OXFORD JOURNAL
OF STUDENT
SCHOLARSHIP

A Garment-Integrated Sacral TENS System for Overactive Bladder in Older Adults: A Design Proposal and Narrative Evidence Synthesis

Ishaan Subramanian
ishsub3333@gmail.com

ABSTRACT

Overactive bladder (OAB) can substantially affect quality of life in older adults. This paper presents a garment-integrated transcutaneous electrical nerve stimulation (TENS) design concept: two 3 cm × 3 cm conductive-fabric electrodes integrated into stretchable shorts over the intended sacral stimulation region and connected by leads to a portable stimulator. The supporting evidence comes from separate published studies, not tests of this prototype. In a two-week randomised study involving 40 women, Sharma et al. (2016) reported within-group improvements in four Overactive Bladder Symptom Score (OABSS) domain scores, including daytime frequency (1.49 to 0.45) and nocturnal frequency (1.70 to 0.50); placebo participants also improved, so these p-values do not establish between-group effectiveness. In a crossover study of 10 healthy adults, Jafari et al. (2025) detected no statistically significant differences on several comfort and stimulation measures between lotion-hydrated textile and hydrogel electrodes during thigh neuromuscular electrical stimulation. Those electrodes were substantially larger and used at a different anatomical site and stimulation setting. No electrode impedance, clinical outcome, fit, electrical-output, safety or durability measurements were performed on the garment described here. Lotion application, anatomical alignment and repeated-use safety remain unresolved. The system should therefore be considered a prototype design requiring bench and prospective clinical validation, not a clinically demonstrated treatment.

Keywords: *conductive fabric electrode; electrode–skin impedance; home-based therapy; overactive bladder; urinary incontinence; transcutaneous electrical nerve stimulation; wearable medical devices*

INTRODUCTION

Garment-Integrated Sacral Stimulation: Design Rationale and Existing Evidence

Overactive bladder (OAB) is prevalent and can impair quality of life, including among older adults (Irwin et al., 2006). Management is not limited to anticholinergic drugs: behavioural measures are generally used early, and beta-3 adrenergic agonists are among other pharmacological options. Anticholinergic drugs may lead to dry mouth and constipation, and may be linked to increased dementia risk, although this link

has not been proven (Coupland et al., 2019). The use of transcutaneous electrical nerve stimulation (TENS) has also been investigated at sacral and tibial locations as a non-invasive neuromodulation technique (Sharma et al., 2016; Jacomo). et al., 2020). In particular, Booth et al. (2018) looked at transcutaneous tibial nerve stimulation, not sacral stimulation.

Sharma et al. (2016) reported improvements in OABSS domain scores after sacral TENS, but the trial was small, short, and conducted in women not selected specifically as older adults; the placebo arm also improved. Its within-group p-values must not be interpreted as proof of superiority over placebo. Tibial stimulation, administered near the ankle, is an important alternative that may be easier to reach than the sacral region (Booth et al., 2018; Jacomo et al., 2020). The present garment explores fixed sacral electrode placement as a design option; comparative advantage over an ankle-based device has not been established.

Conductive textile electrodes could reduce handling of separate adhesive pads, but dry textile interfaces may have higher skin-contact impedance. Jafari et al. (2025) found no significant difference on several selected measures when lotion-hydrated garment electrodes were compared with hydrogel electrodes during quadriceps neuromuscular electrical stimulation (NMES) in healthy adults. This finding does not demonstrate statistical equivalence or establish safety or comfort for the smaller sacral electrodes proposed here. The prototype described below illustrates one approach to incorporating electrodes into stretchable shorts; no performance measurements are reported for it.

MATERIALS AND METHODS

Study Design

This paper describes an assembled garment prototype and offers a narrative evidence synthesis, not a systematic review or an experimental evaluation of the prototype. Sharma et al. (2016) was used to examine the clinical rationale for sacral TENS in OAB; Jafari et al. (2025) was used to examine a related textile-electrode interface. Jacomo et al. (2020), Booth et al. (2018), and supporting textile-engineering papers provide additional context. No reproducible database-search strategy, formal study screening, pooled analysis or new participant testing was conducted. The two primary studies answer different questions and cannot validate their combination in the proposed garment.

