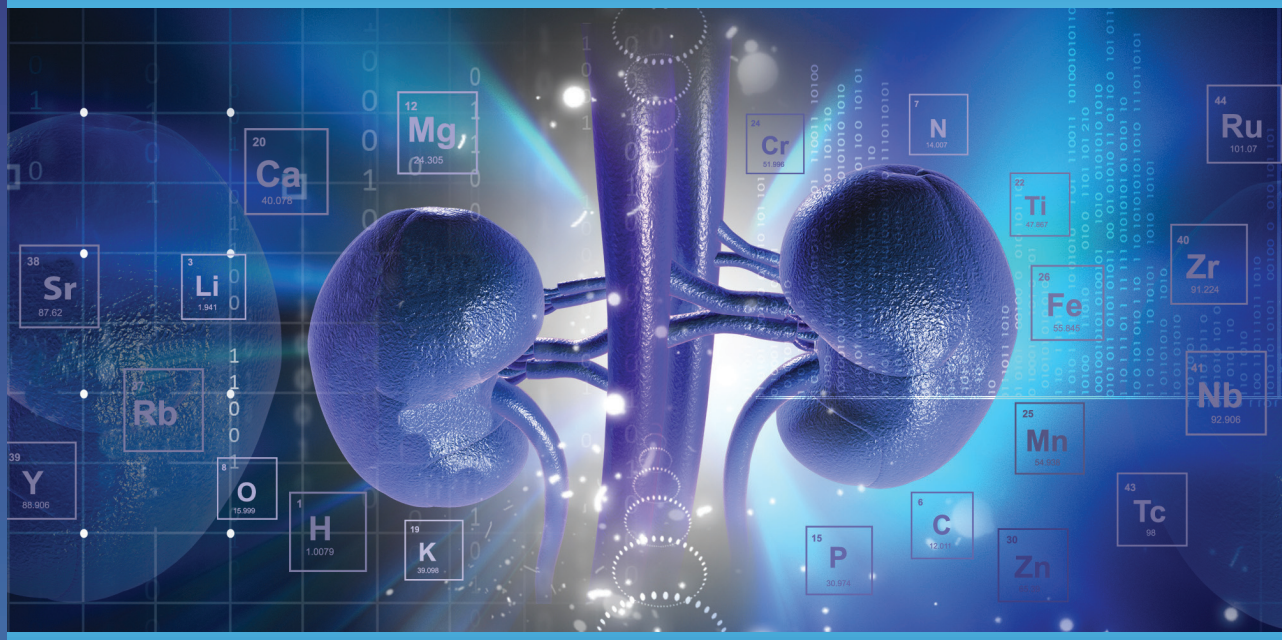
Nutrition Therapy for Chronic Kidney Disease



Edited by
Lynn K. Thomas
Jennifer Bohnstadt Othersen

CRC Press
Taylor & Francis Group

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CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

Version Date: 20120215

International Standard Book Number-13: 978-1-4398-4950-7 (eBook - PDF)

To the many terrific dietitians that I have worked with
and learned from over the years: Thank you.

Lynn K. Thomas

To Biemann for your patience and support,
to my amazing children who inspire me,
and to the patients whom I have had the privilege to treat.

Jennifer Othersen

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Preface

Kidney disease is a global health concern. It has been classified into many stages and affects people of all ages and races. It can be acute or chronic. The National Kidney Foundation Disease Outcomes Quality Initiative (NKF KDOQI)™ and the Kidney Disease: Improving Global Outcomes (KDIGO)™ Foundation have done an outstanding job of outlining the many facets of the disease and describing the parameters for adequate care of patients with kidney disease. This book builds on those guidelines in the area of nutrition therapy.

Nutrition Therapy for Chronic Kidney Disease begins with a chapter on the history of the disease, which documents some of the early treatments for kidney disease. The next several chapters cover physiology, imbalance of electrolytes, acute kidney injury, and the techniques of dialysis. There are additional chapters on special populations and the unique concerns associated with end-stage disease and chapters on quality improvement programs and counseling strategies. Most of all, this book provides an expansive discussion on optimal nutritional management, which can improve the quality of life of people with kidney disease.

This book would not have been possible without the contribution of experts from many different professions who devoted their time and effort freely to construct chapters that are timely and practical and also provided guidance regarding the stages of kidney disease and the accompanying dietary restrictions. We, the editors, are forever grateful for their contributions.

Lynn K. Thomas
University of South Carolina School of Medicine
Columbia, South Carolina

Jennifer Othersen
WJB Dorn VA Medical Center
Columbia, South Carolina

Editors

Dr. Lynn K. Thomas is the assistant dean for preclinical curriculum in the Office of Medical Education and a clinical associate professor in the Department of Family and Preventive Medicine, University of South Carolina School of Medicine. She also serves as the director of the Nutrition Vertical Curriculum for the School of Medicine. She holds an associate degree in secondary education from Shawnee State University; dual bachelors' degrees in English and Dietetics plus a master's degree in Home Economics/Nutrition from Marshall University; and a doctorate in Public Health with an emphasis on nutrition education, from the University of South Carolina. She is a registered dietitian, licensed in South Carolina, and a certified nutrition support clinician. Dr. Thomas has over 25 years of experience as a nutrition support and renal dietitian. She publishes in both the nutrition and the education fields. In addition, she is a member of numerous professional organizations including the American Dietetic Association, American Society of Parenteral and Enteral Nutrition, and the National Kidney Foundation Council on Renal Nutrition.

