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Emerging Implantable Tibial Nerve Stimulation Devices for Overactive Bladder

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Overactive bladder (OAB) substantially reduces quality of life (QoL), and novel implantable percutaneous tibial nerve stimulation (iPTNS) devices have emerged as promising alternatives to conventional management. This review provides a comprehensive comparative analysis of iPTNS devices for OAB, evaluating clinical outcomes, technical specifications, regulatory status, innovative features, and limitations—key aspects insufficiently addressed in prior studies. A narrative synthesis was conducted by reviewing clinical trials, technical reports, and regulatory documents related to 7 iPTNS devices. The analysis focused on improvements in health-related QoL (HRQoL), reductions in urgency urinary incontinence (UUI), device design variability, and regulatory distinctions. Our review revealed substantial differences among devices in terms of clinical efficacy (HRQoL and UUI reduction), technical design (including power sources and implantation methods), and regulatory status, with some devices approved by the U.S. Food and Drug Administration and others still under development. While iPTNS devices show considerable promise in OAB management, significant gaps remain regarding long-term outcomes and real-world adherence. Future innovations, particularly closed-loop neuromodulation, hold promise for improving efficacy and advancing personalized therapy.

Keywords: Urinary bladder, Overactive; Tibial nerve; Electrical stimulation; Urinary incontinence, Urge; Implantable neurostimulators

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INTRODUCTION

Overactive bladder (OAB) is a chronic urological syndrome characterized by urgency, frequency, nocturia, and urge incontinence, all of which significantly impair quality of life (QoL) [1]. It is highly prevalent, with global rates approaching 20%, and prevalence has risen over the past 2 decades from 18.1% to 23.9%. Large-scale surveys such as the EPIC (European Prospective Investigation into Cancer and Nutrition) study report similar prevalence across sexes, although higher rates are observed among women, older adults, and individuals who are overweight or obese [2]. OAB imposes a substantial burden on physical, social, and emotional well-being. Current treatment options remain suboptimal. First-line therapies, including behavioral modifications and pelvic floor exercises, are noninvasive but often yield only limited relief. Second-line treatments, such as oral anticholinergics and beta-3 agonists, provide pharmacological management but are frequently associated with

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adverse effects — including dry mouth, constipation, and cognitive changes — that limit long-term adherence [3]. Third-line options such as botulinum toxin injections, sacral nerve stimulation (SNS), and percutaneous tibial nerve stimulation (PTNS) demonstrate efficacy but involve invasive procedures and repeated clinic visits [4].

In recent years, neuromodulation therapies have progressed from externally delivered stimulation methods such as PTNS and SNS to fully implantable solutions, providing more consistent and patient-friendly treatment. Unlike traditional PTNS, which requires frequent clinic visits, implantable PTNS (iPTNS) (Fig. 1) offers continuous stimulation without repeated procedures, thereby improving long-term efficacy and reducing patient burden. These limitations of existing approaches have driven the development of iPTNS devices, which are designed to enhance both efficacy and adherence. By eliminating patient-dependent therapy sessions, these systems increase adherence while also allowing greater flexibility in adjusting stimulation parameters, including frequency, duration, and intensity. Novel leadless (lacking transcutaneous leads or connectors), battery-free (without an internal power cell, relying on external energy transfer), and wireless (energy delivered noninvasively across intact skin via inductive coupling) iPTNS devices further improve patient comfort by minimizing surgical complexity and lowering infection risk. These features position iPTNS as a superior alternative to office-based PTNS and intradetrusor botulinum toxin injections, both of which require repeated interventions [4, 5]. However, previous reviews have addressed only 2 to 6 devices, leaving a gap in comprehensive evaluation. This review addresses that gap by analyzing 7 major iPTNS platforms, examining their clinical outcomes, technical designs, regulatory status, and future prospects, including closed-loop neuromodulation.

