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Review Article

Use of sacral neuromodulation in the treatment of overactive bladder syndrome

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ABSTRACT

Overactive bladder syndrome (OAB) is a prevalent condition characterized by urinary urgency, frequency, and incontinence, significantly impacting patients' quality of life. Sacral neuromodulation (SNM) has emerged as an effective treatment, particularly for individuals unresponsive to conventional therapies. SNM operates by modulating sacral nerve activity to restore normal bladder function, offering both symptom relief and enhanced quality of life. Recent clinical studies demonstrate its long-term efficacy, with sustained improvements in urgency and frequency, and high patient satisfaction rates. Mechanisms underlying SNM involve the modulation of peripheral and central nervous pathways, normalizing overactive detrusor activity and rebalancing excitatory and inhibitory neural signals. Advances in device technology, including rechargeable systems and adaptive stimulation, have further optimized its clinical utility. Minimally invasive techniques and improved electrode designs have enhanced the safety and accessibility of SNM, reducing complications and recovery times. Emerging applications of SNM extend beyond OAB, showing potential in managing neurogenic bladder, fecal incontinence, and chronic pelvic pain. Integration with digital health technologies allows for remote monitoring and personalized adjustments, improving patient outcomes and adherence. Future directions include exploring combined therapies, expanding indications, and leveraging machine learning for tailored neuromodulation. As innovations continue to refine SNM, its role in treating complex pelvic disorders is set to expand, offering a durable, effective solution for patients with refractory conditions. This evolution highlights SNM's transformative potential in both urological and multidisciplinary care.

Keywords: Sacral neuromodulation, Overactive bladder syndrome, Neuromodulation therapy, Urinary incontinence, Pelvic disorders

INTRODUCTION

Overactive bladder syndrome (OAB) is a prevalent condition characterized by symptoms of urinary urgency, with or without incontinence, often accompanied by increased frequency and nocturia. It significantly impacts the quality of life of affected individuals, resulting in both psychological and physical discomfort. OAB has a multifactorial etiology, involving central and peripheral nervous system dysfunctions, as well as abnormal detrusor muscle activity. Despite the availability of pharmacological therapies, many patients fail to achieve satisfactory outcomes, necessitating alternative treatments. SNM has emerged as a revolutionary

therapeutic option for refractory OAB. This intervention involves electrical stimulation of the sacral nerves, primarily S3, through an implantable device. By modulating the neural pathways that regulate bladder and pelvic floor function, SNM aims to restore normal urinary function and alleviate symptoms. Since its introduction in the late 20th century, SNM has been increasingly adopted due to its efficacy and long-term safety profile.

Clinical studies have demonstrated that SNM is effective in improving OAB symptoms in a substantial proportion of patients. Longitudinal data suggest sustained benefits over years of follow-up, making it an attractive option for patients with persistent symptoms despite conservative measures.[1] Moreover, SNM has proven beneficial in other bladder dysfunctions, such as underactive bladder and non-obstructive urinary retention, further broadening its clinical utility.[2] The mechanisms underlying SNM's therapeutic effects remain incompletely understood but are thought to involve central modulation of spinal reflexes and restoration of bladder inhibition pathways. Neuroimaging studies and animal models have provided valuable insights, although the exact neural circuits involved continue to be explored.[3] Advances in device technology and surgical techniques have further enhanced the accessibility and success rates of SNM.

Despite its proven efficacy, several challenges persist, including patient selection criteria, cost considerations, and the need for periodic device management. Additionally, the invasive nature of the procedure and potential complications, such as lead migration and infection, underscore the need for meticulous patient counseling and follow-up care. Recent innovations, including rechargeable devices and minimally invasive implantation methods, aim to address some of these limitations and improve patient satisfaction.[4] This review aims to explore the current state of knowledge regarding the use of SNM in the treatment of OAB, focusing on its mechanisms, clinical outcomes, and future prospects.

