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*Review Article*

# Sacral Root Neuromodulation in the Treatment of Various Voiding and Storage Problems

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**Abstract:** This paper reviews the use of sacral neuromodulation as a treatment modality for patients with bladder dysfunction. The dual functions of the urinary bladder are to act as a reservoir and to evacuate under voluntary control. Bladder dysfunction is a descriptive term describing the loss or the impairment of one or both of these functions. In the first part of the manuscript we describe the different components of sacral neuromodulation: the screening test known as percutaneous nerve evaluation (PNE), which involves screening patients who could potentially benefit from the therapy. Those who show a satisfactory response will have a permanent neuroprosthesis implanted. The technical aspects of both components of neuromodulation are described in detail, as well as the technical difficulties encountered. In the second part we present our long-term results in patients with sacral neuromodulation. Sacral neuromodulation is a safe and efficient therapeutic modality that helps patients with refractory voiding dysfunction restore their bladder function.

**Keywords:** Incontinence; Neuromodulation; Retention; Sacral roots; Urge

## Introduction

Sacral root neuromodulation is a relatively recent concept for the treatment of various voiding and storage dysfunctions, but is gaining wide acceptance among the international urology community. The principles were laid down by Tanagho and Schmidt [1,2] early in the 1980s. Since then, hundreds of patients have had neuroprostheses implanted to treat various dysfunctions. Several reports have been published addressing different aspects. The indications have expanded, and now include urge incontinence and sensory urgency [3–5], idiopathic chronic urinary retention [4–8], pelvic pain [4,7] and interstitial cystitis [9].

The reasons why neuromodulation is especially beneficial for women are unclear: it could be that women are more vulnerable than men to pelvic pathology. Many female patients showed the symptoms of voiding dysfunction following gynecological or obstetric procedures. In our experience, of 38 patients implanted with sacral root neuroprostheses only 3 were male [5,8].

## Procedure

Patients in any of the previously mentioned categories of bladder dysfunction undergo a screening test called percutaneous nerve evaluation (PNE), in which a temporary wire electrode is inserted in the S3 foramen. The patient is sent home with an external pulse generator for a few days. Responders are then implanted with a permanent sacral foramen implant and an implantable pulse generator (IPG).

### *Percutaneous Nerve Evaluation*

This was first described as a clinical test to evaluate detrusor innervation [10]. The technique used previously was different from that used in recent publications. The test was done under spinal anesthesia

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and the patient was positioned laterally. The aim was to test the response of the urinary bladder, manifested in pressure changes, to S3 electrostimulation in candidates for neuroprosthetic implants designed for bladder evacuation. The current procedure used for PNE is the one described by Thon and colleagues [7]. The patient is positioned prone with slight flexion of the hips. The S3 foramen is located one fingerbreadth off the midline at the level of the sciatic notch. The entire procedure is conducted under local anesthetic. In their description, Thon et al. used an angiocatheter with a finder needle to probe the foramen. Currently this has been replaced with a relatively atraumatic needle supplied with the PNE kit from Medtronics (Medtronics Inc., Minneapolis, MN). The angle recommended by the authors was 60° to the skin. The more tangential the angle the narrower the contact with the nerve. The stimulation current used ranges between 3 and 5 mA, 15 Hz and 200 $\mu$s. Each foramen is separated with one fingerwidth in the vertical plane from adjacent foramina. Once the desirable somatic response is found, an electrode wire is passed through the needle sheath and secured in place by adhesive tapes.

Hassouna and Elhilali [11] reported a slightly different technique, using a 30–40° angle to the horizontal plane of the skin.

### *Somatic Responses to Sacral Roots Neurostimulation*

The sacral roots S2–4 are responsible for the nervous supply of most of the pelvic organs, giving rise to both the pelvic and the pudendal nerves. The pelvic nerve is the one carrying the autonomic innervation, whereas the pudendal carries the somatic innervation. In addition, some somatic fibers arise from S2 and 3 and run in close proximity to the pelvic nerve to supply the levator muscle and the striated rhabdosphincter around the membranous urethra [2].