Fig. 1. Implantable percutaneous tibial nerve stimulation (iPTNS) devices. (A) BlueWind Revi System. Reprinted from Heesakkers et al. Neurourol Urodyn 2024;43:1491-03 [8]. (B) eCoin. Reprinted from Rogers et al. J Urol 2021;206:399-408 [13]. (C) TITAN TNM System. Reprinted from Lee et al. Contemp Clin Trials Commun 2023;35:101198 [17]. (D) INTIBIA Device. Reprinted from Sethi et al. Neurourol Urodyn 2025;28:832-9 [20]. (E) Urgent-SQ system: (a) internal body with electromagnetic pulse receiver; (b) position of the external stimulator with electromagnetic pulse generator on the ankle; (c) minimally invasive surgical procedure for implant placement adjacent to the tibial nerve and connection to a subcutaneous receiver plate; (d) dermal scar at the ankle 9 years after implantation. Reprinted from te Dorsthorst et al. Continence 2022;1:100002 [30].

METHODS

We conducted a narrative review of English-language publications from January 2017 to March 2025 using PubMed, IEEE Xplore, and ClinicalTrials.gov. Keyword combinations included "implantable PTNS," "tibial nerve stimulation," "overactive bladder," "neuromodulation," and "closed-loop," yielding 2,320 records. After removing duplicates and consolidating synonyms and model variants, 19 unique devices were identified. We included studies of iPTNS devices tested in human clinical trials and excluded those that were SNS only (sacral neuromodulators only; n=5), non-implantable (n=1), transcutaneous-only (n=4), or not targeting the tibial nerve (n=2). Seven devices met the inclusion criteria: Revi, eCoin, Protect PNS, Titan TNM, Intibia, StimRouter, and Urgent-SQ. These underwent full-text review. Data were extracted on clinical efficacy, technical specifications, regulatory status, innovative features (e.g., closed-loop control), and reported limitations. The study selection process is illustrated in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart (Fig. 2). Findings are synthesized into a narrative review and presented with 1 comparative figure (Fig. 1) and 3 summary tables (Tables 1–3).

BLUEWIND REVI SYSTEM (BLUEWIND MEDICAL)

The Revi System (Fig. 1A), formerly RENOVA iStim, is a minimally invasive implantable tibial nerve stimulator developed by BlueWind Medical (Herzliya, Israel). It received CE (Conformité Européenne) Marking in 2016 and U.S. Food and Drug Administration (FDA) approval in 2023, establishing its safety and efficacy [3, 6]. The battery-free, magnetic resonance imaging (MRI)-conditional implant (≈30×13×2.7 mm) contains 2 electrodes and a wireless receiver. Under local or general anesthesia, a ~5-cm incision is made above the ankle for subfascial placement near the posterior tibial neurovascular bundle. Intraoperative testing confirms positioning before the device is sutured to the fascia, with the procedure averaging 34 minutes [7].

Power and stimulation are delivered by an external control unit worn around the ankle, magnetically coupled to the implant in a closed-loop system that ensures consistent energy transfer without a battery [8]. Daily sessions last 30–60 minutes (up to 120 minutes) with programmable parameters: default 14 Hz/210 μsec (range, 2–30 Hz, 190–790 μsec, 0.2–10 mA). Clinicians adjust settings via a tablet interface, while patients can independently switch between 2 presets [8]. Closed-loop energy transfer reduces risks of lead migration, breakage, and battery-related complications common in other neuromodulation systems [9]. Fixating wings and suture holes enhance device stability.

In the OASIS (Overactive Bladder Stimulation System) pivotal study (ClinicalTrials.gov Identifier: NCT03596671), a prospective, multicenter, single-arm, open-label trial, 151 participants received implants, and 97 completed 24-month follow-up [10]. Results showed that 79% achieved ≥50% reduction in urgency urinary incontinence (UUI) episodes, 56% achieved ≥75% reduction, and 28% became completely dry. Mean UUI episodes decreased from 4.8 to 1.3 per day (72.9% reduction). Health-related QoL (HRQoL) improved by ≥10 points in 87% of completers, 97% reported feeling "better" to "very much better," and 100% expressed willingness to continue therapy. No device- or procedure-related serious adverse events were reported, and only 2% of implants were explanted [11]. Clinical efficacy metrics for all devices are summarized in Table 1.