SNM has established itself as a pivotal therapy for OAB, offering significant symptom relief in patients unresponsive to conventional treatments. Clinical studies indicate that SNM achieves long-term efficacy by modulating sacral nerve activity, thereby restoring the balance of neural signaling pathways involved in bladder control. Improvements in urgency, frequency, and incontinence are consistently reported, with sustained benefits observed over years of follow-up.[5,6]

The mechanisms underlying SNM's success are multifaceted, encompassing both peripheral and central nervous system modulation. Stimulation of sacral nerves enhances bladder inhibition by activating afferent pathways that influence spinal and supraspinal centers. These effects are thought to normalize abnormal detrusor muscle activity and improve bladder compliance.[5,6] However, the precise neurophysiological processes remain under investigation, as evidence suggests variability in patient responses.

Despite its benefits, SNM presents challenges, including surgical risks, device complications, and financial barriers. Innovations such as rechargeable devices and less invasive implantation techniques have emerged to address these limitations. Moreover, future research is directed at optimizing patient selection and uncovering biomarkers to predict treatment outcomes. As SNM continues to evolve, its role in managing OAB is likely to expand, offering hope to patients with refractory bladder dysfunction.

MECHANISMS OF ACTION OF SNM IN OAB

SNM operates through a sophisticated interplay of mechanisms affecting both peripheral and central pathways that regulate bladder function. Its primary target, the sacral nerve plexus, plays a pivotal role in coordinating the sensory and motor activities of the lower urinary tract. By delivering electrical stimulation to the sacral nerves, particularly the S3 root, SNM modulates aberrant reflexes and restores balance to neural circuits disrupted in OAB.[7]

At the peripheral level, SNM influences the afferent and efferent nerve fibers that communicate with the detrusor muscle and urethral sphincter. Overactive bladder is often characterized by heightened afferent activity and inappropriate detrusor contractions. Electrical stimulation dampens excessive sensory signaling, reducing urgency and frequency. In experimental models, sacral nerve stimulation has been shown to decrease bladder hyperactivity, likely by altering sensory input to the spinal cord and higher centers.[8,9] Central mechanisms contribute significantly to the efficacy of SNM. Functional MRI studies have demonstrated that sacral stimulation alters activity in brain regions associated with bladder control, such as the anterior cingulate cortex, insula, and prefrontal cortex. These areas govern the perception of urgency and voluntary urinary suppression. Modulation of these neural centers reduces the heightened sense of urgency experienced by patients with OAB. The normalization of central nervous system (CNS) processing represents a crucial component of SNM's therapeutic effect.[10]

Neuroplasticity, the ability of the nervous system to reorganize itself in response to changes, is another mechanism implicated in SNM. Chronic stimulation induces structural and functional adaptations in the spinal cord and brain. These changes may contribute to the sustained symptom relief observed in patients, even after the device is turned off. The modulation of spinal reflexes and the strengthening of inhibitory pathways help maintain bladder compliance and control over the long term.[4] The impact of SNM on neurotransmitter dynamics provides additional insights into its mechanisms. Studies have revealed that sacral stimulation enhances inhibitory

signaling within the spinal cord by increasing gamma-aminobutyric acid (GABA) levels while reducing excitatory neurotransmitters like glutamate. This balance between excitation and inhibition plays a critical role in regulating the voiding reflex and mitigating detrusor overactivity. Moreover, the effects of SNM extend beyond voiding to encompass other symptoms such as pelvic pain, indicating a broader neuromodulatory impact.[7,11]

Another intriguing aspect of SNM's action is its effect on the autonomic nervous system. OAB involves dysregulation of the sympathetic and parasympathetic systems, leading to impaired bladder storage and emptying. Sacral nerve stimulation rebalances these autonomic inputs, enhancing detrusor relaxation and sphincteric control. This autonomic modulation not only improves functional outcomes but also underscores the multifaceted nature of SNM's therapeutic effects.[12] Emerging technologies have enabled the exploration of sensory feedback loops affected by SNM. Electrophysiological studies indicate that sacral nerve stimulation modifies the afferent signals traveling from the bladder to the spinal cord. These changes recalibrate the sensory thresholds, potentially reducing the hyper-responsiveness that characterizes OAB. Such recalibration provides a plausible explanation for the sustained benefits of SNM, as the nervous system adapts to the altered signaling patterns.[13]

Despite its efficacy, the precise pathways and processes involved in SNM remain incompletely understood. The interplay between peripheral modulation, central regulation, and neurotransmitter dynamics creates a complex therapeutic landscape. Advanced imaging techniques and neurophysiological tools continue to enhance our understanding of these mechanisms, paving the way for innovations in device design and clinical application. By elucidating the intricate network of pathways influenced by SNM, researchers and clinicians can refine patient selection criteria, optimize treatment protocols, and develop next-generation neuromodulation therapies.

