

Predictive Factors in Sacral Neuromodulation: A Systematic Review

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Keywords

Predictive factors · Sacral neuromodulation · Overactive bladder · Nonobstructive urinary retention · Lower urinary tract symptoms

Abstract

Introduction: Sacral neuromodulation (SNM) is an effective treatment in patients with overactive bladder syndrome or nonobstructive urinary retention when conservative treatment fails. Several factors that could impact outcome with SNM have been studied. This systematic review investigated these predictive factors and their relevance for clinical practice. **Methods:** Systematic review according to the PRISMA guidelines was conducted. This review is registered in the PROSPERO register (CRD42015016256). **Results:** Seventy-eight studies (of which 11 abstracts) were included. Females, younger patients, and a tined lead procedure tend to be predictive in successful SNM outcome. Factors that did not influence SNM outcome were prior back surgery, surgery for stress urinary incontinence, affective symptoms, and duration of complaints. Reduced detrusor contractility is associated with a lower success rate. The level of evidence of most studies (graded according to the Centre for Evidence-Based

Medicine) was 3b. **Conclusion:** Even though this systematic review investigated predictive factors (gender, age, type of procedure, type of lead, and detrusor contractility), no general consensus on predictive factors could be made. Most studies are small, retrospective, and involve a heterogeneous population. Therefore, prospective research in larger specific patient groups remains necessary to find predictors of SNM outcome.

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Introduction

Sacral neuromodulation (SNM) is an effective treatment option in patients with lower urinary tract symptoms, when conservative treatment fails. Successful test stimulation is defined as a reduction of one or more micturition symptoms of $\geq 50\%$ compared to baseline, determined by voiding diaries. Following a successful test stimulation, permanent implantation of the implantable pulse generator is performed.

Jamie Drossaerts and Ranjana Jairam contributed equally to this work.

In 2007, Van Kerrebroeck et al. [1] reported the long-term results of SNM in a multicenter, worldwide clinical trial. Of the implanted patients, 68% with urgency urinary incontinence, 56% with urgency frequency (overactive bladder syndrome [OAB]-dry), and 71% with nonobstructive urinary retention (NOR) had a successful outcome 5 years after initial implantation [1]. In addition, Siegel et al. [2] recently published data from the USA and reported success rates in OAB patients 5 years after implantation. Of the 340 subjects who completed the test stimulation, 272 had an implant, of which 82% had a therapeutic success rate at 5 years [2]. A more recent prospective multicenter study evaluated the effectiveness and quality of life (QoL) of patients with OAB or NOR who were treated with SNM and showed a significant improvement of OAB symptoms and QoL during a 10-month follow-up [3].

In order to select the optimal candidates for SNM and to know who will achieve treatment success both in the short and long term, it is crucial to identify factors that can predict the treatment outcome. Although several predictive factors for success in SNM have been identified, the test stimulation has been found to be the only reliable factor in predicting success [4]. Nonetheless, a more reliable selection of patients with highest chance of treatment success (or highest chance of treatment failure) may be improved by identifying additional factors that can predict a successful response. As predictive factors have been the subject of many studies, the goal of this review was to sort out which patient or technical factors potentially could represent a positive or negative prediction for success with SNM therapy (short and long term) in patients with OAB or NOR undergoing SNM test stimulation.

Methods

This systematic review was registered in PROSPERO under the number CRD42015016256.

Inclusion and Exclusion Criteria

A literature search for full-length original articles and abstracts was carried out, meeting the following inclusion criteria: (a) adults ≥ 18 years; (b) diagnosis of refractory OAB; (c) or diagnosis of NOR not satisfied with clean intermittent self-catheterization or problematic clean intermittent self-catheterization, without other treatment options being successful or sufficient; and (d) published in English in a peer-reviewed journal. Primary endpoints were SNM success, both test evaluation and long-term success. Reviews, expert opinions, and comments were excluded. Since the focus of this review is on urinary complaints, we excluded patients with diagnosis of bladder pain syndrome or other pelvic pain. Also, studies regarding nonurinary indications for SNM (i.e., fecal incontinence) were excluded.

Literature Search

PRISMA guidelines were used concerning preferred reporting items for systematic reviews. The following databases were searched: Medline (PubMed) and Cochrane (RCT). There was no date restriction on the searched articles, and the last search was dated 14 August 2020. MeSH terms, free hand terms and wildcards were used, the detailed query is listed in the online supplementary material (please see www.karger.com/doi/10.1159/000513937). These database searches were supplemented by hand searching the reference lists of eligible articles. Two authors (J.D. and C.d.R.) independently examined titles, abstracts, and full-text articles. Names of authors, institution, and journal of publication were not blinded.

Data Extraction

Population characteristics such as gender and age of patient groups have been noted, and the results of the study are summarized. The main data items extracted from the articles were study characteristics such as type of study, sample size and methods of recruiting, setting, success rate, and adverse events (AEs). Later, a general classification was made based on all factors that were discussed in the articles: gender, age, duration of complaints, affective symptoms, history of surgery, technical factors, and urodynamics.

Two authors (J.D. and R.J.) independently performed the data extraction. Consensus was obtained in 85% of the manuscripts; the remaining 15% of disagreements were handled by discussion. 415 abstracts were identified in the database search, and after removal of duplicates, 437 remained for screening on relevance. In the reference lists, an additional 22 articles were found. Eventually, 156 full-text articles were assessed for eligibility, and 90 articles were excluded resulting in a final set of 67 articles, which were included in this review. Additionally, 11 abstracts published at international meetings were included. Errata would have been examined if articles have been retracted since publication; there were none. A flowchart of the selection process is depicted in Figure 1.

Results

Quality Assessment of the Included Literature

Level of evidence was stated per article as defined in publications of the University of Oxford's Centre for Evidence-Based Medicine (CEBM) [5]. Risk of bias assessment was performed according to the Cochrane Collaboration guidelines (Table 1) [6].

Most articles described cohort study designs (70%). The remainder were case series and randomized controlled trials (25 and 5%, respectively). In most studies, primary outcome was a successful SNM test result defined as a $\geq 50\%$ improvement in urinary symptoms. In 34 studies, test stimulation success was the main outcome [7–40]. In 19 studies, both test stimulation outcome and permanent SNM outcome were investigated [41–59]. In 14 studies, only permanent SNM outcome was investigated [60–73].

In 15 studies, a percutaneous nerve evaluation (PNE) was performed and in 23, a tined lead procedure (TLP). In 19 studies, patients underwent either PNE or TLP. In

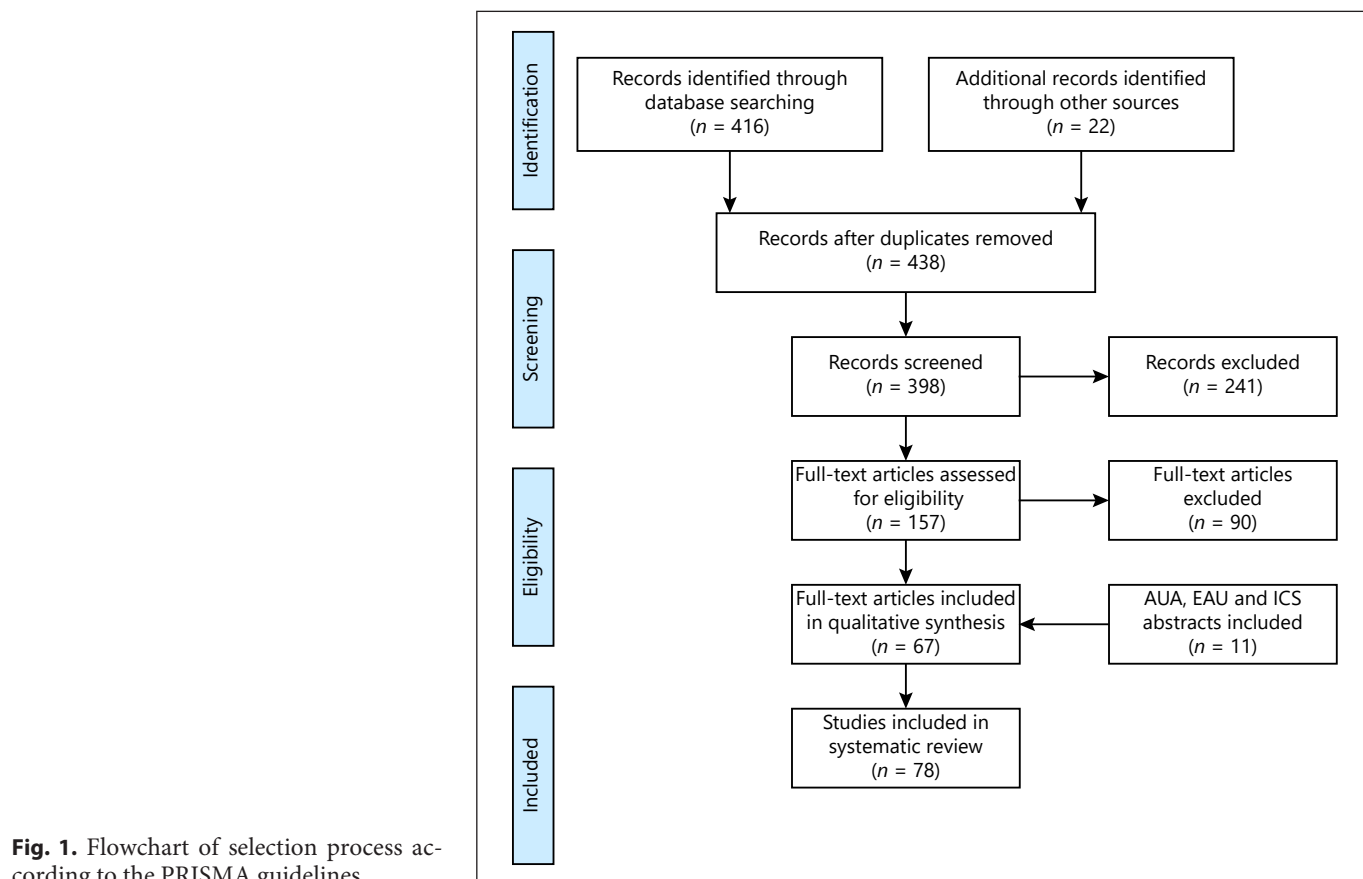


Fig. 1. Flowchart of selection process according to the PRISMA guidelines.