Dr. Jennifer Othersen is the chief of the Division of Nephrology at the WJB Dorn VA Medical Center in Columbia, South Carolina. She is also a DVAMC assistant professor of clinical internal medicine at the University of South Carolina. She earned a BS in biology at Francis Marion University followed by a second BS in chemistry at the University of South Carolina. She holds an MD from the Medical University of South Carolina where she also received her training in internal medicine and nephrology. She is board certified in internal medicine and nephrology. She is active in clinical research and is a principal investigator on several research studies currently being conducted at the WJB Dorn VA Medical Center.

Contributors

Nicole Armellino-Nitti
Loyola University Medical Center
Maywood, Illinois

Malcolm L. Buford
Department of Medicine
Division of Nephrology and Hypertension
School of Community Medicine
University of Oklahoma-Tulsa
Tulsa, Oklahoma

Tai-Gen Cui
Department of Nephrology
Beijing Chaoyang Hospital
Capital Medical University
Beijing, China

Taixing Cui
Department of Cell Biology and Anatomy
University of South Carolina School of Medicine
Columbia, South Carolina

Charles J. Foulks
Department of Medicine
Division of Nephrology and Hypertension
School of Community Medicine
University of Oklahoma-Tulsa
Tulsa, Oklahoma

Ann Grothe
DaVita Peninsula Dialysis
Newport News, Virginia

Joseph Janicki
Department of Cell Biology and Anatomy
University of South Carolina School of Medicine
Columbia, South Carolina

Tamara Karosanidze
University of Virginia Health System
Charlottesville, Virginia

Pranay Kathuria
Department of Medicine
Division of Nephrology and Hypertension
School of Community Medicine
University of Oklahoma-Tulsa
Tulsa, Oklahoma

Anand Khurana
Department of Medicine
Division of Nephrology and Hypertension
School of Community Medicine
University of Oklahoma-Tulsa
Tulsa, Oklahoma

Fran Kittell
American Family Children's Hospital
University of Wisconsin–Madison
Madison, Wisconsin

Jeannine C. Lawrence
College of Human Environmental Sciences
Department of Human Nutrition and Hospitality Management
University of Alabama
Tuscaloosa, Alabama

Emily Dill McDonald
WJB Dorn VA Medical Center
Columbia, South Carolina

Lesley McPhatter
Renal Nutrition Services
University of Virginia
Charlottesville, Virginia

Tanis Vye Mihalynuk
School of Nutrition and Dietetics
Acadia University
Wolfville, Nova Scotia, Canada

Claire Moise
WJB Dorn VA Medical Center
Columbia, South Carolina

Matthew Orr
Department of Family and Preventive Medicine
University of South Carolina School of Medicine
Columbia, South Carolina

Jennifer Othersen
Division of Nephrology
WJB Dorn VA Medical Center
and
Clinical Internal Medicine
University of South Carolina School of Medicine
Columbia, South Carolina

Beth Parris
Blue Cross Blue Shield of South Carolina
Columbia, South Carolina

C.J. Parris
Columbia Nephrology
Columbia, South Carolina

Peggy Solan
Clinical Nutrition Service
Division of Nephrology
Seattle Children's Hospital
Seattle, Washington

Kim S. Stote
Empire State College
State University of New York
Saratoga Springs, New York

Lynn K. Thomas
Office of Medical Education and Curricular Affairs
University of South Carolina School of Medicine
Columbia, South Carolina

Kyle Thompson
Department of Nutrition and Health Care Management
Appalachian State University
Boone, North Carolina

L. Britt Wilson
Department of Pharmacology, Physiology, and Neuroscience
University of South Carolina School of Medicine
Columbia, South Carolina

1 Brief History of Kidney Disease

Lynn K. Thomas
University of South Carolina School of Medicine

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1.1 THE PAST

In most prehistoric cultures, there was a shared basic belief that all diseases and pain are caused by external means. Man had no control on unfriendly spirits and demons. He knew of no way to ease his suffering. It was in the Neolithic era (9500–3000 BCE) that man first tried to change the course of illness. Shamans, priests, and medicine men provided magical cures and herbal potions for use against supernatural illnesses. During the "Golden Age of Babylonia," physicians placated angry gods in return for good health. Physicians at this time were religious and were closely associated with temples. Ancient Egyptian medical papyri, *circa* 2000 BCE, describe the use of concoctions empowered with magical spells. This was early medicine (Longrigg, 1993).

In the sixth century BCE, Babylonian physicians started documenting symptoms and naming disease states, such as discharge diseases, kidney stones, and strictures. They also developed an extensive collection of prescriptions and procedures. However, if the patient was incurable, they still deferred the patient to the local incantation priest. This Babylonian system of observing symptoms is very similar to the one noted in the *Hippocratic Corpus*, and it most likely contributed greatly to the advancement of Greek medicine (Geller and Cohen, 1995).

