Peritoneal Dialysis Therapy and Devices

1 Peritoneal Dialysis Overview

Kidney failure is a condition where the kidneys can no longer function well enough to remove waste products and excess fluid from your body. The three treatment options for patients with severe loss of kidney function are transplantation, hemodialysis (HD), or peritoneal dialysis (PD). Peritoneal Dialysis (PD) will be discussed in this document.

Peritoneal Dialysis may be an acute therapy or a longer-term recurring therapy for chronic End Stage Kidney Disease (ESKD). There are multiple indirect causes of Acute Renal Failure (ARF) such as trauma from an accident, burns or surgery, alcohol abuse, crush injury including direct injury to the kidney, infections, urinary tract obstructions, malignant hypertension, and disorders associated with childbirth, such as postpartum renal failure. Peritoneal Dialysis is provided to the acute renal failure patient in a hospital care unit where clinical staff monitor every aspect of the therapy, including blood pressure, urine output, and laboratory results from blood samples.

Peritoneal Dialysis (PD) uses the peritoneum, a membrane that lines the abdominal cavity and covers most of the intra-abdominal organs, to exchange fluid and dissolved substances with the blood.

During PD, dialysate is placed into the patient's peritoneal cavity via a peritoneal catheter—either manually or by a Cycler. This process is called filling. The fluid then stays in the patient's peritoneum for a period called "dwell time," during which the dialysate absorbs the waste, toxins, and excess fluid from the patient's blood that the patient's kidneys can no longer filter out. Waste products are removed from the patient's blood, through diffusion and convection, and transported to the dialysate. There is glucose in the dialysate that creates osmotic pressure that draws excess fluid from the blood into the dialysate. When the dialysate is drained from the patient's peritoneal cavity, the waste, toxins, and excess fluid are removed along with it. (See Figure 1) The completion of this peritoneal dialysis procedure—filling, dwelling, and draining—is called an exchange. This procedure is repeated several times during a 24-hour period. The filling and draining of the cleansing solution can be done manually or by using a medical device called Cycler.

