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Modern Approaches to the Diagnosis and Treatment of Lower Urinary Tract Disorders

Jakub Buczkowski, Weronika Biaduń, Mateusz Dobosz, Aleksandra Romanowska, Aleksandra Padkowska, Kinga Rogowska, Michał Borawski, Aleksandra Ciuła, Klaudia Arciszewska, Jakub Maciej Pieniążek

Jakub Buczkowski
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland jakubbuczkowsky@gmail.com
https://orcid.org/0009-0005-0309-5222

Weronika Biaduń
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences Chrobrego 27, 26-600 Radom, Poland w.biadun1@gmail.com https://orcid.org/0009-0009-2650-5991

Mateusz Dobosz
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland mdobosz.mat@gmail.com
https://orcid.org/0009-0006-2407-7522

Aleksandra Romanowska
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland olarrromanowska@gmail.com
https://orcid.org/0009-0001-9829-2659

Aleksandra Padkowska
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland ola.padkowska@gmail.com
https://orcid.org/0009-0000-3939-7349

Kinga Rogowska
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland kinga.rogowska0504@gmail.com
https://orcid.org/0009-0003-7987-6477

Michał Borawski
Brothers Hospitallers of Saint John of God Hospital in Cracow
Trynitarska 11 Street, 31-061 Cracow, Poland michal.borawski1@gmail.com
https://orcid.org/0009-0008-4864-7336

Aleksandra Ciuła
Brothers Hospitallers of Saint John of God Hospital in Cracow
Trynitarska 11 Street, 31-061 Cracow, Poland https://orcid.org/0009-0000-0425-863X
ciula.aleksandra@gmail.com

Klaudia Arciszewska
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland k-arciszewska@wp.pl
https://orcid.org/0009-0009-5099-6313

Jakub Maciej Pieniążek
Casimir Pulaski University of Radom Faculty of Medical Sciences and Health Sciences
Chrobrego 27, 26-600 Radom, Poland kubapieniazek99@gmail.com https://orcid.org/0009-0005-9063-6575

Abstract

Lower urinary tract disorders, including conditions such as overactive bladder (OAB), stress urinary incontinence (SUI), neurogenic voiding dysfunction, and nocturia, represent a significant health concern that greatly affects patients' quality of life worldwide. These disorders not only diminish life comfort but can also lead to physical and psychological complications, including chronic pain, urinary tract infections, sleep disturbances, depression, and social isolation. It is estimated that these conditions affect both adults and children, with prevalence rates ranging from 1% to 20% in pediatric populations and up to 67% among older adults.
Modern medicine offers a variety of treatment options for lower urinary tract disorders, including pharmacotherapy, behavioral therapies, surgical interventions, and advanced technological approaches such as neuromodulation. Advances in the understanding of the pathophysiology of these conditions, along with the development of medical technologies, have significantly improved diagnostic and therapeutic capabilities. Nonetheless, managing patients

with lower urinary tract disorders remains a clinical challenge, particularly for those with treatment-resistant symptoms who do not respond to conventional therapies.

Keywords: Overactive bladder (OAB), stress urinary incontinence (SUI), nocturia, lower urinary tract symptoms (LUTS), β3-adrenergic receptor agonists

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Introduction

The management of these conditions requires a multidisciplinary approach that includes comprehensive diagnostics and individually tailored treatment plans. Traditional diagnostic methods, such as urodynamic testing and voiding diaries, remain the standard in patient assessment. However, advanced diagnostic technologies are gaining increasing importance, including brain function imaging and bladder volume measurements using modern ultrasound techniques. A breakthrough in diagnostics also includes the understanding of the circadian rhythm of bladder function, which has a significant impact on the occurrence of nocturia—one of the most burdensome symptoms among patients with lower urinary tract disorders (Carter et al. 2023, Padmanabhan et al. 2023).