It was not until the Greek physician Hippocrates Asclepiades (460–377 BCE; Figure 1.1) started his medical school on the island of Kos that the treatment of disease became based on science instead of religion. During this time, Hippocrates truly shifted the cause of illness from the mystic to the natural (Dolan and Adams-Smith, 1978). He borrowed documentation methods from the Babylonians and pharmacopeia, medical practices, and surgical techniques from the early Egyptians (Figure 1.2; Greek Medicine, 2010).

The faculty and students of the Kos medical school explored many diverse diseases and documented various descriptions of signs and symptoms of diseases (Bloom, 1997). They established

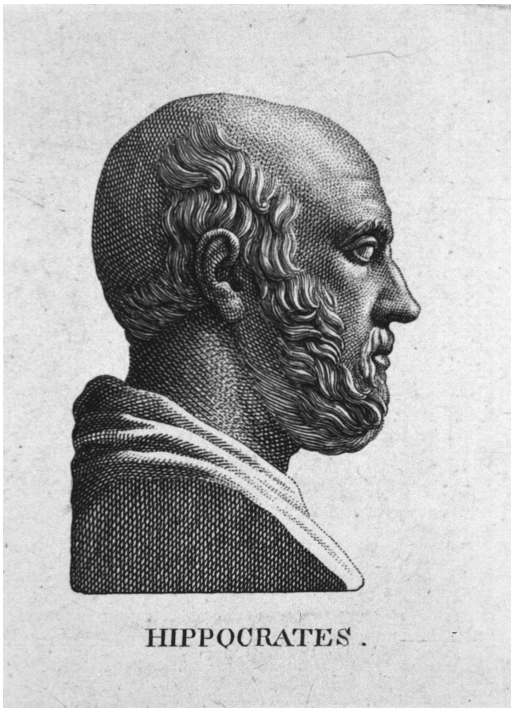

FIGURE 1.1 Hippocrates (460–377 BCE). (Courtesy of the National Library of Medicine.)

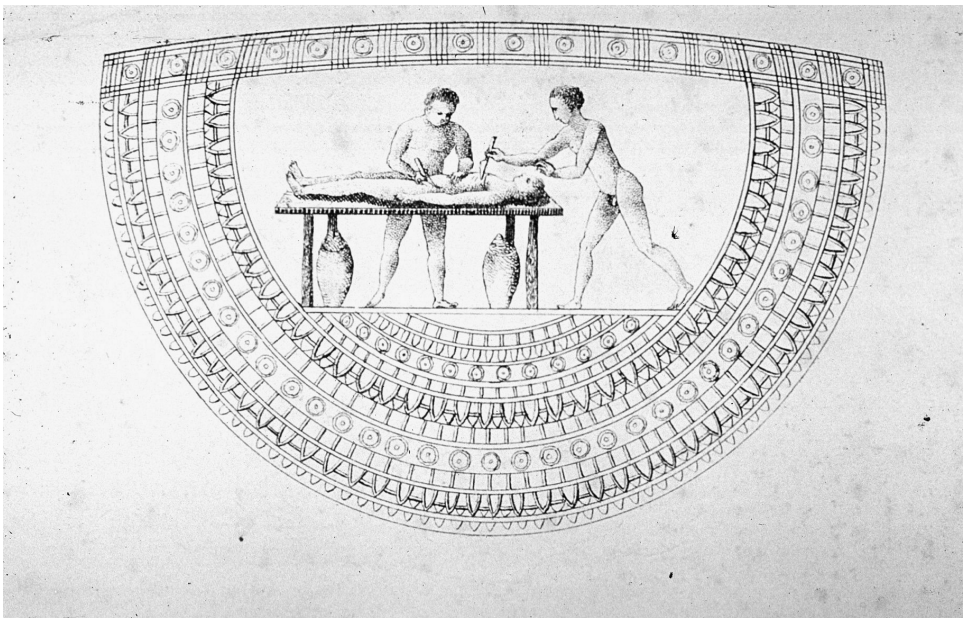

FIGURE 1.2 Early Greek medical practice. (Courtesy of the National Library of Medicine.)

TABLE 1.1
Humors

Characteristics	Empedocles's Elements	Hippocrates's Humors	Hippocrates's Seasons	Hippocrates's Organs
Bad temper	Fire	Yellow bile	Summer	Liver
Despondent	Earth	Black bile	Autumn	Brain/lungs
Calm	Water	Phlegm	Winter	Gall bladder
Hopeful	Air	Blood	Spring	Spleen

the belief that every living being contained certain mixtures of four humors (yellow bile, black bile, phlegm, and blood). This belief was based on another popular theory, *Essentialism*, postulated by Empedocles (495–435 BCE), which described four material elements (air, earth, water, and fire). The four material elements were controlled by forces called love and strife. The forces would continuously act on the elements, which would be either held together by love or driven apart by strife. The goal was to have both the elements and the forces in balance (Empedocles, 2010; Kirk et al., 1983).