Wearable Device Design

The prototype design places two nominally 3 cm × 3 cm conductive fabric electrode patches inside stretchable shorts near the intended S2–S4 sacral stimulation region (Figures 1 and 2). This is the sacral, not lumbar, region. Their exact spacing, offset from the waistband, anatomical registration and contact pressure were not documented quantitatively. Neither electrode positioning across sizes nor the selection of the 3 cm × 3 cm dimensions has been validated. The following three-layer description is a proposed material specification rather than verified construction of the photographed sample:

1) A possible skin-contact layer of conductive silicone elastomer containing conductive particles; no ISO 10993 conformity or material biocompatibility testing is documented for this prototype.

2) A conductive textile layer, potentially silver-coated polyamide or a conductive-polymer textile; the actual supplier, product identity and coating of the photographed electrodes are not documented.

3) A thermoplastic hot-melt adhesive backing as a proposed garment-bonding layer; the adhesive brand and composition have not been documented.

Garment integration. The manuscript design specifies stretchable shorts (74% polyamide, 26% elastane) and a hot-press lamination procedure of 130–150 °C, 20–30 s, and 3–4 bar. These are described as design/process specifications; no recorded peel-strength, wash-cycle, electrode-resistance or retained-conductivity results are available for this garment. Gunnarsson et al. (2023) provides context on the garment-integration but cannot prove for this prototype.



Figure 1. Interior of the assembled shorts showing two electrode patches on either side of the centre seam (each nominally 3 cm × 3 cm), snap-style connectors and visible lead wires. The photograph is not a calibrated anatomical-placement or waistband-distance measurement.

Electrical connection. The garment patches are attached to a portable commercial TENS that is placed near the waistband by the leads as depicted in Figure 2. The output current limits, electrical isolation characteristics, actual waveform and stimulator make and model were not provided; not all verified to be compatible with the Sharma et al. protocol. No wireless operation is shown or claimed.

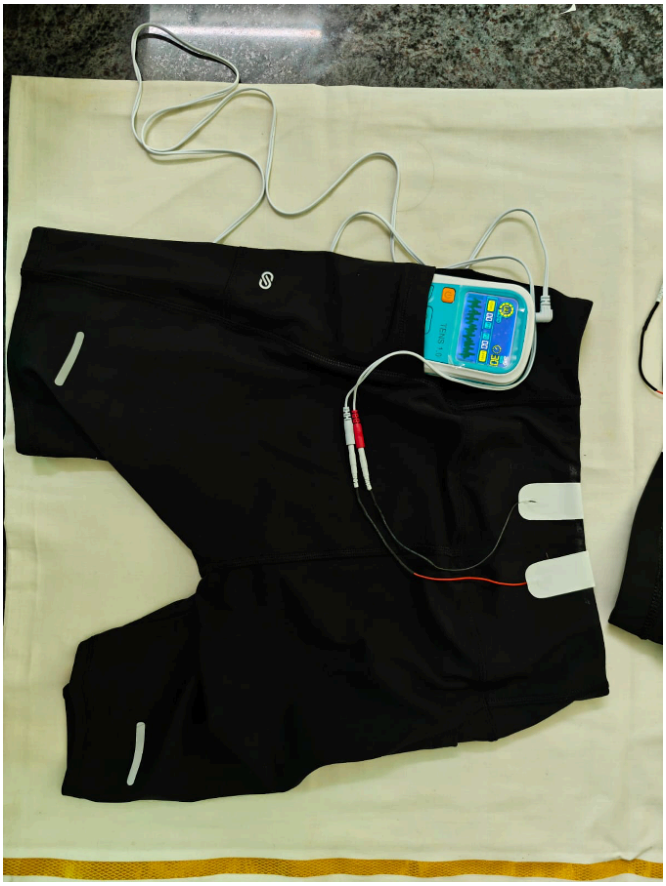


Figure 2. All (assembled) shorts with clearly visible lead wires attached to a portable TENS unit around the waistband; nominal patch size is 3cm x 3cm. This photo does not show a calibrated anatomical-placement or a waistband distance.

Impedance management. Because of the study by Jafari et al. (2025) that measured the lower impedance of lotion-hydrated textile electrodes as compared to dry ones, skin hydration with the use of a ceramide-based lotion is proposed for future assessment. This is not a measured result for the present prototype. Applying lotion to the lower back may itself be difficult for older users with restricted reach; caregiver assistance or application to an electrode surface would require separate usability and electrical-safety assessment. An accessible, validated hydration procedure has not yet been established.