The sacral root of interest to us is the S3 root. A typical response to stimulation of this nerve is seen in the perineum and the foot: electrostimulation results in contraction of the detrusor, levator and, to a lesser extent, the urethral sphincter, in addition to the big toe muscles. During percutaneous nerve evaluation, this response is translated into a below reflex, which is inward movement of the anus and deepening of the gluteal cleft. Subjectively, the patient feels a pulling sensation in the rectum, with variable sensation in the labia. Stimulation of S2 produces contraction of more superficial perineal muscles, causing a clamp-like effect. It may cause some sphincteric contraction but not detrusor response. Furthermore, it causes plantar flexion of the foot and lateral rotation of the leg. S4 causes below like action with no foot movement. Occasionally there is an overlap between the dermatomes [7]. The same responses were observed by Hassouna and Elhilali in their report [11].

### *Complications of PNE*

Very minor complications were reported in a large series at UCSF of more than 1500 patients undergoing this test. These included some local discomfort at the puncture site, accentuation of the symptoms after the trial period, and wire displacement. No cases of infection were encountered [7]. Similar results were reported by Hassouna and Elhilali [11].

### *Subchronic Wire Test*

After the desirable response is obtained and the wire secured in place, the patient is sent home with the wire coupled to a portable pulse generator for a 5–7 day trial period of outpatient stimulation. Responders are those who show considerable improvement of their symptoms during the subchronic testing period. The choice of implant side depends on the side that gave the best response [7].

### *Results of the PNE*

Out of 50 patients tested by PNE for various voiding and storage problems, Elabbady et al. [4] reported a satisfactory response to the subchronic testing in 17. It has to be mentioned that the response criteria in this study were rather strict, as only patients who showed more than 70% improvement in their main baseline symptoms were considered to be qualifiers. The rest of the patients either showed no response or the response was subobtimal. Siegel [12] has reported a 51% response rate in 49 patients undergoing PNE. In his series, 4 patients had a sustained improvement of their baseline symptomatology long after the PNE [12]. When 50% improvement was used as a cutoff value in patients undergoing PNE, results improved to 61% [3].

Hasan and colleagues [13] compared the results of transcutaneous electrical stimulation (TENS) of the sacral roots and that of PNE of S3 roots in patients with idiopathic detrusor instability. They reported that the symptomatic relief in patients undergoing PNE was more pronounced than in those having TENS, but did not reach statistical significance. Both tests showed favorable effects on the ambulatory urodynamics. It has to be mentioned that the duration of the TENS was 2–4 weeks compared to the 4–8 days of the PNE, reflecting the superior direct specific stimulation of the S3 root in the PNE [13].

### *Permanent Neuroprosthesis Implant*

Patients are put in the prone position. An incision is made over the lower two-thirds of the sacrum and carried down to the thoracolumbar fascia. The fascia is incised and the gluteal and the paraspinous muscles are retracted over the side that demonstrated a satisfactory response during PNE testing. The foramen is identified and a quadripolar electrode inserted into the foramen and secured in place by non-absorbable material sutured to

the periosteum. The lead is then tunneled subcutaneously and brought out just below the iliac crest from a skin incision. The patient is then positioned on the flank. The implantable pulse generator is implanted in a pouch fashioned for this purpose medial to the anteriosuperior iliac spine, and connected to the electrode by an extension cable tunneled subcutaneously. Patients are placed on antibiotic coverage. The pulse generator is activated on the second postoperative day and the patient is discharged on the third postoperative day [11]. Siegel [12] has used a similar technique with some minor modification. He tested the location of the S3 foramen and then made a 10–12 cm incision determined on that location. He tested the best possible position and direction for electrode insertion with an insulated test needle before inserting the permanent electrode. The direction of the electrode insertion was inferolaterally towards the greater trochanter to follow the course of the sacral root. The four contact points of the electrode were checked at this point. An ideal response is the one obtained with a current of 0.5 mA. A lower current denotes a very close position and higher current indicates that the electrode is too far. If a less than ideal response was demonstrated, the electrode was removed and repositioned. He also used another fixation cuff to fix the electrode more proximally [12].

