated with relapsing peritonitis. Include susceptibilities of the original organism.
- Directed therapy should be based on in vitro susceptibility of the isolated organism; cefazolin should be avoided.

Table 10.6 Antibiotic dosing for IP therapy

Antibiotics	Dose	
	Loading	Maintenance
Cefazolin/cephalothin	250–500 mg/l	125 mg/l
Cefepime	500 mg/l	125 mg/l
Ceftazidime	250–500 mg/l	125 mg/l
Penicillin G	–	50,000 units/l
Ampicillin	–	125 mg/l
Cloxacillin	–	100–200 mg/l
Vancomycin	500 mg/l	25–30 mg/l
Teicoplanin	200 mg/l	20 mg/l
Tobramycin/gentamicin	8 mg/l	4 mg/l
Cefuroxime	250 mg/l	125 mg/l
Cefotaxime	500 mg/l	250 mg/l
Gentamicin	–	8–10 mg/l
Netilmicin	70 mg/l	4–6 mg/l
Amikacin	150–250 mg/l	6–8 mg/l
Amphotericin B	–	5 mg/l

Table 10.7 Terminology of peritonitis

Recurrent	Episode occurring within 4 weeks of completion of therapy of a preceding peritonitis, but caused by a different organism
Relapsing	Episode occurring within 4 weeks of completion of therapy of preceding peritonitis by the same organism (or a sterile peritonitis)
Repeat	Episode occurring more than 4 weeks after completion of therapy for preceding peritonitis, but caused by the same organism
Refractory	Failure of effluent to clear after 5 days of appropriate antibiotic therapy
Catheter-related	Episode occurring together with an exit site or tunnel infection caused by the same organism (lack of growth from one of the sites)

From: Warady BA et al. Perit Dial Int 2012;32:S29–S86

- Instillation of fibrinolytic agent is suggested.
- PD catheter removal is recommended once peritonitis is controlled.

10.1.5.6 PD Catheter-Related Infections

- Catheter *exit site infection* is diagnosed in the presence of pericatheter swelling, erythema, and tenderness.
- *Tunnel infection* is defined by the presence of erythema, edema, and tenderness along the subcutaneous portion of the catheter, with or without purulent drainage from the exit site (Warady BA et al. Perit Dial Int 2012;32:S29–86).
- A scoring system has been developed to describe changes to the exit site (Table 10.8).
- Oral antibiotic therapy is suggested for the treatment of uncomplicated catheter exit site infections (exit site score ³4, or at least 2 with a pathogenic isolate) for a minimum of 2–3 weeks (1 week after resolution of the infection) (see Table 10.9).
- Tunnel infection is treated by oral, IP, or IV route (IP or IV glycopeptides e.g., vancomycin in case of MRSA tunnel infection) (see Table 10.10).

Table 10.8 Exit site infection and exit site scoring system

	Score[a]		
Indication	0	1	2
Swelling	No	Exit only (<0.5 cm)	Including part of or the entire tunnel
Crust	No	<0.5 cm	>0.5 cm
Redness	No	<0.5 cm	>0.5 cm
Pain on pressure	No	Slight	Severe
Secretion	No	Serous	Purulent

[a]Infection should be assumed with a cumulative exit site score of 4 or greater regardless of culture results or in the presence of pericatheter swelling, redness, and tenderness (exit site score of 2 or greater in the presence of a pathogenic organism). From Schaefer F et al. *J Am Soc Nephrol* 1999

Table 10.9 Exit-site infection and corrective measures

Signs and symptoms	Confirm diagnosis	Corrective measures
Redness, tenderness, and/or discharge at the exit site	Patient should be examined by a PD nurse and/or a nephrologist Do a gram stain and culture of the catheter insertion site (if discharge). If exit site is dry, inject sterile saline into exit site and then culture	If the infection is very mild, begin local therapy – mupirocin ointment for 14 days If there is no significant improvement after 24–48 h, begin systemic oral or intraperitoneal antibiotic therapy If the infection is severe, proceed directly to systemic antibiotic therapy. Antimicrobial therapy should be continued for a minimum of 2 weeks resulting in a normal exit site for 1 week. If the infection does not resolve, catheter removal will be necessary

