Operational Characteristics

Anticoagulation

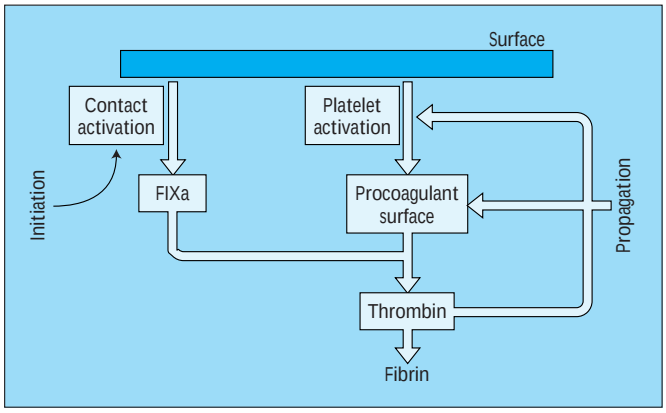


FIGURE 19-4

Pathways of thrombogenesis in extracorporeal circuits. (*Modified from* Lindhout [8]; with permission.)

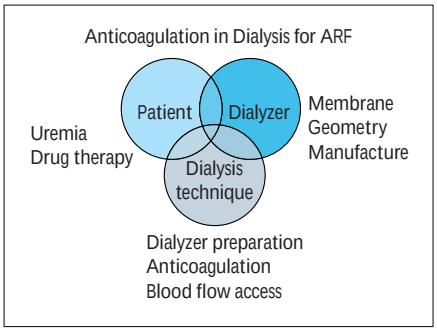
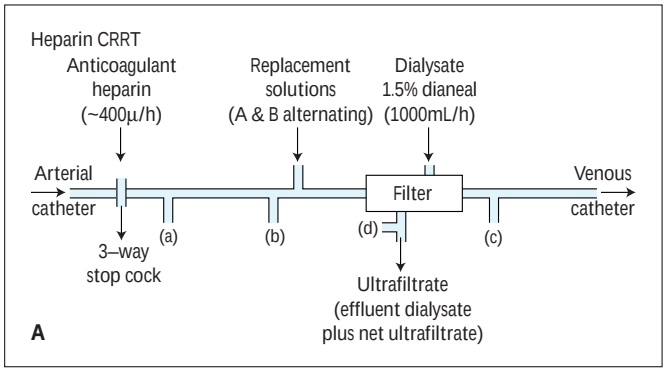


FIGURE 19-5

Factors influencing dialysis-related thrombogenicity. One of the major determinants of the efficacy of any dialysis procedure in acute renal failure (ARF) is the ability to maintain a functioning extracorporeal circuit. Anticoagulation becomes a key component in this regard and requires a balance between an appropriate level of anticoagulation to maintain patency of the circuit and prevention of complications. Figures 19-4 and 19-5 show the mechanisms of thrombus formation in an extracorporeal circuit and the interaction of various factors in this process. (*From* Ward [9]; with permission.)



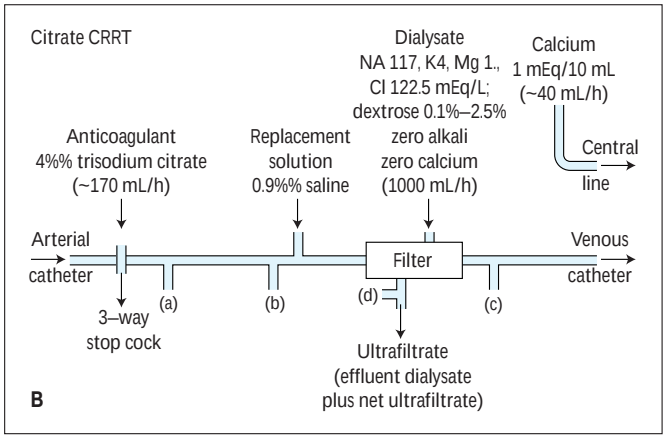
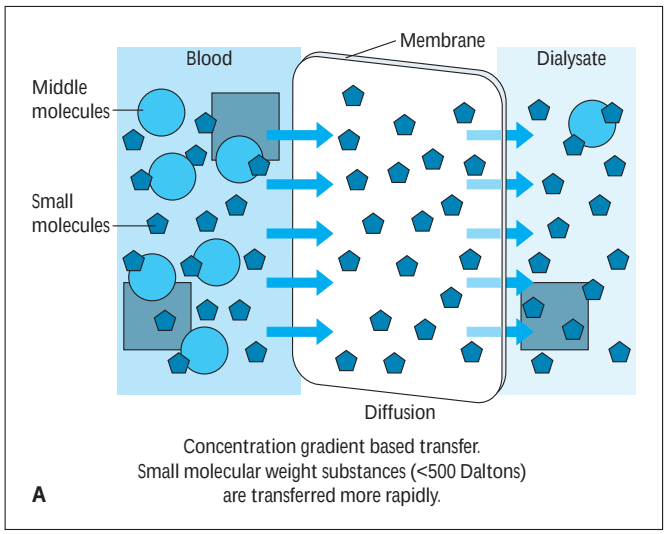