CLINICAL EVIDENCE SYNTHESIS: EFFICACY OF SACRAL TENS IN OAB

The clinical evidence described here is from Sharma et al. (2016), a randomised trial in 40 women with idiopathic OAB (20 active TENS; 20 placebo). The study applied electrodes reported as 4 cm² in the source summary over S2–S4, used a biphasic square-wave stimulation frequency of 75–100 Hz, and scheduled 30-minute sessions five times weekly over two weeks. The pulse-width and current settings

necessary to establish correspondence to the photographed stimulator were not verified from the materials supplied here and should not be inferred.

Outcomes were measured using the four-item Overactive Bladder Symptom Score (OABSS), an ordinal questionnaire: daytime frequency is scored 0–2, nighttime frequency 0–3, urgency 0–5, and urge incontinence 0–5 (Homma et al., 2006). Reported means are domain scores, not counts of voids or incontinence episodes. The source manuscript describes paired t-tests, Wilcoxon signed-rank tests and Mann–Whitney U tests; the individual test underlying each tabled p-value and relevant between-group inferential statistics could not be confirmed from supplied materials. Analysing ordinal domain scores with parametric paired tests is a methodological limitation.

Published Textile-Electrode Comparison: Limitations of Transfer

Jafari et al. (2025) studied 10 healthy adults in a randomised crossover trial using 5 cm × 9 cm (45 cm²) garment-integrated textile electrodes and equal-sized adhesive hydrogel electrodes during quadriceps NMES. The textile electrodes were pre-hydrated with ceramide-based lotion. The experiment involved motor-level thigh stimulation and a 40-minute session, rather than sensory-level sacral TENS during long-term home use in older adults. The planned 3 cm × 3 cm (9 cm²) garment electrodes have only one-fifth of the area, so the same delivered current could result in higher nominal current density; safe intensity limits and local current distribution have not been established for this design. The following measures were taken in the source trial:

1) Comfort: burning sensation intensity (BSI) and maximum tolerable current intensity (Imax), in milliamperes (mA);

2) Temporal consistency: the linear regression slope of the BSI values measured on repeated measurements within a 40-minute session; and

3) Stimulation efficiency: Minimum current for measurable torque (Imin); and active torque vs. stimulation intensity; and

4) Electrical impedance: source-reported impedance spectroscopy and comparisons of electrode conditions. In that experimental context, the terms root-mean-square (RMS) input are used. The scanned frequency range was inconsistent, ranging from 20–100 Hz to 20–1000 Hz in the original manuscript; the range needs to be verified against Jafari et al. (2025). There is no substitute for a 40 Hz impedance value. For measuring current delivered by pulsed TENS.

SUPPORTING LITERATURE ON TEXTILE ELECTRODE ENGINEERING

A systematic review of literature on textile-based electrodes for electrostimulation (Euler et al., 2022) was conducted to verify the methods used for their production (weaving, knitting, embroidery, printing, coating), the conductive materials employed (mainly silver-coated polyamide yarns), and their levels of integration for wearable electrostimulation garments. The results of the review clearly guided the choice to use a hydrated silicone–textile electrode over dry electrodes and the need to achieve uniform current distribution to prevent stinging sensation. It is not a completely dry fabric electrode, but rather an interface.

SCOPE AND LIMITATIONS OF THE SYNTHESIS APPROACH

The evidence lines are independent: Sharma et al. studied sacral stimulation for OAB using conventional electrodes, whereas Jafari et al. studied larger textile electrodes on the thigh in healthy adults. In neither study did the completed garment, where the electrodes were placed, the 3 cm × 3 cm electrode configuration, the application of lotion at the sacrum, repeated wear or the aging population with OAB symptoms get tested. The results here below are due to those publications, and not to the prototype of the author. Evidence Synthesis (Published Studies; No Prototype Testing)

EFFICACY OF SACRAL TENS IN OVERACTIVE BLADDER MANAGEMENT

Within-group OABSS domain scores were found to be reduced over 2 weeks in the active arm of Sharma et al. (2016). The significant difference for the placebo arm also occurred, and paired within-arm statistical significance alone does not prove the superiority of the active arm over placebo.

In the active group, mean daytime-frequency domain scores changed from 1.49 ± 0.69 to 0.45 ± 0.51, nighttime-frequency scores from 1.70 ± 0.98 to 0.50 ± 0.61, urgency scores from 3.60 ± 1.23 to 1.65 ± 1.04, and urge-incontinence scores from 4.15 ± 1.09 to 2.15 ± 1.18. The $p = 0.0001$ reported for each is for "within" groups only and should not be interpreted as p for between group comparisons. These scores don't qualify as a measure of symptom episode counts. A verified total OABSS change and comparison to a published minimal clinically important difference were not available in the supplied study materials; they are not invented here.

