Hypothesis

Normal lower urinary tract motility. Hypothesis

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Abstract. The objective: To clarify the mechanisms of urinary continence and micturition. *State of the problem:* Based on the assumption that all peristaltic organs obey the same laws we offer a hypothesis of motor function of the lower urinary tract. *Hypothesis*: The pressure on the wall of the empty bladder is equal to intra-abdominal pressure (IAP). During the intake of urine, the pressure in the bladder rises to a threshold level of the first order (TP-1) and remains unchanged to volume 300-400 ml (main volume). In the volume of the more basic the pressure in the bladder is increased to the threshold pressure of the 2nd order (TP-2), which causes relaxation of the internal urethral sphincter (IUS). Urine, penetrating to the neck of bladder, stimulates the urge to urinate. At this moment, retention of urine is provided by the contraction of the external urethral sphincter (EUS) and puborectal muscle (PRM). If the implementation of urination is not possible, detrusor relaxes adapting to the new volume and intravesical pressure decreases from TP-2 to TP-1, which leads to a reflex contraction of IUS and passive relaxation EUS and PRM. Inflow to the bladder of an additional urine volume causes again an increase in pressure to TP-2, followed by relaxation of IUS and contraction of the EUS and PRM. While the EUS and PRM contract, the IUS relaxes to recover its contractile capacity and vice versa. This ensures continued retention of urine. Urination begins with tension of the abdominal wall, which causes an increase in intra-abdominal pressure and the pressure increase in the bladder from TP-2 to TP-3. All sphincters (IUS, EUS, and PRM) relax, and the urine under the same pressure flows through the urethra opening as the result of coordinated contraction of the bladder micromodules. The maximum volume of urine after a long delay can be up to 1 liter (main and reserve volume, which entered to the bladder as result of the forced delay). In men, when a large amount of urine is accumulated in the bladder, the prostate contraction squeezes the urethral lumen at the level of IUS for supporting of a prolonged urinary retention.

Keywords: External urethral sphincter; Detrusor; Internal urethral sphincter; Hypothesis; Physiology of urination; Prostate.

Abbreviations: IAP – intra-abdominal pressure; TP-1 - threshold pressure-1 (filling); TP-2 - threshold pressure-2 (urge); TP-3 - threshold pressure-3 (urgency); IUS – internal urethral sphincter; EUS – external urethral sphincter; PRM – puborectalis muscle, LAM – levator ani muscle.

STATE OF THE PROBLEM

Paired ureters, urinary bladder, and urethra constitute the lower urinary tract. Oblique passage of ureters through the bladder wall results in compression of the distal ureter to preclude urine reflux. Ureters are anchored by longitudinal ureteral musculature that outlines the bladder trigone and extends into dorsal submucosa of the urethra as urethral crest. The male urethra has penile and pelvic components, the latter is divisible into preprostatic, prostatic, and postprostatic regions. The muscle coat of the bladder-urethra forms three functional entities in craniocaudal series. These are the detrusor muscle (to effect voiding), the smooth muscle of the internal urethral sphincter (IUS) for generating tonic resistance, and the striated urethralis muscle of the external urethral sphincter (EUS) for phasic and voluntary continence. The vesical neck is a transition region. It is part of the IUS by virtue of its histology and innervation, but it contains detrusor fascicles that pull it open during micturition. Viscous accommodation plus sympathetic reflex inhibition of the vesical wall allows the urinary bladder to greatly expand in volume with minimal increase of intravesical pressure, within limits. At low volumes continence can be maintained by passive resistive elements of the urethral outlet. As volume increases, sympathetic reflex activity is necessary for continence. The striated external urethral sphincter is reflexly contracted to counter abrupt elevations of intravesical pressure and to maintain continence voluntarily[1].

