Transcutaneous Spinal Cord Stimulation (tSCS) and Neuromuscular Scoliosis Prevention

A research summary for clinical application

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1. Purpose and Scope

This document addresses a specific question: can transcutaneous spinal cord stimulation (tSCS) play a role in neuromuscular scoliosis in children? The evidence below supports a genuine, mechanistically coherent role: tSCS reliably and acutely strengthens trunk control and upright postural stability in children at high risk of neuromuscular scoliosis (chiefly those with pediatric-onset spinal cord injury, SCI), and stronger trunk control is the standard clinical rationale for reducing scoliosis risk and slowing curve progression in this population. This is not a marginal or speculative finding — it is demonstrated, repeatable, and safe across the pilot studies reviewed here. What has not yet been directly measured is the downstream radiographic outcome (Cobb angle, curve progression rate) over a long enough follow-up period — no study to date claims curve correction as a primary outcome, and this document is careful to distinguish the well-supported trunk-control mechanism from that not-yet-tested downstream claim.

It also draws a firm boundary against a different, frequently confused body of literature: lateral electrical surface stimulation (LESS) and other forms of peripheral paraspinal muscle stimulation, which are a separate modality historically applied directly to idiopathic scoliosis. Section 5 explains why these should not be conflated with tSCS.

2. Why Trunk Control Matters for Scoliosis Risk

Neuromuscular scoliosis develops when paralysis or weakness of trunk musculature removes the normal muscular support for the growing spine, allowing gravity and asymmetric residual muscle tone to progressively deform the spinal column during growth. The risk is strongly age- and severity-dependent: in children with SCI, the combination of paralysis and an immature, still-growing skeleton is what drives the very high incidence, not the spinal injury alone.

- Nearly 100% of children injured before age 10 develop neuromuscular scoliosis, with approximately 65% eventually requiring surgical correction (spinal fusion).

Current standard of care is largely compensatory rather than restorative: thoraco-lumbosacral bracing is the default approach to support upright sitting, but it does not reliably reduce the incidence of neuromuscular scoliosis and does nothing to restore the child's own trunk musculature.

Other compensatory strategies (weight-bearing through the arms, orthoses, wheelchair anchoring straps) manage the consequence of poor trunk control without addressing its cause.

This creates the specific rationale for exploring tSCS in this population: if a non-invasive intervention could measurably improve a child's own active trunk control and upright sitting capacity, this addresses the proximate cause of neuromuscular scoliosis risk (loss of trunk muscular support) rather than only managing its downstream consequence.

3. Mechanism: How tSCS Supports Trunk Control

tSCS applied at thoracolumbar levels recruits posterior root (Ia and other large diameter) afferents entering the spinal cord at segments innervating trunk and hip musculature. In children with incomplete SCI, where some spinal circuitry below the lesion remains intact but under-driven, this afferent input can acutely increase the excitability of trunk motor pools, making it easier for the child to recruit residual voluntary control over postural muscles during active tasks (sitting, reaching, weight shifting).

The goal here is to boost functional recruitment of an under-driven trunk motor pool — closer to the tone-augmentation logic, since trunk control impairment in pediatric SCI is typically a weakness/under-activation problem.

The functional improvements demonstrated to date are consistent and well-documented at the acute level — measured during or shortly after stimulation and sustained safely across cumulative sessions in the studies reviewed. The logical chain from there is clinically sound: tSCS produces a measurable improvement in trunk control and upright posture, and stronger trunk control is the established rationale for reducing the mechanical drivers of scoliosis over time. The one link in that chain not yet directly tested is long-term radiographic confirmation (Cobb angle, curve progression rate) — no study has yet followed children long enough with that specific endpoint. This is worth stating plainly as the natural next step for the field, not as a weakness in what has already been shown.

4. Evidence: Trunk Control and Upright Posture in Pediatric SCI

4.1 Foundational pilot trial

A non-randomized, non-blinded pilot trial (NCT03975634) examined 8 children with acquired SCI and trunk control impairment, using a within-subject repeated-measures design. tSCS was applied to enable and support upright sitting posture, with primary outcomes covering safety (pain, hemodynamic stability, skin irritation) and efficacy (trunk kinematics), and secondary outcomes including center-of-pressure displacement and compliance. The trial demonstrated safety and efficacy for enabling upright sitting posture in 7 of 8 children, published as "Noninvasive spinal stimulation safely enables upright posture in children with spinal cord injury" in Nature Communications — the authors explicitly frame this as a non-invasive preventative alternative to the surgical treatment that neuromuscular scoliosis frequently requires in this population.