Hippocrates associated his idea of "humoralism" with the four elements and the four seasons (Hippocratic Seasonal Diseases, 2010). He then related Empedocles's balance theory to the humors. A person in good health was considered "eucrasic." An ill person was someone with an imbalance of humors or "dyscrasic." Hippocrates also linked the humors to body organs (Table 1.1). The use of this system for diagnosis led the physicians to look for symptoms, or what is now known as "doing a clinical observation" (Hippocratic Method and the Four Humors in Medicine, 2010). An example is as follows: a fever was thought to be caused by too much blood in the body. This clinical observation led to the practice of "bleeding" the patient (Cataldi, 1998; Diamandopoulos et al., 2009; Figures 1.3 through 1.6).

Around the same time that Hippocrates was establishing scientific methods and describing diseases, the Medical School of Knidos, Asia Minor, was concerning itself with the classification of diseases by symptoms. In a book attributed to the school, *About Inner Sufferings*, four renal diseases were classified first. Two descriptions that are considered accurate even today include those of nephrolithiasis with renal colic and renal tuberculosis. The symptoms of the third disease resemble those of possible renal vein thrombosis or bilateral papillary necrosis. The fourth disease corresponds to chronic suppurative renal infection or sexually transmitted urethritis (Dardioti et al., 1997).

1.2 EARLY UNDERSTANDING OF KIDNEYS

Throughout antiquity, kidneys were not considered as important as the heart, liver, lungs, and intestines. One of the earliest references to the kidneys came from Aristotle Stagiritis (384–322 BCE). He wrote in his work *De Partibus Animalium* that "the human kidneys are of similar shape; being as it were made up of numerous small kidneys, and not presenting one unbroken surface …" Aristotle believed that the kidneys served two functions. One was to remove surplus liquid from the blood, and the other was to funnel this liquid through the ureter, bladder, and urethra. During this passage, the liquid would be filtered and transformed into "residuum" or urine.

Erasistratus of Ceos (304–250 BCE) was one of the early physicians to consider the kidneys as the source of urine (Twardowski, 2008). Another Greek physician, Claudius Galen (129–214 CE), in his book on functions of body parts, rejected the work of Aristotle and Erasistratus. He believed that the thin watery liquid in the blood was a vehicle for nutrients and that when the nutrients were depleted, the liquid would be extracted from the blood by the kidneys and directly passed to the ureters and then to the bladder. Galen (1968) rejected the possibility that

FIGURE 1.3 Black bile humor. (Courtesy of the National Library of Medicine.)

FIGURE 1.4 Blood humor. (Courtesy of the National Library of Medicine.)

FIGURE 1.5 Phlegm humor. (Courtesy of the National Library of Medicine.)

FIGURE 1.6 Yellow bile humor. (Courtesy of the National Library of Medicine.)

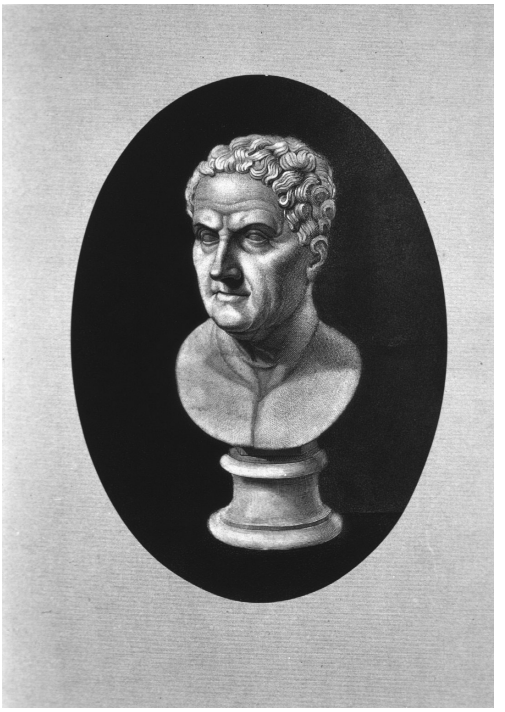

FIGURE 1.7 Claudius Galen (129–214 CE). (Courtesy of the National Library of Medicine.)

the kidneys filtered urine. He instead determined that the kidneys "attracted" the depleted liquid or urine (Galen, Translated by May, 1968; Figure 1.7).

For centuries, the gross anatomy of the kidneys was well documented. Leonardo da Vinci (1452–1519 CE) portrayed the anatomical features of the kidneys more accurately and artistically than anyone before him. Unfortunately, he did not provide any new knowledge about the urinary system. There continued to be little understanding of the functionality of the kidneys until the publication of *Opuscula Anatomica* (1564 CE) by Bartolomeo Eustachio (Figure 1.8). He illustrated the kidneys in 47 copper-plated engravings and first described renal collecting ducts. Eustachio proposed that the tiny ducts moved the urine from the kidney to the renal pelvis. He also described the adrenal glands and the differing locations of the left and the right kidney (Mezzogiorno, 1999).