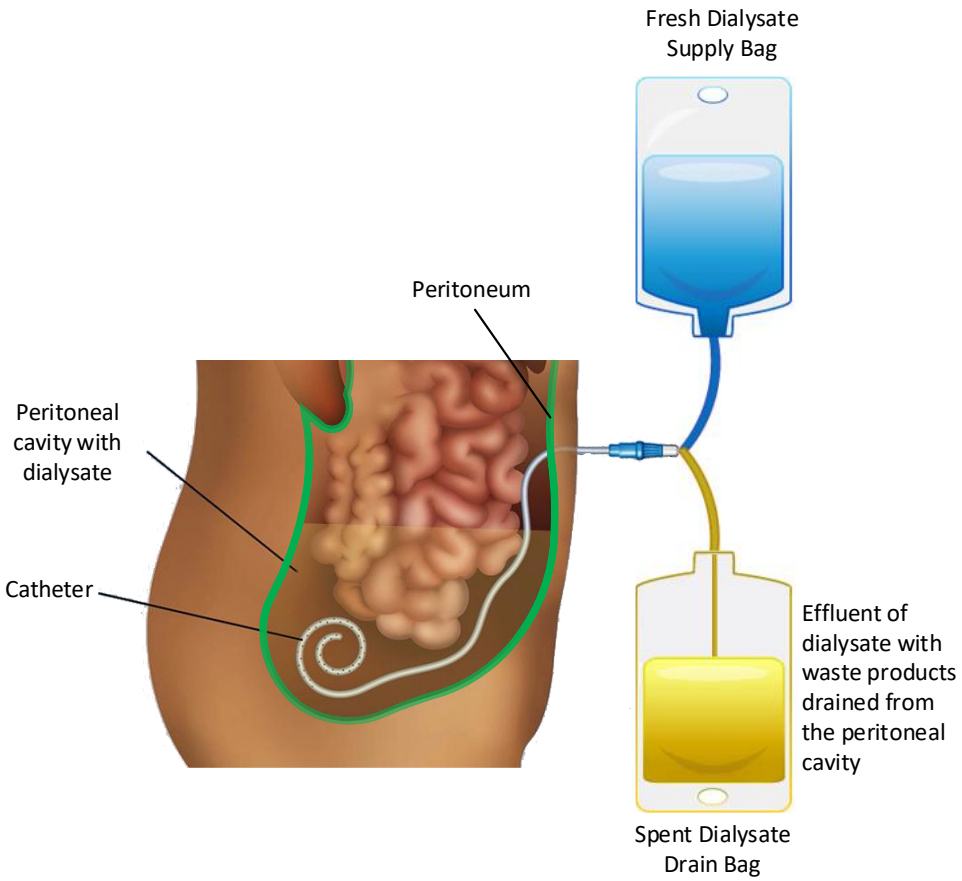

Figure 1 - Concept of Peritoneal Dialysis

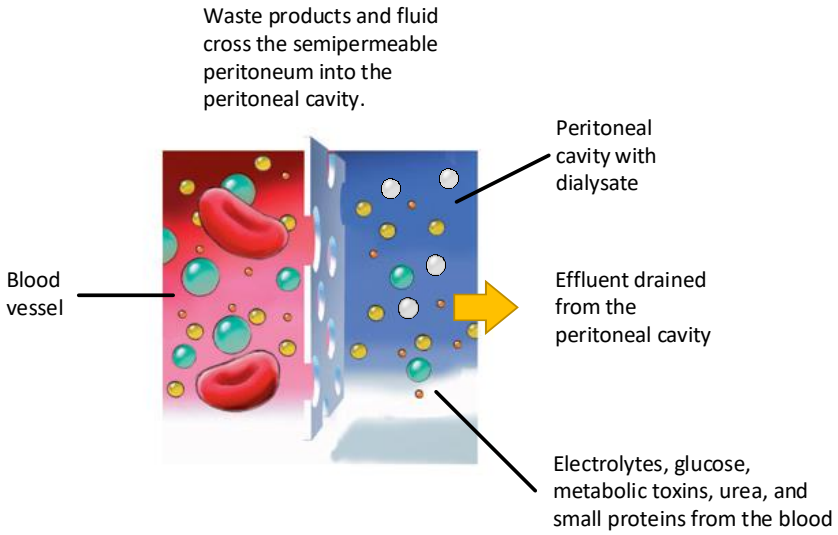

Figure 2 – Transport across peritoneum

2 Peritoneal Dialysis Therapies

There are two types of peritoneal dialysis (PD): Continuous Ambulatory Peritoneal Dialysis (CAPD) and Automated Peritoneal Dialysis (APD).

Around 80-90% of people on PD do CAPD, and 10-20% do APD. The main factors determining the choice of therapy is a person's lifestyle, size and characteristics of their peritoneum. CAPD is simple since it requires no machine and can be done in almost any clean area. APD requires a machine but can provide higher doses of dialysis and may also be suitable for patients who work or study full-time.

In peritoneal dialysis the patient, or a care giver, normally manages the therapy on their own, in their own homes. The therapy is normally performed 7 days a week.

2.1 Continuous Ambulatory Peritoneal Dialysis (CAPD)

CAPD is performed manually, by using gravity to move fluid into and out of the abdomen (the peritoneal cavity). Typically, patients fill and drain 2 to 3L of PD fluid 3 to 4 times per 24-hour period. The PD fluid can dwell in the peritoneal cavity for 4 to 6 hours for each daytime exchange and 8 to 10 hours during the overnight exchange. After the dwell period, the fluid is manually drained. An exchange, a drain followed by a fill, takes between 30 and 40 minutes.

