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Urine Production

Urine production is the result of continuous filtration of plasma through the kidneys, which receive approximately 20% to 25% of the cardiac output. Normally, less than 1% or approximately 1500 mL of the 180 L of plasma filtered daily leaves the body as urine. However, this quantity can vary from 600 to 2500 mL/d. Urine production generally occurs at a rate of 1 to 2 mL/min but can reach a maximum of 20 mL/min and depends on several factors. Urine volume has a direct relationship with fluid intake and the rate of renal circulation and an inverse relationship with the amount of water lost through other routes. In addition, the volume of urine depends on hydrostatic (blood) pressure; the number of active glomeruli; the permeability of the glomerular membrane; tubule reabsorption, which depends on antidiuretic hormone; and the osmotic pressure within the renal tubules.

Urine output is reduced when patients are hyperventilating or feverish or lose fluid via vomiting, a nasogastric tube, burns, or wounds. Output also can be decreased as a result of reduced renal blood flow and glomerular filtration, as occurs...
in patients undergoing surgery with cardiopulmonary bypass. Low cardiac output for these patients during the perioperative period can lead to renal dysfunction 12 to 18 hours after surgery. Depressed renal function is also a concern postoperatively in elderly patients and after traumatic injury. An adequate urine flow is greater than 500 mL/24 h per square meter or greater than 20 mL/h per square meter. In critical care, accurate hourly measurements of urine output are thus essential for evaluation of fluid status and renal perfusion.

**Urine Transport and the Urinary Bladder**

The bladder is the body’s repository for storage of urine. This highly compliant receptacle generally stores 500 mL of urine or more and is composed of an adventitial layer of soft connective tissue, an intermediate nonstriated smooth muscle coat (detrusor muscle), and an interior lining of mucous membrane. Upon filling, the bladder distends, and its walls are stretched, resulting in a thinning of the layers of transitional epithelium as the layers slide past each other.

Situated behind the symphysis pubis (Figure 1), the bladder lies entirely in the lower part of the pelvic cavity when empty and expands into the abdominal cavity upon distension. Its position also varies according to sex; it lies in front of the vagina and the uterus in females and anterior to the rectum in males. Various geometric shapes of human urinary bladders have been noted.

Urine formed in each kidney is propelled into the bladder via the ureters. These structures, each approximately 4 to 5 mm in diameter and 27 to 30 cm long, are composed of an external adventitial layer, a thick intermediate nonstriated muscle layer, and an inner mucosal layer that is extensively folded. The ureters lie beneath the parietal peritoneum and follow the posterior part of the abdominal wall to the pelvic brim, where they follow the lateral wall of the pelvis and the pelvic floor to enter the posterior part of the bladder wall. Peristaltic activity, influenced by urine volume, moves urine along the ureter into the bladder in boluses. These peristaltic waves occur at a limited rate of approximately 1 to 6 per minute. Because of the limited peristaltic rate, increased flow rates are accommodated by the formation of larger urine boluses within the ureters. A sphincterlike muscular fold guards the opening between the ureter and the bladder and opens with the arrival of a peristaltic wave.

Urines exits the body from the inferior side of the bladder via the urethra, which is considerably shorter in females (3-4 cm) than in males (18-20 cm). In most persons, complete or almost complete emptying of the bladder occurs with each void and generally less than 10 mL of urine remains.

**Indwelling Urinary Bladder Catheters**

Approximately 10% of all hospitalized and long-term care patients in the United States require an indwelling urethral catheter. Bladder catheterization via the urethra is the most frequent retrograde procedure performed on the urinary tract and is a common occurrence for many patients undergoing surgery with general anesthetics, including cardiac surgery patients. In critically ill patients, urethral catheterization is used to assess urinary output. A 14F, 16F, or 18F catheter with a 5-mL balloon is recommended in adults, although a 16F catheter is commonly used. A larger volume of fluid than that stated on the balloon port is required to account for filling of the inflation lumen and valve arm. For example, 10 mL of sterile water is the recom-
mended amount for inflating a 5-mL balloon.15,18 This amount ensures even inflation of the balloon and prevents deflection of the catheter tip1 (Figure 2). Larger balloons, however, such as the 30-mL size originally designed to decrease postoperative bleeding, result in greater impairment to bladder drainage15 because the eyes of the catheter tip sit higher in the bladder8 (Figure 2).