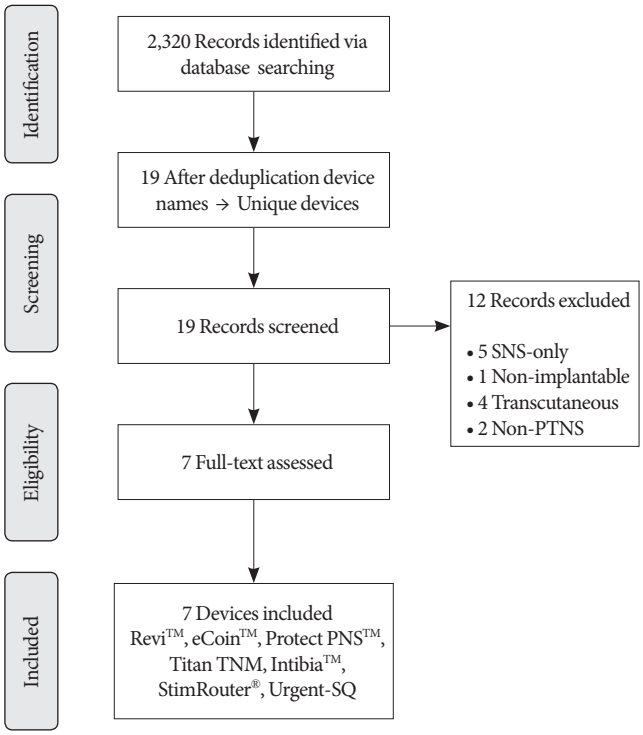

Fig. 2. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) flowchart of the literature screening and selection process for implantable percutaneous tibial nerve stimulation (iPTNS) devices in overactive bladder (OAB). SNS, sacral nerve stimulation.

Table 1. Comparison of clinical efficacy (QoL and UUI reduction) and regulatory status of iPTNS devices

Device name	Regulatory status	Study (N & duration)	UUI reduction	QoL improvement	Safety
BlueWind Revi	FDA approved (2023); CE mark (2016)	OASIS: 151 (97); 24-mo follow up	72.9% mean reduction (4.8 → 1.3 episodes/day)	87% ≥ 10-point score gain; 97% felt better	No serious events; 2% explant rate
Valencia eCoin	FDA approved (2022)	Extension: 72; 96 wk	68.8% mean reduction (-2.97 episodes/day)	~34-point symptom-bother drop; similar HRQoL gain	No unanticipated events; 4.2% explant rate
Uromedical Protect PNS	Under FDA review	Pilot: 7; 12 mo	74% ≥ 50% responders; 50% dry	80% reported improved satisfaction	No migrations/infections; iterative refinements
Medtronic Titan TNM	Investigational (FDA)	TITAN 1: 24 (20); 14 day; TITAN 2 ongoing	Target ≥ 50% at 6 M (TITAN 2)	Not reported	Few device/procedure-related events
Coloplast INTIBIA	Investigational (FDA)	Feasibility: 10	89% reduction; frequency ↓ 8.5 → 6.3/day; voids ↓ 10.6 → 7.8/day	HRQoL ↑ 52.8 → 92.0; severity ↓ ($p < 0.001$)	Effective; manageable adverse outcomes
Bioness StimRouter	FDA (pain); CE mark (OAB, 2019)	STIMROUTER: 23 MS; 24 wk; feasibility: 7	27.9% symptom-score drop; urgency ↓ 83.3%	QoL ↑ 18.8% (OAB q)	Minimal adverse events
UrgentSQ	Pilot studies (no FDA approval)	Pilot: 8; 12 mo; 9 yr; 18-yr follow up	Significant but unquantified	Substantial subjective gains	Early failures over long-term

QoL, quality of life; UUI, urgency urinary incontinence; iPTNS, implantable percutaneous tibial nerve stimulation; FDA, U.S. Food and Drug Administration; CE, Conformité Européenne; OASIS, Overactive Bladder Stimulation System; HRQoL, health-related QoL; OAB-q, overactive bladder questionnaire.
QoL improvement refers to either (1) mean change in validated questionnaire scores (points) or (2) proportion of subjects achieving a clinically meaningful increase (≥10 points on HRQoL scales).
UUI reduction is reported as percent change from baseline; absolute change in episodes per day is given in parentheses.
Responder is defined as ≥50% reduction in baseline UUI episodes unless otherwise specified.
All safety data refer to device- or procedure-related serious adverse events and explant rates where available.

eCOIN (VALENCIA TECHNOLOGIES)