One of the main treatment methods for overactive bladder and other lower urinary tract disorders is pharmacotherapy, which includes the use of anticholinergic drugs and β3adrenergic receptor agonists such as vibegron. These therapies effectively reduce OAB-related symptoms, although their efficacy is sometimes limited by side effects and treatment resistance. Consequently, there is growing interest in modern neuromodulation techniques that enable modulation of the neural signals controlling bladder function. Neuromodulation, including percutaneous tibial nerve stimulation (PTNS) and sacral neuromodulation (SNM), is gaining recognition as an effective treatment method for patients with pharmacologically refractory forms of urinary incontinence (Malallah et al. 2023).

Innovative surgical therapies, such as the implantation of mid-urethral slings (MUS), artificial urinary sphincters (AUS), and the use of laser technologies, have become key methods in the treatment of refractory stress urinary incontinence. Despite the success of surgical interventions, the associated risks—such as mesh erosion, infections, and mechanical damage to implants—must be considered, requiring careful postoperative monitoring of patients. Socioeconomic and

racial disparities in access to surgical treatment are also of importance, highlighting the need for more equitable access to modern therapeutic options for all patients (Laude et al 2023, Sobh et al. 2023).

In the pediatric population, the treatment of lower urinary tract disorders—such as nocturnal enuresis and other forms of bladder dysfunction—poses a challenge due to the delicate nature of this group and their limited ability to tolerate invasive procedures. PTNS and other forms of neuromodulation are increasingly being used in children as less invasive alternatives for treating refractory overactive bladder. These therapies have shown effectiveness in improving symptoms related to bladder overactivity, although the need for long-term maintenance therapy remains an open question (Kitta et al. 2023, Hadir et al. 2023).

The COVID-19 pandemic has introduced new challenges in the management of lower urinary tract disorders. Infection with the SARS-CoV-2 virus may exacerbate bladder-related symptoms, a condition described as COVID-19 Associated Cystitis (CAC). Patients who have recovered from COVID-19 have demonstrated worsening of OAB symptoms and nocturia, suggesting that the pandemic may have long-term consequences for urinary tract health (Kitta et al. 2023).

The aim of this paper is to provide a comprehensive review of the latest diagnostic and therapeutic methods for lower urinary tract disorders, including overactive bladder, stress urinary incontinence, and nocturia. This includes a focus on both modern pharmacological treatments and innovative surgical and neuromodulatory techniques. The goal is to compile current scientific evidence on the effectiveness of these therapies and to discuss their role in clinical practice, particularly in the context of long-term patient management and their impact on quality of life (Kitta et al. 2023).

Modern Approaches to the Treatment of Overactive Bladder

Overactive bladder (OAB) is one of the most common lower urinary tract dysfunctions, affecting a significant portion of the population, particularly older adults. It is characterized by symptoms such as sudden, uncontrollable urgency to urinate, frequent urination, and urgency urinary incontinence (UUI). OAB has a serious impact on patients' quality of life, leading to

limitations in physical, social, and occupational activities, as well as psychological issues such as depression and anxiety. Despite the wide range of available treatment methods—including lifestyle modifications, pharmacotherapy, and behavioral therapies—a considerable number of patients fail to achieve adequate symptom control. Therefore, the search for new and more effective treatment options has become a priority in OAB research. Key areas of innovation include neuromodulation, next-generation pharmacotherapy, and advanced diagnostic approaches that allow for more precise monitoring of bladder function (Malallah et al 2023).

Pharmacotherapy remains a cornerstone in the treatment of overactive bladder. Anticholinergic drugs, such as oxybutynin and solifenacin, are commonly used to reduce detrusor overactivity by blocking muscarinic receptors. However, their use is often associated with adverse effects such as dry mouth, constipation, and blurred vision, which limit their long-term efficacy and tolerability (Laude et al. 2023).