Unfortunately, indwelling urinary catheters and urological procedures are a major source of urinary tract infections. For ICU patients, indwelling catheters should be removed when a patient’s condition is stable because a direct relationship exists between dwell time and incidence of infection.13 Additional risk factors for urinary tract infection are being female (because of the short urethra and its proximity to the anus) and extended ICU stay.19 In a recent Canadian multisite study,19 the incidence of ICU-acquired urinary tract infection was 9%. In a study of 112 medical ICUs in 97 hospitals across the United States, urinary tract infections were responsible for 31% of the nosocomial infections, and 95% of these were associated with urinary catheters. Connecting the catheter to an aseptic closed drainage system assists in reducing the incidence of infection,13 and the maintenance of a sterile continuously closed drainage system is recommended by the US Centers for Disease Control and Prevention.21

Sources of urinary tract infection can be both endogenous and exogenous.21 Although a major entry point is the periurethral area, additional entry points for infectious organisms are the juncture of the catheter and tubing and the collection container.13 Although not extensively studied, incomplete emptying of the bladder, defined as residual urine, also has been implicated as a factor in the development of urinary tract infections in catherized patients.21 Despite continuous drainage when a catheter is in place, the remaining urine continually reinoculates the bladder with urethral and other organisms.24 This situation led to a recommendation that attempts be made to reduce the amount of residual urine to zero.25

Implications of the Current Design of Indwelling Bladder Catheters for Patients’ Care

Probably the most common indwelling urinary catheter is the Foley catheter, originally designed by Frederick Foley in the 1930s.1 The standard Foley catheter generally has 2 lumens, 1 for drainage of urine and 1 for inflation of the balloon. Currently, each catheter has a solitary drainage hole near the tip, approximately 1.5 cm above the base of a 5-mL balloon. As a result, residual urine occurs as urine accumulates below the balloon15 (Figure 2), leading to inaccurate measurements of urine output and possibly an increased predisposition to urinary tract infection.24,25 Increased residual urine occurs if larger balloon sizes are used15,25 or if balloons are overinflated to more than the recommended volume (Figure 2). Although investigation has been limited, the results of preliminary studies with fluoroscopic imaging also suggest that for some patients, tenting of the catheter up the dome of the bladder may be the cause of incomplete urine evacuation26 (Figure 1). Last, anatomical and physiological properties of the bladder, such as bladder shape or bladder sacculcation and diverticula,27 also may play a role in residual urine.

Residual urine both with catheters in situ and immediately after catheter removal have been reported in several studies. In a study of 24 women of whom 11 had a urethral Foley catheter in place, a mean volume of
77 mL of urine remained in the bladder immediately after catheter removal. The authors reported that Foley catheters are relatively ineffective in completely emptying the bladder. In another study, this potential for incomplete bladder emptying, confirmed by fluoroscopy, also was noted. Although 70% of men (n = 116) and 73% of women (n = 148) had no residual urine when a catheter was in situ, mean true residual was 76 mL (SD 76 mL) for the remaining 30% of men and 52 mL (SD 36 mL) for the remaining 27% of women. A mean residual urine volume of 22 mL (SD 25 mL) not removed by catheterization also occurred in a later study of 95 ambulatory women. Last, incomplete emptying of the bladder by means of an indwelling catheter occurred in 25 (69%) of 36 catheterizations of 12 patients with spinal cord injury who were in the supine position.