The Electroceutical Coin (eCoin) (Fig. 1B) is a fully implantable, leadless tibial nerve stimulator developed by Valencia Technologies (USA) for the treatment of urge urinary incontinence. FDA approval was granted in 2022 [12]. The device delivers automated neuromodulation, maximizing adherence while minimizing patient effort [13]. About the size of a nickel (23.2-mm diameter × 3.2-mm thickness), it is housed in a titanium shell with integrated platinum electrodes and powered by an internal battery, eliminating the need for external power sources [5]. Comparative technical parameters, including implant size, pulse widths, amplitudes, rates, and session durations, are shown in Table 2. Implantation is performed under local anesthesia via a small subcutaneous incision adjacent to the posterior tibial nerve, usually within 20–30 minutes on an outpatient basis [14]. After a 4-week healing and activation period, the device initiates 30-minute stimulation sessions every 3 days for 18 weeks, then every 4 days thereafter. Stimulation parameters are fixed at 0.2-msec pulse width and 20 Hz, with amplitude adjustable between 0.5–15 mA using an external controller [13]. This regimen automates therapy delivery, ensuring near-complete adherence without patient input. The device is MRI-conditional at 1.5 T and 3 T, supporting diagnostic imaging without explantation [9].

In the pivotal 2-year extension trial of eCoin (ClinicalTrials.gov Identifier: NCT03556891), a prospective, single-arm, open-label study, 72 participants completed the 96-week evaluation. Sustained efficacy and QoL benefits were observed. At 96 weeks, 78% (95% confidence interval [CI], 67%–87%) achieved ≥50% reduction in UUI episodes, 48% (95% CI, 36%–60%) achieved ≥75% reduction, and 22% (95% CI, 13%–33%) became completely dry. Mean UUI episodes declined from 4.32/day at baseline to 1.35/day (-2.97; 68.8% reduction), and daily voids decreased by 1.89 from a baseline of 13.06. Mean symptom-bother and HRQoL scores improved by approximately 34 points each. Additionally, 91.3% of patients maintained therapy without adjunctive OAB medications. The safety profile was ex-

Table 2. Comparison of technical features across iPTNS devices

Device name	Size	Session duration	Pulse width	Pulse amplitude	Pulse rate	External component
BlueWind Revi	~30 mm × 13 mm (implant; ~2.7 mm diameter)	30–60 Min (up to 120 min)	210 μsec (range, 190–790 μsec)	0.2–10 mA (adjustable)	14 Hz (range, 2–30 Hz)	External wearable ECU
Valencia eCoin	~23.2-mm diameter, 3.2-mm thickness	Automated 30 min (every 3 then 4 days)	Fixed 200 μsec	0.5–15 mA (adjustable)	Fixed 20 Hz	None (fully implantable)
Uromedical Protect PNS	~1.35-mm diameter, 70-mm length	>6 Hr daily	Not specified	Not specified	Not specified	External power via fabric wrap
Medtronic Titan TNM	Compact; proprietary dimensions	30 Min every other day	Fixed 200 μsec	Adjustable (range not reported)	Fixed 20 Hz	None (fully implantable)
Coloplast INTIBIA	Generator: 44.5 mm; overall diameter: 6.54 mm; lead: 139.5 mm	Initially daily 30 min (2 wk), then weekly	Fixed 200 μsec	Adjustable 0.1–10 V	Fixed 20 Hz	None (fully implantable)
Bioness StimRouter	Multielectrode tined lead (~12 cm; size not given)	Typically, 60 min, 5–7 days/wk (customizable)	Fixed 200 μsec	Adjustable (not specified)	Fixed 20 Hz	External transmitter, programmer, patch, charger
UrgentSQ	Receiver ~4-cm diameter; electrodes 1 cm^2 each	On-demand; duration not specified	Not specified	Not specified	Not specified	External pulse generator worn on leg

iPTNS, implantable percutaneous tibial nerve stimulation; ECU, external control unit.
Size dimensions are given as implant length × width (× thickness) in millimeters.
Session duration is mean minutes per session; ranges (minimum–maximum) are shown in parentheses.
Pulse width is reported in microseconds; pulse rate in hertz.
Pulse amplitude is given in milliamperes or volts as originally reported.
"None" under "external component" indicates a fully implantable, leadless design.

cellent, with no device- or procedure-related serious adverse events and an explant rate of 4.2% (3 of 72) [15].