In 1662, Lorenzo Bellini (1643–1704 CE) suggested that small, intertwined masses in the kidney were responsible for keeping urine separated from the blood. In 1666, at the University of Messina, Sicily, Marcello Malpighi, a professor of medicine and founder of microscopic anatomy discipline, was finally able to describe kidney histology and give physicians the first insight into the mechanism of urine formation. He described the actual structure of the kidney, including the glomerulus and the renal pyramids. Professor Malpighi utilized a microscope, made possible by the invention of the lens, and two different staining techniques to identify the tubular structures and the vascular tree (Andreucci, 1972; Eknoyan, 1996; Figure 1.9).

1.3 MORE DISCOVERIES

As medicine advanced, the documentation of the gross and microscopic anatomical description of the kidneys became more accurate. Frederich Henle (1809–1885) was a physician interested in the fine structure of organs and tissues. In 1862, he described the presence of perpendicular tubular loops imbedded on the kidney surface. He further described the tissue of the convoluted and straight cortical tubules found in the kidneys as epithelial in nature and declared that the same type of tissue

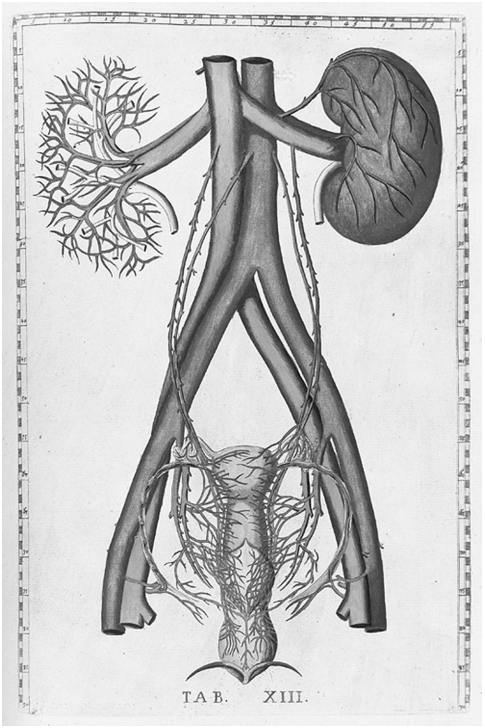

FIGURE 1.8 Depiction of urinary system in *Opuscula Anatomica* by Bartolomeo Eustachio. (Courtesy of the National Library of Medicine.)

FIGURE 1.9 Marcello Malpighi. (Courtesy of the National Library of Medicine.)

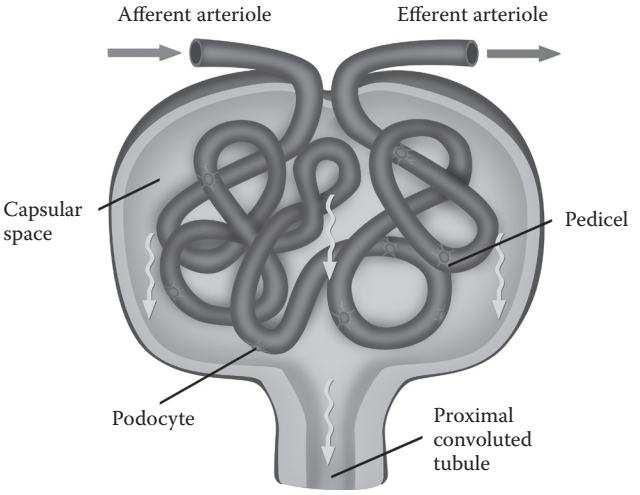

FIGURE 1.10 Bowman's capsule. (From Shaun Riffle, University of South Carolina School of Medicine, Columbia, SC. With permission.)

formed protective layers in the medullary and papillary collecting tubules and the duct of Bellini. Henle assigned no function to the structures. Urine-formation principles were the subject of intense debate during this period (Cataldi, 1998; Morel, 1999).

In 1842, William Bowman (1816–1892), a physiologist, investigated the relationship between the glomerulus and the renal tubules. He studied thin slices of kidneys using the high-power microscope of his days (300×) and described the glomerular capillary tuft and its relation to the afferent and efferent arterioles. He was the first to describe the basement membrane of the tubules and to demonstrate the function of the capsules. He concluded that the glomerular capsule functioned as a receptacle of filtrate separated from "blood in the capillaries" (Eknoyan, 1996; Todd and Bowman, 1856; Figure 1.10).

1.4 URINE

The work of Hippocrates in 400 BCE, *Corpus Hippocraticum*, contains approximately 400 aphorisms that refer to the practice of medicine. Several of these describe how the urine reflects different stages of renal disease.