3 studies, it was unknown which procedure was used (Table 2). In most articles, risk of bias domains was assessed as low risk or unclear risk (Fig. 2). A graphical summary of the results is depicted in Figure 3.

Gender

Fifteen studies investigated gender as a predictive factor in SNM outcome [7, 10, 13, 19, 23, 26, 27, 30, 37, 38, 45, 49, 63, 64, 69]. In 9 studies, the patient population was heterogeneous with both OAB and NOR patients [10, 23, 26, 30, 38, 45, 49, 64, 69]. Four out of 10 studies reported a higher chance of successful test stimulation in females in a mixed group of OAB and NOR patients [10, 23, 27, 49]. However, 2 of these studies were conducted in the same study population [10, 23]. Three studies found less successful test stimulation outcomes in men: in one study, only in patients with NOR [7, 13, 38]. In 5 studies, gender did was not predictive in successful test stimulation outcome [19, 26, 30, 37, 45].

Three studies reported on permanent SNM and found gender not to be a predictive factor [63, 64, 69]. Two of these studies included a heterogeneous group of patients

with either OAB or NOR, and 1 study reported AEs at follow-up.

Age

Several studies reported on age as a predictive factor for SNM test success. In total, 32 studies and 4 abstracts were included [7, 8, 10, 13, 16, 19, 21–24, 26, 30, 31, 34, 37–39, 43, 45, 49, 52, 55–60, 62, 63, 67, 68, 72, 74–77].

Overactive Bladder Syndrome

Twelve studies investigated age as a predictive factor in patients with OAB [8, 21, 22, 31, 34, 37, 43, 56, 57, 62, 63, 72]. Five of these studies included only women [21, 34, 56, 57, 72]. Two of these found younger age to be predictive in successful test stimulation outcome [21] and long-term outcome [57]. Eight studies reported on successful test stimulation of which 3 found a younger age predictive in successful test stimulation [8, 21, 22, 31, 34, 37, 43, 56]. In 2 other studies, age was not predictive in neither successful test stimulation nor successful treatment with the implant [62, 63].

Table 1. Level of evidence (CEBM) and risk of bias (Cochrane)

	CEBM	Selection bias – random seq. generation	Selection bias – allocation concealment	Performance bias – blinding personnel pts	Detection bias – blinding outcome	Attrition bias – incomplete data	Reporting bias – selective reporting
<i>Case series retrospective</i>							
Marcelissen et al. [44, 45]	3b	High risk	Unclear	High risk	High risk	Unclear	Unclear
Amundsen and Webster [8]	3b	High risk	Unclear	High risk	High risk	High risk	High risk
Janknegt et al. [14]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Saber-Khalaf et al. [16]	3b	High risk	Unclear	High risk	High risk	High risk	High risk
<i>Case series prospective</i>							
De Ridder et al. [60]	2b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Bertapelle et al. [9]	2b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Drossaerts et al. [40]	2b	Unclear	Unclear	High risk	High risk	Unclear	Unclear
<i>Cross sectional</i>							
Cameron et al. [10]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
<i>Cohort retrospective</i>							
Dobberfuhl et al. [38]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Kaaki and Gupta [72]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Morgan et al. [58]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Schonburg et al. [59]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
High et al. [57]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Berthelot et al. [37]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Adelstein et al. [7]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Greenberg et al. [43]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Pizarro-Berdichevsky et al. [71]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	High risk
Gahzi et al. [61]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Jairam et al. [12, 13]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Ismail et al. [62]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Everaert et al. [42]	3b	Unclear	Unclear	Unclear	Unclear	Unclear	Unclear
Janknegt et al. [63]	3b	Unclear	Unclear	High risk	Unclear	Unclear	Unclear
Kessler et al. [15]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Blandon et al. [41]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Bannowsky et al. [17]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
White et al. [56, 64]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Marcelissen et al. [44, 45]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Ghazwani and Hassouna [77]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Cameron et al. [66]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Drossaerts et al. [40]	3b	High risk	Unclear	Unclear	Unclear	Unclear	High risk
Everaert et al. [18]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Sherman et al. [21]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Goh and Diokno [19]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Guralnick et al. [67]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Siddiqui et al. [68]	3b	High risk	Unclear	High risk	High risk	Unclear	Unclear
Arlen et al. [46]	3b	High risk	Unclear	Unclear	Unclear	Unclear	Unclear
Yazdany et al. [52]	3b	High risk	Unclear	High risk	High risk	Unclear	Unclear

Table 1 (continued)

CEBM	Selection bias – random seq. generation	Selection bias – allocation concealment	Performance bias – blinding personnel pts	Detection bias – blinding outcome	Attrition bias – incomplete data	Reporting bias – selective reporting
Bartley et al. [47, 48]	3b	High risk	Unclear	High risk	High risk	Unclear
Killinger et al. [20]	3b	High risk	Unclear	Unclear	Unclear	Unclear
Jairam et al. [12, 13]	3b	High risk	Unclear	Unclear	Unclear	Unclear
Bartley et al. [47, 48]	3b	High risk	High risk	Unclear	Unclear	High risk
South et al. [31]	3b	High risk	Unclear	Unclear	Unclear	Unclear
Scheepens et al. [29, 30]	3b	High risk	Unclear	Unclear	Unclear	Unclear
Anger et al. [23]	3b	High risk	Unclear	Unclear	Unclear	Unclear
Faris et al. [49]	3b	High risk	Unclear	Unclear	Unclear	Unclear
<i>Cohort prospective</i>						
Nguyen et al. [27]	2b	Unclear	Unclear	Unclear	Unclear	Unclear
Vaganee et al. [51]	2b	Unclear	High risk	Unclear	Unclear	Unclear
Weissbart et al. [32]	2b	Unclear	Unclear	Unclear	Unclear	Unclear
Noblett et al. [73]	2b	Unclear	Unclear	Unclear	Unclear	Unclear
Nobrega et al. [28]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Spinelli et al. [50]	2b	High risk	Unclear	Unclear	High risk	Unclear
Cohen et al. [25]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Kessler et al. [15]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Leong et al. [26]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Peters et al. [54]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Weil et al. [69]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Bross et al. [24]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Amundsen et al. [22]	2b	High risk	High risk	High risk	High risk	High risk
Groenendijk et al. [36]	2b	High risk	High risk	High risk	High risk	High risk
White et al. [56]	2b	High risk	Unclear	Unclear	Unclear	Unclear
Peters et al. [55]	2b	High risk	Unclear	High risk	High risk	Unclear
Gleason et al. [35]	2b	High risk	Unclear	High risk	High risk	High risk
Malaguti et al. [33]	2b	High risk	Unclear	Unclear	Unclear	Unclear
<i>RCT</i>						
Gupta et al. [39]	1b	Low risk	Low risk	Unclear	Unclear	Unclear
Borawski et al. [34]	1b	Low risk	Low risk	Low risk	Low risk	Unclear
Groenendijk et al. [36]	1b	Low risk	Unclear	Low risk	Low risk	Unclear
Scheepens et al. [29, 30]	1b	Low risk	Low risk	Unclear	Low risk	Unclear

Table 2. Study characteristics [93]

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, <i>n</i>	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
<i>A. Gender (N = 4,942)</i>									
Cohort prospective	Weil et al. [69]	PNE	Long term	3–5 days	36 (30 OAB, 6 NOR)	75	45±22	Improvement ≥50% at FU	No
Cohort retrospective	Janknegt et al. [63]	PNE	Long term	Unknown	96 OAB	89	50±28	Improvement ≥50% at FU	No
Cohort retrospective	Scheepens et al. [30]	PNE	Test stimulation	4–7 days	211 (89 NOR, 126 OAB)	76	51±10	Improvement ≥50%	No
Cohort retrospective	Goh and Diokno [19]	PNE and TLP	Test stimulation	14 days	29 NOR	50	59±19	Improvement ≥50%	No
Cohort prospective	White et al. [64]	TLP	Long term (AEs)	7 days	221 (184 OAB, 37 NOR)	85	49±35	AE during FU	No
Case series retrospective	Marcellissen et al. [45]	PNE	Test stimulation and long term	Unknown	54 (38 OAB, 16 NOR)	81	56±14	Improvement ≥50%	No
Cohort prospective	Leong et al. [26]	PNE and TLP	Test stimulation	3 (PNE) to 7 days (TLP)	100 (69 OAB and 31 NOR)	82	55±13	Improvement ≥50%	No
Cross sectional	Cameron et al. [10]	TLP and PNE	Test stimulation	Unknown	1,490 Medicare, 1,060 Ingenix	74	Unknown	IPG implantation	Yes. Ingenix population: success rates were greater in females than in males (51.5 vs. 38.5%, <i>p</i> < 0.0001). Medicare population: females achieved more success than males (41.6 vs. 27.7%, <i>p</i> unknown)
Cohort retrospective	Anger et al. [23]	PNE and TLP	Test stimulation	Unknown	1,490 (939 OAB, 142 NOR, 409 others)	74	Unknown	IPG implantation	Yes. Same population as Cameron [13] (Medicare population); IPG implantation rates were greater among females (41.6 vs. 27.7%, <i>p</i> < 0.0001, OR 1.861, 95% CI: 1.379–2.512)
Cohort retrospective	Jairam et al. [13]	TLP	Test stimulation	28 days	189 (105 OAB, 84 NOR)	68	51±14	Improvement ≥50%	Yes. In patients with NOR, sex seemed to predict successful outcome (<i>p</i> = 0.004)
Cohort retrospective	Faris et al. [49]	PNE and TLP	Test stimulation + long term	Unknown	356 (292 OAB, 64 NOR)	85	56±17	Improvement ≥50%	Yes. Successful trial stimulation was more likely in females compared to males (OR 2.87, 95% CI [1.32–6.04], <i>p</i> = 0.009)
Cohort retrospective	Adelstein et al. [7]	TLP (curved)	Test stimulation	Unknown	127 (114 OAB, 11 NOR, 2 FI)	87	68±na	Improvement ≥50%	Yes: male gender was associated with SNM failure (<i>p</i> = 0.01)
Cohort prospective	Nguyen et al. [27]	TLP and pudendal	Test stimulation	Unknown	534 (348 OAB, 45 NOR, 141 others)	92	61±17	Improvement ≥50%	Yes: more women than men received an IPG (450/488; 92.2 vs. 84/102; 82.4%; <i>p</i> = 0.0011)
Cohort retrospective	Dobbebfuhl et al. [38]	TLP and PNE	Test stimulation	Unknown	1,396 (983 OAB, 121 neurogenic, 119 IC, 155 NOR, 18 others)	78	Unknown	Implantation of a pulse generator	Yes: male patients had less success (OR 0.51, 95% CI [0.38–0.67])
Cohort retrospective	Berthelot et al. [37]	TLP	Test stimulation	7–14 days	43 OAB	81	71±9	Improvement ≥50%	No
<i>B. Age (N = 9,069)</i>									
Cohort retrospective	Janknegt et al. [63]	PNE	Long term	Unknown	96 OAB	89	50±28	Improvement ≥50%	No
Case series retrospective	Amundsen and Webster [8]	PNE	Test stimulation	7 days	25 OAB	Unknown	69±na	Improvement ≥50%	No
Cohort retrospective	Scheepens et al. [30]	PNE	Test stimulation	4–7 days	211 (89 NOR, 126 OAB)	76	51±10	Improvement ≥50%	No
Cohort prospective	Bross et al. [24]	PNE	Test stimulation	Unknown	24 NOR	Unknown	46±16	Improvement ≥50%	No
Cohort retrospective	Sherman et al. [21]	PNE and TLP	Test stimulation	5–7 days	34 OAB	100	62±na	Improvement ≥50%	Yes: women (previous SUI surgery) aged <55 years had a better response (<i>p</i> = 0.01)
Cohort prospective	Amundsen et al. [22]	Unknown	Test stimulation	Unknown	105 OAB	87	60±na	No daily leakage episodes (cure)	Yes: lower cure rate in individuals aged >55 years (<i>p</i> < 0.05)
Cohort retrospective	Goh and Diokno [19]	PNE and TLP	Test stimulation	14 days	29 NOR	50	59±19	Improvement ≥50%	No