PROTECT PNS (UROMEDICAL)

The Protect PNS system, developed by Uro Medical Corporation (USA; formerly StimGuard LLC/Micron Medical), is a novel iPTNS device currently under FDA review for the treatment of OAB symptoms. The system comprises a chronic, wireless percutaneous pulse generator with an integrated quadripolar electrode array and a rechargeable external transmitter. The compact implant measures 1.35 mm in diameter and 70 mm in length, minimizing tissue disruption and supporting minimally invasive delivery [16].

Implantation is performed in-office under local anesthesia using an innovative injectable retrograde technique. A 5- to 6-mm incision is made on the medial lower leg, approximately one-third of the distance from the medial malleolus to the Achilles tendon. A blunt-tip introducer is advanced parallel to the tibial nerve. Proper placement is confirmed intraoperatively with a transcutaneous electrical nerve stimulation (TENS) unit by eliciting sensory and motor responses such as foot pulsation and toe flexion. Once positioned, the percutaneous implantable pulse generator is deployed with integrated tines and secured with an absorbable suture. Table 3 provides a comparative matrix of implantation, energy transfer, and maintenance across systems. Following implantation, patients wear a fabric leg wrap containing an external power source that wirelessly delivers over 6 hours of stimulation daily [16].

In the pilot study (NCT02781636), 7 patients with refractory OAB demonstrated rapid and sustained reductions in UUI. At 12 months, 74% (95% CI, 57%–89%) achieved ≥50% reduction in UUI episodes, while 50% (95% CI, 29%–71%) achieved complete dryness. Approximately 80% reported improved QoL and satisfaction with therapy. Design refinements addressed early mechanical issues, with 3 of 6 patients maintaining therapy beyond 4 years. The system demonstrated a strong safety profile, with no device migrations, infections, or serious adverse events reported during 30–48 months of follow-up. Based on these results, the 200-patient PROTECT trial (vs. InterStim)

Table 3. Comparison of implantation, energy transfer, and maintenance features of iPTNS devices

Device	Implantation	Energy transfer	Maintenance	Advantages	Disadvantages
BlueWind Revi	Open surgery, subfascial (~5-cm incision; sutured to fascia)	Wireless closed-loop; no battery	No battery; requires external wearable unit	Customizable settings; secure, stable energy delivery	Requires external unit; more invasive procedure
Valencia eCoin	Outpatient, small incision near posterior tibial nerve; subcutaneous	Battery-powered; automated schedule	Battery lasts 3–5 yr; replacement needed	Fully implantable and leadless; minimally invasive	Fixed stimulation schedule; battery replacement disrupts therapy
Uromedical Protect PNS	Percutaneous injection (5–6 mm incision); subcutaneous placement	Externally powered via fabric wrap	No battery; relies on external power	Minimally invasive; reduced tissue trauma	Depends on external wrap; stimulation parameters not defined
Medtronic Titan TNM	Outpatient, minimally invasive; small incision near tibial nerve	Fully implantable; internal battery, autonomous	Standard internal battery maintenance	Autonomous operation; adjustable amplitude; fully implantable	Proprietary dimensions limit details; still investigational
Coloplast INTIBIA	Outpatient; subcutaneous/subfascial via ~10–12 cm incision at medial malleolus	Fully implantable; nonrechargeable lithium battery	Battery replacement required eventually	Shifting regimen optimizes therapy balance; clinically effective	Fixed settings; nonrechargeable battery interrupts therapy
Bioness StimRouter	Outpatient; 2 small incisions with imaging; subcutaneous lead placement	Wireless power via external transmitter	External power system; no implanted battery	Programmable regimens; highly customizable	Complex external system; multiple components increase complexity
UrgentSQ	Open, minimally invasive; subcutaneous electrodes adjacent to tibial nerve	External pulse generator worn on leg	Requires ongoing external technical support	On-demand stimulation reduces needle use; minimally invasive	External stimulator reliability issues; long-term failures

iPTNS, implantable tibial nerve stimulation.
Implantation describes the surgical approach and incision size in centimeters (cm) or millimeters (mm).
Energy transfer indicates whether the device uses an internal battery, external wireless coupling, or both.
Maintenance refers to battery replacement schedules or external power requirements over the device lifespan.
Advantages and disadvantages summarize key design trade offs; see main text for details.

has completed enrollment, and the 600-patient Guardian randomized controlled trial (vs. medical management) is ongoing [16].