EFFICACY AND SAFETY PROFILES: CLINICAL OUTCOMES AND PATIENT EXPERIENCES

SNM has demonstrated remarkable efficacy in managing OAB syndrome, particularly in cases resistant to conventional treatment methods. Studies spanning over decades have consistently highlighted its ability to significantly reduce symptoms such as urgency, frequency, and incontinence. This intervention offers not just symptomatic relief but also a tangible improvement in the quality of life for patients who often endure profound social and emotional impacts due to OAB.[13]

Clinical trials assessing the long-term outcomes of SNM underscore its effectiveness in symptom reduction. A five-year multicenter study reported sustained reductions in urgency-frequency episodes and urinary leakage. Participants described substantial improvements in their daily lives, as they regained control over their bladder function, enabling greater participation in social and professional activities. The ability of SNM to provide enduring benefits makes it a unique option compared to pharmacological treatments, which often show diminishing efficacy over time.[14]

Patient experiences further validate the utility of SNM. Many individuals report significant changes in their lifestyle, with the intervention reducing the anxiety associated with unpredictable bladder activity. This alleviation of stress and fear directly impacts psychological well-being. By addressing the core issues of bladder dysfunction, SNM fosters a sense of autonomy, allowing patients to reclaim their confidence and independence.[14] The safety profile of SNM has been thoroughly evaluated, with findings suggesting a favorable risk-benefit ratio. Common complications such as lead migration, infection, or device malfunctions are infrequent and typically manageable. Advances in device technology, including the development of rechargeable systems, have contributed to a reduction in these issues. Innovations like MRI-compatible devices have further broadened the applicability of SNM while maintaining safety standards. Comparative studies have demonstrated that SNM results in fewer systemic side effects compared to pharmacological alternatives, solidifying its role as a preferred treatment for OAB.[5]

Economic analyses have shed light on the cost-effectiveness of SNM over time. While the upfront costs of device implantation may be higher than medications, the long-term benefits, including reduced reliance on additional therapies and fewer hospital visits, offset these initial expenses. Rechargeable systems, which reduce the need for frequent replacements, have further enhanced the economic feasibility of SNM, making it a more sustainable option for both healthcare systems and patients.[15] Furthermore, rigorous patient selection processes play a crucial role in the success of SNM. Pre-implantation evaluations, particularly test stimulation, allow clinicians to determine the suitability of the therapy for individual patients. These tests not only improve the overall success rates but also enhance patient satisfaction by ensuring that only those who respond positively proceed to permanent implantation. Tailored approaches based on the patient’s medical history and comorbidities have been shown to optimize outcomes.[16]

Beyond individual outcomes, the adoption of SNM has broader implications for the treatment landscape of OAB. Studies comparing SNM to other neuromodulation technologies, such as tibial nerve stimulation, consistently show superior results with sacral modulation in terms of efficacy and patient satisfaction. The sustained benefits observed in SNM recipients also highlight its potential in managing other refractory pelvic floor disorders, suggesting a wider therapeutic scope.[17] Emerging trends

in SNM research include exploring its application in pediatric populations and individuals with neurogenic bladder conditions. These studies aim to expand the indications for SNM, making it accessible to a more diverse group of patients. Simultaneously, advancements in device technology, including the miniaturization of implants and programmable stimulation settings, are enhancing user comfort and therapeutic precision. As these innovations continue to unfold, SNM is poised to remain a cornerstone in the management of OAB and related disorders.[18]