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, <i>n</i>	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
Cohort retrospective	Guralnick et al. [67]	TLP	Long term (wound infection)	Unknown	76 (54 OAB, 11 NOR, 13 PBS)	17	49±na	Wound infection	No
RCT	Borawski et al. [34]	PNE and TLP	Test stimulation	5–7 days	30 OAB (>55 years)	100	70±na	Improvement ≥50%	No
Case series prospective	De Ridder et al. [60]	PNE	Long term	Unknown	62 NOR	100	52±12	PVR <100 mL at FU	No
Abstract	Powell and Kredner [76]	TLP	Test stimulation + long term	2–3 weeks	244 (OAB/NOR)	Unknown	Unknown	Improvement ≥50% at FU	Yes: patients >70 respond less favorably than younger patients (<i>p</i> = 0.0006, OAB group)
Cohort prospective	White et al. [56]	TLP	Test stimulation + long term	7 days	189 OAB (19 >70 years)	100	46±na	Improvement ≥50%	No
Abstract	Ghazwani and Hassouna [77]	PNE	Unknown	Unknown	124 NOR	78	Unknown	Improvement ≥50%	Yes: advanced age of patients correlated with the failure of PNE (<i>r</i> = −0.3, <i>p</i> = 0.001)
Abstract	Game et al. [74]	PNE	Unknown	Unknown	100 NOR	100	37±11	Unknown	No
Cohort retrospective	Siddiqui et al. [68]	PNE and TLP	Long term	Unknown	112 (OAB/NOR)	90	59±14	Lead migration	No
Cross sectional	Cameron et al. [10]	TLP and PNE	Test stimulation	Unknown	1,490 Medicare, 1,060 Ingenix	74	Unknown	Patient receiving a battery implant	Yes: for the staged procedure, the younger age categories (<79 years) were associated with improved success (<i>p</i> = 0.034, Medicare population)
Case series retrospective	Marcelissen et al. [45]	PNE	Test stimulation + long term	Unknown	54 (38 OAB, 16 NOR)	81	56±14	Improvement ≥50%	Yes: older patients had a significantly lower chance of successful PNE outcome (OR 0.95, 95% CI: 0.90–0.99, <i>p</i> = 0.008)
Cohort retrospective	Yazdany et al. [52]	TLP	Long term	1–3 weeks	78 (50 OAB wet, 10 mixed incontinence, 9 NOR, 9 OAB dry)	100	61±13	Improvement ≥50%	No
Cohort prospective	Leong et al. [26]	PNE and TLP	Test stimulation	3 (PNE) to 7 days (TLP)	100 (69 OAB and 31 NOR)	82	55±13	Improvement ≥50%	Yes: a successful response was negatively related to the patient's age (univariate OR = 0.96, 95% CI: 0.93–1.00, <i>p</i> = 0.036, TLP only). Optimal cutoff point 65 years
Cohort prospective	Peters et al. [55]	TLP	Test stimulation + long term	14 days	328 (73 IC, 225 OAB, 26 NOR, 4 pelvic pain)	83	Unknown	Improvement ≥50%	No
Abstract	Elneil et al. [75]	TLP	3–8 weeks	Unknown	169 NOR	100	Unknown	Postvoid residual <100 mL	No
Cohort retrospective	Anger et al. [23]	PNE and TLP	Test stimulation	Unknown	1,490 (939 OAB, 142 NOR, 409 others)	74	Unknown	IPG implantation	No
Case series retrospective	Saber-Khalaf et al. [16]	TLP	Test stimulation	3–12 weeks	21 NOR	0	42±11	Postvoid residual <100 mL	Yes: nonresponders were significantly older when compared to responders (<i>p</i> = 0.025, all men)
Cohort retrospective	Ismail et al. [62]	PNE and TLP	Long term	Unknown	34 OAB	91	58±na	Improvement ≥50% at long term	No
Cohort retrospective	Jairam et al. [113]	TLP	Test stimulation	28 days	189 (105 OAB, 84 NOR)	68	51±14	Improvement ≥50%	Yes: in patients with NOR, age seemed to predict successful outcome (<i>p</i> = 0.02)
Cohort retrospective	South et al. [31]	PNE and TLP	Test stimulation	7 days	104 OAB	Unknown	63±na	Improvement ≥50%	Yes: responders were significantly younger than nonresponders (59.7 vs. 67, <i>p</i> = 0.01)
Cohort retrospective	Faris et al. [49]	PNE and TLP	Test stimulation + long term	Unknown	356 (292 OAB, 64 NOR)	85	56±17	Improvement ≥50%	No
Cohort retrospective	Adelstein et al. [7]	TLP (curved)	Test stimulation	Unknown	127 (114 OAB, 11 FI)	2 87	68±na	Improvement ≥50%	No
Cohort retrospective	Greenberg et al. [43]	TLP	Test stimulation	14 days	374 OAB	63	61±na	Improvement ≥50%	No
RCT	Gupta et al. [39]	PNE	Test stimulation	5–7 days	74 (OAB, NOR, mixed, w/o FI)	100	58±14	Placement of IPG within 3 mo of PNE	No

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, n	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
Cohort retrospective	Schonburg et al. [59]	TLP	Test stimulation + long term	28 days	95 (48 OAB, 47 NOR)	62	53±16	Improvement ≥50%	No
Cohort retrospective	High et al. [57]	PNE and TLP	Test stimulation + long term	1–10 days	864 OAB	100	65±na	IPG implantation	Yes: nonresponders were significantly older (OR 0.73, 95% CI [0.61–0.88], $p < 0.0001$). Odds of postimplantation success: OR 0.87, 95% CI [0.78–0.97], $p < 0.0001$
Cohort retrospective	Morgan et al. [58]	TLP	Test stimulation + long term	Unknown	198 OAB, NOR or FI	100	63±15	Improvement ≥50%	Yes: age above 65 years was a significant negative predictor for successful stage I (OR 0.2, 95% CI [0.06–0.8])
Cohort retrospective	Dobberfuhl et al. [38]	TLP and PNE	Test stimulation	Unknown	1,396 (983 OAB, 121 neurogenic, 119 IC, 155 NOR, 18 others)	78	Unknown	Implantation of a pulse generator	No
Cohort retrospective	Kaaki and Gupta [72]	TLP and PNE	Long term	35 days	66 OAB	100	63±na	Improvement ≥50%	No
Cohort retrospective	Berthelot et al. [37]	TLP	Test stimulation	7–14 days	43 OAB	81	71±9	Improvement ≥50%	No
<i>C. Duration of symptoms (N = 1,044)</i>									
Cohort retrospective	Janknegt et al. [63]	PNE	Long term	Unknown	96 OAB	89	50±28	Improvement ≥50% at FU	No
Case series retrospective	Amundsen and Webster [8]	PNE	Test stimulation	7 days	25 OAB	Unknown	69±na	Improvement ≥50%	No
Cohort retrospective	Scheepens et al. [30]	PNE	Test stimulation	4–7 days	211 (89 NOR, 126 OAB)	76	51±10	Improvement ≥50%	Yes: longer lasting complaints resulted in a higher risk of a negative test (OR 1.09, 95% CI [1.03–1.16], $p = 0.01$)
Cohort retrospective	Sherman et al. [21]	PNE and TLP	Test stimulation	5–7 days	34 OAB	100	62±na	Improvement ≥50%	Yes: nonresponder group had more women with incontinence surgery performed >4 years before the test stimulation procedure (no p value)
Case series prospective	De Ridder et al. [60]	PNE	Long term	Unknown	62 NOR	100	52±12	PVR <100 mL at FU	No
Cohort retrospective	Goh and Diokno [19]	PNE and TLP	Test stimulation	14 days	29 NOR	50	59±19	Improvement ≥50%	Yes: in the patients who underwent permanent implantation, the duration of retention (mean 8.2±6.1 years) was significantly longer than those who did not undergo implantation (mean 3.6±2.4 years) ($t = 2.73$, $p = 0.01$)
Abstract	Ghazwani and Hassouna [77]	PNE	Unknown	Unknown	124 NOR	78	Unknown	Improvement ≥50%	Yes: negative correlation between duration of urinary retention and the success of PNE ($r = -0.23$, $p = 0.009$)
Cohort retrospective	Yazdany et al. [52]	TLP	Test stimulation + long term	1–3 weeks	78 (50 OAB wet, 10 mixed incontinence, 9 NOR, 9 OAB dry)	100	61±13	Improvement ≥50%	No
Abstract	Cerruto et al. [79]	PNE	Unknown	Unknown	103 OAB	Unknown	Unknown	Improvement ≥50%	No
Abstract	Yoon and Jun [80]	TLP	Unknown	Unknown	31	Unknown	Unknown	Unknown	Yes: there was a significant difference in symptom duration, between successful IPG implants (40.1 months) and failures (91 months)
Case series retrospective	Saber-Khalaf et al. [16]	TLP	Test stimulation	3–12 weeks	21 NOR	0	42±11	PVR <100 mL	No
Cohort retrospective	Ismail et al. [62]	PNE and TLP	Long term	Unknown	34 OAB	91	58±na	Improvement ≥50% at long term	No
Cohort retrospective	Jairam et al. [12]	TLP	Test stimulation	28 days	130 (78 OAB, 52 NOR)	68	49±15	Improvement ≥50%	No
Cohort retrospective	Kaaki and Gupta [72]	TLP and PNE	Long term	35 days	66 OAB	100	63±na	Improvement ≥50%	No (OR 0.99, 95% CI [0.98–1.02], $p = 0.89$)
<i>D. History of surgery (N = 2,887)</i>									