The bladder is a large organ, generally serving as a reservoir for urine, but with intermittent expulsion of urine as perceived timely be the individuals; this alternation between storage and voiding phases is known as the "micturition cycle". Functionally, the bladder structure may comprise modules with variable linkage, which supports presence of localized micromotions, propagating contractions and the shifting of micromotions over time. Conceptually, such activity could facilitate the ability to transition to voiding at any bladder volume. Thus, the urination takes place at constant intravesical pressure, and it is possible for any urinary bladder volume[2]. Urine constantly arrives to the bladder after its emptying. Small-volume vesical distension effected no significant urethral or vesical pressure changes while distension with 350 and 400 mL of saline produced vesical pressure elevation ($P < 0.01$) and urethral pressure decrease ($P < 0.01$). Vesical distension after individual vesical and urethral anesthetization effected no change in the urethral pressure[3]. The rise in intravesical pressure leads to the disclosure of the vesical neck, i.e, IUS, and the emergence of the urge[1]. During urination the vesical pressure rises, and the tonus of the IUS reduced[4]. Hence the perfectly obvious fact, indicating that there is a certain threshold volume of urine, below which the pressure in the bladder remains unchanged. This gradual uninterrupted relaxation of the bladder is the result of coordination of muscle relaxation of different micro modules. In the research of Shafik et al has been shown that external urethral sphincter (EUS) contraction effected the inhibition of vesical contraction and suppression of the desire to micturate[5]. The pressure rise in the bladder increases the tone in the ureterovesical junctions and renal pelvis[4]. Shafik et al determined the reaction of the bladder and urethral sphincters to the distention of the adjacent parts of urinary system as specific reflexes. For example: vesicoureteral inhibitory reflex, vagino-urethrovesical reflex, meato-vesico-urethral reflex and others. When analyzing reflexes described above, it is clear that they obey the law of Bayliss-Starling, which explains the mechanics of peristaltic movement. In accordance with this law, the distention of the lumen in any part of the gut leads to the increased pressure cranial and decreased tone caudal to the extension zone[6]. Analysis of the reactions to distension of the different parts of the urinary tract lumen is fully consistent with this law. For example, "…the vesical pressure drop on renal pelvis distension postulates a reflex relationship that we call the "reno-vesico-sphincteric reflex"[7]. Considering the same laws for both the urinary tract and anorectal area, which is responsible

for fecal retention and defecation, we can extrapolate with the high reliability the normal and pathological reactions of the anorectal zone to the reactions of different parts of the urinary system.

The EUS does not connect directly with the bones. In women, its lower part is tightly connected to the levator ani muscle (LAM) through the tendon ligament. Contraction of the EUS pulls the urethra back and down. Contraction of the LAM compresses the rectum and moves the rectovaginal complex forward and upward. The simultaneous contraction of the EUS and LAM results in bending the middle urethra forward and closing its lumen. In men, there is no connection between the EUS and LAM[8]. Many authors called the LAM all the muscles of the pelvic floor. However, despite the fact that all the muscles of the pelvic floor are difficult to be separated from each other they have different function. Consolidating all the muscles in a single name causes much confusion. For example, it is known that puborectalis muscle (PRM) relaxes during defecation. Since the PRM is considered to be part of the LAM, for a long time it has been thought that all parts of the LAM, including iliococcygeus and coccygeus, during defecation also relax[9,10]. If the LAM during defecation relaxes, it means that in the other times it is in a contracted state. This is contrary to common sense, because striated muscle cannot be in the contracted state for a long time. Secondly, there is a question about its role in long-term contraction. It is known that this massive muscle is not involved in the retention of feces. Recently, there were reports that the LAM during defecation does not relax, but contracts, creating a channel for the passage of stool[11,12]. Thus, from the pelvic floor muscles only the PRM participates in the retention of urine and feces. Different parts of the LAM surround the urethra, vagina and rectum, it allows to some authors call them, respectively: pubourethralis, pubovaginalis, puboperinealis and puboanalis[10].

