Henry Ford Hospital Medical Journal

Volume 40 | Number 1 Article 28

3-1992

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The concept of urodynamics was first introduced in the United States in 1926 by D. K. Rose, a urologic surgeon at Washington University Medical Center, who reported the results of a new test of bladder function which he called "cystometry" (1):

> "I believe that measurement of intracystic pressure, with known quantities of fluid, might throw much light, not only on the question of whether or not a given case of incontinence is neurogenic in origin, but also on the question as to which set of nerves is chiefly involved."

The above quotation is a modest understatement of the clinical value which this test would later prove to have. In fact, the expansion of cystometry into present day urodynamics is just one of many medical advances contributing to the understanding of bladder function and malfunction and leading to successful treatment of one of the major urologic problems in America today: urinary incontinence. Urinary incontinence is a disorder that has serious personal as well as social consequences. Afflicting more than 12 million Americans, it accounts for over half of nursing home admissions and causes a number of ill effects on the physical and psychological well-being of the incontinent individual (2). It also generates a billion dollar pad and appliance industry. The total direct health care costs in America were estimated at $10.3 billion in 1987 alone; thus urinary incontinence represents a significant drain on the medical economy (3). Women appear to be particularly afflicted by this disabling condition; incontinence occurs two to three times more often in women than in men. Because the incidence of incontinence increases with age, the problem is most severe in the elderly female population. It is estimated that 30% of women over 60 years of age are incontinent (4). Yet, incontinence is a curable disease if the underlying problem is properly diagnosed and treated.

In the past 60 years since Dr. Rose introduced the concept of urodynamics, urologic and gynecologic surgeons have addressed the problem of precise diagnosis and greatly improved our abilities to understand, classify, and treat the different types of female urinary incontinence. Clinical and basic science research into the problem have been aided considerably by more refined methods of urodynamic evaluation, greater understanding of the pharmacology of the lower urinary tract, and new radiologic techniques such as dynamic fluoroscopic and magnetic resonance imaging of the underlying anatomy. Accurate diagnosis now makes it possible to tailor treatment to the individual underlying pathology. This is especially important as the general population ages and urinary incontinence becomes a larger and more persistent problem.

Pathophysiology

Urinary incontinence in the female falls into two causally defined categories: detrusor dysfunction, and bladder outlet-related dysfunction. Dr. Rose's work helped to establish the causal differentiation by demonstrating that irritability of the detrusor muscle correlated with motor dysfunction, which resulted in incontinence. Incontinence therefore can result either from a dysfunctional detrusor, which fails in its storage or emptying capacity, or to problems with the outlet—the sphincter and urethra.

Detrusor-related incontinence refers to reduced bladder capacity, either organic or functional, and is generally referred to as "urge incontinence." This type of incontinence may be due to an underlying focal neurologic disorder such as multiple sclerosis, but it also may occur without a recognized neurologic lesion. Treatment of detrusor-related incontinence begins with a pharmacologic trial of bladder relaxant medication to increase bladder capacity. This treatment is administered in conjunction with conservative measures, which include fluid restriction, timed voiding, and exercises of the pelvic musculature to prevent leakage of urine.

Outlet-related incontinence occurs when increases in intra-abdominal pressure exceed the bladder outlet closing pressure, as happens when a patient coughs or strains. It is commonly termed "stress incontinence." In this condition, the pathophysiology is clearly a result of abnormalities in the involved anatomical structures. Historically, results of treating female stress incontinence have been less than optimal; however, more refined evaluation and development of surgical techniques specific for the underlying abnormality have improved the success rate.

Submitted for publication: October 16, 1991.
Accepted for publication: January 27, 1992.
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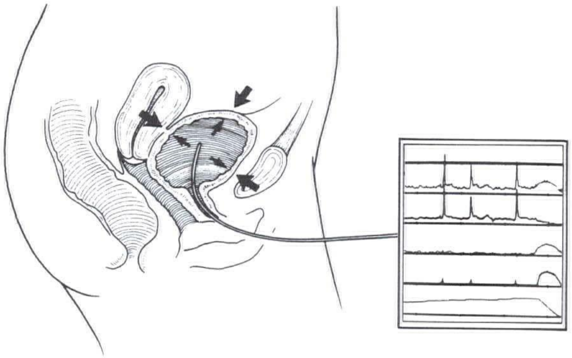

Fig 1—Urodynamic evaluation with catheter performing simultaneous bladder filling and intravesical pressure measurement.