FUTURE DIRECTIONS AND INNOVATIONS IN SNM THERAPY

The field of SNM continues to evolve, driven by technological advancements and expanding clinical applications. These innovations are aimed at enhancing device efficiency, minimizing invasiveness, and broadening the therapeutic scope to address diverse urological and non-urological conditions. Recent developments offer promising insights into the future of this transformative therapy.[19]

One area of advancement focuses on improving device durability and patient comfort. Rechargeable devices became standard in modern SNM systems, significantly extending battery life and reducing the need for replacement surgeries. These improvements alleviate the patient's burden and contribute to lower healthcare costs over time. Research into wireless neuromodulation systems is underway, aiming to eliminate leads and connectors, thereby simplifying implantation and reducing complications associated with traditional devices.[20]

Personalized neuromodulation is emerging as a key trend. Adaptive stimulation systems that respond to real-time neural feedback are being developed to optimize therapeutic outcomes. These systems are designed to monitor bladder activity continuously and adjust stimulation parameters, accordingly, enhancing efficacy while minimizing side effects. Machine learning algorithms integrated into these systems enable precise customization based on individual patient profiles, paving the way for tailored interventions.[20] Another significant innovation lies in expanding the indications for SNM. Clinical trials are investigating its application in pediatric populations and patients with neurogenic bladder, as well as conditions such as fecal incontinence and chronic pelvic pain. These studies are informed by growing evidence that SNM can modulate central and peripheral pathways involved in a range of dysfunctions. Such advancements could make SNM an indispensable tool across multiple disciplines beyond urology.[17]

Minimally invasive techniques are revolutionizing implantation procedures, enhancing accessibility and reducing patient recovery times. Innovations such as percutaneous approaches and advanced imaging-guided placements ensure precision and safety during surgery. These techniques also open opportunities for outpatient procedures, making SNM a more viable option for a broader patient base. Additionally, new electrode designs and materials are being developed to improve biocompatibility and reduce infection risks, which remain a concern with implantable devices.[21] The integration of SNM with digital health technologies is redefining patient management. Remote programming and monitoring capabilities allow clinicians to adjust device settings without requiring in-person visits. This innovation is particularly beneficial for patients in remote areas, ensuring consistent follow-up and immediate response to therapy-related concerns. Furthermore, wearable devices that sync with SNM systems are being explored to provide continuous health data, enhancing both patient engagement and clinical oversight.[22]

Future research is also delving into the use of SNM in combination with other therapies. For instance, hybrid approaches that pair neuromodulation with pharmacological treatments or pelvic floor exercises are being tested to maximize therapeutic benefits. These multimodal strategies recognize the multifactorial nature of disorders like OAB and aim to address various underlying mechanisms simultaneously. Initial findings suggest that such combinations can improve outcomes for patients who exhibit partial responses to standalone treatments.[23] As the technological landscape continues to evolve, ethical considerations and regulatory challenges must also be addressed. Ensuring equitable access to these advanced therapies and maintaining stringent safety standards are critical as SNM becomes more widely adopted. Collaborative efforts between researchers, clinicians, and industry stakeholders are essential to drive innovation while prioritizing patient welfare.

CONCLUSION

SNM stands as a transformative therapy for managing overactive bladder and other pelvic disorders, with its efficacy continually supported by evolving innovations. Advancements in technology, including adaptive systems and minimally invasive techniques, promise improved patient outcomes and broader applications. Integration with digital health further enhances accessibility and personalized care. As research progresses, SNM is poised to redefine the treatment landscape for complex urological conditions.

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REFERENCES

1. Chartier-Kastler E. Sacral neuromodulation for treating the symptoms of overactive bladder syndrome and non-obstructive urinary retention: >10