## Results

Few studies have been conducted in this subject to date, and less than a handful of these address specific pathological conditions. In the following text the two main indications for sacral root neuromodulation will be discussed separately and other minor indications will be discussed collectively.

### *Urge Incontinence and Sensory Instability*

Urge incontinence and sensory instability were among the first indications for the use of this modality. The principle arose from observations of the ability to restore reservoir function in patients with suprasacral spinal cord injury during sacral root neurostimulation [14]. In that study, the primary aim was to induce voiding. It should be noted that most patients in this study had undergone extensive dorsal rhizotomy, which may be the main reason for the restoration of continence.

In 1995, Bosch and Groen [3] reported their results in 18 implanted patients with urge incontinence secondary to detrusor instability. The voiding diaries of these patients showed a highly significant drop in leakage episodes and frequency, with a significant increase in the average voided volume. The number of protective pads used per day dropped significantly as well. The effect was durable, as 13 patients who were followed up for more than 2 years maintained the same initial improvement. Urodynamically, the bladder instability disappeared in 8 of the 18 patients, and the other 10 showed an increased infused volume to the first uninhibited contraction and to the maximum uninhibited contraction. This was associated with increased bladder volume at capacity and first sensation. There was no complete correlation between the urodynamic findings and patient symptomatology. Three of the 9 patients who were completely dry showed persistence of the uninhibited contractions, whereas 2 of the 9 who were not completely dry showed a stable bladder [3].

Thon and colleagues [7] showed similar results. Out of 20 patients with urge urinary incontinence 17 showed an improvement of more than 50% compared to the baseline, which persisted for more than a year of follow-up. Elabbady and colleagues [4] presented their results in patients with urgency frequency and/or urge incontinence: frequency improved by 73%, urgency by 42% and incontinence by 50%. Urodynamically, bladder instability disappeared in 1 patient and bladder volume at first sensation increased by 50% [4].

### *Idiopathic Non-Obstructive Chronic Urinary Retention*

This is another major indication for sacral root neuromodulation, but very few reports have been published concerning this issue. Thon and colleagues [7] reported their results in patients within this category: 33 patients with chronic urinary retention were given permanent neuroprothestic implants; 23 showed a long-lasting significant improvement, but in the remaining 10 the improvement did not reach 50% compared to baseline [7]. Vapnek and Schmidt [6] reported their experience in 7 patients with chronic retention: 5 are now voiding normally, whereas of the other 2, 1 is voiding with hesitancy and straining and 1 was doing well but lost his implant through infection [6]. Elabbady and colleagues [4] presented their data in 8 implanted patients: all were able to void postoperatively. Average voided volume improved significantly and was associated with a marked reduction in residual urine and a significant improvement in the uroflowmetry data. The authors denied any change in the cystometrogram data, including bladder volume at first sensation and capacity and resting pressure, and detrusor pressure at maximum capacity [4].

### *Miscellaneous Indications*

Pelvic pain or discomfort is a very common symptom associated with other storage or voiding dysfunctions. In much of the literature on sacral root neuromodulation, associated pelvic pain has improved remarkably. This improvement ranged from 85% to 90% when post-implant status was compared to baseline [3,7].

Tanagho [15] presented his data on sacral root neuromodulation in various voiding dysfunctions and storage problems in children. Nineteen patients with meningomyelocele were tested with PNE: 11 showed a

good response. Of these, 7 were implanted: 6 of these demonstrated a very good response, and 1 failed. Children with voiding dysfunction with no apparent cause all responded to PNE (6/6). In addition, they all showed a fair to good response postoperatively. Two patients with neonatal hypoxia were treated with neuroprothestic implants, 1 of which failed because of behavioral problems [15].

## Complications

Complications in general were minimal and within expectations. These included electrode migration, electrode failure and pain at the IPG site [3,12]. Cessation of the response with time was encountered by some investigators. Thon et al. [7] theorized that this was due to electrode–nerve interface problems resulting from high charge injection. The reason for this is placement of the electrode far from the nerve: close proximity of the electrode to the nerve prevents the use of high current amplitude, thereby preventing nerve damage [7]. Pain, whether referred or at the IPG site, constituted a problem in 8 out of 17 implanted patients. This was dealt with by adjustment of parameters in 7 patients. Local pain at the IPG site necessitated removal of the implant in 1 patient [3].