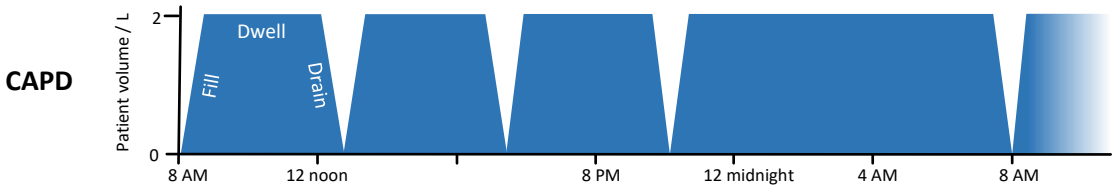

Figure 3 – CAPD therapy with three day-time exchanges and one longer nighttime exchange

2.2 Automated Peritoneal Dialysis (APD)

In APD, also known as Continuous Cycling Peritoneal Dialysis (CCPD), the filling and draining of PD fluid is done automatically by a machine, called a Cycler. The treatment is often done during the night when the patient is sleeping. During 8 to 12 hours, there are 5 to 8 exchanges done. It is possible to have additional exchanges during the day, either performed manually or using the cycler, to increase the dialysis dose. A fill takes around 10 minutes and the drain between 15-20 minutes.

Automated Peritoneal Dialysis therapies include various forms of treatments for chronic renal failure, including:

- Continuous Cycling Peritoneal Dialysis (CCPD) – APD therapy performed during the night with one long day dwell
- Nocturnal Intermittent Peritoneal Dialysis (NIPD) - APD therapy performed during the night with no fluid in the abdomen during the daytime.

- PD Plus Therapy (PD+), High-dose APD or Optimized Continuous Peritoneal Dialysis (OCPD) – APD during the night with 2 additional dwells during daytime.
- Tidal Peritoneal Dialysis (TPD) – APD therapy where only part of the fluid is drained out.
- Adapted Automated Peritoneal Dialysis (aAPD) – APD therapy where the cycles have different duration and different fill volumes.
- Intermittent Peritoneal Dialysis (IPD) – APD therapy performed three times per week, often in a hospital.

