**DIFFERENCES BETWEEN HIGH- AND LOW-EFFICIENCY HEMODIALYSIS**

<table>
<thead>
<tr>
<th></th>
<th>High efficiency, mL/min</th>
<th>Low efficiency, mL/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dialyzer $K_oA$</td>
<td>$\geq 600$</td>
<td>$&lt;500$</td>
</tr>
<tr>
<td>Blood flow</td>
<td>$\geq 350$</td>
<td>$&lt;350$</td>
</tr>
<tr>
<td>Dialysate flow</td>
<td>$\geq 500$</td>
<td>$&lt;500$</td>
</tr>
<tr>
<td>Bicarbonate dialysate</td>
<td>Necessary</td>
<td>Optimal</td>
</tr>
</tbody>
</table>

$K_o$—mass transfer coefficient; $A$—surface area.

**TECHNICAL REQUIREMENTS FOR HIGH-EFFICIENCY DIALYSIS**

- High-efficiency dialyzer
  - Large surface area ($A$)
  - High mass transfer coefficient ($K_o$)
  - Both ($K_oA$)
- High blood flow (≥350 mL/min)
- High dialysate flow (≥500 mL/min)
- Bicarbonate dialysate

**CONCENTRATION OF DIALYSATE IN HIGH-EFFICIENCY DIALYSIS**

<table>
<thead>
<tr>
<th>Dialysate</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sodium</td>
<td>139-145 mEq/L</td>
</tr>
<tr>
<td>Potassium</td>
<td>0-4 mEq/L</td>
</tr>
<tr>
<td>Acetate</td>
<td>2.5-4.5 mEq/L</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>35-40 mEq/L</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1 mEq/L</td>
</tr>
<tr>
<td>Calcium</td>
<td>2.5-3.5 mEq/L</td>
</tr>
<tr>
<td>Glucose</td>
<td>0-200 mg/dL</td>
</tr>
</tbody>
</table>

**FACTORS INFLUENCING BLOOD FLOW IN HIGH-EFFICIENCY HEMODIALYSIS**

- Type of access
  - Native arteriovenous fistulae, polytetrafluoroethylene grafts, twin catheter systems: high blood flow rate, >350 mL/min
  - Permanent catheters, temporary intravenous catheters: low blood flow rate, <350 mL/min
- Needle design: size, thickness, and length
- Blood tubing
- Pump design

**FIGURE 3-8** Differences between high- and low-efficiency hemodialysis. Conventional hemodialysis refers to low-efficiency low-flux hemodialysis that was the popular modality before the 1980s [3,6].

**FIGURE 3-9** Technical requirements for high-efficiency dialysis. The $K_oA$ is the theoretic value of the urea clearance rate under conditions of infinite blood and dialysate flow. High blood and dialysate flow rates are necessary to achieve optimal performance of high-efficiency dialyzers. Bicarbonate-containing dialysate is necessary to prevent symptoms associated with acetate intolerance (i.e., nausea, vomiting, headache, and hypotension), worsening of metabolic acidosis, and cardiac arrhythmia [6,8,9]. $K_o$—mass transfer coefficient; $A$—surface area.

**FIGURE 3-10** Concentration of dialysate in high-efficiency dialysis. Although the concentration of other ions is variable, high bicarbonate concentration, relative to that of acetate, is essential for high-efficiency dialysis in order to minimize the transfer of acetate into the patient.

**FIGURE 3-11** Factors influencing blood flow in high-efficiency hemodialysis. Arteriovenous fistulae often have blood flow rates of over 1000 mL/min, as measured by current noninvasive devices. Polytetrafluoroethylene grafts and the newly introduced twin catheter systems also are capable of providing the blood flow rates necessary for high-efficiency hemodialysis. In contrast, most other temporary or semipermanent catheters cannot provide sufficient blood flow reliably enough for adequate dialysis delivery in a short time period. Needles, blood tubing diameter, and blood pumps may also contribute to this problem [8,9].
### Causes of High-Efficiency Dialysis Failure

Access-related
- Low blood flow rate
- High recirculation rate
- Time-related
- Patient not adherent to prescribed time
- Staff not adherent to prescribed time
- Failure to adjust time for conditions such as alarm, dialysate bypass, and hypotension

### Benefits of High-Efficiency Dialysis

- Higher clearance of small solutes, such as urea, compared with conventional dialysis without increase in treatment time
- Better control of chemistry
- Potentially reduced morbidity
-Potentially higher patient survival rates

### Limitations of High-Efficiency Dialysis

- Hemodynamic instability
- Low margin of safety if short treatment time is prescribed
- Potential vascular access damage
- Dialysis disequilibrium syndrome

### Characteristics of High-Flux Dialysis

- Dialyzer membranes are characterized by a high ultrafiltration coefficient ($K_{uf} > 20$ mL/h/mm Hg)
- High clearance of middle molecular weight molecules occurs (e.g., β₂-microglobulin)
- Urea clearance can be high or low, depending on the urea $K_A$ of the dialyzer
- Dialyzers are made of either synthetic or cellulosic membranes
- High-flux dialysis requires an automated ultrafiltration control system

### Figure 3-12

Causes of high-efficiency dialysis failure. The maintenance of a high blood flow rate (>350 mL/min) is essential for high-efficiency hemodialysis. Fistula recirculation, regardless of the blood flow rate, compromises achievement of the urea $Kt/V$ goal. Interruptions during the prescribed short treatment time further compromise the overall delivery of the prescribed $Kt/V$ [6,7]. $K$ — urea clearance; $t$ — time of therapy; $V$ — volume of distribution.