FIGURE 19-6

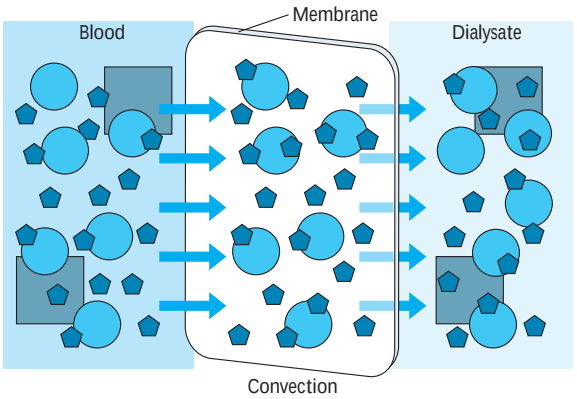
Modalities for anticoagulation for continuous renal replacement therapy. While systemic heparin is the anticoagulant most commonly used for dialysis, other modalities are available. The utilization of these modalities is largely influenced by prevailing local experience. Schematic diagrams for heparin, **A**, and citrate, **B**, anticoagulation techniques for continuous renal replacement therapy (CRRT). A schematic of heparin and regional citrate anticoagulation for CRRT techniques. Regional citrate anticoagulation minimizes the major complication of bleeding associated with heparin, but it requires monitoring of ionized calcium. It is now well-recognized that the longevity of pumped or nonpumped CRRT circuits is influenced by maintaining the filtration fraction at less than 20%. Nonpumped circuits (CAVH/HD/HDF) have a decrease in efficacy over time related to a decrease in blood flow (BFR), whereas in pumped circuits (CVVH/HD/HDF) blood flow is maintained; however, the constant pressure across the membrane results in a layer of protein forming over the membrance reducing its efficacy. This process is termed concentration repolarization [10]. CAVH/CVVH—continuous arteriovenous/venovenous hemofiltration. (*From* Mehta RL, *et al.* [11]; with permission.)

Solute Removal



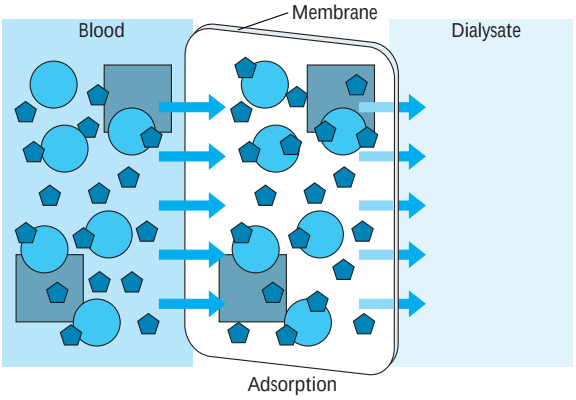
Concentration gradient based transfer.
Small molecular weight substances (<500 Daltons) are transferred more rapidly.

A



Movement of water across the membrane carries solute across the membrane.
Middle molecules are removed more efficiently.

B



Several solutes are removed from circulation by *adsorption* to the membrane. This process is influenced by the membrane structure and charge.

C

FIGURE 19-7

Mechanisms of solute removal in dialysis. The success of any dialysis procedure depends on an understanding of the operational characteristics that are unique to these techniques and on appropriate use of specific components to deliver the therapy. Solute removal is achieved by diffusion (hemodialysis), **A**, convection (hemofiltration), **B**, or a combination of diffusion and convection (hemodiafiltration), **C**.