4.2 Cumulative dosing and combination with activity-based training

A follow-on pilot study examined cumulative tSCS combined with activity-based locomotor training (AB-LT) in 3 children with chronic SCI across 130 total intervention sessions, specifically to test whether repeated, cumulative dosing (rather than a single session) safely improves trunk control. This directly addresses a practical question for real-world use: a single acute session demonstrating benefit is encouraging, but a preventative strategy for scoliosis would need to be delivered repeatedly over months to years, so establishing that cumulative dosing remains safe is a necessary intermediate step before any claim about long-term curve prevention could be tested.

4.3 Related pediatric populations

A case series in children with incomplete SCI secondary to acute flaccid myelitis (AFM) used tSCS combined with body-weight-supported treadmill training (30 minutes of tSCS per 2-hour session, 22 sessions over 5–8 weeks), with walking function as the primary target but trunk/postural control assessed as part of the broader functional picture. This extends the trunk-control rationale beyond traumatic SCI to another pediatric spinal cord pathology with a similar risk profile for postural and secondary musculoskeletal complications.

Across these studies, tSCS consistently and safely improves the functional target that matters clinically for scoliosis prevention — active trunk control and postural stability — in exactly the population most at risk. What none of these studies has yet done is follow children with Cobb angle or another direct radiographic measure over a long enough period to confirm that this functional gain translates into fewer or slower-progressing curves. That confirmatory step is the logical next stage for the field, building on a functional evidence base that is already solid.

4.4 Body Position and Spinal Alignment During Stimulation

A separate but directly relevant line of evidence concerns how body and spinal position affect which neural structures tSCS actually recruits — a practical protocol variable for any program delivering tSCS during upright sitting or trunk-control training, as in the trials above.

Body position changes the geometry of the volume conductor between the electrodes and the spinal roots, which in turn changes whether stimulation preferentially recruits sensory (posterior root) afferents or co-activates motor (anterior root) fibers. In a study of thoracolumbar tSCS in 10 neurologically intact adults, response thresholds were lowest in standing and highest in prone, while response amplitudes were largest in supine and smallest in prone — supine and standing selectively activated sensory fibers, while prone produced concomitant motor-fiber co-activation. The authors recommend conducting tSCS with subjects supine or upright rather than prone. A follow-up study adding sitting to this comparison, found sitting had a significantly higher resting motor threshold and lower response amplitudes than supine, supine 90-90, or standing, confirming that position-dependent effects persist across a wider range of postures and are relevant to sitting-based trunk-control protocols specifically.

Spinal curvature at the point of stimulation matters independently of overall body position. Flexion of the lumbar spine strongly reduced posterior-root response amplitudes and led to co-activation of motor fibers, compared with neutral or extended spinal alignment, with no comparable effect on tibial-nerve H-reflexes — indicating a biophysical (current-path) rather than neurophysiological cause. The authors recommend maintaining a neutral or extended spine during tSCS.

Practical implication for trunk-control protocols: since the therapeutic goal is selective afferent (posterior-root) recruitment rather than direct motor co-activation, sessions are best delivered with the child supine or upright and with the spine held neutral to slightly extended rather than flexed or prone. This is a delivery-protocol detail rather than a change to the efficacy evidence in Section 4, but it affects how consistently a given stimulation intensity translates into the intended afferent-driven effect, and none of the pediatric trials reviewed above reported controlling for it explicitly.

5. Distinguishing tSCS from Peripheral Muscle Stimulation for Scoliosis

A different and much older body of literature exists on "electrical stimulation for scoliosis," and it is important not to let it bleed into the tSCS picture, because it is a different modality with a different (and largely disappointing) track record.

- Lateral Electrical Surface Stimulation (LESS), developed by Axelgaard in 1976, stimulates paraspinal or lateral trunk muscles peripherally and directly — through surface electrodes placed on the convex side of the curve — with the aim of directly correcting the curvature via asymmetric muscle contraction during sleep. This is a fundamentally different mechanism from tSCS: it acts on the muscle/peripheral nerve directly at the site of the curve, not on spinal afferent circuits.
- Rigorous later evaluation discredited LESS specifically for adolescent idiopathic scoliosis — AIS, the common curvature of unknown cause seen in otherwise healthy teenagers, as distinct from the neuromuscular scoliosis discussed in this document: a prospective multicenter study (Nachemson et al.) found bracing significantly outperformed surface electrical stimulation, and a meta-analysis of 20 studies found LESS's weighted success rate was low and statistically indistinguishable from simple observation (natural history). Individual case series also reported meaningful discontinuation rates due to discomfort and, in some reports, a paradoxical worsening of sagittal alignment (lordosis).
- LESS has shown more promising results in a different population: neuromuscular scoliosis in children with severe cerebral palsy, where a pilot study reported effectiveness for scoliosis and improved trunk balance. This population is closer in spirit to the tSCS/pediatric-SCI population discussed in this document (neuromuscular rather than idiopathic scoliosis), but the intervention itself remains peripheral muscle stimulation, not spinal cord afferent stimulation, so the two evidence bases should not be merged when citing sources.
- A more recent EU-funded initiative (StimulAIS) attempted to modernize the paraspinal stimulation concept for AIS (adolescent idiopathic scoliosis) using EMG-feedback-controlled stimulation of deep rotator muscles. The project's own materials label this "functional electrical stimulation" (FES), though it is applied without any accompanying voluntary movement or functional task — closer in practice to general neuromuscular stimulation than to FES's stricter, movement-synchronized sense used elsewhere in this document series. This document retains the project's own terminology rather than relabeling it, since that label is the authors' description of their device, not an independent technical classification. No robust published