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, n	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
Cohort retrospective	Everaert et al. [42]	PNE	Test stimulation + long term	At least 4 days	53 (38 NOR, 22 OAB, perineal pain 19)	85	43±12	Improvement ≥50%	Yes; patients with a history of incontinence surgery were more likely to be treated efficiently with the implant ($p = 0.001$)
Cohort retrospective	Janknegt et al. [63]	PNE	Long term	Unknown	96 OAB	89	50±28	Improvement ≥50% at FU	No; surgical history did not statistically influence long-term results (with respect to frequency of incontinence episodes, $p = 0.66$)
Cohort retrospective	Scheepens et al. [30]	PNE	Test stimulation	4–7 days	211 (89 NOR, 126 OAB)	76	51±10	Improvement ≥50%	Yes; previous surgery to treat an IDP reduced the chance of a negative test outcome (OR 0.27, $p = 0.03$)
Cohort retrospective	Sherman et al. [21]	PNE and TLP	Test stimulation	5–7 days	34 OAB	100	62±na	Improvement ≥50%	No; type of stress incontinence surgery and whether a sling incision and release were performed were not statistically significant factors between responders and nonresponders ($p = 0.95$)
Cohort retrospective	Arlén et al. [46]	PNE and TLP	Test stimulation + long term	7–14 days	32 NOR/OAB	50	56±na	Improvement ≥50%	Yes; in patients with UII who had undergone previous spinal surgery, 52.9% reported a successful outcome compared to 80.3% in patients without previous spinal surgery ($p = 0.018$)
Cohort retrospective	Yazdany et al. [52]	TLP	Test stimulation + long term	1–3 weeks	78 (50 OAB wet, 10 mixed incontinence, 9 NOR, 9 OAB dry)	100	61±13	Improvement ≥50%	No; prior prolapse surgery did not impact the success of stage I trial ($p = 0.08$)
Abstract	Scott et al. [93]	Unknown	Unknown	Unknown	390 (289 OAB, 101 NOR)	71	Unknown	Improvement ≥50% at follow-up	Yes; history of TUIP in men was predictive of SNM failure ($p = 0.04$)
Cohort retrospective	Bartley et al. [48]	Unknown	Long term	14 days	210 (204 OAB, 5 NOR, 1 pdvic pain)	100	64±13	Improvement ≥50% at 3 months	No; (prior SUJ/POP surgery; Bladder suspension, vaginal sling, uterine prolapse repair, artificial urinary sphincter, and urethral bulking agents) >comparable efficacy in both subjective and objective outcomes, but in some measures, especially with further time from implant, patients without prior SUJ/POP surgery showed greater benefit
Cohort retrospective	Bartley et al. [47]	PNE and TLP	Test stimulation + long term	3–5 days	560 (54 NOR, 382 OAB, 119 IC/BPS, 5 FI)	83	59±16	Improvement ≥50% at 3 months	No; prior back surgery does not appear to impact clinical outcomes ($p = 0.34$)
Cohort retrospective	Ismail et al. [62]	PNE and TLP	Long term	Unknown	34 OAB	91	58±na	Improvement ≥50% at long term	No; history of surgery for incontinence was not a predictor for success ($p = 0.78$)
Cohort retrospective	Adelstein et al. [7]	TLP (curved)	Test stimulation	Unknown	127 (114 OAB, 11 NOR, 2 FI)	87	68±na	Improvement ≥50%	Yes; patients with a history of previous SNM (with a straight stylet) were less likely to progress to stage 2 SNM implant (5/8, 62.5%) when compared to patients without a history of previous SNM (108/119; 90.8%; $p = 0.03$)
Cohort retrospective	High et al. [57]	PNE and TLP	Test stimulation + long term	1–10 days	864 OAB	100	65±na	IPG implantation	Yes; hysterectomy was associated with implantation (OR 2.61, 95% CI [1.53–4.45], $p < 0.0001$)
Cohort retrospective	High et al. [57]	PNE and TLP	Test stimulation + long term	1–10 days	864 OAB	100	65±na	IPG implantation	No; previous stress incontinence surgery, prolapse surgery, and vertebral or disk surgery were not associated with implantation ($p = 0.30$, $p = 0.97$, and $p = 0.06$, resp.)
Cohort retrospective	Morgan et al. [58]	TLP	Test stimulation + long term	Unknown	198 OAB, NOR, or FI	100	63±15	Improvement ≥50%	Yes; prior onaBoNT-A was a negative predictor for successful stage I (OR = 0.2, 95% CI [0.06–0.9])
<i>E. Affective symptoms (N = 608)</i>									
Cohort prospective	Weil et al. [69]	PNE	Long term	3–5 days	36 (30 OAB, 6 NOR)	75	45±22	Improvement ≥50% at FU (37.8 mo)	Yes, median duration of the therapeutic effect in patients with a previous history of psychological disorder was shorter (12 vs. 36 months) ($p = 0.008$)
Cohort retrospective	Everaert et al. [42]	PNE	Test stimulation + long term	At least 4 days	53 (OAB/NOR/perineal pain, N unknown)	85	43±12	Improvement ≥50% before, during, and at the end of the study	Yes; test stimulation was less reliable in patients with a psychiatric history ($p = 0.025$)
Cohort retrospective	Janknegt et al. [63]	PNE	Long term	Unknown	96 OAB	89	50±28	Improvement ≥50%	No
Case series prospective	De Ridder et al. [60]	PNE	Long term	Unknown	62 NOR	100	52±12	PVR <100 mL at FU	No