Table 10.10 Tunnel infection and corrective measures

Signs and symptoms	Confirm diagnosis	Corrective measures
Extension of a skin exit-site infection with pain, swelling, nodularity, and redness over the subcutaneous portion of the catheter	Patient should be examined by PD nurse and/or nephrologist	Antibiotics IV or PO are begun as soon as the diagnosis is made
Systemic signs such as fever or malaise "Relapsing" peritonitis due to the same organism	Do a gram stain and culture of the catheter insertion site (if discharge). If exit site dry, inject sterile saline into exit site and then culture	If there is no response after 2 weeks, the catheter must be removed Antimicrobial treatment is then continued for 2–3 weeks

10.1.5.7 Indications for PD Catheter Removal

- Refractory peritonitis
- Relapsing peritonitis
- Repeat (refractory) exit site or tunnel infection
- Fungal peritonitis

- Simultaneous PD catheter removal and replacement after cleaning of the peritoneal effluent (WBC < 100/mm^3) in repeated, relapsing peritonitis
- Minimum period of 2–3 weeks between catheter removal and replacement for fungal, enteric, and refractory bacterial peritonitis

10.1.5.8 Non-infectious Complications

- Non-infectious complications of PD, their differential diagnoses, and corrective measures are summarized in Table 10.11.

Table 10.11 Noninfectious complications of PD

PD complication	Confirm diagnosis	Corrective measures
PD catheter exit site leak	Confirm leak with glucose dipstick	Discontinue dialysis for 7–10 days
	CT or nuclear scan with peritoneal infusion	Lower dialysate volume
Outflow failure	Abdominal X-ray (plain and lateral)	Improve bowel motility
		Heparinize dialysis fluid or instill streptokinase or tissue plasminogen activator (TPA) in PD catheter
		Reposition PD catheter under fluoroscopy
Dehydration	Excessive UF	Notify nephrologist. Reassess dry weight
	Twice daily weight	↑ BP: hold PD exchange/dwell, ↑ fluid/salt intake
	Decreased fluid intake	↓ PD dextrose concentration
	Nausea/vomiting (rule out peritonitis and pancreatitis)	Bed rest with legs elevated, restrict activity
Fluid overload	Inadequate UF	Notify nephrologist. Reassess dry weight
	Increased fluid intake	↓ fluid/salt intake
	Hypotonic PD solution	↑ PD dextrose concentration
	Excessive dwell time	Reassess fluid intake and output
Muscle cramps	Excessive UF	Notify nephrologist
	Too rapid UF (e.g., dextrose 3.86% solution)	Check serum electrolytes and calcium
	Electrolyte imbalance (↓Ca^{++}, ↓K^{+})	Relief measures: apply heat to area, rub cramp
Air in peritoneal cavity	Infusion of air with the dialysate	Shoulder pain usually resolves in a few days
	Misplacement of the catheter	Notify physician if pain persists
	Bowel perforation	Lie on back, pillow under hips, and drain the fluid
Blood in effluent	Menstruation/ovulation	Pink: clears up in two to three exchanges without specific treatment
	Rupture of tiny peritoneal capillaries	Bloody fluid: check BP and HR. Observe.
		Adjust heparin → prevent clotting of PD catheter
	Possible serious abdominal injury	Call nephrologist

Table 10.11 (continued)

PD complication	Confirm diagnosis	Corrective measures
Protein loss	Average protein losses in effluent: 9 g/day Peritonitis can ↑ protein losses	Check serum albumin and total proteins Call nephrologist and dietician to modify protein intake
Accidental disconnection		Refer to *Accidental Disconnection Protocol*
Pain during dialysate inflow	"Jet" effect Abnormally low tidal volume Omentum attachment to PD catheter	Slower infusion rate Have incomplete drainage Reposition PD catheter
Ultrafiltration failure	Increasing edema, dyspnea, worsening of hypertension	Short dwell times, tidal PD, use of icodextrin
Metabolic complications	Hyponatremia, hypernatremia, hypokalemia, hyperglycemia, metabolic alkalosis, hypoalbuminemia	Take appropriate corrective measures
Intestinal perforation (rare)	Presence of fecal material in the dialysate effluent, new onset of watery diarrhea	Surgical intervention may be necessary
Respiratory distress	When large volumes are used, common in newborns	Reduce dialysate volume, rule out underlying pneumonia, pleural effusion, or atelectasis