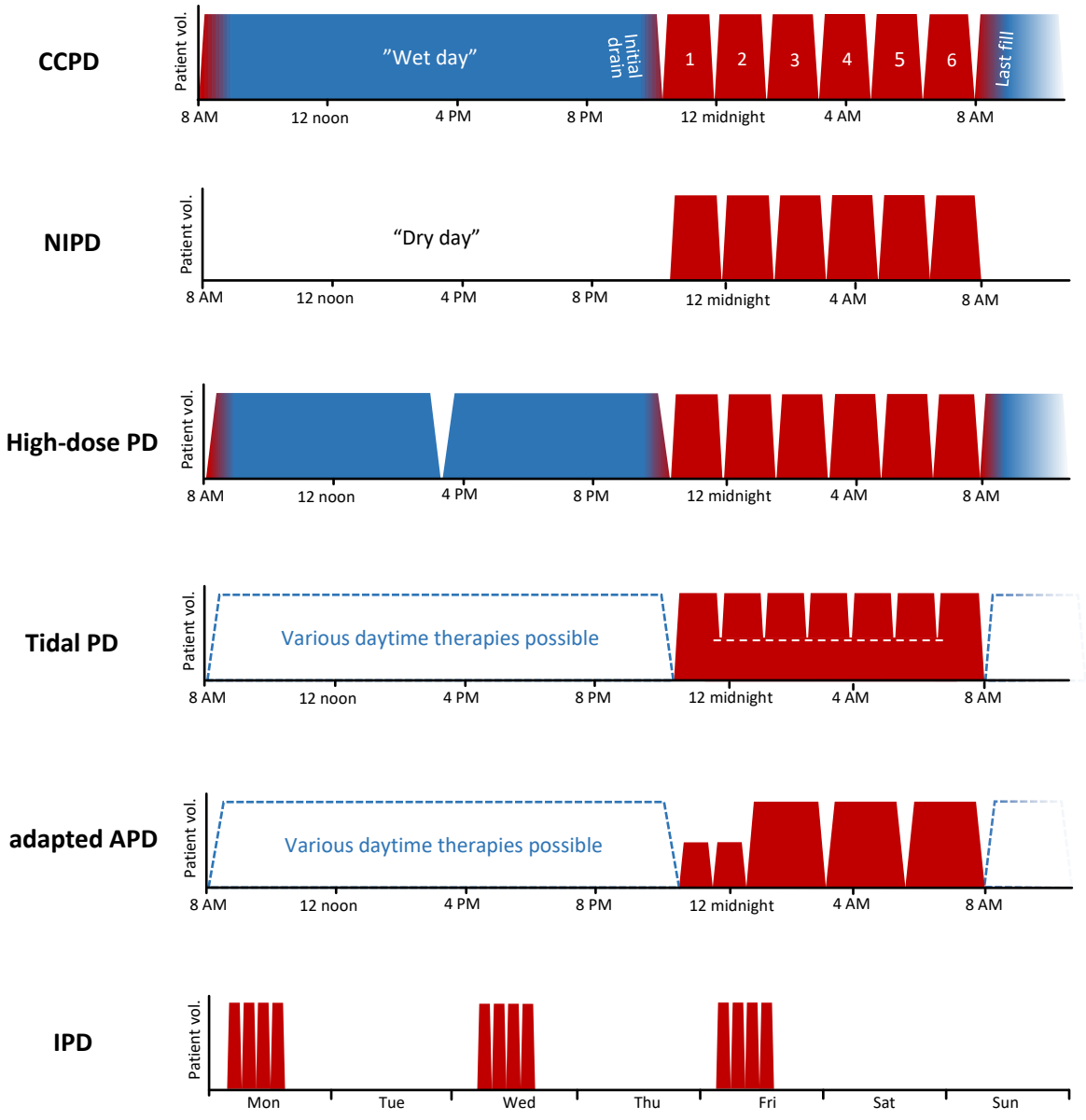

Figure 4 – Various APD modalities. During the red periods the patient is connected to a cycler.

3 Dialysis Environments

The Peritoneal Dialysis treatment is predominately performed by the patient themselves in the home environment but may also be performed in a clinical setting (professional healthcare).

3.1 Home Peritoneal Dialysis

Home Peritoneal Dialysis is the common mode of care for ESKD PD patients and has been safely performed since the 1960s. Home Peritoneal Dialysis programs train patients and their care partners in chronic dialysis facilities for approximately two –to four weeks. The patient's home is also evaluated for the required space for managing the treatment equipment and supplies such as the dialysis machine, dialysate solution, disposable supplies, carts, and treatment peripherals.

3.2 In-Clinic Peritoneal Dialysis

Peritoneal Dialysis may be provided in a dialysis clinic supervised by clinical staff.

In addition, patient and care partner training is often conducted in a clinic.

3.3 Nursing homes (Skilled nursing facilities)

"Nursing Home" care is structured to support the elderly or special care patients. The dialysis treatment may be performed in the patient room or in a specialized location where the patient is temporarily transported for trained staff supervision.

3.4 Hospital Peritoneal Dialysis

Peritoneal Dialysis may be provided in a hospital care unit or patient room supervised by clinical staff.

4 Peritoneal Dialysis Equipment and Devices

4.1 CAPD

Continuous Ambulatory Peritoneal Dialysis (CAPD) is performed manually without using a device. Normally a double-bag system is used, with one bag filled with dialysate and the second an empty drain bag. Both bags are connected to a Y-connector that is connected to the PD catheter. During an exchange, the fluid in the peritoneal cavity is first drained to the drain bag, and then in the next step the patient abdomen is filled with fresh PD solution from the other bag.

A standalone heater plate can be used to warm the bag with fresh dialysate before it is infused.

4.2 APD

In Automated Peritoneal Dialysis (APD) the exchanges are done using a medical device, called a Cycler. The Cycler consists of mechanisms to pump fluid in and out of the patient while monitoring and controlling pressures, flow rates, and temperatures of the dialysate.