> *When the urine is transparent and white, it is bad; it appears principally in cases of phrenitis.*
>
> **Hippocrates (Section 4, Aphorsim 72 from Adams translation)**

> *In those cases in which urine is thin at first, and the sediments become bilious, an acute disease is indicated.*
>
> **Hippocrates (Section 7, Aphorism 32 from Adams translation)**

> *Diseases about the kidneys and bladder are cured with difficulty in old men.*
>
> **Hippocrates (Section 6, Aphorism 6 from Adams translation)**

Early Babylonian medicine also looked at urine as the diagnostic tool for kidney disease. Markham Geller writes that the ancient physician consulted a list comprising statements such as *If his urine is like beer dregs, man suffers from discharge disease* (Geller and Cohen, 1995). Much later, Antoine François, comte de Fourcroy, a physician, and Louis Vauquelin, a pharmacist and chemist, in the early nineteenth century completed the analysis of urine and for the first time

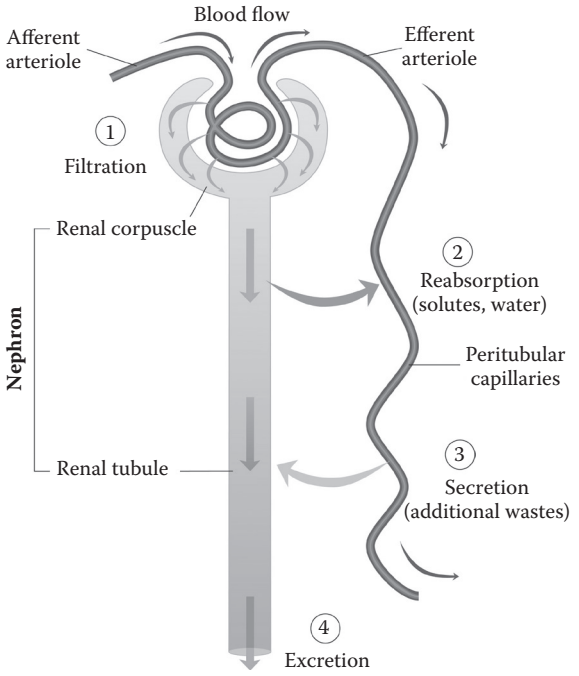

FIGURE 1.11 Urine formation. (From Alila07/Dreamstime.com, Dreamstime USA Headquarters, Brentwood, TN. With permission.)

noted the presence of nitrogen. They also were the first to surmise that urea overload could be capable of causing diseases, and that urea was a toxin. In the second half of the nineteenth century, further analytical studies concluded that potassium was the most toxic constituent of urine (Richet, 1999).

The mechanism of urine formation remained controversial from the time of William Bowman in 1856. Scientists supported either the "Filtration Theory" or the "Secretion Theory." Arthur Cushny (1866–1926) proposed a unified, modern theory in 1916 and reported that urine was formed by simple ultrafiltration in the glomeruli. By the mid-twentieth century, Alfred Richards (1876–1966) established the theory of salt and water reabsorption. He was one of the pioneers who established the true function of the kidneys (Morel, 1999; Figure 1.11).

1.5 DIALYSIS

Although nineteenth-century physicians and physiologists discerned the content and purpose of urine, Thomas Graham, a Scottish chemist (1805–1869), was the first scientist to separate colloids and crystalloids by using a "dialyzer." His dialysis technique involved the separation of a mixture of substances dissolved in a solution by passing the solution through semipermeable membranes (Figure 1.12).

"It may perhaps be allowed to me to apply the convenient term dialysis to the method of separation by the method of diffusion through a system of gelatinous matter" (Graham, 1854). The word "dialysis" was not new to Graham. It was derived from Greek and means "to part asunder." However, he did provide its new meaning, which is still in use. His research earned him the name "father of modern dialysis."

Thomas Graham constructed several simple devices during his study of diffusion and dialysis. His hoop dialyzer was made of gutta-percha and was closed on one end with parchment paper. The hoop floated on the water surface in a large basin. "Half a liter of urine, dialyzed for 24 hours, gave

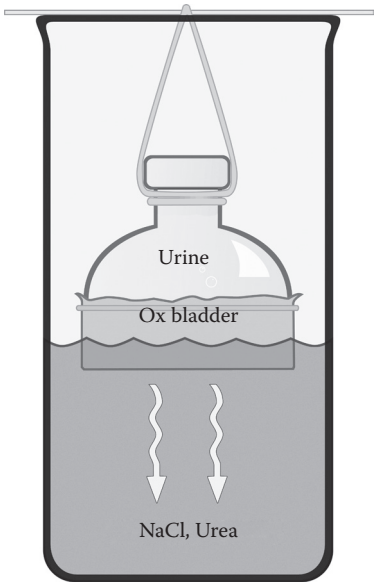

FIGURE 1.12 Depiction of the Graham dialyzer. (From Shaun Riffle, University of South Carolina School of Medicine, Columbia, SC. With permission.)

its crystalloid constituents to the external water. The latter, evaporated by a water bath yielded a white saline mass. From this mass, urea was extracted …" Graham designed at least two other dialyzers, a water-jar type and a bulb type. He fitted these with a variety of membranes. He studied the effect of temperature and the efficacy of purification when using differing crystalloids. It was his work and later that of John Abel (Baltimore in 1913), who developed the first artificial kidney, which led to the current forms of hemodialysis treatment for kidney failure (Eknoyan, 2009; Graham, 1854; Gottschalk, 1998). Willem Kolff is considered the inventor of the first reliable artificial kidney. His rotating drum artificial kidney, in 1943, offered an effective method of dialysis. Dr. Kolff quickly put his artificial kidney into clinical use by successfully dialyzing a patient with acute kidney failure (AKF) (Kolff, 1965).