TITAN TNM SYSTEM (Medtronic)

The Titan TNM System (Fig. 1C), developed by Medtronic (USA), is a fully implantable, leadless tibial nerve stimulator for OAB that is currently undergoing FDA investigational review, with approval expected following the pivotal TITAN 2 trial. The system is encased in a compact titanium housing designed for subcutaneous implantation in the lower leg, ensuring long-term biocompatibility and mechanical durability. A rechargeable internal battery powers integrated electrodes, delivering precise 20 Hz, 200-μsec electrical pulses directly to the tibial nerve without external leads, thereby providing autonomous and reliable neuromodulation [17].

Implantation is performed in an outpatient setting under local anesthesia using a minimally invasive procedure lasting about 30 minutes. A small incision is made near the posterior tibial nerve to create a subcutaneous pocket above the deep fascia. Intraoperative testing, typically evidenced by toe flexion, confirms correct placement before securing the device. Activation occurs within 24 hours, and the device is programmed to deliver 30-minute stimulation sessions every other day (200-μsec pulse width, 20 Hz), with amplitude adjusted at follow-up visits. This autonomous regimen promotes adherence, accelerates recovery, and reduces anesthesia-related risks [17].

In the TITAN 1 feasibility study (ClinicalTrials.gov Identifier: NCT04873271), 24 subjects were enrolled and 20 received implants across multiple clinical sites. The device consistently produced both motor and sensory responses, confirming effective tibial nerve stimulation. Imaging showed minimal device migration post-implantation, and the safety profile was favorable, with only a few device- or procedure-related adverse events reported during the 14-day follow-up period [18]. Building on these findings, the TITAN 2 pivotal trial (NCT05226286) is currently underway. This prospective, multicenter U.S. study is enrolling up to 200 participants at approximately 30 sites. The primary endpoint is achieving at least a 50% reduction in daily UUI episodes at 6 months, with secondary endpoints including reductions in urinary frequency, improvements in urgency, and HRQoL enhancement measured by validated patient-reported outcomes. Together, these trials aim to confirm the Titan TNM System as an effective, long-term, and patient-friendly treatment for OAB [19].

INTIBIA DEVICE (COLOPLAST)

The Intibia device (Fig. 1D), developed by Coloplast (Denmark; acquired from Nine Continents Medical in 2020), is a fully implantable tibial nerve stimulator under FDA investigational oversight for UUI [20]. The system includes a compact pulse generator (44.5 mm) with an integrated lead (139.5 mm; 6.54-mm diameter), powered by a nonrechargeable lithium cell. It is MRI-conditional at both 1.5 T and 3 T.

The device is implanted in an outpatient setting under local anesthesia, with or without mild sedation, through a 10- to 12-cm incision above the medial malleolus. A subcutaneous pocket accommodates the generator, while a subfascial lead is placed near the tibial nerve. Intraoperative testing confirms appropriate motor or sensory responses. The procedure lasts 20–30 minutes and delivers 200 μs pulses at 20 Hz, with amplitude adjustable between 0.1–10 V. After a 4-week healing period, the device is activated to provide 30-minute daily sessions for 2 weeks, followed by weekly maintenance therapy [20].

In the first-in-human ITNS Clinical Feasibility Study (ClinicalTrials.gov Identifier: NCT04115228), 10 participants experienced marked symptom improvement. UUI episodes were reduced by approximately 89%; urinary frequency decreased from 8.5 ± 2.5 to 6.3 ± 1.9 per day ($P = 0.008$); daily voids dropped from 10.6 ± 2.5 to 7.8 ± 2.1 ($P = 0.002$); and leakage episodes fell from 2.5 ± 1.8 to 0.3 ± 0.5 ($P < 0.001$). HRQoL scores improved from 52.8 ± 29 to 92.0 ± 12.7 ($P < 0.001$), and symptom severity scores declined from 58.3 ± 24.5 to 18.3 ± 12.4 ($P < 0.001$) [21]. The ongoing INTIBIA Pivotal Study (NCT05250908) will assess ≥ 50% reduction in UUI episodes at 6 months, along with secondary outcomes including urinary frequency, urgency perception, and HRQoL [22]. Collectively, these trials aim to establish Intibia as a durable, patient-centered therapy for OAB.