There were also improvements in domain scores in the placebo arm. For instance, the post-treatment daytime scores were 0.45 for active TENS and 0.55 for placebo; and the nighttime scores were 0.50 and 0.75, respectively. The difference in scores was difficult to interpret as baseline urgency and urge-incontinence scores were higher in the active group. Reported within group p values cannot answer if there is a difference between groups. The duplicated baseline mean and sd of 1.20 ± 0.41 (daytime/nighttime frequency) as shown in Table 1 is not verified and should be compared to the source published. No efficacy result in this subsection was generated by testing this garment.

Table 1. OABSS ordinal domain scores from Sharma et al. (2016): original reported means ± SD and within-group p-values; inferential between-group differences were not verified. The identical placebo baseline values in the first two rows require source checking.

OABSS parameter	TENS pre-test	TENS post-test	p-value	Placebo pre-test	Placebo post-test	p-value
Diurnal voiding	1.49 ± 0.69	0.45 ± 0.51	0.0001	1.20 ± 0.41	0.55 ± 0.60	0.0001
Nocturnal voiding	1.70 ± 0.98	0.50 ± 0.61	0.0001	1.20 ± 0.41	0.75 ± 0.64	0.0009
Urgency	3.60 ± 1.23	1.65 ± 1.04	0.0001	3.15 ± 0.99	2.55 ± 1.23	0.0067
Urge incontinence	4.15 ± 1.09	2.15 ± 1.18	0.0001	3.55 ± 0.83	2.90 ± 1.21	0.0010

A change in self-reported OABSS scores does not establish a particular neural mechanism. Sacral stimulation has been proposed to modulate afferent input affecting bladder reflexes, but this trial did not directly measure such signalling. It also cannot determine the performance of the textile-garment prototype.

Textile Versus Hydrogel Electrodes: Published Comparison, Not Equivalence

Comfort. In Jafari et al. (2025), the reported burning sensation intensity (BSI) was 42.6 ± 15.6 mA for hydrogel and a median of 40.5 mA for textile electrodes ($p = 0.557$). Maximum tolerated current (Imax) was 66.0 ± 23.4 mA with hydrogel and 67.3 ± 28.6 mA with textile ($p = 0.586$). No statistically significant difference was detected on these measures, but the study did not establish formal equivalence.
Temporal consistency. BSI slopes during a 40-minute stimulation session did not differ significantly ($p = 0.919$) in Jafari et al. (2025). This observation does not demonstrate long-term comfort stability, especially for smaller electrodes, other anatomical sites, or older skin.

Stimulation efficiency. Jafari et al. (2025) did not find any significant difference in the minimum current required for measurable motor output (Imin; median 24.0 mA for hydrogel and 23.6 ± 3.6 mA for textile, respectively, $p = 0.500$). The model revealed a main effect of stimulation intensity on active torque ($F(1,160) = 189.58$, $p < 0.001$), but no main effect or interaction of electrode type. These are NOT difference tests, they are NOT proof of equal performance.

Table 2. Published Jafari et al. (2025) summaries. Values mix means ± SD and medians (as shown in each cell): Statistical tests/comparisons should be checked against the original article prior to publication.

Parameter	Hydrogel	Textile (lotion)	p-value
Average BSI (mA)	42.6 ± 15.6	40.5 (median)	0.557

Imax (mA)	66.0 ± 23.4	67.3 ± 28.6	0.586
BSI slope (mA/min)	0.075 (median)	0.09 (median)	0.919
Imin (mA)	24.0 (median)	23.6 ± 3.6	0.500

ELECTRICAL IMPEDANCE BEHAVIOUR

The supplied manuscript attributes impedance values to Jafari et al. (2025): at 40 Hz, dry textile electrodes 46.7 ± 31.1 kΩ, lotion-hydrated textile 7.5 ± 0.8 kΩ, and hydrogel 10.1 ± 1.5 kΩ. This is to support hydration as a source configuration interface variable. Methods and Results differ in the range of the spectroscopy (20–100 Hz vs. 20–1000 Hz), which needs to be verified in the sources. The full electrical response to TENS pulses can't be characterised by a 40 Hz sinusoidal impedance measurement.

