Neuromuscular electrical stimulation for motor recovery in pediatric neurological conditions: a scoping review

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ABBREVIATIONS

FES	Functional electrical stimulation
NMES	Neuromuscular electrical stimulation
RCT	Randomized controlled trial
SCI	Spinal cord injury

AIM To explore the breadth of pediatric neurological conditions for which neuromuscular electrical stimulation (NMES) has been studied.
METHOD Databases (PubMed, Google Scholar, Scopus, and Embase) were searched from 2000 to 2020, using the search terms 'neuromuscular electrical stimulation' OR 'functional electrical stimulation' with at least one of the words 'pediatric OR child OR children OR adolescent', and without the words 'dysphagia OR implanted OR enuresis OR constipation'. Articles focused on adults or individuals with cerebral palsy (CP) were excluded.
RESULTS Thirty-five studies met the inclusion criteria, with a total of 353 pediatric participants (293 unique participants; mean age 7y 4mo, range 1wk–38y). NMES was applied in a range of pediatric conditions other than CP, including stroke, spinal cord injury, myelomeningocele, scoliosis, congenital clubfoot, obstetric brachial plexus injury, genetic neuromuscular diseases, and other neuromuscular conditions causing weakness.
INTERPRETATION All 35 studies concluded that NMES was well-tolerated and most studies suggested that NMES could augment traditional therapy methods to improve strength. Outcome measurements were heterogeneous. Further research on NMES with larger, randomized studies will help clarify its potential to improve physiology and mobility in pediatric patients with neuromuscular conditions.

Neuromuscular electrical stimulation (NMES) is a technology that applies electrical stimulation to specific muscles, to increase strength and function. Similarly, functional electrical stimulation (FES) is a form of electrical stimulation used during a specific task to augment a function. The terms NMES and FES are often used interchangeably, as the devices can often be used both at rest and during activity. The generic term NMES will be used for the remainder of this review.

In children, NMES has primarily been studied and used clinically in patients with cerebral palsy (CP), the most common childhood motor disability.[1] Even though the initial neonatal brain injury that causes CP is non-progressive, the resulting neuromuscular impairments can evolve and limit mobility as the child grows and muscle growth fails to keep pace with skeletal growth.[2] NMES has been found to increase muscle fiber diameter, muscle size, and muscle strength in children with CP, which can lead to an increase in the muscle-tendon unit length.[3] NMES also reduces spasticity by decreasing stretch reflex sensitivity.[4–7] Furthermore, NMES can indirectly improve selective motor control by applying it during specific movement phases such as wrist extension during reach and grasp when the elbow is flexed, or during knee extension at the end of the swing phase of gait when the hip is flexed.[4,5] The mechanisms of action of NMES in children with CP are applicable to a broader set of clinical conditions that involve neuromuscular control. For example, as CP is caused by a perinatal stroke or brain injury, there is strong reason to believe that patients with brain injury or stroke at other time points in development will also benefit from NMES.

In the adult population, NMES has been used to aid stroke rehabilitation. Stroke directly impairs upper motor neuron control of muscles and often results in weakness or paralysis of upper and lower limbs. Currently, common treatments for impaired mobility arising from stroke include use of an ankle-foot orthosis, physical therapy, spasticity medications such as GABA agonists, tendon surgeries, and focal alcohol neurolysis.[8] NMES is an emerging method of treating post-stroke weakness and/or spasticity and is often used to stimulate the neuromuscular activity of the paretic limbs.[7–9] NMES is also able to assist with upper and lower limb motor relearning and reduction of shoulder subluxation and pain.[10] In addition, it has been found to improve gait velocity, balance, spasticity, and range of motion of the lower limbs.[11] Overall, in adult stroke rehabilitation, NMES has shown notable benefits for muscle strengthening, motor recovery, reducing spasticity, and improving swallowing function, but research

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and clinical application in pediatric poststroke rehabilitation has been limited.

Spinal cord injury (SCI) is another condition in which NMES has shown promise in adults, with relatively less investigation in pediatric populations. SCI disrupts the neural inputs between the upper and lower regions of the spinal cord and can result in muscle paralysis. SCI also causes functional impairment in the muscles by reducing the muscle activation, which can lead to increased intramuscular fat and muscle atrophy; thus, the muscles are unable to generate torque and strength.[12,13] Currently, common treatments for adult SCI include progressive resistance training, robotic gait training, cycle ergometer, and NMES. In particular, NMES is used to increase the voluntary strength of the partially paralyzed muscles.[14] Despite promise in the adult population, the use of NMES in pediatric SCI is limited.