STIMROUTER (BIONESS)

The Bioness StimRouter is a wireless, MRI-compatible, battery-free implantable neuromodulation device designed to stimulate the posterior tibial nerve. Developed by Bioness (now part of Bioventus), it received FDA approval in 2015 for chronic pain and CE Mark approval in 2019 for refractory OAB and UUI [23]. The system consists of a 12-cm multielectrode tined lead with an integrated receiver, an external pulse transmitter (StimRouter EPT), a patient programmer, and a disposable electrode patch [9, 23, 24].

Implantation is performed in an outpatient setting under local anesthesia, using ultrasound or fluoroscopic guidance to target the posterior tibial nerve [3]. A small incision is made near the medial malleolus, and the lead is inserted subfascially, then tunneled approximately 10 cm. Intraoperative testing confirms proper positioning by eliciting paresthesia in the foot or toe flexion [25]. After a 6-week healing period, neuromodulation begins with the external transmitter. Stimulation is delivered at 20 Hz with a 200-μsec pulse width for 60 minutes, 5–7 times per week, with intensity adjusted to a tolerable level [9, 26]. The system supports up to 8 programmable regimens and avoids the need for an implanted battery by using wireless transdermal energy transfer [26]. With only 2 small incisions, the procedure reduces surgical trauma and risk of device migration [3].

In the StimRouter prospective, single-center clinical trial, 23 patients with multiple sclerosis and refractory lower urinary tract symptoms were treated and followed for 24 weeks. Primary outcomes included OAB symptom severity and QoL. Median baseline OAB-questionnaire score was 43; it declined by 0.50 points weekly ($\beta = -0.50$, $P < 0.001$), for a 12-point (27.9%) reduction over 24 weeks ([12/43] × 100). QoL scores rose by 0.47 points weekly ($\beta = 0.47$, $P < 0.001$), yielding an 11.28-point (18.8%) gain ([11.28/60] × 100) [25]. In an earlier feasibility study, "30 Months Results of a Multi-Centre Study on the Effec-

tivity of a Novel Implantable Device (StimRouter)," 7 refractory OAB patients were enrolled. Among 5 with complete data, urgency episodes decreased from 36 to 6 per day, with an 83.3% reduction in UUI episodes [27]. These findings demonstrate that the StimRouter system provides durable, clinically meaningful improvements in OAB symptoms and QoL. Ongoing multicenter, randomized, double-blind trials aim to further validate its long-term efficacy and safety in refractory OAB [9].

URGENT-SQ

The Urgent-SQ system (Fig. 1E) is an early implantable tibial nerve stimulation (ITNS) device developed at Radboud University Medical Centre (Netherlands) by Dr. Dick A. Janssen, Fawzy Farag, and John P. Heesakkers for refractory OAB and chronic pain. It consists of 2 1-cm² electrodes and a 4-cm diameter receiver, functioning as a passive wireless interface for external stimulation. This design allows on-demand tibial nerve activation without repeated needle insertions, reducing patient discomfort and procedural invasiveness [28].

Implantation involves a minimally invasive open procedure under local anesthesia. A small incision on the medial leg enables placement of electrodes near the tibial nerve, with subcutaneous fixation of the receiver. Intraoperative testing with a standard TENS unit confirms correct placement by eliciting motor or sensory responses such as toe flexion or foot pulsation. Once implanted, an external pulse generator worn on the lower leg wirelessly delivers stimulation during prescribed daily sessions [28].

In a pilot study of 8 patients, 12-month results demonstrated reductions in incontinence episodes, improvements in voiding frequency within 3 months, and enhanced QoL. Transient adverse effects, including walking difficulty and radiating foot sensations, resolved without intervention. A 9-year follow-up confirmed long-term safety, with 3 patients continuing use despite mild implant tenderness. However, no formal statistical analysis was conducted. At 18 years, the implant remained safe and structurally intact, but external stimulator failures caused all patients to discontinue therapy. These findings emphasize the importance of sustained technical support to ensure long-term ITNS efficacy [29, 30]. A full comparison of clinical efficacy, QoL improvements, and regulatory status across all iPTNS systems is provided in Table 1.