Georg Ganter performed the first human peritoneal dialysis in 1923 (Teschner et al., 2004). This type of dialysis was prone to complications and often failed secondary to peritoneum access issues.

Howard Frank, Arnold Seligman, and Jacob Fine at Boston's Beth-Israel Hospital established more successful peritoneal treatments for AKF in 1946. A new stylet catheter made access to the peritoneal cavity much easier and safer. Today, peritoneal dialysis, done at home, provides an alternative method to in-center hemodialysis.

Successful kidney transplants soon followed with the first successful transplant between identical twins in 1954 (Boston). In 1962, cadaver transplants and the first use of antirejection drugs began in Boston. The number of kidney transplants now exceeds 17,500 per year from both living related and cadaveric donors (National Institute of Diabetes and Digestive and Kidney Diseases, 2010).

1.6 NUTRITION

The link between diet and declining kidney function came to prominence in mid-1800s when Richard Bright suggested a milk diet to temporarily treat edema and proteinuria (Bright's disease) (Beebe, 1896). This type of extremely restricted diet was used well into the twentieth century (Fahnestock, 1896). Fritz Bischoff (1932) conducted one of the first scientific examinations to confirm the linkage between diet and kidney function. He used evidence from numerous studies on animals to conclude that nephrotoxic factors could be a result of dietary intake. Several decades

later, studies on humans confirmed his hypothesis (Maschio et al., 1982; Rosman et al., 1984). In the interim, various practitioners proposed restricted diets to minimize uremic toxicity and delay the loss of kidney function (Addis, 1948). Patients with either acute or chronic kidney disease (CKD) were managed with a variety of diets that primarily limited sodium, protein, and fluids. These therapeutic diets extended the lives of patients in a time when treatment options were almost nonexistent (Addis et al., 1948).

1.6.1 Diet and AKF

Earlier diets for patients with AKF contained little, if any, protein, no salt, and a severely limited fluid allowance. For many years, they served as alternatives to dialysis. Professor J.G.G. Borst, Amsterdam 1948, formulated a gruel that provided approximately 1750 Cal/day to sustain patients with AKF. He also made butterballs from water (1.5 L), custard powder, sugar, and butter mixture (Table 1.2). Some amounts of protein were occasionally permitted in the diet. In 1955, Rose and Wixom established a minimal daily requirement for essential amino acids, and in 1963, Giordano established a ranking system so that high-biological value protein foods would be the preferred items in a protein-restricted diet. Today, the diet for patients with AKF is still very restricted until the kidney function is normal. Protein is now an essential part of the diet and is carefully calculated to ensure adequacy for the patient (Borst, 1948; Giordano, 1963; Rose and Wixom, 1955).

1.6.2 Diet and Stage 4 CKD

In 1934, the famous Rice Diet was developed by Walther Kempner, a doctor at Duke Hospital in Durham, NC, as a no-salt dietary treatment for patients with malignant hypertension and CKD. Besides restricting sodium, the diet limited calories and protein. Dr. Kempner named the diet after the bowl of white rice eaten at every meal. Today, this diet is generally regarded as a low-sodium, low-fat, low-calorie diet for weight reduction. White rice has been replaced with the healthier brown rice (Rice Diet Program, 2010).

Very low protein diets, first advocated in the 1960s, can be used to delay the start of dialysis. Protein is limited to 18–20 g/day of essential amino acids, ketoanalogs, or proteins of high biological value (eggs, soy, and whey). Special low-protein starches are also used to make breads and pastas. These diets help to reduce urea production. Symptomatic improvement is widely documented in those patients who are able to follow the very low protein diet, which requires many restrictions and special foods. The very low protein diet is also advocated as a way to completely avoid the start of dialysis in the elderly who do not wish to be treated or who have only a short time to live (Robson, 1969).

Typically, a 60-g protein, 2-g sodium, and 2-g potassium diet with adequate calories is prescribed for patients with CKD. Fluid restriction usually of 500–800 mL plus an amount equal to daily urine output of the patient is also recommended as kidney failure progresses. Currently, this diet is in use for patients with CKD who are considered for predialysis.

TABLE 1.2
Borst Soup and Butterballs

Borst Soup	Butterballs
Ingredients: Sugar 3/4 cup or ~150 g	Ingredients: Powdered sugar 1/2 cup or 100 g
Unsalted butter 2/3 cup or ~150 g	Unsalted butter 1/3 cup or ~80 g
Flour 1–2 tablespoons or ~20 g	Vanilla extract 3/4 teaspoon
Water 11/4 cups or ~ 300 g	Peppermint, lemon, or other flavorings (3–4 drops)
Mix all ingredients and heat slowly. Do not boil. Serve as soup. Divide into three servings	Combine sugar and butter; add peppermint (optional). Divide the mixture into 10 balls. Roll in powdered sugar. Store in a freezer until use. ~100 kcal/ball. Low protein
~590 calories per serving with <1 g of protein	

1.6.3 Diet and Stage 5 CKD

1.6.3.1 Hemodialysis

Once dialysis starts, protein restriction is lifted. Increased protein intake helps correct or prevent malnutrition. Sodium and potassium are generally limited to 2–3 g/day. Phosphorus restriction in the diet is based on the amount of protein intake. A limit of 10 mg of phosphorus in 1 g of protein is generally used. Fluids are also restricted to 800–1000 mL plus an amount equal to the urine output of the patient. Other restrictions are imposed as needed for management of comorbidities such as diabetes and cardiovascular disease.