In the above-mentioned conditions, the muscles initially have no intrinsic injury, but over time they develop atrophy, decreased strength, and spasticity if not receiving regular input. Electrical stimulation can substitute or augment the efferent neural input to muscles that is usually supplied by the upper and lower motor neuron pathways in a typically functioning neuroaxis. Additionally, by providing sensory stimulation, it can augment the afferent pathways, including joint position sense, to the injured brain and potentially help to rebuild damaged neural pathways more expeditiously.[15,16]

Other non-neurological conditions may also show benefit from surface electrical stimulation. For example, in adults, NMES has been shown to be safe and effective after orthopedic surgery. After anterior cruciate ligament repair, a common problem is reduced voluntary contraction of the quadriceps muscle, resulting in atrophy. Traditional recovery from surgery involves physical therapy, but NMES can be combined with these exercises to more effectively improve quadricep strength.[17,18] Similarly, total knee arthroplasty often results in a postoperative period of decreased mobility, resulting in reduced voluntary quadriceps muscle contraction and strength. These postoperative changes are associated with decreased gait speed, balance, stair-climbing ability, ability to rise from a seated position, and an increased risk for falls. NMES can be used in combination with physical therapy to prevent muscle atrophy and re-establish typical quadricep muscle function and performance.[19,20]

Despite the demonstrated efficacy of NMES in both adults with a variety of conditions, and in children with CP, much less research has explored the safety and efficacy of electrical stimulation in children with a variety of conditions resulting in acute or chronic neuromuscular weakness. In 2013, the US Food and Drug Administration approved the first FES device for use in children with a neurological disease, and now Bioness and WalkAide devices are on the market to assist in pediatric foot drop; the WalkAide has shown benefit in children with CP.[21] Despite this existing technology, the use of NMES is still not widespread clinically and is primarily confined to research. One of the possible hindrances is the lack of research on pediatric NMES use in conditions other than CP. Another challenge is the limited advancement of NMES technology, as most existing devices are either bulky and/or require skilled operators, limiting ambulatory use. The pediatric brain has substantial potential for plasticity after injury and, generally, more potential for robust recovery. Augmentation of recovery with technology and high-dose therapy, such as that provided by NMES, may allow for faster and more complete recovery. Thus, children with a wide range of conditions, including neurological, orthopedic, and systemic illnesses, may benefit from use of electrical stimulation as part of their acute and long-term rehabilitation.

What this paper adds

- Neuromuscular electrical stimulation (NMES) appears to be tolerated by pediatric patients.
- NMES shows potential for augmenting recovery in pediatric patients with a range of rehabilitation needs.

This paper reviews the existing research literature on the use of NMES in children with neurological and musculoskeletal conditions other than CP. We had two primary aims in this scoping review: (1) to understand the spectrum of pediatric neurological and neuromuscular conditions for which NMES has been used, and (2) to characterize the various protocols used in pediatric NMES studies to inform future research.

METHOD

We produced a scoping review to provide a broad overview of the use of NMES in pediatric neurological and musculoskeletal conditions beyond CP, as the literature contains numerous case reports and small case series but few summative articles. We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist to structure our review of the literature.[22] We had an a priori search methodology that we developed based on preliminary searches to ensure the search criteria were both sensitive and specific enough to identify as many relevant articles as possible.

We performed our searches using PubMed, Google Scholar, Scopus, and Embase databases. MEDLINE was included in the PubMed and Scopus searches. In each database we searched for the exact phrase 'neuromuscular electrical stimulation', with at least one of the words 'pediatric OR child OR children OR adolescent', and without the words 'dysphagia OR implanted OR enuresis OR constipation' in the entirety of the article. We used these exclusion terms because there is a subset of electrical stimulation devices used for these purposes that are generally implanted and we wanted the review to focus on transcutaneous, non-implanted devices used primarily for motor recovery after brain injury or illness. In addition, we did the same search in all databases but with the exact phrase

changed to 'functional electrical stimulation'. We searched all articles published between 2000 and 2020 and collected articles that included pediatric patients (≤22y) that had a complete, peer-reviewed manuscript available. For the final round of screening, we only included studies with primary data, though we looked at references within review articles to confirm that any relevant primary studies were included in our search results.

Both authors of this review examined the search results for relevance to the research topic. For the first round of screening, we preliminarily categorized solely based on the article titles and sorted them as follows: Category 1, NMES in pediatric patients without CP; Category 2, NMES in pediatric patients with CP; or Category 3, other. Category 1 articles were the primary focus of the scoping review, but Category 2 articles were assessed to quantify relative research in pediatric patients without versus with CP. Category 3 articles were those that were clearly not relevant to electrical stimulation, pediatrics, or had other clear exclusion criteria. A second screening was then performed on all articles initially categorized as Category 1 or 2 in more depth, based on abstracts and/or full text when necessary. Articles were sorted into Category 1 if the majority of patients were children with other brain or spine injuries or neuromuscular conditions and received NMES to enhance motor function. Articles were sorted into Category 2 if the majority of the participants were children with a diagnosis of CP and/or a history of perinatal stroke (occurring prenatally or at <4wks of age) and who received NMES. Articles not clearly meeting inclusion criteria were excluded from further analysis. Exclusion criteria included age of participants (>22y), focus on non-motor uses of NMES (such as sensory stimulation or pain management), implanted electrical stimulation devices, lack of primary data (i.e. review articles), conference posters/papers, or lack of peer review (such as doctoral theses). To increase interrater reliability, both authors examined all articles in the first and second screening rounds to confirm accurate classification.