Modern representations about the normal anatomy and physiology of the lower urinary tract are fragmented, i.e. not systematized. The role of the prostata in urodynamics of the healthy men has not been clear yet. It is found that its contraction during ejaculation prevents the release of sperm into the bladder[13]. Therefore, at this time the prostata contraction overlaps the urethral lumen. In prostatic hypertrophy, the contraction of muscle fibers of the prostata plays an essential role in the violation of urodynamics until the development of the urethral obstruction[14].

Based on published data, and general laws for the peristaltic organs, we propose the hypothesis of the normal urodynamics (physiology of storage, retention and urination).

HYPOTHESIS OF THE NORMAL MOTILITY OF THE LOWER URINARY TRACT

The accumulation and retention of urine.

The view that the urethral sphincters beyond the urination are in the constantly contracted state, raises some questions. Have the urethral sphincters a constant tonus? Second, how to explain the ability of smooth muscle sphincter to be in the contracted state for a long time, if it is known that every muscle fiber during contraction expends its contractile capacity and then inevitably comes relaxation, during which the muscle restores its ability to contract. This equally applies to the muscle of bladder - to the detrusor[15,16]. We hypothesize that many groups of the muscle bundles are in the various stages of recovery of the contractile capacity. At any moment an electrical stimulus that excited by the Cajal cells[17], leads to the contraction of the groups, which are ready to contraction. During the next electric wave, other groups of muscle bundles are contracted, while the previous muscle fibers relaxed for recovery of their contractile ability. All groups of the muscle bundles are contracted at different times in a vicious circle. This is manifested in the form of slow regular waves of electrical activity[18]. This can explain the ability of the IUS to provide the continuous continence. If there is a need to enhance the tone of the IUS, the extra-bladder center sends the more intense electrical stimulus that causes contraction of an additional number of the groups "almost ready to contraction". In this case, the tone of each muscle fiber is not changed, but the tone of the IUS rises[11,18]. The functional structure of bladder can be represented as muscle modules[19], each of which consists of the number of muscle bundles. After complete emptying of the bladder, all or almost all of the modules are in the contracted state, while muscle bundles make a circular cycle from contraction to relaxation and vice versa.

In an empty bladder the pressure on its wall is equal to intra-abdominal pressure (IAP). There is a continuous portioned flow of urine from kidneys to bladder. Each urine portion slightly increases the total volume of urine and the intraluminal bladder pressure. In response, the internal computer, the role of which performs the intramural nervous system, increases the number of the relaxed muscle modules. As a result, of such continuous correction the pressure inside the bladder is maintained at the same level. We call this pressure the threshold pressure of the 1st order (TP-1), which slightly higher than IAP. At this time, the IUS is in the closed state, but its tone is changed in accordance with the minimal necessity. When the pressure within the bladder rises, the tone of the IUS increases, and when the pressure in the bladder decreases the tone of the IUS decreases. This reflex reaction provides retention at the required level without excessive overload of the muscle fibers. And it manifests, as was shown by Shafik et al as an undulating electric activity of the IUS[18].

When the volume of urine in the bladder increases up to a certain level (main volume ≈ 300-400 ml), the further increase in volume causes an increase in pressure inside the bladder - the threshold pressure of the 2nd order (TP-2). It causes the reflex disclosure of the IUS (the neck of bladder) in the form of a cone, the tip of which directed to the urethra. At this time, the urethra closed by the contracted EUS and PRM. In this case there is a complete analogy with the rectoanal inhibitory reflex[11]. Disclosure of the IUS leads to the penetration of urine into the neck of bladder, which causes a feeling the urge to urinate. Thus, at a time when the IUS ceases to perform urine retention function, this role is performed by the contraction of the EUS and PRM. Striated muscle of the EUS and PRM is not capable to the long-term contraction and relaxes. If urination is not possible, the bladder pressure is reduced from TP-2 to TP-1, as the result of relaxation of a certain amount of muscle modules. The IUS again contracts and the urge to urinate disappears[5]. The newly arrived urine portion causes the pressure rise in the bladder, resulting in relaxation of the IUS and contraction of the EUS and PRM. After a few seconds, the bladder relaxes, the IUS contracts again, and the EUS and PRM relax. During contraction of the IUS the muscles of the EUS and PRM restore the ability to contraction. The EUS and PRM compress the urethra when the IUS relaxes and restores its ability to contraction. Such periodicity of the different muscles contraction, preventing leakage of urine, lasts as long as there will be an opportunity to empty the bladder. The bladder can take additionally to the main