1.6.3.2 Peritoneal Dialysis

Continuous ambulatory peritoneal dialysis was introduced in the 1970s. In the beginning, most patients were placed on an unrestricted diet since they received daily peritoneal exchange treatments. Now increased amounts of protein are recommended (1.2–1.3 g/kg) to offset protein losses due to dialysis. Additional dietary changes include modest restrictions on the intake of sodium and phosphorus. The intake allowance of potassium is liberalized to 4 g/day and fluid restrictions are minimal.

1.7 SOCIALIZED MEDICINE

In the 1960s, dialysis treatments became a standard of care for stage 5 CKD. Countries with socialized medicine started building local dialysis centers and increased the number of persons able to receive dialysis. The opportunity for dialysis in the United States during the same time was decided by patients' ability to pay and their social worth. Only one in seven patients considered suitable for treatment actually obtained it.

In 1967, a congressional committee, the Gottschalk Committee, stated that federal assistance was mandatory to defray the high cost of dialysis or transplant surgery for patients with CKD. The committee set up a national program that would ensure that 100% of candidates suitable for dialysis would be treated by 1973 (Kerr, 1973). The role of the renal dietitian expanded at that time, and the availability of dialysis brought a new approach to dietary management.

Approximately 10,000 Americans were eligible for the new program in 1973 (Nissenson and Rettig, 1999). Twenty-four years later (2007 data), the number of Americans receiving treatment for end-stage renal disease (ESRD) had grown to 368,544 (National Institute of Diabetes and Digestive and Kidney Diseases, 2010). Other countries have also seen large increases in the number of persons eligible for dialysis. This is accounted for by the increase in the number of patients with diabetes and hypertension, which are the primary causes of kidney failure, and by the increase in the number of elderly (65 years or older) who are now dialyzed. The cost of the ESRD program in the United States in 2007 was $35.32 billion in public and private spending or an annual average cost of $68,253 for every patient on hemodialysis and $56,807 for each patient on peritoneal dialysis.

1.8 SUMMARY

Future research holds the possibility of eliminating kidney disease. Until then, efforts would remain focused on the prevention and/or control of illnesses that contribute to the decline of kidney function. Dialysis techniques and equipment continue to be refined. Dialysis is becoming more "portable" with new peritoneal techniques. Nutritional therapy, for now, is the key stone that can prevent and control chronic renal diseases and make current dialysis techniques more effective.

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2 Renal Physiology

L. Britt Wilson
University of South Carolina School of Medicine

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2.1 OVERVIEW OF FUNCTION OF KIDNEYS

Kidneys are remarkable organs, and they play a pivotal role in whole-body homeostasis. In short, the kidneys regulate the extracellular environment, specifically extracellular water and electrolytes. In addition, they eliminate nitrogenous products from protein metabolism (urea) and creatinine, which is released from skeletal muscle. Mostly everyone, laypersons and professionals alike, recognizes the importance of the elimination function of the kidneys and the fact that the failure of the kidneys to eliminate urea (uremia or azotemia) does indeed cause profound pathologic disturbances. However, the ability of the kidneys to maintain extracellular water and electrolytes within an acceptable range has a profound influence on all the organs of the body because all cells reside in the extracellular environment. Retaining extracellular volume, for example, can result in hypertension, and disturbance in kidney function is one known cause of this disease (Dibona, 2002; Ganong, 2006; Kotchen, 2008). In fact, the use of diuretic therapy to treat hypertension illustrates the connection between the kidneys and blood-pressure regulation (Hoffman, 2006). Failure of the kidneys to eliminate or retain hydrogen and/or bicarbonate can result in acid–base disturbances, which of course affects the function of other organs of the body (Rose and Post, 2001). Extracellular potassium must be maintained within a narrow range; otherwise, fatal arrhythmias can result. In this chapter, we review some of the basic physiological processes of the kidneys, thus providing a foundation for understanding how alterations in these processes result in pathologic changes that occur in patients with renal disease. Understanding this underlying physiology also aids in making therapeutic and nutritional choices in treating patients with kidney disease.

The body is divided into two compartments (Figure 2.1): (1) intracellular and (2) extracellular. About two-thirds of the total body water is distributed in the intracellular compartment, whereas about one-third remains in the extracellular. The cell membrane divides these two compartments, and its fundamental function is to serve as a barrier. Although it acts as a barrier to some solutes, it does not act as a barrier to water because of water channels known as aquaporins (Barrett et al., 2010; Eaton and Pooler, 2009; Koeppen and Stanton, 2007). Thus, water moves easily between the