4.2.1 Device Logical Architecture

The Cycler treatment settings are programmed by the clinician based on the patient's specific prescription. During treatment, the Cycler heats the peritoneal dialysate prior to infusion into the

peritoneal cavity, measures and delivers a predetermined amount of fluid to the patient and monitors the drained volume from the patient.

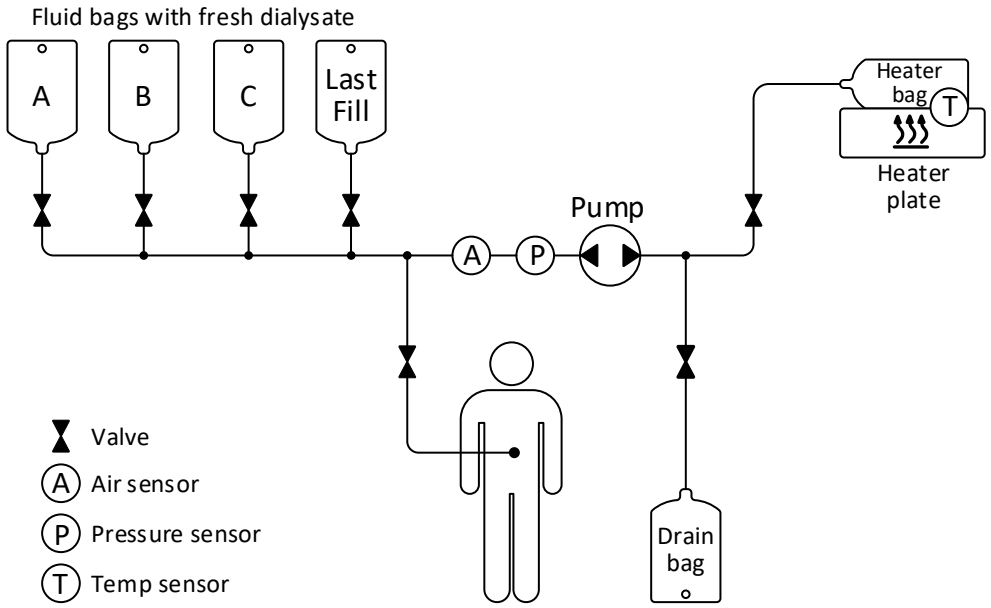

Figure 5- PD cycler with heater plate and drain bag

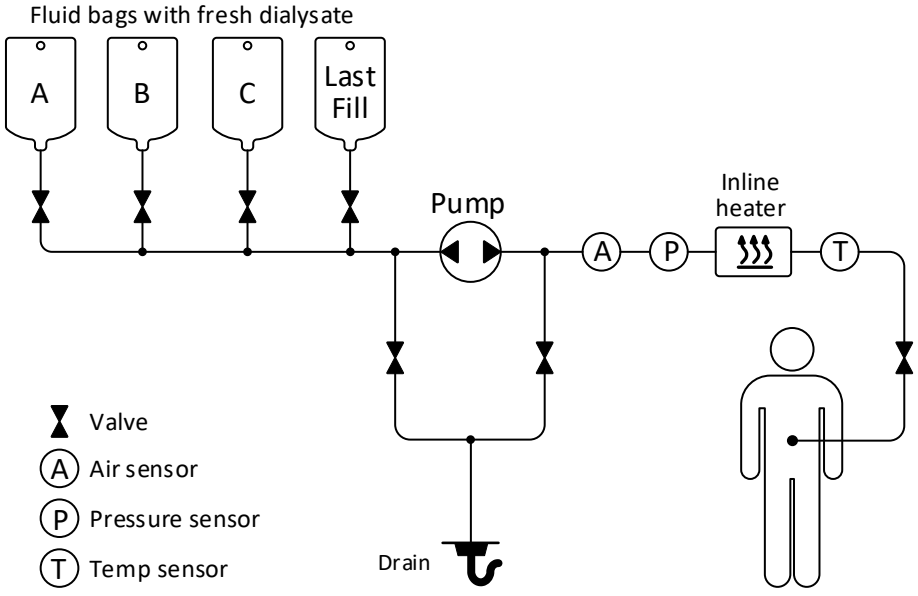

Figure 6 - PD cycler with inline heater and drain line

To achieve an exchange, a fluid path to and from the patient is provided by the disposable cycler set which interfaces with the Cycler's pump module and valves. The disposable cycler set connects the fresh dialysate supply bags to the patient's catheter and from the patient's catheter to the drain. The Cycler's software controls and monitors the pumping action needed to move the dialysate