In response to these limitations, new-generation drugs have been introduced, such as the β3adrenergic receptor agonist vibegron. Clinical trials have demonstrated that vibegron effectively reduces OAB symptoms, including urinary frequency and incontinence episodes, while minimizing side effects typically seen with anticholinergics. Three-month results from the COMPOSUR trial indicate that vibegron is well tolerated by patients and associated with high treatment satisfaction. Thanks to its mechanism of action—stimulating β3-adrenergic receptors—vibegron promotes relaxation of the detrusor muscle, thereby reducing its hyperactivity without affecting other bodily functions. Its efficacy has been confirmed in clinical studies showing that the majority of patients experience significant improvement following treatment initiation (Malallah et al. 2023). Neuromodulation has become a key area of interest in the treatment of OAB, especially in cases resistant to conventional pharmacological therapies. It involves stimulating specific nerves that influence bladder function, allowing modulation of the neural signals responsible for bladder overactivity. One of the most commonly used neuromodulation methods is percutaneous tibial nerve stimulation (PTNS). PTNS is a minimally invasive procedure that stimulates the tibial nerve, indirectly affecting the nerves controlling bladder function. Clinical studies have shown that combining PTNS with pharmacotherapy, particularly with mirabegron, leads to a significant reduction in incontinence episodes and improves patients' overall quality of life. Neuromodulation is also applied through more advanced devices, such as the UCon neurostimulator, which stimulates

the dorsal genital nerve (Padmanabhan et al 2023). Clinical trials have demonstrated that this device effectively reduces incontinence episodes and is well tolerated by patients. However, further studies are needed to assess the long-term efficacy of such therapies. In addition to PTNS, other forms of electrical stimulation are being developed, such as medium-frequency stimulation (AUSSIE) (Malallah et al. 2023, Padmanabhan et al. 2023). Studies comparing AUSSIE with traditional low-frequency TENS stimulation have shown that both methods are effective in reducing OAB symptoms, although no significant superiority of one method over the other has been demonstrated. Clinical research on dorsal genital nerve stimulation using the UCon device has also revealed positive outcomes, including a reduction in urinary incontinence episodes and improvement in patients' overall quality of life . The COVID-19 pandemic has had a significant impact on the development and exacerbation of various conditions, including overactive bladder. Studies have shown that SARS-CoV-2 infection can aggravate OAB symptoms—a phenomenon described as COVID-19 Associated Cystitis (CAC). Patients infected with COVID-19 have exhibited a notable increase in symptoms such as frequent urination and urinary incontinence, which may persist for many months after recovery. A study conducted among patients who had recovered from SARS-CoV-2 infection found that OAB symptoms persisted for up to 12 months post-recovery, with those testing positive by PCR showing higher symptom severity compared to individuals without the infection. These findings highlight the need for further research into the long-term consequences of COVID-19 on bladder function (Malallah et al. 2023, Padmanabhan et al. 2023).

Modern approaches to the treatment of overactive bladder—including pharmacotherapy with vibegron, neuromodulation, and electrical stimulation—represent important advances in improving the quality of life for patients with this condition. With ongoing technological progress in both therapy and diagnostics, it has become possible to better understand the pathophysiological mechanisms of OAB and to develop more precise treatments that are both effective and well tolerated. The impact of the COVID-19 pandemic on the progression of OAB further emphasizes the importance of monitoring and managing these patients, which will be crucial in future research and therapeutic strategies. The dynamic development of new therapies, such as vibegron and neuromodulation, offers hope for continued progress in the treatment of this burdensome disorder (Santoso et al. 2023).

Diagnostics and Evaluation of Treatment Effectiveness in Overactive Bladder

Accurate diagnosis of overactive bladder (OAB) and monitoring treatment efficacy are key elements in managing this condition. Traditional diagnostic approaches, such as voiding diaries and urodynamic studies, remain standard in the assessment of bladder function, but their invasiveness and limited precision pose certain challenges. In response to these limitations, modern technologies have been developed that allow for more accurate and less burdensome monitoring of lower urinary tract function. These technologies include advanced ultrasound devices, brain imaging techniques, and innovative methods for assessing functional parameters of the bladder, enabling more precise diagnosis and better evaluation of treatment effectiveness (Wilson and Gaido 2004).