10.1.5.9 Rare Complications

Eosinophilic Peritonitis

- Defined by the presence of >100 eosinophils/mm^3 of peritoneal dialysis fluid, eosinophils >10 % of the total WBC count of PD fluid.
- There may be a peripheral blood eosinophilia.
- May occur after catheter insertion or during the treatment phase of peritonitis.
- Peritoneal dialysis fluid cultures are negative, may occur in association with fungal and parasitic infections.
- It is benign and usually resolves spontaneously over 2–6 weeks; intraperitoneal hydrocortisone may be helpful.

Chronic Sclerosing Peritonitis

- Defined by the presence of thickened, fibrosed peritoneal membrane (Inflammation?)
- Presenting clinically with abdominal pain, fever, hemorrhagic PD effluent, deteriorating UF capability.
- Peritoneal calcification, thickened bowel loops may be seen on ultrasound; peritoneal biopsy confirms the clinical diagnosis.
- Associated with a history of prolonged peritoneal dialysis, use of high glucose content of PD solution, recurrent peritonitis.
- May lead to gut obstruction and malnutrition.

- Surgical intervention may be required. Immunosuppression has been tried with no or limited success.
- The patient may have to be transferred to hemodialysis.
- High mortality.

10.1.6 General Antibiotic Prophylaxis for PD Patients

- Procedure prophylaxis recommendations are summarized in Table 10.12.

Table 10.12 Antimicrobial prophylaxis for PD patients

Situation	Indication	Antimicrobial
Presence of risk factors for fungal peritonitis	High baseline rate of fungal peritonitis in the PD unitPEG/GT placement	Nystatin PO 10 000 U/kg daily Fluconazole 3–6 mg/kg IV or PO q 24–48 h (max 200 mg)
Touch contamination	Instillation of PD fluid after disconnection during PD	Cefepime 250 mg/l IP for 3 days Cefazolin 125 or 250 mg/l IP, or Vancomycin 25 mg/l IP (if known colonization with MRSA) ⇒ Positive culture result directs subsequent therapy
Invasive dental procedures		Amoxicillin 50 mg/kg PO (max 2 g) *If allergic to penicillin:* Clindamycin 20 mg/kg PO (max 600 mg) *Alternatives:* Ampicillin 50 mg/kg IV or IM (max 2 g) Cefazolin 25 mg/kg IV (max 1 g) Ceftriaxone 50 mg/kg IV or IM (max 1 g) Clarithromycin or azithromycin 15 mg/kg PO (max 500 mg)
Gastrointestinal procedures	High-risk procedures (esophageal stricture dilation, treatment of varices, ERCP, PEG/GT)	Cefazolin 25 mg/kg IV (max 2 g) *Alternatives:* Clindamycin 10 mg/kg IV (maxi 600 mg) Vancomycin 10 mg/kg IV (max 1 g), if high risk for MRSA infection
	Other gastrointestinal or genitourinary procedure	Cefoxitin/cefotetan 30–40 mg/kg IV (max 2 g) *Alternatives:* Cefazolin 25/kg IV (max 2 g) *plus* metronidazole 10 mg/kg IV (max 1 g), or Clindamycin 10 mg/kg IV (max 600 mg) *plus* aztreonam 30 mg/kg IV (max 2 g)

Based on the "Consensus Guidelines for the Prevention and Treatment of Catheter-Related Infection 2012" (Warady et al. 2012)

Abbreviations: *ERCP* endoscopic retrograde cholangiopancreatography, *GT* gastrostomy tube, *IV* intravenously, *IP* intraperitoneally, *MRSA* methicillin-resistant *Staphylococcus aureus*, *PEG* percutaneous endoscopic gastrostomy, *PO* orally

10.2 Hemodialysis

- Hemodialysis (HD) is an extracorporeal, intermittent form of renal replacement therapy (RRT).
- Technical advances have substantially improved the safety of the procedure. HD is now technical possible in a child of any age, even in infants.
- Acute dialysis serves to prevent death or severe morbidity due to acute kidney injury (AKI) or intoxication with water-soluble (and dialyzable) substances.
- HD is a lifesaving therapy for children with AKI and end-stage renal disease (ESRD). However, any chronic dialysis is inferior to kidney transplantation with respect to normal development and growth, and survival.
- Some aspects of hemodialysis in the setting of AKI are discussed in Chap. 8. The current section describes aspects of chronic HD.