DETERMINANTS OF SOLUTE REMOVAL IN DIALYSIS TECHNIQUES FOR ACUTE RENAL FAILURE

	IHD	CRRT	PD
Small solutes (MW <300)	Diffusion: Q_b Membrane width Qd	Diffusion: Q_d Convection: Q_f	Diffusion: Q_d Convection: Q_f
Middle molecules (MW 500–5000)	Diffusion Convection: Q_f SC	Convection: Q_f SC	Convection: Q_f SC
LMW proteins (MW 5000–50,000)	Convection Diffusion Adsorption	Convection Adsorption	Convection
Large proteins (MW >50,000)	Convection	Convection	Convection

FIGURE 19-8

Determinants of solute removal in dialysis techniques for acute renal failure. Solute removal in these techniques is achieved by convection, diffusion, or a combination of these two. Convective techniques include ultrafiltration (UF) and hemofiltration (H) and they depend on solute removal by solvent drag [6]. As solute removal is solely dependent on convective clearance it can be enhanced only by increasing the volume of ultrafiltrate produced. While ultrafiltration requires fluid removal only, to prevent significant volume loss and resulting hemodynamic compromise, hemofiltration necessitates partial or total replacement of the fluid removed. Larger molecules are removed more efficiently by this process and, thus, middle molecular clearances are superior. In intermittent hemodialysis (IHD) ultrafiltration is achieved by modifying the transmembrane pressure and generally does not contribute significantly to solute removal. In peritoneal dialysis (PD) the UF depends on the osmotic gradient achieved by the concentration of dextrose solution (1.55% to 4.25%) utilized the number of exchanges and the dwell time of each exchange. In continuous arteriovenous and venovenous hemodialysis in most situations ultrafiltration rates of 1 to 3 L/hour are utilized; however recently high-volume hemofiltration with 6 L of ultrafiltrate produced every hour has been utilized to remove middle– and large–molecular weight cytokines in sepsis [12]. Fluid balance is achieved by replacing the ultrafiltrate removed by a replacement solution. The composition of the replacement fluid can be varied and the solution can be infused before or after the filter.

Diffusion-based techniques (hemodialysis) are based on the principle of a solute gradient between the blood and the dialysate. In IHD, typically dialysate flow rates far exceed blood flow rates (200 to 400 mL/min, dialysate flow rates 500 to 800 mL/min) and dialysate flow is single pass. However, unlike IHD, the dialysate flow rates are significantly slower than the blood flow rates (typically, rates are 100 to 200 mL/min, dialysate flow rates are 1 to 2 L/hr [17 to 34mL/min]), resulting in complete saturation of the dialysate. As a consequence, dialysate flow rates become the limiting factor for solute removal and provide an opportunity for clearance enhancement. Small molecules are preferentially removed by these methods. If both diffusion and convection are used in the same technique (hemodiafiltration, HDF) both dialysate and a replacement solution are used and small and middle molecules can both be easily removed.

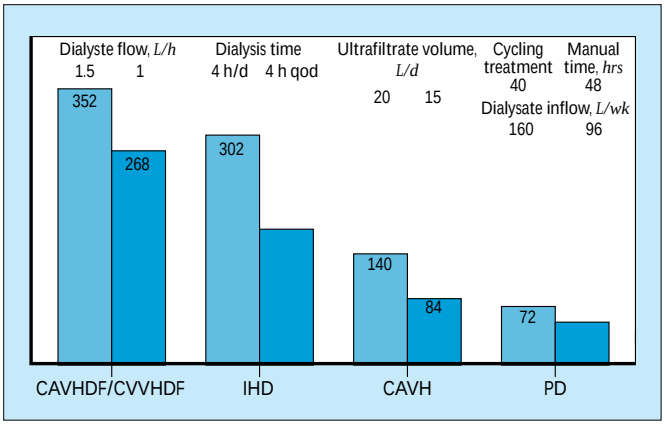


FIGURE 19-9

Comparison of weekly urea clearances with different dialysis techniques. Although continuous therapies are less efficient than intermittent techniques, overall clearances are higher as they are utilized continuously. It is also possible to increase clearances in continuous techniques by adjustment of the ultrafiltration rate and dialysate flow rate. In contrast, as intermittent dialysis techniques are operational at maximum capability, it is difficult to enhance clearances except by increasing the size of the membrane or the duration of therapy. CAV/CVVHDF—continuous arteriovenous/venovenous hemodiafiltration; IHD—intermittent hemodialysis; CAVH—continuous arteriovenous hemodialysis; PD—peritoneal dialysis.