Ultrasound technologies form the basis of modern methods for assessing bladder volume. Traditionally, bladder volume has been assessed using B-mode ultrasound, but the development of A-mode technology has revolutionized the speed and accuracy of these measurements. Studies have shown that A-mode devices are as precise as B-mode devices, but they offer faster and more efficient readings, making them more useful in clinical settings, especially when time and precision are critical. Moreover, A-mode technology enables bladder volume monitoring without frequent medical intervention, which is particularly important for patients with chronic bladder dysfunctions such as OAB. Research has shown that regular bladder monitoring using these devices can significantly enhance treatment outcomes by providing accurate real-time data on bladder function (Wilks et al. 2023, Siafarikas et al. 2023).

Advanced neuroimaging techniques, such as functional magnetic resonance imaging (fMRI), are playing an increasingly important role in the diagnosis of OAB. OAB is not solely a peripheral disorder; it has a significant neurological component, with the central nervous system playing a key role in bladder regulation. fMRI studies allow researchers to assess brain activation during bladder filling, helping to identify which brain structures are responsible for the sensation of urgency. These studies have shown that areas such as the brainstem, thalamus, and prefrontal cortex are highly activated during the urge to urinate (Wilks et al. 2023, Santoso et al. 2023).

The use of these techniques facilitates the development of more precise treatment methods, especially in the context of neuromodulation. Neuromodulation, which aims to modulate neural activity associated with bladder function, is becoming an increasingly popular therapeutic

option. Neuroimaging can support a better understanding of neuromodulation mechanisms and help evaluate its effectiveness by observing changes in brain activity. Patient-reported outcomes play a vital role in the diagnosis and management of OAB. To monitor treatment effectiveness and its impact on quality of life, several validated questionnaires are used, including the Overactive Bladder Questionnaire Short Form (OAB-q SF), the International Consultation on Incontinence Questionnaire Overactive Bladder Module (ICIQ-OAB), and the Urogenital Distress Inventory (UDI-6). These tools assess the severity of symptoms such as urinary frequency, incontinence episodes, and their effect on daily functioning (Wilson and Gaido 2024). Studies have shown that patients treated with modern therapies—such as neuromodulation or pharmacotherapy with vibegron—demonstrate significant improvement in questionnaire scores, indicating an enhanced quality of life. These questionnaires are also useful for monitoring long-term treatment efficacy and identifying patients who may require therapy adjustments. Modern diagnostic technologies also play a critical role in monitoring complications associated with OAB treatments. An example is the management of catheterassociated urinary tract infections (CAUTIs) in patients who require long-term catheterization. The use of catheters increases the risk of urinary tract infections, posing a significant clinical challenge. Modern urine sampling devices and ultrasound-based technologies allow for the early detection of infection symptoms, enabling prompt intervention and reducing the risk of complications. Additionally, research into antibacterial coatings for catheters has shown that these can significantly reduce the risk of infection by limiting bacterial adherence and reducing biofilm formation. Such innovations are crucial for ensuring long-term care in patients requiring extended catheter use (Brooks and Keevil 1997, Lo et al. 2014, Siafarikas et al. 2023). Progress in understanding brain control of bladder function has led to the discovery of key mechanisms associated with central nervous system activation during the sensation of bladder filling.

Notably, studies on the functional connectivity between the periaqueductal gray (PAG) and the pons have shown that these two brain regions play a crucial role in micturition regulation. Research has demonstrated that bladder filling triggers opposing patterns of activation in various PAG clusters, suggesting a complex role for PAG in mediating the perception of urinary urgency (Teodorescu and Bercea 2015). These studies help clarify how the brain regulates lower urinary tract function and may contribute to the development of new therapies targeting central control mechanisms. Further research in this area may provide valuable insights for treating

patients with bladder disorders that are resistant to traditional peripheral treatments (Carter et al. 2023, Malallah et al. 2023, Padmanabhan et al. 2023).