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, <i>n</i>	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
Cohort retrospective	White et al. [64]	TLP	Long term	7 days	221 (184 OAB, 37 NOR)	85	49±35	AE at FU	No
Case series retrospective	Marcelissen et al. [45]	PNE	Test stimulation + long term	Unknown	54 (38 OAB, 16 NOR)	81	56±14	Improvement ≥50%	No
Case series prospective	Drossaerts et al. [11]	TLP	Test stimulation + long term	28 days	86 (66 OAB, 20 NOR)	76	58±12	Improvement ≥50%	No
<i>F. Technical aspects (N = 4,996)</i>									
Abstract	Gousse and Tunuguntla [82]	PNE	Unknown	Unknown	28 OAB	61	56±na	Unknown	Yes: motor responses obtained during first-stage Interstim appear to be more predictive of subsequent IPG implant when compared to sensory response (no <i>p</i> value)
Case series retrospective	Janknegt et al. [14]	PNE	Test stimulation	4–7 days	10 (6 OAB, 4 NOR)	Unknown	Unknown	Improvement ≥50%	Yes: two-stage implant (with a permanent electrode) may lead to an improvement of testing technique and better selection between nonresponders and failures (no <i>p</i> value)
RCT	Scheepens et al. [29]	PNE (uni- and bilateral)	Test stimulation	4–6 days	33 (18 OAB and 15 NOR)	81	46±na	Improvement ≥50%	No difference in success rates between uni- and bilateral stimulation
Cohort prospective	Malaguti et al. [33]	PNE and TLP	Test stimulation	Unknown	24 (16 NOR, 8 OAB)	100	46±na	Improvement ≥50%	Yes: a modification of somatosensory-evoked potentials induced by SNM seems to be a prognostic factor of clinical outcomes (<i>p</i> < 0.05)
Cohort retrospective	Kessler et al. [15]	TLP (uni- and bilateral)	Test stimulation	4–7 and 14 days	20 (13 OAB, 7 NOR)	80	52±na	Improvement ≥50%	Yes: the eligibility for IPG implantation was significantly increased from 50% after the usual (4–7 days) to 80% after the prolonged evaluation period (14 days, <i>p</i> = 0.031)
Cohort prospective	Cohen et al. [25]	TLP	Test stimulation	7 days	35 OAB	21 (60%)	56±na	Improvement ≥50%	Yes: in this study, 95% of successful patients demonstrated a positive motor response during placement and stimulation of the quadripolar lead while this was only 21.4% in the unsuccessful group (<i>p</i> < 0.001)
RCT	Borawski et al. [34]	PNE and TLP	Test stimulation	5–7 days	30 OAB (>55 years)	100	70±na	Improvement ≥50%	Yes: patients in the TLP group were significantly more likely to proceed to implantation of the IPG than those in the PNE group (RR 1.91, 95% CI: 1.04–3.53, <i>p</i> = 0.02)
Cohort prospective	Kessler et al. [53]	PNE and TLP (uni- and bilateral)	Test stimulation + long term	7–23 days	209 (153 OAB, 39 NOR, 17 pelvic pain)	13	58±na	Improvement ≥50%	Yes: there was a significantly higher success rate of initial SNM testing when definitive rather than temporary leads were used (<i>p</i> = 0.03)
Cohort retrospective	Blandon et al. [41]	PNE and TLP	Test stimulation + long term	3–7 days	151 (103 OAB, 35 NOR, and 13 IC)	100	53±15	Improvement ≥50%	Yes: the timed lead chronic staged implant had a statistically better response rate than the other techniques (PNE 40%, staged with fascia anchoring 36%, vs. staged with timed lead, 67%, <i>p</i> = 0.01)
Cohort retrospective	Bannowsky et al. [17]	PNE and TLP, bilateral	Test stimulation	5–7 days	53 (30 NOR, 23 OAB)	68	50±na	Improvement ≥50%	Yes: permanent quadripolar electrodes during PNE prior to chronic neuromodulator implantation leads to significant higher responder rates (81.8 vs. 47.6%, <i>p</i> < 0.05)
Cohort retrospective	Siddiqui et al. [68]	PNE and TLP	Long term	Unknown	112	90	59±14	Lead migration	No significant difference in surgical revision for lead migration between those receiving fascial anchors and timed leads
Cohort retrospective	Marcelissen et al. [44]	PNE and TLP	Test stimulation + long term	5 (PNE) to 28 (TLP) days	92 (OAB or NOR)	Unknown	Unknown	Improvement ≥50% on long term	No relation between screening method (PNE vs. TLP) and long-term success (χ^2 test, <i>p</i> = 0.94)
Cohort retrospective	Ghazwani et al. [65]	PNE	Long term	4–7 days	6 OAB, 3 NOR	100	47±14	Loss of efficacy at FU	Yes: the baseline amplitude levels in the loss of efficacy group were significantly higher than those of the control group (<i>p</i> = 0.008). The impedance levels were significantly higher in the loss of efficacy group than the control (<i>p</i> = 0.025)
Abstract	Rasmussen et al. [83]	Unknown	Unknown	Unknown	103 (OAB 64, NOR 17, pelvic pain 22)	83	Unknown	Improvement ≥50%	No: there were no statistically significant differences in successful test stimulation between sensory and motor responses (no <i>p</i> value)
Cohort prospective	Peters et al. [54]	TLP	Test stimulation + long term	14 days	141 (88 OAB, 45 IC/PBS, 6 NOR)	82	59±16	Improvement ≥50%	No: the 2 groups (sensory and no sensory testing) did not differ on rate of subsequent IPG implant (implant rate 76/84, 90% for sensory/48/55, 87% for no sensory, no <i>p</i> value mentioned)

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, <i>n</i>	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
Cross sectional	Cameron et al. [10]	TLP and PNE	Test stimulation	Unknown	1,490 Medicare, 1,060 Ingenix	74	Unknown	IPC implantation	Yes: percutaneous procedures were only successful in 24.1% of cases, compared with 50.9% following staged procedures ($p < 0.0001$, Ingenix)
Cohort prospective	Leong et al. [26]	PNE and TLP	Test stimulation	3 (PNE) to 7 days (TLP)	100 (69 OAB and 31 NOR)	82	55±13	Improvement ≥50%	Yes: significantly more patients responded positively to the TLP test compared to the PNE test (Wilcoxon test, $p < 0.001$)
Cohort retrospective	Cameron et al. [66]	PNE and TLP	Long term	Unknown	561	81.50	Unknown	Battery explantation	No: TLP and PNE did not differ in rate of battery explants (OR of removal = 0.69, 95% CI: 0.38–1.27)
Abstract	Blasco et al. [81]	Unknown		60 days	31 (19 OAB, 12 NOR)	Unknown	Unknown	Improvement ≥50% or <90 residual urine	No difference between different frequencies and positives rates (no p value)
Cohort prospective	Spinelli et al. [50]	PNE and TLP	Long term	30 days	127 (87 OAB, 50 NOR, 4 pelvic pain, 3 IC, 8 others)	93 (73%)	51±14	Improvement ≥50%	No significant difference in symptom improvement (>50%) between TLP and PNE (77 vs. 70%, no p value)
Cohort retrospective	Jairam et al. [13]	TLP	Test stimulation	28 days	189 (105 OAB, 84 NOR)	68	51±14	Improvement ≥50%	No: position of the lead (measured by depth, angle, and deflection) and the number of active electrodes are not related to SNM test outcome. Also, motor reaction (bellows and toe) did not predict successful outcome
Cohort retrospective	Gahzi et al. [61]	TLP	Long term	Unknown	69 (42 OAB, 21 NOR, 9 CPP and LUTS)	88	55±na	Improvement ≥50%	No: univariate analysis did not show any correlation between SNM response and the electrode position or angle
Cohort prospective	Vagancee et al. [51]	TLP	Test stimulation + long term	21 days	55 (40 OAB, 15 NOR)	76	52±17	Improvement ≥50%	Yes: success rates were significantly higher in the curved group, that is, 94% in the curved versus 65% in the straight group (χ^2 , $p = 0.005$). At 24 months, success in the curved group was 91% on ITT analysis compared to 45% in the straight group (χ^2 , $p < 0.001$)
Cohort retrospective	Pizarro et al. [71]	TLP	Long term	Unknown	176 (148 OAB, 25 NOR, 3 FI)	86	58±na	Unknown	Yes: fewer toe responses were associated with SNM lead revision
Cohort prospective	Weissbart et al. [32]	TLP	Test stimulation	7 days	12 OAB	100	64±na	Improvement ≥50%	Yes: pretreatment brain activity levels in the bilateral anterior cingulate cortex, right insula, bilateral dorsolateral prefrontal cortex, right orbitofrontal cortex, right supplementary motor area, and right sensorimotor cortex were higher in women who underwent successful treatment (all $p < 0.05$)
RCT	Gupta et al. [39]	PNE	Test stimulation	5–7 days	74 (OAB, NOR, mixed, w/o FI)	100	58±14	Placement of IPG within 3 mo of PNE	No: PNE without fluoroscopy is not inferior to PNE with fluoroscopy (RR 1.23, 95% CI [0.78–1.94], $p = 0.35$)
Cohort retrospective	High et al. [57]	PNE and TLP	Test stimulation + long term	1–10 days	864 OAB	100	65±na	IPC implantation	Yes: TLP (vs. PNE) was significantly associated with implantation (OR 1.95, 95% CI [1.0–3.8], $p < 0.0001$)
Cohort retrospective	Morgan et al. [58]	TLP	Test stimulation + long term	Unknown	198 OAB, NOR, or FI	100	63±15	Improvement ≥50%	No: there was no difference in test outcome in patients who had motor responses with either all 4 electrodes or <4 electrodes in any endpoint (test outcome, long-term outcome, lead revision rate) ($p > 0.05$)
<i>G. Urodynamics (N = 2,535)</i>									
Cohort retrospective	Everaert et al. [18]	PNE	Test stimulation	4–26 days	27 NOR	85	33±15	Improvement in symptoms and normal micturition	Yes: contractility at diagnosis was significantly lower in those not responding ($p = 0.01$; $z < 0.01$)
Cohort retrospective	Sherman et al. [21]	PNE and TLP	Test stimulation	5–7 days	34 OAB	100	62±na	Improvement ≥50%	Yes: lack of pelvic floor muscular activity best correlated with nonresponding to SNM (in women >55 years with previous SUI surgery, $p = 0.03$)
Cohort prospective	Groenendijk et al. [36]	PNE	Test stimulation	Unknown	19 OAB	100	46±8	Improvement ≥50%	Yes: in this study urethral instability appeared to be a valuable urodynamic parameter for predicting successful outcome of sacral nerve stimulation (no p value)
Case series prospective	De Ridder et al. [60]	PNE	Long term	Unknown	62 NOR	100	52±12	PVR <100 mL at FU	Yes: patients with Fowler's syndrome benefitted significantly longer from SNS (log-rank test, $p = 0.005$)
RCT	Borawski et al. [34]	PNE and TLP	Test stimulation	5–7 days	30 OAB (>55 years)	100	70±na	Improvement ≥50%	No: presence of DOA was not predictive of a response (in both TLP and PNE)

Table 2 (continued)