10.2.1 Principles of HD

The goal of HD is to remove accumulated solutes (clearance) and water (ultrafiltration). This is accomplished using a dialysis filter with a semipermeable membrane.

10.2.1.1 Solute Clearance

This occurs by diffusion and convection. Major factors affecting solute clearance are dialyzer size (surface area), blood flow rate, dialysis flow rate (normally 500–800 ml/min; 200 ml/min in SLED – slow low-efficiency dialysis, see Chap. 8) and dialyzer membrane characteristics. Most dialyzers clear solutes up to a molecular weight 5,000–10,000 KD.

1. Diffusion refers to migration of solutes across the semipermeable membrane down a concentration gradient. Small solutes such as urea nitrogen and potassium diffuse rapidly.
2. Convection refers to the passive movement of solutes across the semipermeable membrane along with solvent (solvent drag) in response to a transmembrane pressure. Middle size and larger molecules do not diffuse to a great extent, but may pass through the dialyzer membrane by convection.

Too rapid removal of solutes during dialysis will result in a rapid decrease in serum osmolality and an imbalance between serum and brain cell osmolality causing movement of water into (higher osmolar) brain tissue and cerebral edema. This phenomenon is known as “disequilibrium syndrome” (DES) presents with headache, nausea, and vomiting in mild cases and altered sensorium and seizures in severe cases. High predialysis blood urea concentration increases the disequilibrium risk. To prevent DES, urea clearance should be limited during the first few dialysis sessions, aiming at a blood urea reduction of not more than 30 %.

10.2.1.2 Ultrafiltration

The goal is to finish the dialysis session with the patient at the target weight, often referred to as “dry weight”. It is defined as the weight beyond which no further

fluid removal is tolerated. Excess fluid removal will result in hypotension, cramps, abdominal pain, headache, nausea, and vomiting. Insufficient fluid removal will result in persistent fluid overload, contributing to hypertension and congestive cardiac failure. Since the fluid is removed from intravascular space and the redistribution of fluid from extravascular to intravascular space is not immediate, aggressive fluid removal rates can lead to hypovolemic symptoms even if correct dry weight is targeted. The child's dry weight adjusted periodically, to balance true body mass increase (and growth) against weight loss due to poor nutrition or chronic inflammation.

Measures to achieve fluid removal without causing symptomatic hypotension are "sodium modeling", where the sodium concentration of the dialysate is set higher during early dialysis, and gradually reduced during the course of the dialysis session, and "noninvasive volume monitoring" (acute change in hematocrit depicts acute change in blood volume).

10.2.2 Differences between "Pediatric Dialysis" and HD in Adults

1. Vascular access problems are common in small children.
2. Low blood flow increase the risk of clotting events.
3. Extracorporeal circuit volume needs be scaled to body size and blood volume using special neonatal or pediatric blood lines. The circuit (tubings and dialyzer) has to be primed with blood or albumin, when it exceeds 8–10 % of the child's total blood volume to prevent hypotension.
4. Cardiac dysfunction is less common in children, compared to adults.
5. Dialysis treatment (frequency and duration), fluid allowance and nutrition have to be optimized to facilitate near normal growth and development.
6. Seizures/CNS manifestations are more commonly encountered in uremic children, in comparison to adults.
7. Support and attention for children and their families needs be individualized. Trained social workers, dieticians, play therapists, school teachers become a part of the dialysis team.