Modern pathophysiologic concepts concerning stress urinary incontinence have grown out of the findings of urodynamic and radiologic studies combined with the results of surgical treatment. According to a prevalent current theory, passive continence in the female relies upon a functional bladder neck and proximal urethra as a sphincteric unit. In the normal continent female, anatomic support of the bladder neck and proximal urethra allows for the through-transmission of intraabdominal pressure increases, as are occasioned by coughing or straining. Proper through-transmission sustains the continuous underlying pressure gradient which maintains continence. Furthermore, the proximal urethra is believed to perform an important function in female continence by providing a continuous mucosal seal and thereby adding to outlet closing pressure.

Though still imperfect, the concepts outlined above help to explain why surgery to correct anatomic derangements can cure stress incontinence. Certainly, other less well-understood factors play a role, too, including neurologic function, the hormonal milieu, and the viscoelastic properties of the tissues themselves. Surgery is not the only means of treatment for stress incontinence; pelvic floor muscle exercises, hormonal manipulations, and medication can be effective in many cases. However, when an underlying anatomical abnormality can be identified, surgery designed to correct that abnormality can be curative.

Diagnosis and Evaluation

Physical examination and history of the incontinent patient will determine whether the problem falls in the category of detrusor dysfunction or bladder outlet-related dysfunction. Patients can help the clinician with this evaluation by relating the circumstances of each urinary leakage episode (i.e., whether it occurred with coughing or straining or was accompanied by an associated sensation of involuntary bladder contraction). The purpose of urodynamics is to reproduce and visualize functional activity of the bladder precisely. Urodynamic studies can determine whether the incontinence is detrusor- or bladder outlet-related or is a combination of the two (5). Moreover, through the pattern of pressure that develops in and around the bladder on filling, other important functional characteristics can be evaluated (Fig 1). These include estimation of the bladder capacity, its emptying ability, and the presence or absence of obstruction.

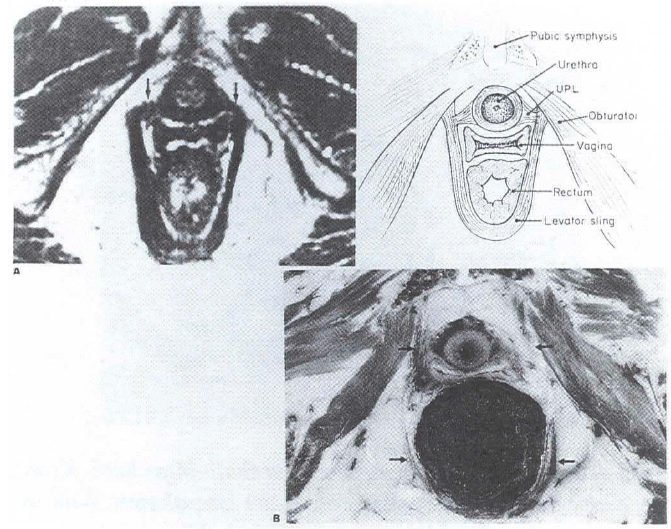

Fig 2—A) Magnetic resonance image in axial section at the level of the bladder neck and proximal urethra in a normally continent female. Arrows point to the urethropelvic ligaments passing from the levator muscle laterally at the level of the tendinous arc to the proximal urethra. B) Axial cadaver section at the level of the bladder neck. Arrows point to levator muscle extending around the urethra, vagina, and rectum. (From Klutke CG, Golomb J, Barbaric Z, Raz S. The anatomy of stress incontinence: Magnetic resonance imaging of the female bladder neck and urethra. J Urol 1990;143:563-6. Reproduced with permisson.)

In studying the bladder and bladder outlet, it is important to evaluate both the anatomy and physiology of the bladder and urethra. Radiologic evaluation requires that radiopaque objects such as a catheter, metallic bead chain, or contrast material be placed within the urethra in order to visualize this area in relation to the bladder itself (6,7). Microthin pressure transducer catheters are the current state of the art. Because they also utilize contrast material, these can be localized by fluoroscopy and they provide a real-time pressure readout. Because of their small size, they produce less artifact and are an improvement over the radiopaque objects previously employed.

Magnetic resonance imaging gives excellent soft tissue resolution of the pelvic anatomy and allows visualization of the anatomic structures involved in female continence and incontinence (8). The appearance of discreet musculofascial extensions from the lateral pelvic side wall to the bladder neck and proximal urethra, as well as the appearance of the normal tissue constituents of the urethra, provide insights into the mechanism of female continence and into the pathophysiology of stress incontinence (Fig 2). In the future, magnetic resonance imaging may help to identify patients needing specific surgical procedures to correct urinary incontinence.