GAP ANALYSIS AND FUTURE DIRECTIONS FOR CLOSED-LOOP NEUROMODULATION SYSTEMS

Despite encouraging outcomes with current iPTNS devices for OAB, several limitations persist. First, there is no standardization of clinical endpoints. Variation in how UUI is defined and how QoL is measured complicates cross-study comparisons and hinders meta-analyses. Second, most trials employ relatively short follow-up periods, limiting available data on long-term safety and effectiveness. Because these devices are intended for chronic OAB management, the absence of extended monitoring raises concerns about durability, neural habituation, and the risk of unexpected adverse effects.

Future research should address these gaps by designing head-to-head clinical trials that directly compare iPTNS devices. Such studies would clarify relative effectiveness and safety while revealing device-specific advantages in design, usability, and patient adherence. Developing standardized outcome measures is equally important. For example, consensus on a ≥50% reduction in UUI episodes as a benchmark, combined with uniform use of validated QoL metrics, would make results more comparable and reproducible across populations and clinical settings.

Currently, most iPTNS devices function using open-loop paradigms with preset stimulation protocols. In contrast, emerging closed-loop neuromodulation systems represent a transformative direction for OAB therapy. Closed-loop systems incorporate real-time monitoring of bladder activity using biomarkers such as intravesical pressure, electromyographic signals, and afferent nerve activity. These inputs enable automatic adjustment of stimulation parameters. Such dynamic feedback has the potential to reduce neural habituation and tissue stress, extend device longevity, and enhance overall safety.

Recent technological developments support this paradigm shift. Advances include microelectromechanical systems-based and piezoelectric bladder pressure sensors, as well as advanced signal-processing methods such as sparse regression and nonlinear autoregressive moving average models for detecting subtle physiologic changes. Integration of these sensor technologies with artificial intelligence-driven adaptive algorithms could enable truly personalized neuromodulation. In this model, patient-specific physiological data would be continuously analyzed and stimulation automatically adjusted in real time, ensuring therapy remains optimized to each patient's fluctuating clinical status [31].

DISCUSSION AND CLINICAL IMPLICATIONS

Our review of 7 major iPTNS devices for OAB demonstrates clear distinctions in clinical efficacy, technical design, and regulatory status. Revi and Intibia produced robust reductions in UUI along with substantial QoL improvements, whereas eCoin and Protect PNS emphasized minimally invasive implantation and automated stimulation to enhance adherence. These differences highlight the importance of tailoring device selection to individual patient needs, balancing long-term efficacy, ease of use, and opportunities for personalization.

Although acquisition costs of iPTNS devices are relatively high, improved adherence and reduced need for repeated clinic visits may help offset long-term expenses. A notable limitation across the current literature is the absence of standardized clinical endpoints, which complicates cross-device comparisons and poses challenges for reimbursement pathways. Furthermore, many studies provide only short- to intermediate-term follow-up, limiting insights into durability of outcomes and adherence over extended periods.

Additional limitations in the literature warrant consideration. Few head-to-head randomized controlled trials directly compare different iPTNS platforms or evaluate them against alternative neuromodulation or pharmacologic therapies. Many published studies are small-scale, open-label, or industry-sponsored, raising potential concerns about bias in outcome reporting, particularly for subjective measures such as symptom relief and patient satisfaction. These methodological constraints reduce the generalizability of available findings and underscore the need for independent, large-scale randomized trials employing standardized endpoints.

Overall, current iPTNS devices exhibit promising safety and effectiveness profiles. Ongoing development, coupled with advances in closed-loop neuromodulation, may support broader adoption in routine practice. The results of this review reinforce their clinical viability as a third-line treatment for OAB.

CONCLUSION

This review confirms that iPTNS devices provide clinically meaningful reductions in UUI and consistent improvements in QoL among patients with OAB. Key differences in design, implantation methods, and regulatory status underscore the importance of individualized device selection. Despite limitations such as short follow-up durations, inconsistent clinical endpoints, and limited comparative evidence, current iPTNS systems demonstrate strong therapeutic potential. These findings support their role as viable and patient-centered alternatives to existing OAB treatments in appropriately selected populations.

AUTHOR CONTRIBUTION STATEMENT

- Conceptualization: *THN, EP*
- Funding acquisition: *EP*
- Methodology: *THN*
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