10.2.3 Vascular Access

- Stable, large-bore vascular access is essential for effective dialysis and can pose a challenge, particularly in small children.
- Uncuffed (percutaneous) double lumen catheters are reserved for temporary HD over no more than 1–2 weeks. Different sizes are available for different age groups – newborns (two separate 5 F single lumen or 6.5 F), 3–15 kg (7 F, 12–15 cm), 16–30 kg (9 F, 20 cm), >30 kg (11.5 F, 24 cm).
- Cuffed, tunneled permanent ("perm") catheters are used for long-term use.

- Site of catheter insertion – femoral (restricts mobility and increases infection risk), subclavian (risk of stenosis), internal jugular (preferred). In newborns, umbilical artery (5 F) and vein (8 F) can be considered.
- Arteriovenous shunts (brought out externally) are not recommended. They have a high risk of infection and discconnection with dangerous blood loss; vessels cannot be used later for a permanent vascular access.
- Arteriovenous fistula: the best option for long-term HD, but may be challenging to create in small children; takes 2–3 months to mature.
- Synthetic grafts are usually made from teflon or polytetrafluoroethylene.

10.2.4 Dialysis Prescription

- Dialyzer surface area/body surface area ratio = 0.8–1.0
- Examples of dialyzers and their specifications are listed in Table 10.13 and the following paragraph

Other dialyzers: Cobe – 100HG (prime volume 18 ml, surface area 0.22 m^2, for <10 kg), F_6 (surface area 1.3 m^2, prime volume 82 ml, for 30–40 kg), F_8 (surface area 1.8 m^2, prime volume 110 ml, for >40 kg), Polyflux 140 (surface area 1.4 m^2, prime volume 94 ml, for >30 kg)

- Adult blood lines, pediatric lines, and infant/neonatal lines are available. Choice can be made depending on the size of the child. The prime volumes are 140, 75, 20 ml, respectively.
- Blood flow rate 5–8 ml/kg/min.
- Dialysate flow rates should be at least 1.5–2 times the blood flow rates. Higher dialysate flow rates achieve little additional clearance benefits.
- Dialysate sodium should be equal to or more than serum sodium. Dialysate K concentration is adjusted according to predialysis serum K levels. Standard dialysate Ca concentration is 2.5 mEq/l (1.25 mmol/l); it can be adjusted if there is hypo- or hypercalcemia.
- Fluid removal is adjusted to target body weight; fluid removal should be less than 5 % body weight or not more than 0.2 ml/kg/min.

Table 10.13 Examples of pediatric dialyzers and their characteristics

	F_3	F_4	F_5
Surface area – met^2	0.4	0.7	1.0
UFR ml/h/mm TMP	1.7	2.8	4.0
Urea clearance (25 ml/min)	25	25	25
Urea clearance (200 ml/min)	145	185	205
Prime volume in ml	28	42	72
Weight of child	<12 kg	12–20 kg	20–30 kg

- Dialysis duration: first dialysis should not reduce blood urea by more than 30 %; may give mannitol 0.5–1.0 g/kg/dose during dialysis to prevent disequilibrium syndrome. If the predialysis blood urea levels are high, HD session should not last more than 1–2 h.
- The standard duration of HD sessions is 4 h, three times a week. Hypercatabolic and very young children may require more frequent dialysis.
- Dialyzer material may be cellulose based (can cause complement activation, activation of coagulation cascade) or synthetic (more biocompatible) – Polysulphone, polyamix, polycarbonate, polyamide, or polyacryl-polyamide acrylate.
- Conventional HD uses a low-flux (small pore size) membrane. High-flux dialyzers are more efficient in removing solutes that are larger than urea but may not be more efficient than conventional hemodialysis in removing small solutes. These membranes are more biocompatible and cause less complement activation when blood comes in contact with the dialyzer membrane.
- Blood prime with WBC reduced packed RBCs diluted to a hematocrit of 35 % or 5 % albumin if circuit volume is >10 % of the patient's estimated volume. Isotonic saline or no prime in stable patients if circuit volume is <10 % of blood volume.
- Anticoagulation: Standard is the use (conventional, unfractionated) heparin. Loading dose of heparin 10–30 units/kg followed by 10 units/kg/h, adjusted to keep activated clotting time around 150 % of baseline. Heparin is stopped 30 min before closure of HD. Heparin-induced thrombocytopenia (HIT) is a rare complication.
- Under special circumstances (bleeding disorder, thrombocytopenia, post-operatively), dialysis can be performed with "tight" or no heparinization. Clotting-free dialysis time may be limited; flush dialyzer with 100–200 ml of isotonic saline every 15–30 min, increase ultrafiltration rate to remove this additional fluid, and carefully monitor venous pressure, drip chamber and dialyzer for signs of clotting.