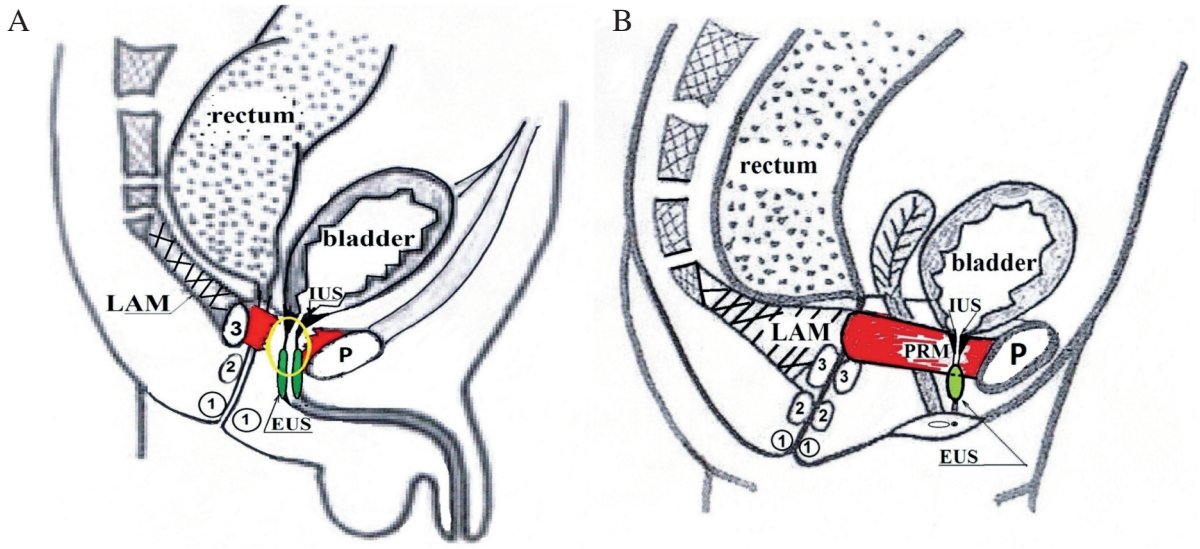

Figure 1. – Schemes of the lower urinary tract in male (A) and female (B).
LAM – levator ani muscle; P- pubis; 1-2-3 – tree parts of the external anal sphincter; IUS – internal urethral sphincter (black); EUS – external urethral sphincter (green); PRM – puborectalis muscle (red); Yellow circle - it is a projection of the prostate location.

volume about 300-500 ml of urine, which we call the reserve volume. In the process of the bladder filling its wall progressively becomes thinner.

Role of the prostate in urine retention in male

It is known that the prostate surrounds the prostatic urethra. It contains smooth muscle fibers, the role of which is extremely simple: its length becomes shorter during contraction.

Since the muscle fibers are arranged circularly, during their contraction the urethral lumen becomes narrow. Professor Shafik et al clearly demonstrated that the contraction of the prostate during ejaculation squeezes the urethra, preventing the sperm to get into the bladder[13]. It is also known that the erection makes it impossible to urinate, thus helping to avoid nocturnal enuresis. This phenomenon is also known as the effect of Bonfield [Wikipedia]. In benign hyperplasia of the prostate, α1- adrenoblockers are used to improve the urodynamics. They causes relaxation of smooth muscles of the prostate and thus increase the urethral lumen[20]. After removal of the urinary catheter, the three-time use of α1-adrenoblocker Xatral 10 mg is recommended for the prevention of prostatic spasm. All these data indicate that the contraction of prostate closes the lumen of the prostatic urethra, i.e., participate in the retention of urine.