Study design	Author	PNE or TLP	Outcome	Duration test stimulation	Patients, <i>n</i>	Women, %	Age (mean, SD), years	Primary outcome	Predictive?
RCT	Groenendijk et al. [70]	PNE	Long term	Unknown	111 OAB	Unknown	Unknown	Improvement $\geq 50\%$	Yes: baseline urodynamic variables that were prognostic for a successful clinical outcome were volume at peak Pdet ($r = -0.25$, $p = 0.03$, $N = 76$), Pdet at the start of flow ($r = -0.37$, $p = 0.004$, $N = 56$), the bladder volume at first detrusor contraction ($r = -0.38$, $p = 0.005$, $N = 52$)
Case series prospective	Bertapelle et al. [9]	PNE	Test stimulation	Unknown	96 NOR	70	Unknown	SNM exclusion	Yes: the detrusor contractility test can be considered a predictive factor for SNS therapy exclusion
Abstract	Ghazwani and Hassouna [77]	PNE	Unknown	Unknown	124 NOR	78	Unknown	Improvement $\geq 50\%$	Yes: there was favorable association between the presence of detrusor contractility during urodynamic and the sensation of urge to void with the success of PNE ($r = 0.23$, $p = 0.009$, and $r = 0.25$, $p = 0.005$, respectively)
Abstract	Game et al. [74]	PNE	Unknown	Unknown	100 NOR	100	37 $\pm$ 11	Unknown	Yes: patients with abnormally elevated urethral closure pressure had significantly better results following stage 2 ($p = 0.04$)
Abstract	Smits and de Wachter [84]	TLP	Unknown	Unknown	14 NOR	29	58 $\pm$ 8	Improvement $\geq 50\%$	Yes: patients with NOR that have a history of bladder overdistension of $>1,500$ cc are very poor candidates for SNM (no <i>p</i> value)
Cohort prospective	Gleason et al. [35]	TLP	Test stimulation	7 days	27 OAB	100	61 $\pm$ 13	Improvement $\geq 50\%$	No: pre-SNM urethral sensation was not significantly different between responders and nonresponders
Case series prospective	Drossaerts et al. [40]	TLP	Test stimulation	28 days	98 NOR	32	54 $\pm$ na	Improvement $\geq 50\%$	Yes: patients with reduced contractility on ambulatory-UDS have a lower chance of SNM success
Cohort retrospective	Killinger et al. [20]	Unknown	Test stimulation	14 days	216 (153 OAB, 62 IC/BPS, 1 FI)	84	59 $\pm$ 17	IPG placement	No: logistic regression analysis of the relationship between preimplant functional bladder capacity and proceeding to IPG implant found no relationship ($p = 0.16$; C-statistic 0.60)
Cohort retrospective	South et al. [31]	PNE and TLP	Test stimulation	7 days	104 OAB	Unknown	63 $\pm$ na	Improvement $\geq 50\%$ during test stim	No: there was no relationship found between the presence or absence of DO and the likelihood for test stimulation success (OR 1.5, 95% CI: 0.5–4.0, $p = 0.47$)
Cohort prospective	Nobrega et al. [28]	TLP	Test stimulation	Unknown	99 OAB	74	56 $\pm$ na	Improvement $\geq 50\%$ during test stim	No: there was no significant difference in any of the pre-FSTLP parameters (mean voided vol, Pdet DO, compliance, volume of first DO, and capacity) assessed between the FSTLP success and FSTLP failure groups
Cohort retrospective	Adelstein et al. [7]	TLP (curved)	Test stimulation	Unknown	127 (114 OAB, 11 NOR, 2 FI)	87	68 $\pm$ na	Improvement $\geq 50\%$	No: presence of DO was not associated with successful progression to SNM stage 2 ($p = 0.07$)
Cohort retrospective	Adelstein et al. [7]	TLP (curved)	Test stimulation	Unknown	127 (114 OAB, 11 NOR, 2 FI)	87	68 $\pm$ na	Improvement $\geq 50\%$	Yes: UUI was positively associated with progression to stage 2 implant (93.0%; 93/100; $p < 0.01$). Patients with UR were less likely to progress to stage 2 SNM implant when compared to other indications (UUI, UF, FI)
Cohort prospective	Noblett et al. [73]	TLP	Long term	14 days	340 OAB	Unknown	Unknown	Improvement $\geq 50\%$	No: both UI and UF success rates were not statistically different between severity groups (less vs. more severe) ($p = 0.57$ and $p = 0.27$, resp.)
Cohort retrospective	Hight et al. [57]	PNE and TLP	Test stimulation + long term	1–10 days	864 OAB	100	65 $\pm$ na	IPG implantation	No: detrusor overactivity was not associated with implantation ($p = 0.10$)
Cohort retrospective	Berthelot et al. [37]	TLP	Test stimulation	7–14 days	43 OAB	81	71 $\pm$ 9	Improvement $\geq 50\%$	No: detrusor activity was not associated with a positive response to SNM ($p = 0.33$)

SNM, sacral neuromodulation; OAB, overactive bladder syndrome; NOR, nonobstructive urinary retention; IPG, implantable pulse generator; PNE, percutaneous nerve evaluation; TLP, timed lead procedure; IDP, intervertebral disk prolapse; AE, adverse event; UUI, urge urinary incontinence; LUTS, lower urinary tract symptoms; SU1, stress urinary incontinence.

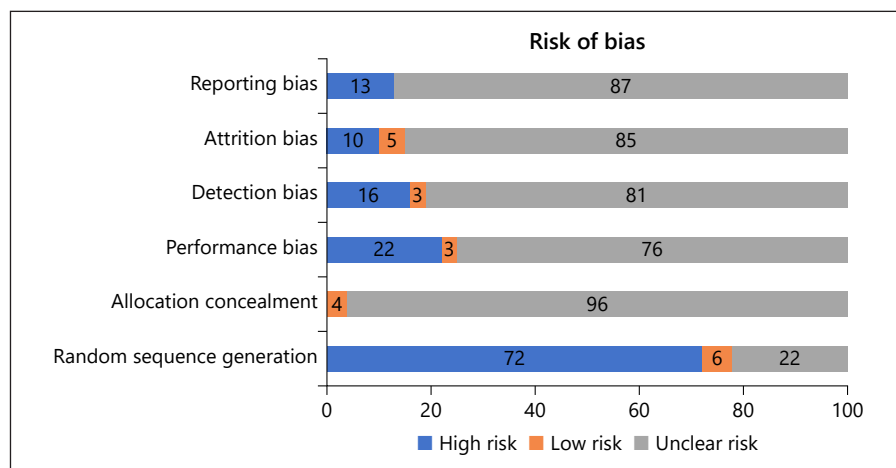


Fig. 2. Risk of bias assessment (Cochrane).

Nonobstructive Urinary Retention

Four studies and 3 abstracts included patients with NOR [16, 19, 24, 60, 74, 75, 77]. Three studies reported on successful test stimulation of which one consisted of only men and reported that nonresponders were significantly older when compared to responders [16]. One study reported on successful treatment at follow-up and found age not to be predictive [60]. Furthermore, 1 abstract concluded that advanced age was correlated with failure of PNE test stimulation [77].

OAB and NOR

Twelve studies and 1 abstract reported on successful test stimulation outcome [7, 13, 23, 26, 38, 39, 45, 49, 55, 59, 68, 76, 78] of which 6 studies also reported on long-term outcome [45, 49, 55, 58, 59, 76]. Marcelissen et al. [45] investigated predictive factors for test stimulation outcome and AEs at long-term follow-up. They found younger age (<65 years) to be a predictor in successful PNE test stimulation, but this was not seen for the occurrence of AEs at follow-up [45]. Leong et al. [26] also found younger age to be predictive in successful test stimulation. However, this was only seen in patients who received TLP, and they did not report long-term outcomes.

Duration of Symptoms

In total, 11 studies and 3 abstracts were included [8, 12, 16, 19, 21, 30, 52, 60, 62, 63, 72, 77, 79, 80]. These studies consist of small groups of patients who had complaints for only a couple of years.

Overactive Bladder Syndrome

Six studies reported on patients with OAB [8, 21, 62, 63, 72, 79]. Two of these reported on outcome after test

stimulation [8, 21] of which one found a shorter duration of complaints to be successful in test stimulation outcome [21]. In this study, women who developed OAB after stress incontinence surgery were included. They found that a test stimulation performed within 4 years of the stress incontinence procedure was positive in predicting successful test stimulation. The other 4 studies (of which one was an abstract) did not find duration of complaints to be predictive in successful treatment with SNM on long term [62, 63, 72, 79].

Nonobstructive Urinary Retention

Regarding NOR patients, 3 studies and 1 abstract were included [16, 19, 60, 77]. Two studies reported on successful test stimulation [16, 19]. One found a longer duration of retention to be a negative predictor in successful test stimulation [19]. Furthermore, an abstract of Ghazwani and Hassouna [77] found a negative correlation between duration of retention and a successful PNE test. One other reported on successful outcome on long term and did not find duration of complaints to be predictive [60].

OAB/NOR

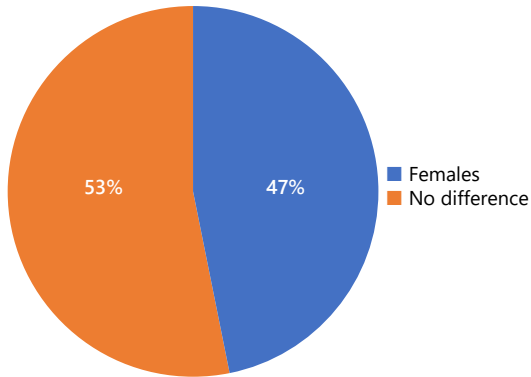
Three studies and 1 abstract consisted of patients with either OAB or NOR [12, 30, 52, 80]. All reported on successful test stimulation, and 2 studies found that longer lasting complaints resulted in a higher risk of a negative test stimulation [30, 80].

History of Surgery

Ten studies reported on prior spinal back surgery and/or abdominal surgery [21, 30, 42, 46–48, 52, 57, 62, 63], one study on previous SNM surgery [7], and one on pre-

Gender as a positive predictor for SNM success
(test stimulation and/or long-term). No study found
male gender to be a positive predictor.

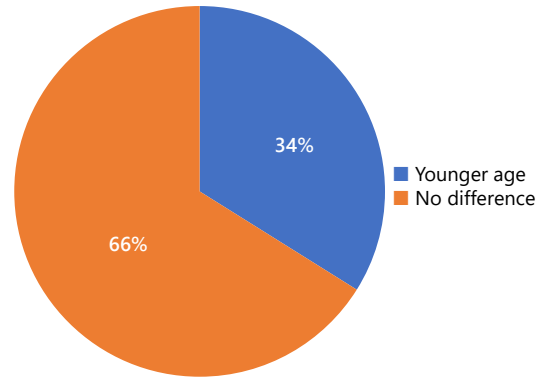
Gender (15 studies)



a

Age as a positive predictor for SNM success
(test stimulation and/or long-term). No definition
of younger age could be made.

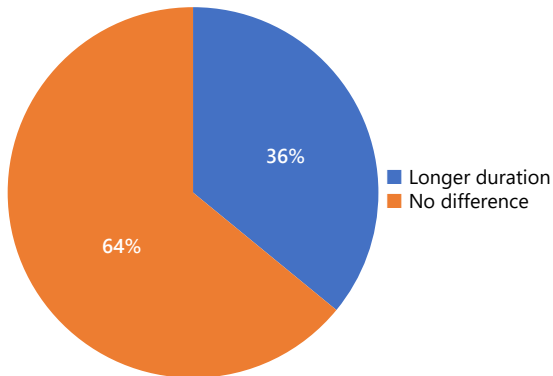
Age (35 studies)



b

Duration of complaints as a negative predictor for
SNM success (test stimulation and/or long-term).
No study found shorter duration to be a
negative predictor.