solution through the fluid circuit. Valves open and close to direct the dialysate solution from the supply to the patient during Fill and from the patient to the drain during Drain. The pump delivers an accurate volume of dialysate solution to the patient. The Cycler typically has the following performance characteristics:

1. The accuracy of the flow rate delivered by the Cycler during inflow to and outflow from the patient is specified for the design. The solution flow rate during inflow is typically in the range of 150–300 mL/min. The solution flow rate during outflow is typically in the range of 100–250 mL/min.
2. The cycler will heat the fluid to the desired temperature before it is pumped to the patient. Heating can be done using a heater tray or an inline heater. The temperature of the dialysate is monitored by an inlet temperature sensor during the Fill phase. Solution temperature is typically adjusted between 35ºC and 37ºC depending on the patient's preference.
3. During the Fill phase, the Cycler monitors the volume per pump rotation and patient pressure. The allowable fill volume range is 250–3500 mL and if a last fill is used, the volume range is 50–3500 mL. During the Fill sequence, if the patient line is blocked, the Fill process stops, and a Patient Line Occlusion alarm is triggered.
4. When the Fill phase is completed, the Cycler performs the Dwell phase based on the prescription settings.
5. After the Dwell phase, the cycler will perform a drain, pumping the fluid out of the patient to a drain bag that is later disposed. It is also possible to directly pump the drained fluid to a plumbing drain.

4.2.2 Elements of the device logical architecture:

Cycler:
Software-controlled electromechanical device with a user interface that allows communication between the end-user and Cycler.

Software:
System-specific medical device software that controls the Cycler's mechanical functions, including treatment delivery and alarms.

User Interface:
Touchscreen display and/or front panel keys which enable user interaction with the Cycler.

Disposable Cycler Set:
Composed of a cartridge and flexible tubing lines used for exchange of fluid between the dialysate bag, patient line, drain line and/or drain bag. The cartridge contains the functional components of the pump that interface with the Cycler to enable fluid exchange.

Cartridge Loading Mechanism:
A mechanism that enables the interface between the Cycler and Disposable Set by moving the cartridge into place when it is inserted into the Cycler.

Fluids:
PD dialysate is delivered in bags, ready to be used. Bags used for CAPD are available in sizes ranging from 1.5 to 3 liters for CAPD and bags for APD from 1 to 6 liters.

Fresh peritoneal dialysate contains electrolytes (Na, Cl, Ca, Mg) to help maintain blood composition, an osmotic agent for fluid removal, and a pH buffer (lactate or bicarbonate). The most common osmotic agent is glucose (dextrose) but others such as glucose polymers and amino acids are also used. Peritoneal dialysate is available with three different glucose/dextrose concentrations, weak (1.36% / 1.5%), medium (2.27% / 2.5%) and strong (3.86% / 4.25%). Stronger bags will provide more fluid removal but also lead to a higher adsorption of glucose into the body.

Pump System:
Mechanical component that transports fresh dialysate to the patient's peritoneal cavity and spent dialysate to a drain bag or plumbing drain.

Heater:
The heater subsystem includes hardware and software components designed to heat fresh dialysate for use in the Peritoneal Dialysis treatment. The Cycler is designed to have one of two heater subsystems:

1) a conventional heating system with a heater plate; or
2) an inline heating system.

A conventional heating system typically involves placing a dialysate solution bag on a heater plate to continually heat the solution to 37˚C or a preset temperature value. An inline heating system typically involves passing dialysate solution between two heater plates to heat the solution to 37˚C or a preset temperature value on demand.