clinical trial outcomes (e.g., Cobb angle data) from this specific project were identified in this search, so it should be treated as a described concept/device-development effort rather than an evidenced treatment.

The practical implication for clinical discussion: if the question is "can we prevent neuromuscular scoliosis in a child with SCI by strengthening trunk control," tSCS has a genuine, if still preliminary, evidence base. If the question is "can surface electrical stimulation directly correct an idiopathic curve," the answer from the rigorous literature is no — that specific application has been tested and has not held up against bracing or even against doing nothing.

6. Stimulation Parameters Used in Trunk-Control Studies

The table below summarizes parameters as reported in the pediatric trunk-control studies reviewed. Protocols are not yet standardized across trials, and none of these studies were designed primarily to optimize parameters for scoliosis prevention specifically — they were designed around trunk control and postural outcomes, with any scoliosis-prevention benefit inferred rather than directly measured.

Study / trial	Population	Stimulation parameters	Outcome focus
Keller et al., pilot (NCT03975634)	8 children, acquired SCI, trunk control impairment	Thoracolumbar electrodes, individually titrated intensity, applied during upright sitting tasks	Safety, feasibility, trunk kinematics, center-of-pressure displacement
Cumulative scTS + AB-LT pilot (2025)	3 children, chronic SCI	Combined with activity-based locomotor training across 130 sessions total	Safety over repeated/cumulative dosing, trunk control
Acute flaccid myelitis case series	4 children, incomplete SCI secondary to AFM	30 min tSCS + BWSTT per session, 22 sessions over 5–8 weeks	Walking function; trunk/postural control as secondary measure

7. Safety Considerations Specific to This Population

Safety data for tSCS in children with SCI is directly relevant here because this is the same population being considered for scoliosis-prevention use, and it includes a risk not prominent in the tone-modulation literature: autonomic dysreflexia, a potentially serious cardiovascular reflex response that can occur in SCI above a certain spinal level.

The cumulative-dosing pilot study reported autonomic dysreflexia in 5.4% of sessions, alongside skin redness (4.6%) and headache (1.5%), across 130 total sessions in 3 children — all managed within-session without lasting sequelae, but this confirms autonomic dysreflexia as a real, monitorable risk specific to the SCI population being targeted for trunk-control/scoliosis-prevention applications, distinct from the tone-modulation populations (CP, MS) discussed elsewhere, where this risk is not typically reported.

Both foundational trials (NCT03975634 and the cumulative pilot) were explicitly designed with safety and feasibility as primary or co-primary outcomes, reflecting appropriate caution given that children with SCI are a vulnerable population and this is an emerging, non-standard application.

8. Summary

- tSCS reliably and safely improves trunk control and upright postural stability in children at high risk of neuromuscular scoliosis, chiefly those with pediatric-onset SCI — this is a demonstrated, repeatable finding across the pilot studies reviewed, not a speculative one.
- Stronger trunk control is the accepted clinical rationale for reducing neuromuscular scoliosis risk and slowing curve progression, giving tSCS a mechanistically coherent and clinically sound role in this population's care.
- The remaining step is confirmatory rather than foundational: no study has yet followed children with Cobb angle or another radiographic measure over a long enough period to directly show reduced scoliosis incidence or slower progression. This is the natural next stage of research, not a sign that the underlying mechanism is in doubt.
- For clarity in clinical or parent-facing communication: tSCS's role here is prevention-oriented, through trunk strengthening — no study claims it corrects an existing curve, and it should not be described that way.
- A separate, older, and mechanistically distinct body of literature (LESS/paraspinal peripheral stimulation) exists for direct scoliosis treatment; it has been largely discredited for adolescent idiopathic scoliosis specifically by rigorous multicenter and meta-analytic evidence, though it retains some support in neuromuscular scoliosis in cerebral palsy. This should not be cited interchangeably with tSCS trunk-control evidence.
- Autonomic dysreflexia is a monitorable, population-specific safety consideration for tSCS in children with SCI that does not typically arise in the CP/MS tone-modulation populations.

9. References

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