### Figure 3-13

Benefits of high-efficiency dialysis. With improved control of biochemical parameters (such as potassium, hydrogen ions, phosphate, urea, and other nitrogenous compounds) the potential exists for reduced morbidity and mortality without increasing dialysis treatment time [5,7].

### Figure 3-14

Limitations of high-efficiency dialysis. Removal of a large volume of fluid over a short time period (2-2.5 h) increases the likelihood of hypotension, especially in patients with poor cardiac function or autonomic neuropathy. The loss of a fixed amount of treatment time has a proportionally greater impact during a short treatment time than during a long treatment time. Thus, the margin of safety is narrower if a short treatment time is used in conjunction with high-efficiency dialysis compared with conventional hemodialysis with a longer treatment time. Although unproved, high blood flow rates may predispose patients to vascular access damage. Rapid solute shifts potentially precipitate the dialysis disequilibrium syndrome in those patients with a very high blood urea nitrogen concentration, especially during the first treatment [3,7,9].

### Figure 3-15

Characteristics of high-flux dialysis. Because of the high ultrafiltration coefficients of high-flux membranes, high-flux dialysis requires an automated ultrafiltration control system to avoid accidental profound intravascular volume depletion. Because high-flux membranes tend to have larger pores, clearance of middle molecular weight molecules is usually high. Urea clearance rates for high-flux dialyzers are still dependent on urea $K_A$, values, which can be either high (i.e., high-flux high-efficiency) or low (i.e., high-flux low-efficiency) [3,4,10]. $K_A$ — mass transfer coefficient; $A$ — surface area.
3.6 Dialysis as Treatment of End-Stage Renal Disease

### TECHNICAL REQUIREMENTS FOR HIGH-FLUX DIALYSIS

- High-flux dialyzer
- Automated ultrafiltration control system

### POTENTIAL BENEFITS OF HIGH-FLUX DIALYSIS

- Delayed onset and risk of dialysis-related amyloidosis because of enhanced β2-microglobulin clearance ([11,12])
- Increased patient survival resulting from higher clearance of middle molecular weight molecules ([12,13,15,16])
- Reduced morbidity and hospital admissions ([14,16])
- Improved lipid profile ([16,17])
- Higher clearance of aluminum ([18])
- Improved nutritional status ([19,20])
- Reduced risk of infection ([16,21])
- Preserved residual renal function ([22])

### LIMITATIONS OF HIGH-FLUX DIALYSIS

- Enhanced drug clearance, requiring supplemental dose after dialysis
- High cost of dialyzers

### EXAMPLES OF COMMONLY USED DIALYZERS

<table>
<thead>
<tr>
<th>Dialyzer type</th>
<th>Material</th>
<th>Surface area, m²</th>
<th>KoA (in vitro), mL/min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-flux low-efficiency</td>
<td>Cellulose acetate</td>
<td>0.9</td>
<td>410</td>
</tr>
<tr>
<td>CA90</td>
<td>Cuprammonium</td>
<td>0.7</td>
<td>418</td>
</tr>
<tr>
<td>Low-flux high-efficiency</td>
<td>Cellulose acetate</td>
<td>1.5</td>
<td>660</td>
</tr>
<tr>
<td>CA150</td>
<td>Cuprammonium</td>
<td>1.5</td>
<td>730</td>
</tr>
<tr>
<td>High-flux low-efficiency</td>
<td>Polysulfone</td>
<td>0.9</td>
<td>520</td>
</tr>
<tr>
<td>F50</td>
<td>Polycrylonitrile</td>
<td>1.0</td>
<td>420</td>
</tr>
<tr>
<td>High-flux high-efficiency</td>
<td>Cellulose triacetate</td>
<td>1.9</td>
<td>920</td>
</tr>
<tr>
<td>CT190</td>
<td>Polysulfone</td>
<td>1.8</td>
<td>945</td>
</tr>
<tr>
<td>F80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

KoA — mass transfer coefficient; A — surface area.
Adapted from Leypoldt and coworkers [4] and Van Stone [22].

### FIGURE 3-16
Technical requirements for high-flux dialysis. Because of the potential for reverse filtration (movement of fluid from dialysate to the blood compartment) to occur, use of a pyrogen-free dialysate is preferred but not mandatory. Bicarbonate concentrate used to prepare dialysate is particularly prone to bacterial overgrowth when stored for more than 2 days [5,8].

### FIGURE 3-17
Potential benefits of high-flux dialysis. Data are accumulating that support many potential benefits of high-flux dialysis. Large-scale randomized prospective trials, however, are unavailable.

### FIGURE 3-18
Limitations of high-flux dialysis. The enhanced clearance of drugs depends on the physicochemical characteristics of the specific drug and dialysis membrane. Because of their relative high costs, high-flux dialyzers are usually reused.

### FIGURE 3-19
Examples of commonly used dialyzers. “Efficiency” refers to the capacity to remove urea; “flux” refers to the capacity to remove water, and indirectly, the capacity to remove molecules of middle molecular weight. Cellulosic membranes can be either low flux or high flux. Similarly, synthetic membranes can be either low flux or high flux. High-efficiency membranes usually have large surface areas.