## University of Toronto Experience

Two reports have recently been published in the *Journal of Urology* concerning our own experience [5,8]. In the following section, the data are summarized.

### *Methodology*

*Inclusion and Exclusion Criteria.* Patients with serious voiding dysfunction refractory to all conservative measures were included in our study. All underwent a detailed history and physical examination. The inclusion criteria were a diagnosis of either urgency–frequency/urge incontinence, or non-obstructive chronic urinary retention either complete or incomplete. Age should be greater than 16 years. A normal upper urinary tract, adequate bladder volume (more than 100 ml) and no significant sphincteric pathology were essential prerequisites. Patients must be willing and competent to complete the diaries and questionnaires of the study, and have the intention to comply with the study visit schedule.

Exclusion criteria included multiple sclerosis; Reiter's syndrome; severe uncontrolled diabetes mellitus or diabetes mellitus with peripheral neuropathy; pregnancy; anatomical limitations that would prevent successful placement of an electrode, such as meningomyelocele; an active disease that can limit the success of the procedure such as active degenerative disk disease; spinal cord injury or cerebrovascular accident less than 6 months old; symptomatic urinary tract infection until treated: stress incontinence; pelvic pain not associated with voiding dysfunction or when it is the primary diagnosis; severe psychological problems; and mechanical infravesical obstruction.

*Study Design.* Patients who fit into the previously mentioned criteria underwent urodynamic study and were asked to complete two voiding diaries for 4 successive days each (baseline diaries). In addition, they completed Beck Depression Inventory and SF36 Quality of Life questionnaires.

After completion of these diaries the patients were subjected to percutaneous nerve evaluation (PNE) and sent home with a mobile pulse generator (Medtronics model 3625 screener) for subchronic testing. They were asked to complete another diary for 4 consecutive days (PNE diaries). A fourth diary was completed after the PNE once the symptoms returned baseline, and the baseline and the PNE diaries were compared. A 50% improvement of at least two major symptoms was chosen as a cutoff value in this study for the patient to qualify for implantation. After implantation, patients were followed up at 1, 3 and 6 months postimplantation, and every 6 months thereafter. Before each visit, a voiding diary and quality of life questionnaire were completed. During each visit, any complication was reported, stimulation parameters could be adjusted if necessary, and a free uroflowmetry was done, except at the 6-month visit when the patients underwent urodynamic studies instead. At this visit and after the urodynamics, the implant was turned off and the patient instructed to complete a diary after returning to the baseline. After completion of the diary the implant was turned on again [5,8].

### *Results*

*Results of the PNE.* One hundred and four patients with various serious voiding dysfunctions underwent percutaneous nerve evaluation (PNE) to determine their responsiveness to neuromodulation. Physical examination disclosed no abnormality except tenderness or inability to control the pelvic floor, demonstrated in an inability to relax or contract the levator ani on command. Upper tract imaging and cystoscopy did not show abnormalities. These patients had failed all other conservative measures and procedures to treat their condition, including pharmacotherapy in the form of antispasmodics, anticholinergics, antidepressants, smooth and skeletal muscles relaxants, $\alpha$-blockers, and antibiotics to treat associated urinary tract infection. In most of the cases several courses of different medications had been tried. In addition, other pharmacotherapeutic agents were instilled in the bladder, such as heparin, DMSO, Chlorpactin etc. Apart from the pharmacotherapy, a wide variety of surgical procedures were of no benefit to these patients. This included urethral dilatation, bladder neck resection or incision,

bladder neck suspension or sling procedure, and enterocystoplasty. The direct causative agent in these patients was not always clear. Pelvic or perineal trauma, in the form of hysterectomy, episiotomy, dilatation and curettage and sexual abuse, was the most common single agent that preceded the occurrence of the symptoms, especially in the retention group.