Surgical Treatment

Anti-incontinence surgery aims to correct the demonstrated abnormalities of abnormal bladder anatomy and physiology. As

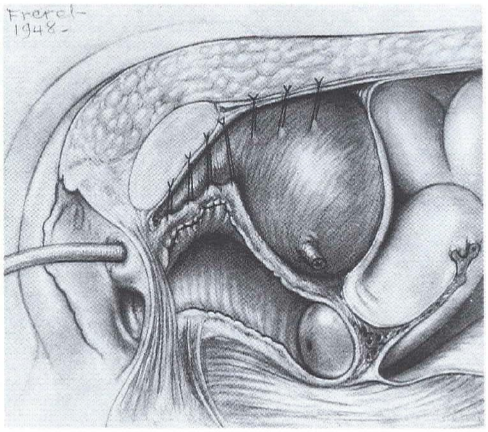

Fig 3—Original diagram of the Marshall–Marchetti–Krantz procedure for bladder suspension in the lateral view. Note sutures suspending bladder neck and proximal urethra to the pubic bone. (From Marshall VF, Marchetti AA, Krantz KE. The correction of stress incontinence by simple vesicourethral suspension. Surg Gynecol Obstet 1949;88:509-18. Reproduced with permission.)

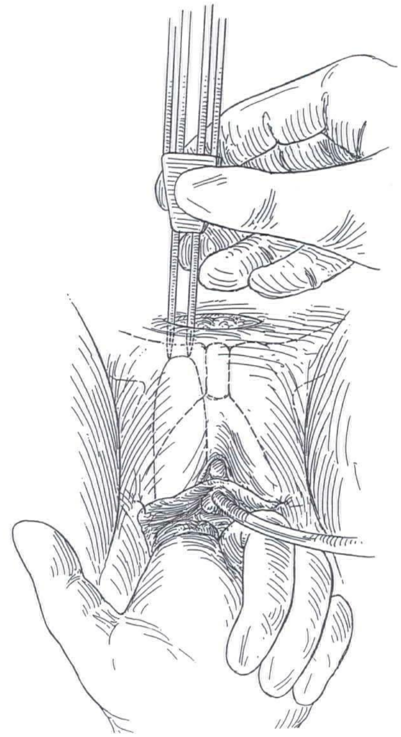

Fig 4—Passage of needle from suprapubic incision to suspending suture at the bladder neck for transfer of the suture up and over the rectus fascia. (From Raz S. Modified bladder neck suspension for female stress incontinence. Urology 1981;17:84. Reproduced with permission.)

we improve the techniques for determining physiologic dysfunctions, the surgical procedures evolve as well. The procedure most commonly performed for the correction of stress incontinence has been the Kelly plication. This procedure, described in the early 20th century, is still used. It involves a vaginal incision with placement of several suburethral plication sutures (9). The intent is to imbricate and narrow the proximal urethra and buttress the tissue beneath the bladder neck. Buttressing from below may correct bladder prolapse, but this has a low success rate for the correction of urinary incontinence because it fails to return the bladder neck to a well-supported retropubic position. Furthermore, this technique can cause urethral obstruction and intrinsic urethral damage. Thus, for treatment of stress incontinence, the Kelly plication should perhaps be of historical interest only.

In 1949, the Marshall–Marchetti–Krantz procedure was introduced in which the bladder neck and proximal urethra are "pinned up" through an abdominal exposure (10). This operation has been the "gold standard" for the cure of stress incontinence due to prolapse of the bladder neck. Several pairs of chromic sutures are placed to suspend the upper vaginal wall and lateral wall of the urethra from the pubic periosteum (Fig 3). Many modifications of the Marshall–Marchetti–Krantz procedure have been developed, among which are the Burch and Richardson operations (11,12). These are successful but require a major abdominal operation, with all of the attendant drawbacks of such procedures, to correct urinary incontinence.

In 1959, Pereyra (13) reported the development of a transvaginal bladder neck suspension as a substitute technique for the abdominal suspension procedures in the treatment of stress urinary incontinence. This breakthrough is akin to the development of the laparoscopic technique of cholecystectomy which affords an innovative alternative to standard open cholecystectomy. Percutaneous bladder neck suspension is associated with reduced morbidity and risk and affords the shortest hospital stay and the quickest return to preoperative activities (Figs 4 and 5). With outpatient self-care of the suprapubic cystostomy tube, patients undergoing a Pereyra-type bladder suspension can be discharged safely on the first or second postoperative day. For this reason alone, costs are dramatically reduced. The percutaneous approach also allows correction of any concurrent vaginal pathology such as cystocele, enterocele, or rectocele. Since Pereyra first described this procedure, a multitude of modifications have been developed, each with its own small advance. Changes in the suspending needle, the use of cystoscopic guidance, more precise placement of suspension sutures, and better means of securing the underlying anchoring tissue have improved the long-term success rate of this operation (14-18).