Safety System:
A PD Cycler contains alarm and safety features. The alarm features may be visual and/or audible notifications. Common device alarms include:

- Drain alarms
- Fill alarms
- Air detection alarms
- Pressure alarms
- Temperature alarms

External Communications:
Device(s) used by both patients and clinical staff to store and transfer prescription and treatment data to and from the Cycler include:

- Universal Serial Bus (USB) drives
- Patient Cards – a card with embedded readable / writeable microchip
- Cloud based platforms

Optional Accessories:
Optional accessories that are typically designed for use with the Cycler or Disposable Set include accessories are carts, travel cases and solution bag cases.

5 Typical APD Device Operations

5.1 Start-up

Start-up of a dialysis device consists of the following steps:

1. Operator turns the power switch to the “On” position.
2. The control unit performs an initialization test to check the system electronics.
3. When the initialization test is successfully completed, the device is ready for operation.

5.2 Setup Mode

Priming and daytime exchanges.

1. During the priming phase, the flow path from the solution bag to the patient line is opened by pumping fluid through the tubing system to remove air in the lines.
2. Prior to starting treatment, the Cycler prompts the user to enter daytime manual exchange information.
3. The user may be prompted to enter pre-treatment Personal Health Data such as Blood Glucose, Blood Pressure, Weight, Pulse, and Temperature.

5.3 Standby Mode

The dialysis device automatically goes into Standby mode after the operator completes all Setup procedures. The patient, or care partner, can now carry out all the operations needed to connect the patient to the primed set and start the treatment.

5.4 Run Mode

Treatment delivery is divided into several exchanges (cycles). Each exchange contains three phases: Drain, Fill and Dwell. After the last cycle during the night therapy, the patient can be filled with fresh dialysate before disconnecting from the cycler or the peritoneal cavity can be left empty.

Drain Phase (Outflow)

Treatment starts with an initial drain prior to the first exchange. When performed, the initial drain empties any spent dialysate remaining in the peritoneum from the previous fill. The pump draws the spent dialysate from the patient to the drain via the drain line. The expected initial drain volume is calculated based on the daytime exchange information. The Cycler continues to drain until the Cycler’s logic determines the patient is empty. In case of an empty peritoneum (or no previous fill) a smaller residual volume is considered a complete drain. The Cycler also drains the patient after each dwell phase.

Fill Phase (Inflow)

When the Drain phase finishes, the treatment proceeds to the Fill phase. The Fill phase is the transfer of fresh dialysate from the supply dialysate bag to the patient. The dialysate solution is

heated to the cyclers set temperature before filling the patient. Fill volumes are based on the patient's prescription. Typical Fill volumes range from 50–3500 mL.

Dwell Phase

The Dwell phase occurs after the Fill phase is completed. During the dwell phase, the dialysate remains in the peritoneal cavity for a prescribed period of time, typically between 60 and 90 minutes. During this period, exchanges (driven by diffusion, convection and osmosis) occur between the dialysate and the blood vessels in the peritoneum.

Once the dwell time expires, the next drain phase begins. The cycle of drain phase-fill phase-dwell phase is repeated until the prescribed number of exchanges is achieved, and the treatment is completed.

5.5 End of Treatment

1. The treatment summary and details are displayed for review. The treatment summary may include parameters such as: Cycler Total Volume, Cycler Total UF, Connected Time, Total Cycles on Machine, and the Number of Events and Alarms.
2. The user may be prompted to enter post-treatment Personal Health Data such as Blood Glucose, Blood Pressure, Weight, Pulse, and Temperature.
3. The patient, or care partner, closes the drain line and drain bag clamps, disconnects the drain solution bag, and removes the disposable set.
4. The Cycler will write treatment data to an external drive or the cloud.
5. The patient, or care partner, disposes of waste products.

5.6 Power down

The user powers down the Cycler by turning the power switch to the off position.