Forty-one of these patients showed a significant improvement in their voiding diary parameters and qualified for a permanent neuroprosthetic implant: 20 of these were in the urgency–frequency/urge incontinence group (urge group), and 21 were in the retention group. Thirty-eight of the qualified patients have been implanted and 3 are still awaiting implantation. The remaining patients did not show an adequate response to PNE and hence did not qualify for a permanent neuroprosthesis.

It was noticeable that all the changes in diary parameters observed during PNE in the good responders persisted after implantation with no significant difference. There was no statistically significant difference between data obtained with PNE and those obtained at any point during follow-up in patients qualified for implantation. All patients returned to their baseline status after completion of the PNE, although in some this took a few days to occur.

*Results of the Urge Group.* Eighteen patients with urge incontinence who showed a significant improvement in response to PNE have been given a sacral root implant (Medtronics, ITREL I, II or Interstim). The mean age at the time of presentation was 42.3 $\pm$ 3.3 (22–67) years, and the duration of the urinary symptoms was 6.6 $\pm$ 1.3 (1.2–18.8) years. All patients except 2 were females. The average follow-up duration in this group was 18.8 (3–83) months [5].

Sacral root neuromodulation effectively improved incontinence in this group of patients. This was reflected in many aspects. Average number of incontinence episodes per 24 hours decreased significantly after implantation and remained statistically lower than pretreatment for as long as the patients were followed up. This was also demonstrated when the data were analyzed on an individual basis. Eight patients became completely dry after the surgery, and 4 had average leakage episodes of one or less daily. In fact, all patients except 1 showed either cure or improvement. Furthermore, urinary urgency and sense of emptying improved significantly. Associated pelvic pain decreased significantly [5].

Eight patients had associated chronic retention. The improvement of their voiding behavior was similar to that of the retention group, which will be discussed in the following section [5].

The clinical improvement was associated with improvement in the urodynamic data. Voided volumes during the uroflowmetry increased up to twofold when comparing the baseline to the postoperative follow-up. Peak and mean flow rate stayed within the preoperative normal ranges. Cystometrograms showed the disappearance of bladder instability in only 1 of the 4 patients who showed it preoperatively. In the other 3 the bladder volume at which these contractions occurred increased from 80 ml to 124 ml. Bladder volume at first sensation increased by 50%, from 133.17 $\pm$ 25.31 ml preoperatively to 203.75 $\pm$ 42.29 ml 6 months postimplant. Cystometric bladder capacity increased by 15% from 291.93 $\pm$ 48.32 to 335.83 $\pm$ 51.05 ml. Pressure–flow studies in the patients with pure urge incontinence, as expected, demonstrated no difference [5]. Patients who completed 18-month follow-up in both groups (urge/frequency and retention) showed that their initial improvement in symptomatology persisted in the long term [5].

The amplitude of the stimulating current needed to be increased within the first 4 weeks and stabilized thereafter. Although variable from one patient to another, the current amplitude was in the 2 V range, with a pulse width of 210 $\mu$s and frequency of 2–15 Hz in most patients [5].

Analysis of the Beck Depression Index and the Quality of Life questionnaires showed some improvement, which was progressive in most of the items. This improvement ranged from 10% to 40% [5].

*Results of the Retention Group.* Twenty patients with idiopathic non-obstructive chronic urinary retention have been implanted to date. All but 1 were female. The average age of presentation was 33.67 $\pm$ 2.2 (19.43–55.66) years. The average duration of urinary retention at the time of presentation was 5.23 $\pm$ 1.1 (1.17–19) years. The mean follow-up was 15.17 (1–74) months. Two patients were lost to follow-up and their data were not included in our study. All patients were dependent on CIC at the time of presentation [8].

There was a significant improvement in both the voided volumes and residual urine. The percentage of the residual urine to total urinary output dropped from 78.3% to 5.5–10.2% in the postoperative follow-up visits. Associated pelvic pain also demonstrated a significant improvement. All patients reported a subjective improvement in all their symptoms, including their sensation of emptiness after voiding. There was also an impressive decrease in the urinary tract infection rate after implantation [8].