Diagnostics for overactive bladder are evolving rapidly, and modern technologies are playing a crucial role in improving the accuracy and effectiveness of bladder function assessment. New diagnostic approaches—such as ultrasound technologies, neuroimaging methods, and advanced bladder volume monitoring devices—represent a significant advancement in the management of OAB. Combined with quality of life questionnaires and the monitoring of therapy-related complications, these technologies enable more comprehensive care for patients with OAB, contributing to improved treatment outcomes and overall quality of life (Wilson and Gaido 2004).

Summary

Lower urinary tract disorders, such as overactive bladder (OAB), stress urinary incontinence (SUI), and nocturia, pose a significant challenge for both patients and clinicians. These conditions have a profound impact on quality of life, leading to limitations in daily activities, sleep disturbances, chronic pain, and psychological problems. Given the growing number of individuals affected by these issues, there is a pressing need to explore modern diagnostic and therapeutic methods that can effectively improve bladder function while minimizing the risk of complications. This paper discussed a range of advanced treatment approaches, including modern pharmacotherapy, surgical therapies, and innovative technologies such as neuromodulation. Pharmacotherapy—particularly anticholinergic agents and β3-adrenergic receptor agonists—remains the first-line treatment for OAB, although it may not be sufficiently effective for all patients. Consequently, neuromodulatory techniques such as percutaneous tibial nerve stimulation (PTNS) and sacral neuromodulation (SNM) are gaining importance as alternative therapeutic options for patients unresponsive to conventional therapies (Malallah et al. 2023, Padmanabhan et al. 2023).

In the treatment of stress urinary incontinence (SUI), surgical procedures such as the implantation of mid-urethral slings (MUS) and artificial urinary sphincters (AUS) offer effective solutions for patients with advanced symptoms. However, it is essential to consider the potential for postoperative complications, including mesh erosion, infections, and device malfunction. Advances in minimally invasive techniques, such as the use of laser technologies,

are opening new possibilities for patients who are not suitable candidates for more invasive procedures. Lower urinary tract dysfunctions such as nocturia are particularly significant in the context of elderly health (Malallah et al. 2023). Nocturia not only disrupts sleep but also increases the risk of falls, posing a serious threat to this population. Understanding the circadian rhythm of bladder function and its disruptions is essential for planning effective therapeutic interventions. In pediatric populations, nocturnal enuresis and other forms of bladder dysfunction place an emotional burden on both children and their caregivers. Neuromodulation and behavioral therapies are important treatment options for this group (Hadir et al. 2023, Padmanabhan et al. 2023).

The COVID-19 pandemic has introduced additional challenges in the management of lower urinary tract disorders. Infection with the SARS-CoV-2 virus may exacerbate bladder-related symptoms, and studies on the long-term effects of COVID-19—including the phenomenon of COVID-19 Associated Cystitis (CAC)—highlight the need for continued research in this area (Laude el al. 2023).

Disclosure:

Author's contribution:

Conceptualization: Jakub Buczkowski, Weronika Biaduń, Jakub Maciej Pieniążek; Methodology: Aleksandra Ciuła, Klaudia Arciszewska; Software: Aleksandra Padkowska, Kinga Rogowska, Michał Borawski, Aleksandra Ciuła; Check: Jakub Buczkowski, Weronika Biaduń, Jakub Maciej Pieniążek, Aleksandra
Padkowska; Formal analysis: Mateusz Dobosz, Jakub Buczkowski, Weronika Biaduń, Jakub Maciej Pieniążek; Investigation: Mateusz Dobosz, Michał Borawski, Aleksandra Ciuła, Jakub Maciej Pieniążek; Resources: Jakub Buczkowski; Data curation: Jakub Buczkowski; Writing - rough preparation: Jakub Buczkowski, Weronika Biaduń, Jakub Maciej Pieniążek; Writing - review and editing: Jakub Buczkowski, Michał Borawski, Aleksandra Ciuła, Aleksandra Romanowska; Visualization: Klaudia Arciszewska, Aleksandra Romanowska; Supervision: Jakub Maciej Pieniążek, Aleksandra Padkowska; Project administration: Michał Borawski, Kinga Rogowska.

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