In a more recent study of the effect of urine flow rate on bladder temperature, cardiac surgery patients with indwelling bladder catheters had urine output measured every 2 minutes for 130 minutes in the postoperative period. One finding was that an increase in urine output occurred with changes in patients' body positions. Most likely this increase was due to the increased drainage of residual urine from within the bladder. As can be seen in Figure 3, patients had noticeable increases in
the need for development of a retention catheter with an additional drainage eyelet in the shaft immediately below the balloon was proposed \(^3\) (Figure 5). Compared with a standard catheter (Figure 6), a catheter with an additional drainage outlet (Figure 7) may eliminate or lessen residual urine volumes and subsequently the associated error in measurements of urine flow rate. Because residual urine within the bladder may predispose patients to urinary infection, reduction of this pool of urine may reduce the occurrence of this infection, particularly in patients who have catheters in place for considerable lengths of time. Interestingly, in a 1983 publication \(^3\) describing various catheters available on the market in the United Kingdom, a 30-mL balloon Pemberton catheter (Warne Surgical Products Ltd., Armagh, Northern Ireland) and a specialized Coudé (elbowed)-tip Roberts catheter (Bard International Ltd., Crawley, England), both with an additional drainage eyelet below the balloon to drain resid-

The effects of residual urine in the bladder on accurate measurement of flow rate and on development of urinary tract infection are unknown. In critically ill patients in whom accurate measurements of urine output are essential, the urine remaining within the bladder leads to an inaccurate and misleading measurement of urine production. This inaccurate measurement is of particular concern for patients for whom renal function is problematic. As a result, unwarranted interventions such as diuretic therapy may be implemented. The additional concern of whether this residual urine contributes to the development of urinary tract infection requires further investigation.

These concerns indicate that a modification in the design of indwelling Foley catheters currently in use in North America is worthy of investigation. In fact, as early as the 1960s, the need for development of a retention catheter with an additional drainage eyelet in the shaft immediately below the balloon was proposed \(^3\) (Figure 5). Compared with a standard catheter (Figure 6), a catheter with an additional drainage outlet (Figure 7) may eliminate or lessen residual urine volumes and subsequently the associated error in measurements of urine flow rate. Because residual urine within the bladder may predispose patients to urinary infection, reduction of this pool of urine may reduce the occurrence of this infection, particularly in patients who have catheters in place for considerable lengths of time. Interestingly, in a 1983 publication \(^3\) describing various catheters available on the market in the United Kingdom, a 30-mL balloon Pemberton catheter (Warne Surgical Products Ltd., Armagh, Northern Ireland) and a specialized Coudé (elbowed)-tip Roberts catheter (Bard International Ltd., Crawley, England), both with an additional drainage eyelet below the balloon to drain resid-

Figure 4 Residual fluid within the bladder of a female catheter with a urethral catheter in situ.

Photograph by W. M. Fallis, 2002.

Figure 5 Modified urinary catheter with an additional drainage opening below the balloon.

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Figure 6 Use of a standard urinary catheter with a solitary drainage opening above the balloon results in residual fluid within the container.

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Clinicians need to be involved in the selection of appropriate devices and/or be advocates for the development and testing of instruments and tools that provide data used in making treatment decisions in the clinical area. Thus, I recommend that the development and testing of a 5-mL balloon retention catheter with one or more additional drainage eyelets below the balloon be considered, particularly for patients in critical care, where monitoring of urine output is a frequent and necessary procedure. Because urine output is used as an indicator of renal function and accurate measurements of urine are essential in evaluating both fluid status and renal perfusion, the importance of a catheter that allows the least amount of urine to remain within the bladder is paramount. Subsequent comparisons of the efficacy of these newly designed catheters in draining urine with the efficacy of the indwelling catheters currently on the market should then ensue. In addition, the incidence of urinary tract infections in patients who have the currently available catheters in place should be compared with the incidence in patients who have the newly designed catheter.

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References


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