Again the clinical improvements were translated to urodynamic data. Voided volumes, peak and mean flow rates and residual volumes were almost normalized. No significant difference was shown in the data of the cystometrogram. Pressure–flow studies after implantation were again within normal values [8].

## *Complications*

None of the complications that we encountered was major or life-threatening: in fact, most were within our expectations. The most important and frequent complication of the PNE is wire migration before the end of the 4-day testing period. Regarding the permanent implant

procedure the complications included superficial wound infection in 2 patients, and implant failure in 1 patient necessitating replacement of the IPG. Erosion of the extension cable towards the skin in 2 patients is corrected by burying the wire under the skin. Electrode migration in 2 patients required exploration and repositioning. Pain at the site of the implant required change of site in 1 patient, and there was persistent back pain radiating to the lower limbs in 2 patients for several weeks after surgery. None of these complications was irreversible and did not result in any nerve damage. Four implants had to be replaced for battery failure after 4–6 years of use [5,8].

## Discussion

Sacral root neuromodulation is becoming an acceptable alternative for the treatment of refractory voiding and storage problems. It is a very appealing concept because the surgery is relatively simple and involves no major morbidity. The good reproducibility of the results of PNE after implantation add to its advantages.

### *Theories of Mechanisms of Action*

The mechanism of action of this therapy is not well understood. There is no solid evidence as to the mechanism of action and not much basic research has been done to address the issue. The theories explaining the results of sacral root neuromodulation all derive from the clinical observations. The activation of spinal inhibitory pathways through stimulation of the afferent input in the S3 root can account for a partial explanation in the urge group [16–18]. There should also be another type of modulation, rather than just a temporary activation of spinal inhibitory reflex that occurs with continuous neural stimulation. This is indicated by the persistence of the response in some of our patients when the stimulation was turned off for variable periods after 6 months of implantation [5,8].

The substantial improvement in the associated pelvic pain and discomfort may give an additional clue to the mechanism of action. The latter observation can be explained by the gate theory first proposed by Melzack and Wall [19]. They suggested that pain perceived to have a visceral origin could be blocked by converging impulses arising from a somatic origin and supplied by the same dermatome. This is supported by the work of Birder and de Groat [20], who demonstrated that electrical stimulation of the pelvic or pudendal nerve afferent axons increases the expression of c-fos protein (proto-oncogene) in the same spinal areas that show increased c-fos expression secondary to noxious stimuli arising from the bladder and the urethra [20]. In other words, these two inputs converge on the same dermatome. In fact, we started to obtain some evidence from the basic research aspect that sacral root neuromodulation blocks the pathological reflexes from the bladder and pelvic floor mediated by the C-afferent fibers (unpublished data).

The explantation of the mechanism of action is even more difficult in patients with chronic retention. There is a general agreement in the literature that these patients lack control of their pelvic floor [4], and it is believed that neuromodulation may function by directing the patient to relocalize her pelvic floor and hence regain the ability to relax it and initiate micturition, especially as most of these patients regained control of their pelvic floor [21]. Detrusor contraction through direct stimulation of the autonomic efferents cannot account for this improvement in those with retention, because the current used is of a very small amplitude compared to that used to induce detrusor contraction [14]. Vapnek et al. [6] theorized that there is an overinhibition of the voiding reflex through certain pathological reflexes, which become inhibited by neural stimulation. This theory is based again on observations of the inability of these patients to relax their pelvic floor. This theory is supported by the work of Wall [22], who presented the enhanced afferent theory, demonstrating that the response threshold of a certain nerve can be lowered by a chronic noxious stimulus, which can be a chronic strain. This may result in the long term in an increase in this aberrant feedback to the spinal cord, which in turn can result in a state of spastic reflexes or inhibition of behavior. Lastly, neuromodulation may increase the awareness of the patient to their pelvic floor, enabling them to relax it to initiate micturition [6,14].