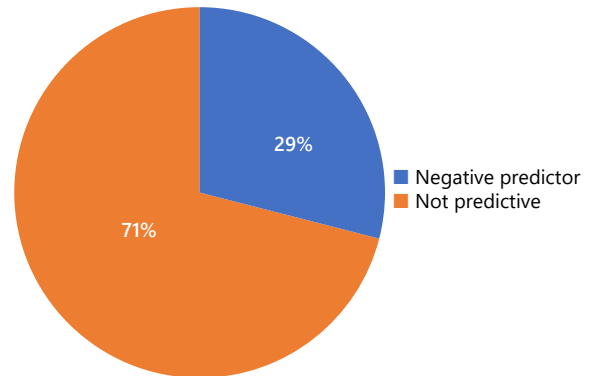
Duration of complaints
(14 studies)



c

Affective symptoms as a negative predictor for
SNM success (test stimulation and/or long term).
No study found affective symptoms to be a
positive predictor.

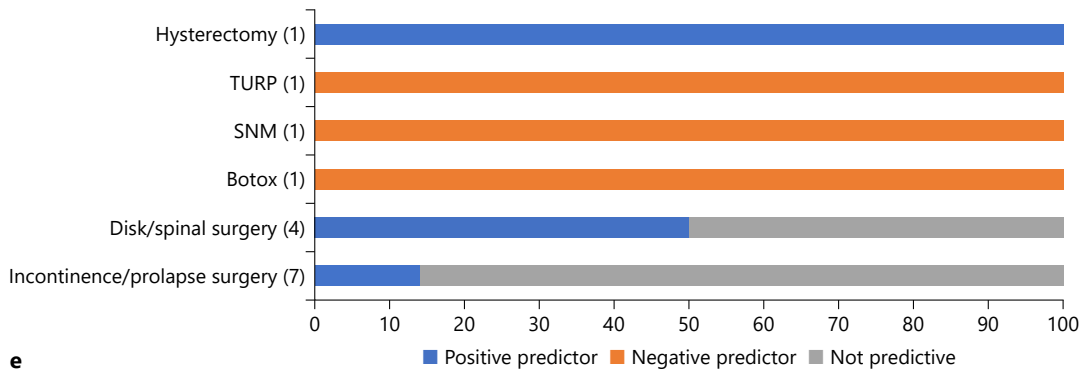
Affective symptoms
(7 studies)



d

Factors related to surgical history with the number of studies
per factor and the outcome (in percentage)

History of surgery (15 studies)



e

(Figure continued on next page.)

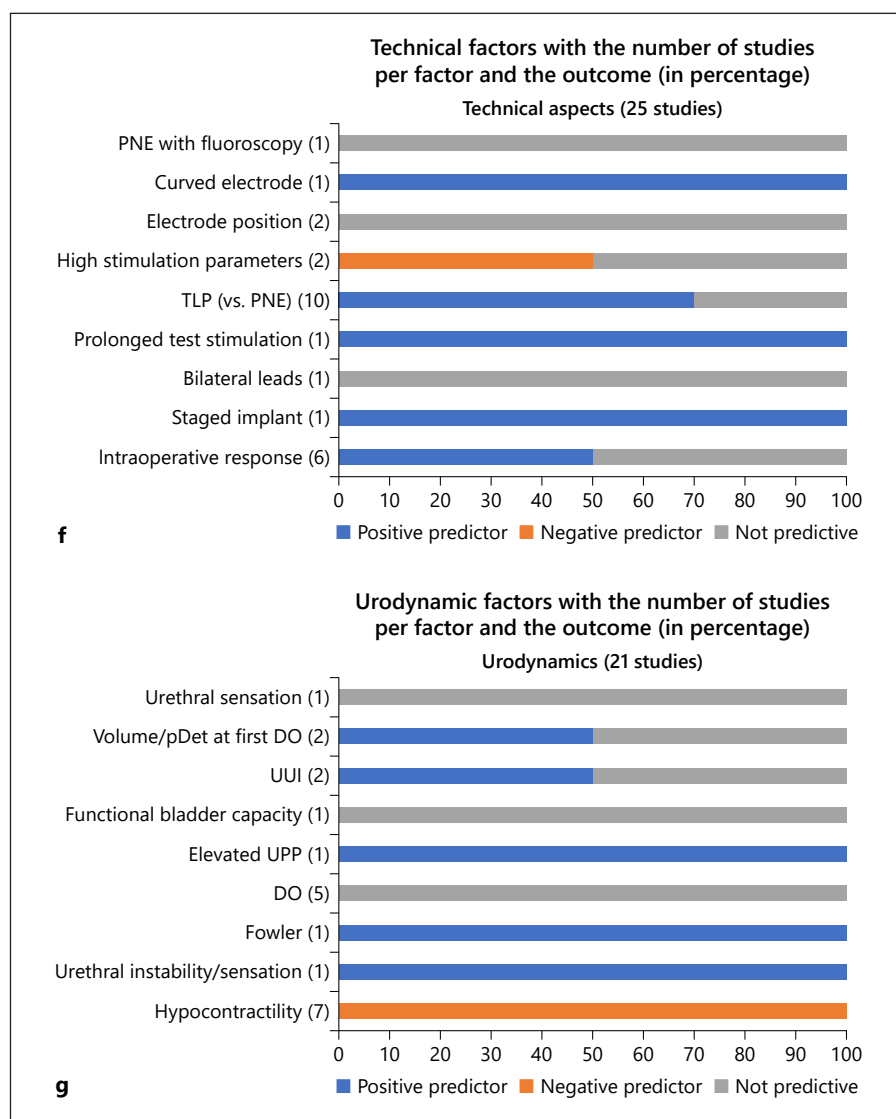


Fig. 3. a-g Graphical summary of the result. SNM, sacral neuromodulation; PNE, percutaneous nerve evaluation; TLP, timed lead procedure; UUI, urge urinary incontinence.

vious treatment with onaBoNT-A [58]. One abstract reported on previous TUIP in men undergoing SNM.

Overactive Bladder Syndrome

Four studies included patients with refractory urinary urgency incontinence [21, 57, 62, 63]. All reported on test stimulation success and 2 also on success on long term. Sherman et al. [21] evaluated the response to SNM in women with refractory, urinary urgency incontinence after stress incontinence surgery. They found no difference between responders and nonresponders with respect to type of stress incontinence surgery [21]. Janknegt et al. [63] studied long-term effectiveness of SNM in 96 patients with OAB. Prior to study enrollment, these patients underwent 177 surgical procedures for the treatment of

urinary problems. Surgical history did not appear to statistically influence the long-term results [63]. Furthermore, Ismail et al. [62] assessed functional outcomes of SNM in 34 patients with a median follow-up of 9.7 years. They did not find a history of incontinence surgery (i.e., sling, artificial urinary sphincter, and colpopexy) to be predictive in long-term outcome. High et al. [57] found previous hysterectomy to be associated with implantation while previous stress incontinence surgery, prolapse surgery, and vertebral or disk surgery were not associated with implantation.

OAB/NOR

The remaining 8 studies and 1 abstract consisted of a heterogeneous group of patients. In 3 studies, patients

had undergone back surgery for different indications prior to SNM test stimulation [30, 46, 47]. Arlen et al. [46] investigated a group of patients with OAB or NOR who had undergone previous spinal cord surgery. The most common indication for spinal cord surgery was disk disease. The authors conclude that patients with voiding dysfunction (OAB or NOR) following spinal surgery can be treated successfully with SNM, but success is less likely in patients suffering from urgency incontinence [46]. This is in contrast to the results of Scheepens et al. [30] who investigated several factors and found intervertebral disk prolapse surgery to be a positive predictor of SNM test success. Another study from Bartley et al. [47] included 560 patients of which 109 had prior back surgery. Indication for back surgery was only clear in 25 patients (bulging disk, spinal stenosis, trauma, and osteoarthritis). Regarding test stimulation and follow-up with the implant (2.3 years), prior back surgery did not appear to impact clinical outcomes [47].

A study of Everaert et al. [42] investigated success rate and complications in 53 patients and found that patients with a history of incontinence surgery were more likely to be treated efficiently with the implant. Previous onabotulinum toxin A (BoNT-A) was studied in 1 study and was a negative predictor for successful implantation [58].

Affective Symptoms

In total, 7 studies evaluated affective symptoms as a predictive factor [11, 42, 45, 60, 63, 64, 69]. In 3 of these studies, the authors studied the presence of psychological factors prior to test stimulation as primary outcome and found no significant relationship between psychiatric history and SNM outcome [11, 45, 60]. In these 3 studies, several questionnaires were used as a screening tool (SCL-90-R, PHQ, and HADS). In the other 4 studies, psychological factors were less well defined, and patients were not screened for psychological factors prior to test stimulation [42, 63, 64, 69].

Overactive Bladder Syndrome

A study of Janknegt et al. [63] concluded that a psychiatric history in 96 OAB patients did not influence the long-term effectiveness with respect to the frequency of incontinent episodes.

Nonobstructive Urinary Retention

One study investigated whether psychologic preimplant screening was predictive in long-term success women with urinary retention. They used the Patient Health Questionnaire as psychologic preimplant screening and

concluded that it did not correlate with long-term outcome [60].

OAB/NOR

In 5 studies, a heterogeneous group of patients was investigated [11, 42, 45, 64, 69]. In 1 study, a difference in outcome between the test stimulation and implantation was significantly related to psychiatric disease in the history [42]. Another study of Marcelissen et al. [45] showed no relationship between psychological characteristics (measured by ABQ or SCL-90-R questionnaires) and both test and long-term outcome. However, a psychiatric history was found to be a positive predictor for the occurrence of AE with permanent SNM treatment. A study of Weil et al. [69] showed that patients with a previous history of psychological disorder had a lower median duration of therapeutic effect at follow-up.