The authors of the source study report reduction of impedance with time for a 40 minute session, possibly due to sweating. Such findings cannot be assumed for older adults, who may have altered sweating and skin characteristics. The effectiveness of the hydration and the current distribution of the 3 cm × 3 cm sacral garment electrodes have not been measured.

SYNTHESIS

All of these published studies provide a basis for the study of sacral neuromodulation and hydrated textile interfaces in isolation. They do not prove that a 3 cm × 3 cm garment electrode will reproduce either clinical outcomes or safety/comfort performance. Jacomo et al. (2020) directly looks at the difference between parasacral and tibial stimulation in the elderly, the detailed results and the ranking. The findings reported in Huang et al. (2023) were not validated using the provided documents and are not shown as quantified results. In the following section, the design assumptions and the prominent restrictions are analyzed.

DISCUSSION

While the prototype could make it easier to manipulate individual adhesive patches, better adhesion and reduced injury risk, or anatomical placement and clinical benefit, are design hypotheses and not actual results.

Sacral Positioning, Garment Fit and Alternative Stimulation Sites

Traditional sacral TENS can need accessing the lower back or help from another person. The static patches have not been demonstrated to overlie the desired sacral anatomy at various heights, torso lengths, W/H ratios, and positions of wear, as would be done in including electrodes in shorts. Patch spacing and waistband offset are not measured; and a lack of. A high local concentration of current may result from pressure or partial contact. Patches close together may also have an impact on the current path. Tibial

stimulation at the ankle, including a possible sock or band arrangement, may be more accessible; no head-to-head comparison justifies selecting the sacral garment as superior.

Skin Contact, Lotion Access and Material Safety

Thinner, less elastic skin and slower healing time in older adults should be taken into account in regard to injury from adhesives (McNichol et al., 2013). Fabric-integrated patches remove the repeated peeling step, but textile friction, coating sensitisation, local heating, electrode lift-off, skin pressure and repeated lotion exposure require evaluation. As the design depends on lotion-hydrated contact, a user with limited reach may still need assistance at the sacrum. Neither the skin-contact material nor the proposed lotion has been tested for repeated use on this prototype.

Place in the OAB Treatment Pathway

Behavioural interventions and available drug classes, including beta-3 adrenergic agonists, remain relevant options for OAB. The observed association between anticholinergic exposure and dementia in Coupland et al. (2019) does not prove causation. A wearable TENS concept might eventually provide a non-drug option for selected patients, but its efficacy relative to established treatments and its suitability for patients with comorbidities are untested.

Durability and Practical Maintenance

The garment's actual electrode resistance, impedance after laundering, adhesive bond strength and skin-contact performance after repeated wear have not been measured. Reported durability from other textile systems (Gunnarsson et al., 2023) cannot be transferred to this sample. Routine use would require washing, drying, replacement of damaged connectors and lotion residue to be defined.

Home-Use Feasibility and Adherence

Home use would still require tight fitting shorts and use of a stimulator, with lead wires and snaps and adequate hydrating of the skin. For those with limited mobility or dexterity, they can all be challenging. No evidence of user testing for improved adherence, ease or self-use compared to adhesive pads or ankle stimulation.

Safety, Standards, Regulatory Considerations and Conclusions

It's a concept for a medical device that's not tested-it's not a proven medical intervention. Prior to human application, the risks would be assessed for cardiac devices, loss of sensation/diabetic neuropathy, poor skin integrity, cognitive impairment controlling output and pregnancy, with clinician-directed screenings for contraindications. Urine leakage may wet fabric and change existing current pathways between electrodes causing skin, hygiene and electrical-safety hazards. Electrode lift-off or high impedance would warrant consideration of automatic shutdown. 60601-9-010) are also integrated in the implementation.Additionally, claims for biocompatibility according to the ISO 10993 standard and the safety and performance requirements for nerve/muscle stimulators in the IEC 60601 series (including IEC 60601-9-010) are incorporated into implementation. Formal assessment would be required by other

medical-device regulation as appropriate (60601-2-10) and the relevant market-specific medical-device regulation. There are no certifications or safeguards shown for this sample.

First engineering validation should be conducted to determine the specific commercial stimulator and output, review existing delivery characteristics and electrode impedances under relevant pulsed conditions, measure mechanical bonding and wash durability, evaluate anatomical positioning and contact pressure across sizes, and assess lotion or caregiver assisted application and urine wetting risks. These are future investigations recommended, not tests that have been completed or reported values. This would then need to be followed by clinical evaluation to demonstrate effectiveness, tolerability and adherence in older people with OAB.