### *Therapy Results*

It has been shown from our experience and that of others that sacral root neuromodulation is an effective therapy for patients with chronic idiopathic non-obstructed retention, urge incontinence, and urgency frequency syndrome. Associated pelvic pain also improved significantly in these patients. This makes the therapy appealing for patients complaining primarily of chronic pelvic pain. Many of those with urge incontinence and urgency–frequency syndrome fit the criteria of interstitial cystitis or interstitial cystitis-like syndrome. This could be an additional indication to be explored in the future, especially as none of the current therapies for these two entities is effective. The last two indications have been discussed, in two different articles [7,9].

There is a general agreement in the literature that PNE is an essential step before implanting the patient with a permanent prosthesis [3,6–11,12]. It provides a true image for both the patient and the physician of what to expect after having the permanent implant. In our opinion it is a milestone in therapy because it not only saves the patient unnecessary surgery, it also increases the cost-effectiveness of the treatment.

The effect is also long-lasting: the initial good response was shown to persist as long as the patient has the implant [5,8]. In fact, we have a follow-up of as

long as 7 years with no deterioration in response with time. On the other hand, patients need the electrostimulation to maintain the response even after a long period of implantation. We switched off the IPG 6 months after implantation to test whether the response is due to behavioral training, but all patients returned to baseline after a variable period, extending up to 6 weeks. This finding indicates that the response is related to a form of neuromodulation that needs some time to be reversed, and is not due to behavioral training. A strong indicator of this is that all the patients failed to maintain their response after few days of turning off the stimulator [5,8].

The stimulation parameters and the active electrodes used need to be changed several times during the first few weeks until healing is complete, after which no further major changes are needed. The introduction of the 'Interstim' IPG allowed the patient to change the current amplitude using a handheld external programmer, within a preset limit, which led to a dramatic decrease in office visits. Basically, all patients need the stimulator to be turned on continuously. Turning it off does not necessarily stop the response instantaneously: usually this starts to deteriorate gradually until it reaches baseline, after a variable period. Nevertheless, most of the patients need a few hours or days to reach the maximum response after turning on the stimulator again. The parameters used were monopolar stimulation and a 210 $\mu$s pulse width. We are aware of other investigators who used bipolar stimulation. Frequency change produced no difference in patient response. We used a frequency of 5–20 Hz. The current was set to the lowest amplitude to give a sensation in the perineum and at the same time not so high as to cause discomfort. In the Interstim system the patient can adjust the amplitude to reach a comfortable zone. The amplitude is set by the physician to not exceed certain limits so to avoid inadvertent overstimulation.

### *Cost-Effectiveness*

Cost-effectiveness is a major issue when it comes to a prosthetic implant. Although no study concerning this point is available, some conclusions can be extrapolated from previous studies and our observations. Currently, cost-effectiveness is not an issue as most of the patients who have been implanted worldwide have been refractory to all different kinds of therapy. The success of this modality will lead to a relaxation of the inclusion criteria and indications. We expect that cost-effectiveness will therefore become an issue, especially as the patient will be given the choice between different modalities of therapy from the start. For a study to be fair regarding cost-effectiveness, several aspects should be included in the analysis. In addition to the direct cost of the therapy, indirect costs should be taken into account, including quality of life, productivity, social involvement, the occurrence of complications and morbidities, and the use of additional equipments and accessories to help the patient deal with their problems socially. If all these aspects are included in the analysis, we believe that this type of therapy will prove to be cost-effective. The stratification of the patients into responders and non-responders by the PNE before implantation dramatically improves the cost-effectiveness, especially when this type of prosthesis is compared to other prosthetic implants for which a screening test is not available.

## Conclusion

We strongly believe that sacral root neuromodulation is an effective modality in the treatment of various voiding and storage problems. Its relative simplicity and the low complication rate has made this concept of therapy very appealing to add to the standard options that can be offered to patients with these indications. Finally, sacral root neuromodulation can be a regular practice among urogynecologists as it is especially effective in female patients.