Technical Procedure

Regarding the technical procedure, several articles were included. In total, 22 studies and 3 abstracts investigated whether technical aspects can predict SNM outcome [10, 13–15, 17, 25, 26, 29, 32–34, 41, 44, 50, 51, 53, 54, 61, 65, 66, 68, 71, 81–83]. Factors that were studied were type of procedure/lead, length of test stimulation, intraoperative testing, and postoperative stimulation parameters. Four studies involved bilateral placed leads [15, 17, 29, 53]. One of these was a randomized trial where the clinical effect of temporary unilateral versus bilateral stimulation was compared in a mixed group of OAB and NOR patients. Significant differences in test stimulation outcome in unilateral versus bilateral stimulation could not be demonstrated [29].

Motor versus Sensory Response

One abstract and 1 study investigated whether intraoperative motor or sensory response is more predictive of successful test stimulation in patients with OAB [25, 82]. The authors found that a positive test stimulation is more likely when intraoperative lead placement results in positive motor response versus only sensory response. This is in contrast to what 2 others found in a mixed group of OAB and NOR patients. Peters et al. [54] performed a prospective study and found no difference in implantable pulse generator implantation rate or clinical outcome at follow-up. An abstract of Rasmussen et al. [83] retrospectively reviewed their results for a successful test stimulation in 103 patients of which 67 had bilateral leads. They did not find a statistically significant difference between sensory and motor responses [83]. Furthermore, Pizarro-

Berdichevsky et al. [71] found that fewer toe responses (on each contact point) were associated with lead revision; however, no association between motor response (bellows and toe) and successful test stimulation was found. This is in line with the results by Morgan et al. [58] who also found no difference in test outcome and long-term outcome between patients who had a motor response on all 4 contact points versus <4 contact points.

Type of Procedure/Lead

Three studies investigated whether a permanent lead (i.e., used during test stimulation) resulted in better test stimulation outcome in a mixed group of OAB and NOR patients. Janknegt et al. [63] implanted a permanent electrode (which was fixed to the sacrum) in 10 patients who failed a previous PNE test. Eighty percent showed a successful test stimulation and received a definitive implant. These results are in line with 2 other studies where a permanent electrode (either fixed to the sacrum or tined) showed more successful test stimulation outcome [17, 53]. Regarding lead migration, Siddiqui et al. [68] did not find a significant difference between the amount of revisions in patients who received fascial anchors and tined leads. Vaganee et al. [51] reported significantly higher success rates in both test stimulation and at long-term follow-up when patients received a curved tined lead, when compared to patients who received a straight tined lead.

Several studies investigated test stimulation success rates in OAB and NOR patients and reported a higher success rate in patients who received TLP when compared to patients who received PNE [10, 26, 34, 41, 57]. Marcelissen et al. [44] investigated 92 patients with OAB or NOR who received either TLP or PNE and found no significant difference in long-term success between the 2 groups. Furthermore, another study of Kessler et al. [15] stated the prolonged testing using permanent (quadripolar) leads is more reliable for accurate patient selection than the evaluation period of 4–7 days.

Intraoperative Testing and Positioning Lead

Two studies investigated whether the position of the electrode in the sacral foramen predicted test stimulation success or permanent SNM success [13, 61]. None found any correlation between the position (depth, angle, and deflection) and test and long-term success. Loss of efficacy was associated with high stimulation parameters at time of implantation in 1 study [65]. Furthermore, 1 RCT found PNE without fluoroscopy was not inferior to PNE with fluoroscopy [39].

Urodynamic Parameters

In total, 16 studies and 3 abstracts investigated urodynamic parameters in patients prior to test stimulation [7, 9, 18, 20, 21, 28, 31, 34–37, 40, 57, 60, 70, 73, 74, 77, 84].

Detrusor Contractility

Three studies and 2 abstracts found that NOR patients with a reduced detrusor contractility had a lower chance of successful test stimulation [9, 18, 40, 77, 84]. Furthermore, De Ridder et al. [60] concluded that patients with Fowler's syndrome benefitted significantly longer from SNM when compared to patients with idiopathic retention.

Detrusor Overactivity

Seven studies confirmed that the presence of detrusor overactivity was not correlated with successful test stimulation [7, 28, 31, 34, 37, 57, 70].

Others

Two studies reported whether primary indication affects successful conversion to implantation. Adelstein et al. [7] retrospectively reviewed their data of 127 patients with OAB, NOR, or fecal incontinence undergoing first-stage SNM. All patients were tested with a curved lead. They found a positive association between urge urinary incontinence and progression to a definitive implant. Furthermore, they also found that patients with NOR were less likely to receive a definitive implant [7].

A study of Noblett et al. [73] found that success rates (at 12 and 24 months after implantation) between patients with less severe and more severe UI and/or UF symptoms did not statistically differ.

Discussion

Currently, the only reliable predictor for treatment success in SNM is test stimulation. Although various studies have evaluated predictive factors in patients with OAB or NOR, no consistent factors have been identified that can be used as an absolute selection criterion in clinical practice.

The studies that were included in this review are heterogeneous which makes it difficult to comprehend the results and to form a general consensus on predictive factors of SNM success. Also, primary outcome among the studies was different: some studies focused on AEs at follow-up, others reported on patient-reported outcome, and some evaluated outcome with voiding diaries.

Several studies showed that patients with younger age and female gender tend to be more successful in SNM. The decrease in success rates in males over females may be due to the complex voiding dysfunction in men partially owing to the influence of prostatic obstruction. There are no studies that confirm this statement. A possible explanation for a reduced success rate among older patients could be that they may have subtle changes in the bladder and neural control systems for the bladder. However, in most studies, age did not predict successful outcome on the long term.

Several urodynamic parameters have been studied in order to find predictive factors. The presence of DO in patients with OAB did not seem to be a negative predictor according to several studies. Furthermore, an acontractile detrusor was found to reduce success rate in patients with NOR considerably [77, 84]. Most probably, a preserved detrusor contraction is obligatory, since SNM exerts its beneficial effect mainly via relaxing the pelvic floor and the external urethral sphincter rather than via direct stimulation of the contraction of the detrusor muscle. However, there are no studies that confirm this statement.

After the introduction of the tined lead, studies reported success rates with the use of a tined lead in patients who initially failed PNE [14, 44]. Interestingly, test stimulation with TLP did not seem to be an independent predictor for success on the long term [44]. It seems that regarding test outcome, TLP provides a better patient selection when compared to PNE, but once implanted, no difference is seen in long-term outcome. Regarding type of lead, a prospective study with a 2-year follow-up showed that the use of a curved stylet was found to be a positive predictor for test success [51]. Even though there is only one study concluding this, the curved lead follows the curvilinear route of the sacral nerve roots which should result in a more precise position of the lead. A randomized prospective crossover study showing lower amplitudes with a curved stylet confirms this statement [85]. The authors did not investigate implantation rates, but most probably, a curved lead will lead to a higher success rate. Another technical aspect such as the presence of perioperative motor response was found to be a positive predictor for a successful test stimulation. A possible reason for this outcome could be that the motor response is more beneficial than a sensory perception since these muscle groups are innervated by the same nerves as those involved in improving urinary control in overactive bladder and refractory urgency incontinence. However, after implantation, patients rely on the sensation to ensure continuity of pelvic neuromodulation. This means that

the sensory perception of the sacral afferent component plays an important role in the course of SNM. During test stimulation, preferably both motor and sensory responses should be considered since neither of the 2 alone can predict successful outcome.

Several studies report a negative impact of lower urinary tract symptoms in general on QoL and on mental health [86, 87]. Also, in the literature, an association is described between the overactive bladder and the presence of affective symptoms [88, 89]. Recent studies show that affective symptoms do not predict SNM outcome (both test stimulation and long term) [45, 60, 63]. The primary outcome of the studies included in this review was not homogeneous, which makes it difficult to compare these results.

In our review, most studies did not find a longer duration of complaints to be predictive in test outcome and long-term outcome. Most probably, SNM facilitates restoration of structural changes that can occur in the untreated, underactive, and overactive bladder or allows to compensate [90]. One study stated that SNM restores the sensory and motor neural pathways of the lower urinary tract and that if a disorder is present for a longer time, restoration of the natural equilibrium (i.e., the normal balance) between the different reflexes is more difficult [30]. Since there are no studies that confirm this statement, in our opinion, SNM remains a feasible treatment option in patients with both long and short duration of complaints.

Studies investigating prior back surgery or stress urinary incontinence (SUI) surgery as a predictive factor expect neurological impairment on local level (bladder) or more central (spinal cord). It is possible that voiding dysfunction after stress incontinence procedures is the result of partial denervation of the external sphincter or the urethra [91], and that these patients are ideal candidates for treatment with SNM [1, 92]. Regarding previous back or SUI surgery, no clear statements can be made. In most studies, patients underwent back surgery for different indications. Also, in studies regarding prior SUI surgery, patients underwent different procedures which makes it difficult to compare all these results.

Conclusion

The results from the studies in this review are mixed and inconclusive because of the difference in patient population (gender, indication, and age), testing technique (type and duration), and primary outcome (test stimula-

tion, long-term outcome, and AEs). Therefore, we could not make a general consensus on the possible factors leading to SNM success. Most studies were small and retrospective, and outcome measures differed between studies which limited the validity of the results. Furthermore, level of evidence of the included studies is low (3b), and prospective studies with larger sample sizes should further investigate factors that are associated with SNM outcome.

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Statement of Ethics

The research was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. This systematic review was registered in PROSPERO under the number CRD42015016256.

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Conflict of Interest Statement

The authors have no conflicts of interest to declare.

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Author Contributions

Ranjana Jairam and Jamie Drossaerts are first authors. Ranjana Jairam is the corresponding author. Ranjana Jairam and Jamie Drossaerts drafted this manuscript. Tom Marcelissen, Desiree Vrijens, Gommert van Koevinge, and Phillip van Kerrebroeck revised it critically for important intellectual content and gave final approval of the version to be published. All of the authors read and approved the final version of this manuscript.

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