Overall, the photo shows a possible design of a set of sacral electrodes embedded in a pair of shorts connected to a portable TENS device. The research discussed is that of independent published research, which only furnishes preliminary design rationale. It is too early to say if the prototype is a safe, effective sacral stimulation or if it is more accessible, or if it decreases maintenance; the device should not be labeled as a proven, equivalent or higher-compliance OAB treatment.

REFERENCES

[1] Booth J, Connelly L, Dickson S, Duncan F, Lawrence M. The effectiveness of transcutaneous tibial nerve stimulation (TTNS) for adults with overactive bladder syndrome: a systematic review. Neurourol Urodyn. 2018;37(2):528–541.

[2] Coupland CAC, Hill T, Dening T, Morriss R, Moore M, Hippisley-Cox J. Anticholinergic drug exposure and the risk of dementia: a nested case-control study. JAMA Intern Med. 2019;179(8):1084–1093. doi:10.1001/jamainternmed.2019.0677

[3] Euler L, Guo L, Persson N-K. Textile electrodes: influence of knitting construction and pressure on the contact impedance. Sensors (Basel). 2021;21(5):1578. doi:10.3390/s21051578

[4] Euler L, Guo L, Persson N-K. A review of textile-based electrodes developed for electrostimulation. Text Res J. 2022;92(7–8):1300–1320. doi:10.1177/00405175211051949

[5] Gunnarsson E, Rödby K, Seoane F. Seamlessly integrated textile electrodes and conductive routing in a garment for electrostimulation: design, manufacturing and evaluation. Sci Rep. 2023;13:17408. doi:10.1038/s41598-023-44622-5

[6] Homma Y, Yoshida M, Seki N, et al. Symptom assessment tool for overactive bladder syndrome — overactive bladder symptom score. Urology. 2006;68(2):318–323.

[7] Huang J, Fan Y, Zhao K, et al. Comparative efficacy of neuromodulation technologies for overactive bladder in adults: a network meta-analysis of randomized controlled trials. Neuromodulation. 2023;26(8):1535–1548. doi:10.1016/j.neurom.2022.06.004

[8] Irwin DE, Milsom I, Hunskaar S, et al. Population-based survey of urinary incontinence, overactive bladder, and other lower urinary tract symptoms in five countries: results of the EPIC study. Eur Urol. 2006;50(6):1306–1314. doi:10.1016/j.eururo.2006.09.019

[9] Jacomo RH, Alves AT, Lucio A, Garcia PA, Lorena DCR, de Sousa JB. Transcutaneous tibial nerve stimulation versus parasacral stimulation in the treatment of overactive bladder in elderly people: a triple-blinded randomized controlled trial. Clinics (Sao Paulo). 2020;75:e1477. doi:10.6061/clinics/2020/e1477

[10] Jafari E, Descollonges M, Deley G, Di Marco J, Popovic-Maneski L, Metani A. Comfort, consistency, and efficiency of garments with textile electrodes versus hydrogel electrodes for neuromuscular electrical stimulation in a randomized crossover trial. Sci Rep. 2025;15:6869. doi:10.1038/s41598-025-91452-8

[11] McNichol L, Lund C, Rosen T, et al. Medical adhesives and patient safety: state of the science — consensus statements for the assessment, prevention, and treatment of adhesive-related skin injuries. Orthop Nurs. 2013;32(5):267–281.

[12] Pesonen JS, Vernooij RWM, Cartwright R, et al. The impact of nocturia on falls and fractures: a systematic review and meta-analysis. J Urol. 2020;203(4):674–683. doi:10.1097/JU.0000000000000459

[13] Sexton CC, Notte SM, Maroulis C, et al. Persistence and adherence in the treatment of overactive bladder syndrome with anticholinergic therapy: a systematic review of the literature. Int J Clin Pract. 2011;65(5):567–585. doi:10.1111/j.1742-1241.2010.02626.x

[14] Sharma N, Rekha K, Srinivasan KJ. Efficacy of transcutaneous electrical nerve stimulation in the treatment of overactive bladder. J Clin Diagn Res. 2016;10(10):QC17–QC20. doi:10.7860/JCDR/2016/21683.8729

[15] Zhou H, Lu Y, Chen W, Wu Z, Zou H, Krundel L, Li G. Stimulating the comfort of textile electrodes in wearable neuromuscular electrical stimulation. Sensors (Basel). 2015;15(7):17241–17257. doi:10.3390/s150717241