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## References

1. Schmidt RA. Applications of neurostimulation. *Urol, Neurourol Urodyn* 1988;7:585
2. Tanagho EA, Schmidt RA. Electrical stimulation the management of neurogenic bladder. *J Urol* 1988;140:1331
3. Bosch J, Groen J. Sacral (S3) segmental nerve stimulation as a treatment for urge incontinence in patients with detrusor instability: results of chronic electrical stimulation using an implantable neural prosthesis. *J Urol* 1995;154:504
4. Elabbady AA, Hassouna MM, Elhilali MM. Neural stimulation for chronic voiding dysfunctions. *J Urol* 1994;152:2076
5. Shaker HS, Hassouna M. Sacral nerve root neuromodulation: effective treatment for refractory urge incontinence. *J Urol* 1998;159:1516–1519
6. Vapnek JM, Schmidt RA. Restoration of voiding in chronic urinary retention using neuroprothesis. *World J Urol* 1991;9:142
7. Thon WF, Baskin LS, Jonas U, Tanagho EA, Schmidt RA. Neuromodulation of voiding dysfunction and pelvic pain. *World J Urol* 1991;9:138
8. Shaker HS, Hassouna M. Sacral root neuromodulation in idiopathic nonobstructive chronic urinary retention. *J Urol* 1998;159:1476–1478
9. Fall M. Conservative management of chronic interstitial cystitis: transcutaneous electrical nerve stimulation and transurethral resection. *J Urol* 1985;133:774
10. Markland C, Merrill D, Chou S, Bradley W. Sacral nerve root stimulation: a clinical test of detrusor innervation. *Br J Urol* 1971;43:453
11. Hassouna MM, Elhilali MM. Role of the sacral root stimulator in voiding dysfunctions. *World J Urol* 1991;9:145
12. Siegel S. Management of voiding dysfunction with an implantable neuroprosthesis. In: Novick A, ed. *Urol Clin N Am* 1992;19:163
13. Hasan ST, Robson WA, Pride AK, Neal DE. Transcutaneous electrical nerve stimulation and temporary S3 neuromodulation in idiopathic detrusor instability. *J Urol* 1996;155:2005
14. Tanagho EA, Schmidt RA, Orvis BR. Neural stimulation for control of voiding dysfunction: a preliminary report in 22 patients with serious neuropathic voiding disorders. *J Urol* 1989;142:340

15. Tanagho EA. Neuromodulation in the management of voiding dysfunction in children. *J Urol* 1992;148:655
16. Vadusek DB, Light JK, Liddy JM. Detrusor inhibition induced by stimulation of pudendal nerve afferents. *Neurourol Urodyn* 1986;5:381
17. Ohlson BL, Fall M, Frankeberg-Sommar S. Effects of external and direct pudendal nerve maximal electrical stimulatino in the treatment of the uninhibited overactive bladder. *Br J Urol* 1989;64:374
18. Wheeler JS, Walter JS, Zaszczurynski PJ. Bladder inhibition by penile nerve stimulation in spinal cord injury patients. *J Urol* 1992;147:100
19. Melzack R, Wall PD. Pain mechanisms: a new theory. *Science* 1965;150:971
20. Birder LA, de Groat WC. Induction of *c-fos* gene expression of spinal neurons in the rat by nociceptive and non-nociceptive stimulation of the lower urinary tract. *Am J Physiol* 1993; 265:326
21. Schmidt RA. Advances in genitourinary neurostimulation. *Neuroscience* 1986;19:1041
22. Wall PD. Neuropathic pain and injured nerve: central mechanisms. *Br Med Bull* 1991;47:631

**EDITORIAL COMMENT: Sacral root neuromodulation is a relatively new technique with which few urogynecologists are familiar. Until now, few clinical studies have been performed on this subject and the mechanism of action is not yet clarified. It appears that this treatment is effective in patients with urge incontinence and sensory instability, and in those with ideopathic non-obstructive chronic urinary retention. In addition, patients with chronic pelvic pain experience significant relief. Percutaneous nerve evaluation can be used as a screening test to select patients eligible for this kind of treatment. From the present study it seems that this type of treatment is restricted to a small group of patients only. The effect of treatment is not long-lasting: voiding dysfunction returns as soon as the neuroprosthesis is switched off. It is clear that more basic and clinical research needs to be done before this treatment can be introduced as a routine procedure in patients with serious voiding dysfunction refractory to conservative measures.**