Correction of stress urinary incontinence due to intrinsic urethral damage, not to abnormal location of the outlet, requires a different surgical approach. Intrinsic urethral damage results in poor proximal urethral coaptation and thus in limited urethral resistance to increased intraabdominal pressure. The goal of treatment for stress incontinence resulting from intrinsic urethral damage is to increase urethral resistance by surgically augmenting urethral coaptation. To achieve this goal, the surgical alternatives are to create compressive slings around the urethra or to inject augmenting substances such as Teflon into the urethral submucosa (19). Sling operations in general attempt to correct deficient urethral coaptation by exerting constant pressure directly on the proximal urethral segment. The sling functions as an elastic strap, fastened at either end with the proximal ure-

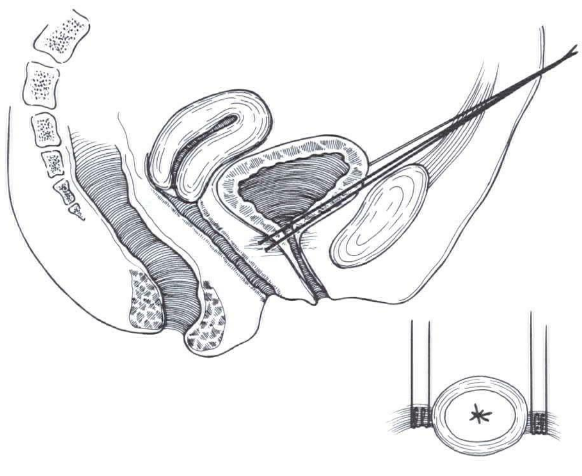

Fig 5—Lateral view showing bladder neck suspension sutures in place lifting bladder neck behind the pubic bone. Inset axial view at the level of the bladder neck reveals sutures grasping the ligaments at the urethra.

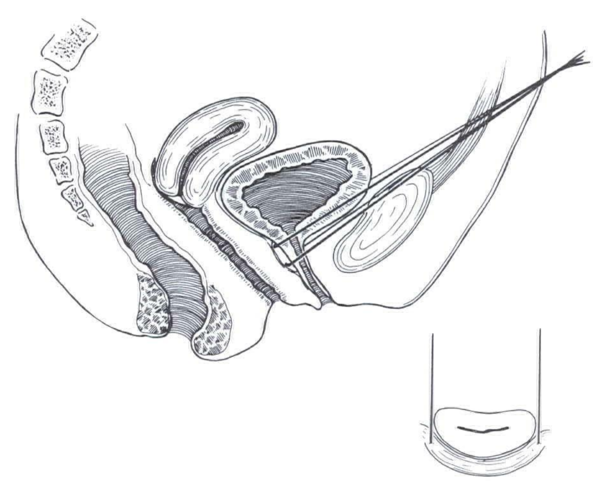

Fig 6—Lateral view of sling procedure in place. Inset reveals coaptation and closure of the proximal urethra by the sling in axial section.

thra passing over the midpoint. Thus, it acts much like a hammock supporting and compressing the open incompetent urethra (Fig 6). Sling procedures differ mainly in the choice of material selected for the sling; these include synthetic nonabsorbable and absorbable meshes as well as the patient's own fibromuscular or fascial tissue (20-23). The advantages of injection of a space augmenting substance into the urethral submucosa include the simplicity of the procedure, the need for only local anesthesia in the office, and the procedure's inherent flexibility which allows the physician to administer repeated injections until continence is attained. Unfortunately, an ideal injectable substance—one that is small enough to inject easily, is inert, does not degrade, and will not migrate—has yet to be developed. Once such a substance is identified, injection techniques may become ideal treatment for this type of stress urinary incontinence.

Present understanding of urinary incontinence is a culmination of extensive clinical and experimental investigations into the physiology and pathology of the lower urinary tract. Over the past 60 years, advances in diagnostic methods have changed our concepts of the pathophysiology of incontinence and led to improved surgical treatment. Although our knowledge is still incomplete, the affliction of urinary incontinence is no longer totally mysterious to be treated by empiric approaches only. Certainly, it is no longer acceptable to expect a patient just to live with such an affliction. Although some pieces of the puzzle remain unknown, with proper evaluation and treatment the incontinent patient can nearly always be rehabilitated.

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