10.2.5 Complications of HD

- Intradialytic hypotension is a common complication in HD. Causes are overzealous or (too) rapid fluid removal (UF), pre-dialysis antihypertensive medication, or bradykinin release. Treat with cessation of ultrafiltration, reduce blood flow, head low position, bolus of saline 5–10 ml/kg. Discontinue dialysis if hypotension is severe. Dry weight of the patient should be reassessed; avoid antihypertensives before dialysis session. Another possible cause is the use of hypotonic (low sodium) dialysate relative to the plasma. Sodium remodeling, online blood volume monitoring, sequential ultrafiltration, and use of intradialytic dobutamine (in patients with poor cardiac reserve) may be beneficial.
- Nausea, vomiting, cramps – treat the cause.

- Disequilibrium – secondary to cerebral edema, gradual reduction of blood urea is recommended. Mannitol may be used as a prophylaxis.
- Air embolism due to technical problem, e.g., at the negative pressure part of the circuit. Air detectors should clamp the return lines. Treatment is to clamp the lines, stop the pump and put the patient head down in left lateral position, give 100 % oxygen, aspirate air from right ventricle if required, and other resuscitative measures.
- Hemolysis – presents with nausea, pains, and dark venous blood. It may be due to contamination, overheating, hypotonicity of dialysate, defective pump, or kinked blood lines. Dialysis should be stopped. Hyperkalemia should be looked for.
- Blood leak – This is due to entry of blood into the dialysate circuit.
- Dialyzer reactions/bioincompatibility – anaphylaxis or first use syndrome, back pain, chest pain, pruritus.
- Fever – pyrogens, presence of contaminants, infection.
- Bleeding – check anticoagulation.
- Related to the access – thrombosis, stenosis, recirculation, infection.

10.2.6 Dialysis Adequacy

- Urea reduction rate (URR) = (1 − urea post HD/urea pre HD) × 100. Adequate dialysis should yield a URR >65 %.
- Formal urea kinetic modeling, single pool – Kt/*V* (Target Kt/*V* >1.2).
- The most commonly used formula:

$$\mathrm{Kt}/V = -\ln\left(R - 0.008 \times t\right) + \left(4 - 3.5 \times R\right) \times \left(\mathrm{UF}/W\right)$$

where R = urea post HD/urea pre HD, t = time of dialysis in minutes, UF = ultrafiltration in liters, and W = post dialysis weight in kg.

- "Single pool" refers to assuming that total body water is all in one compartment and that the immediate postdialysis blood urea concentration is representative of total body urea concentration. However, "urea rebound" occurs at a logarithmic rate in the first hour after a dialysis session reflecting diffusion of urea from the intracellular to extracellular space or a "double pool" compartment. Measuring urea 1 h postdialysis would hence truly reflect the delivered Kt/*V*, referred to as "equilibrated Kt/*V*."
- Calculation of *n*PCR (normalized protein catabolic rate) – This is representative of urea generation between dialysis sessions and protein catabolism and is a valuable indicator of recent protein intake. It is equal to $5.43 \times G/\mathrm{Vd} + 0.17$, where G = urea generation rate mg/minute and Vd = post HD total body water = 0.58 × post HD weight in kg. Target it to >1 g/kg/day. The value <1 g/kg/day is predictive of weight and BMI decrease.
- Other indicators – adequacy of ultrafiltration, good control of blood pressure, anemia, acidosis, bone disease, and patient well-being.

10.2.7 Causes of Inadequate Dialysis

- Improper dialysis prescription
- Inadequate blood flow
- Reduction in treatment time
- Dialyzer clotting, leaks
- Recirculation, calculated as (systemic urea-arterial urea) divided by (systemic urea-venous urea); if lines are reversed during dialysis, 15–20 % increase in recirculation is expected to occur.

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