The prostate plays the role of the urine retention in the case of bladder overflow. When the volume of bladder exceeds the main plus reserve volume, the arrival of a new portion of urine does not cause relaxation of the bladder, the bladder pressure rises to TP-3, what leads to the reflect contraction of the prostate.

Voiding

Urination is a reflex process that coordinates the relaxation of the IUS, EUS and PRM with continuous detrusor contraction. This process takes place under the control of the CNS and under the constant threshold pressure (TP-3), which as a result of contraction of the anterolateral abdominal wall muscle simultaneously with vesical contraction[21].

Internal computer leads to the contraction of such number of micro-modules as is necessary to maintain the constant pressure in the bladder throughout the urination process, with the exception of the last portion which coming out under low pressure. Since TP-1 is not change, regardless of the amount of urine (up to 400 ml), urination can be triggered with any amount of urine by the rise of the intra-abdominal pressure. When it reaches the level of the TP-2, the IUS opens. The urine enters the neck of bladder, causing the urge to urinate. Continuing tension of the anterior abdominal wall leads to an increase in pressure to TP-3, and the voluntary EUS and PRM are instructed to relax. Urination occurs to the complete emptying of bladder. Thus, the wall of bladder has the surprising elasticity since the bladder can be stretched to a volume of 1 liter and reduced to a complete evacuation.

CONCLUSION

Based on the assumption that all peristaltic organs obey the same laws we have offered the hypothesis of motor function of the lower urinary tract. In an empty bladder the pressure on its wall is equal to intra-abdominal pressure (IAP). The accumulation of urine in the bladder occurs at the constant pressure - threshold pressure of the 1st order (TP-1), which slightly higher than IAP. When urine volume reaches 300-400 ml (the main volume), the pressure in the bladder is increased to the threshold pressure of the 2nd order (TP-2), which causes relaxation of the IUS. The urine, penetrating to the neck of bladder, stimulates the urge to urinate. At this moment, retention of urine is provided by the contraction of the EUS and PRM. If the implementation of urination is not possible, detrusor relaxes adapting to the new volume and intravesical pressure decreases from TP-2 to TP-1, which leads to a reflex contraction of IUS and passive relaxation EUS and PRM. Inflow to the bladder of an additional urine volume causes again an increase in pressure to TP-2, following by relaxation of the IUS and contraction of the EUS and PRM. While the EUS and PRM contract, the IUS relaxes to recover its contractile capacity and vice versa. This ensures continued retention of urine. Urination begins with tension of the abdominal wall, which causes the increase in intra-abdominal pressure and the pressure increase in the bladder from TP-2 to TP-3. All sphincters (IUS, EUS, and PRM) relax, and the urine under

the pressure flows through the opened urethra as the result of coordinated contraction of the bladder micromodules. The maximum volume of urine after a long delay can be up to 1 liter (main and reserve volume, which entered to bladder as the result of forced delay). There is a possibility that the prostate contraction can induce urethral compression for supporting of a prolonged urinary retention.

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Disclosures

The proposed hypothesis opens up new possibilities in the diagnosis and treatment of diseases of the urinary system. The article was not sent to another journal and its materials were not previously published. I am the only author of the new hypothesis. I did not get financial support.

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Commentary

I warmly welcome this original contribution to the journal. The PPJ mission statement right from its origin has always been to encourage original thought in any research concerning the pelvic floor, male and female, pediatric to geriatric, investigative and management, conservative or interventional.

This contribution occupies another special category, conceptual. Without hypotheses there is no innovation, no new treatment, no Cochrane, nothing.

For the most part, it is a review. The review is wide ranging in its background information. The references in the review set a basis for the formulation of a hypothesis of normal bladder function which is based on the assumption that all peristaltic organs obey the same motility laws. This is an original concept and it will hopefully lead to a vigorous debate within the pages of the journal.

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