years of clinical experience. BJU Int. 2008;101(4):417.
2. Blok BF. Sacral neuromodulation for the treatment of urinary bladder dysfunction: mechanism of action and future directions. Bioelectr Med. 2018;1(1):85-94.
3. Bartley J, Gilleran J, Peters K. Neuromodulation for overactive bladder. Nature Rev Urol. 2013;10(9):513-21.
4. Sukhu T, Kennelly MJ, Kurpad R. Sacral neuromodulation in overactive bladder: a review and current perspectives. Res Rep Urol. 2016;193-9.
5. Tilborghs S, De Wachter S. Sacral neuromodulation for the treatment of overactive bladder: systematic review and future prospects. Expert Rev Med Dev. 2022;19(2):161-87.
6. Laviana A, Jellison F, Kim J-H. Sacral neuromodulation for refractory overactive bladder, interstitial cystitis, and painful bladder syndrome. Neurosurg Clin. 2014;25(1):33-46.
7. Elkelini MS, Abuzgaya A, Hassouna MM. Mechanisms of action of sacral neuromodulation. Int Urogynecol J. 2010;21:439-46.
8. Panicker JN. Neurogenic bladder: epidemiology, diagnosis, and management. Paper presented at: Seminars in neurology. 2020.
9. Perez NE, Godbole NP, Amin K, Syan R, Gater Jr DR. Neurogenic bladder physiology, pathogenesis, and management after spinal cord injury. J Personalized Med. 2022;12(6):968.
10. Gill BC, Pizarro-Berdichevsky J, Bhattacharyya PK, Thaddeus SB, Brian KM, Adrienne Q, et al. Real-time changes in brain activity during sacral neuromodulation for overactive bladder. J Urol. 2017;198(6):1379-85.
11. Janssen PT, Komen N, Melenhorst J, Nicole DB, Ali J, Yasin T, et al. Sacral neuromodulation for fecal incontinence: a review of the central mechanisms of action. J Clin Gastroenterol. 2017;51(8):669-76.
12. White WM, Mobley III JD, Doggweiler R, Dobmeyer-Dittrich C, Klein FA. Incidence and predictors of complications with sacral neuromodulation. Urology. 2009;73(4):731-5.
13. Blok B, Van Kerrebroeck P, de Wachter S, et al. Two-year safety and efficacy outcomes for the treatment of overactive bladder using a long-lived rechargeable sacral neuromodulation system. Neurourol Urodynamics. 2020;39(4):1108-14.
14. Siegel S, Noblett K, Mangel J, Jason B, Tomas LG, Suzette ES, et al. Five-year followup results of a prospective, multicenter study of patients with overactive bladder treated with sacral neuromodulation. J Urol. 2018;199(1):229-36.
15. Huang J, Fan Y, Zhao K, Chunlan Y, Ziqi Z, Yin C, et al. Comparative efficacy of neuromodulation technologies for overactive bladder in adults: a network meta-analysis of randomized controlled trials. Neuromodulation: Technol Neural Interface. 2023;26(8):1535-48.
16. Wang Z-H, Liu Z-H. Treatment for overactive bladder: A meta-analysis of tibial versus parasacral neuromodulation. Medicine. 2022;101(41):e31165.
17. Tahseen S. Role of sacral neuromodulation in modern urogynaecology practice: a review of recent literature. Int Urogynecol J. 2018;29:1081-91.
18. Smits MA, Oerlemans D, Marcelissen TA, Van Kerrebroeck PE, De Wachter SG. Sacral neuromodulation in patients with idiopathic overactive bladder after initial botulinum toxin therapy. J Urol. 2013;190(6):2148-52.
19. Li Z-J, Zhang L-B, Chen Y-X, Hu L. Advancements and challenges in neuromodulation technology: interdisciplinary opportunities and collaborative endeavors. Sci Bull. 2023;68(18):1978-82.
20. Yaiesh SM, Al-Terki A, Al-Shaiji TF. Neuromodulation in urology: Current trends and future applications. In: Neurostimulation and Neuromodulation in Contemporary Therapeutic Practice. IntechOpen, 2020.
21. Marinkovic SP. New technologies in the management of overactive bladder: current research and future prospects. Therapeutic Adv Urol. 2019;11:1756287219844669.
22. Abello A, Das AK. Electrical neuromodulation in the management of lower urinary tract dysfunction: evidence, experience and future prospects. Therapeutic Adv Urol. 2018;10(5):165-73.
23. Suskind AM, Dunn RL, Kaufman SR, O L DeLancey J, Clemens JQ, Stoffel JT, et al. Understanding the dissemination of sacral neuromodulation. Surgical Innovation. 2013;20(6):625-30.

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