Category 1 articles were included for further scoping review and were examined in detail. All relevant data were summarized in Table S1 (online supporting information), including the number, condition, and age of participants, time since injury (when relevant), intervention details, setting of intervention, target muscle groups, study design, and study funding source. Level of evidence was determined for each study based on Oxford Levels of Evidence.[23]

RESULTS

A total of 233 publications were found on PubMed, 5949 on Google Scholar, 3866 on Scopus, and 224 on Embase. All remaining articles (including pediatric patients with and without CP receiving NMES) were compiled, duplicates were excluded, and categorization was confirmed. Ultimately, 266 articles remained after two rounds of screening, including 35 Category 1 articles and 231 Category 2 articles, as illustrated in Figure S1 (online supporting information).

In the 35 articles[24–58] on NMES in pediatric patients without CP, there were a total of 353 participants (293 unique participants) with a mean age of 7 years 4 months (range 1wk–38y). All but one study had participants who were 22 years old or younger; participants in the Oshima et al. study[29] had a mean age of 18 years 7 months and all had strokes at age 18 years or younger, but several were older than 22 years at the time of intervention. Demographics of the patients are summarized in Table S1 with studies sorted by target condition and author. Fourteen studies (40%) used NMES on the upper extremities (11 exclusively on the upper extremities, one on upper/lower extremities, and two on upper extremities/trunk). Eighteen used NMES on the lower extremities (15 exclusively on the lower extremities, one on upper/lower extremities, and two on the lower extremities/trunk). Six studies used NMES on the trunk (two exclusively on the trunk, two on upper extremity/trunk, and two on lower extremity/trunk). In two studies the location of stimulation was not specified.

Of the included studies, eight were randomized controlled trials (RCTs) that had 13 to 42 participants (level II evidence). One was a cohort study (level III), seven were case series, and one was a non-concurrent cohort study (level IV). The remaining 18 studies were case reports (level V). There was a broad range of conditions for which NMES was implemented, including hemiparesis from stroke, SCI (either traumatic or vascular in etiology), congenital spinal cord anomalies (myelomeningocele), acquired scoliosis, congenital clubfoot, congenital neuromuscular disease (spinal muscular atrophy and Duchenne muscular dystrophy), obstetric brachial plexus injury, musculoskeletal injuries (bilateral leg amputation and forearm fracture), intensive care unit-acquired weakness from membranoproliferative glomerulonephritis, weakness due to type VI osteogenesis imperfecta, and motor impairment due to a neurodegenerative leukodystrophy (Pelizaeus–Merzbacher disease).

Details of the NMES interventions are summarized in Table S2 (online supporting information). Devices used for delivery of NMES therapy were reported in 24 studies and were highly variable, though the RT300-P FES cycle, the Empi 300PV passive stimulation device, and Neurotech NT-2000 were each used in multiple studies. Stimulator settings were reported when available and were variable. Protocols for NMES use were also highly variable: fifteen studies assessed NMES use during activity, 11 assessed NMES use at rest, five assessed NMES use both with activity and rest, and in two studies the details of NMES use were not specified. Many studies combined NMES with other forms of therapy including conventional physical therapy. Dosage of NMES ranged widely in duration of individual sessions (10mins–8h), frequency of sessions (1d/wk–4/d), and duration of overall intervention (2wks–18mo). Twenty-six studies were performed using NMES

in the outpatient setting, of which 13 were in a clinic, nine were in the home, and four were in both clinic and home. The remaining nine studies were performed in the inpatient setting. Outcome measurements were varied and included specific muscle measurements (strength, volume, and electromyographic amplitude), joint measurements (including angles and range of motion), and standardized functional metrics. Overall, NMES was well-tolerated in all studies. Only one study, Motavalli et al.,[40] described an adverse reaction to the NMES in which skin breakdown occurred, but this improved after changing the locations of the electrodes. In multiple studies, parents shared that they wanted to continue using the devices after the research protocol ended.

DISCUSSION

NMES technology has been a promising rehabilitation tool for several decades, but its clinical use remains limited, and research on pediatric NMES has primarily focused on children with CP. This scoping review was designed to identify studies that examined NMES used to treat pediatric neuromuscular disorders other than CP, including stroke, SCI, congenital spinal cord anomalies, idiopathic scoliosis, clubfoot, and other genetic and acquired neuromuscular diseases. Beyond the wide range of indications for NMES explored in this scoping review, the 35 included studies portray the spectrum of potential for NMES use in inpatient and outpatient settings, including in the home, for acute and chronic conditions, and as short-term or long-term therapies to promote motor recovery.

All 35 studies included in this scoping review concluded that NMES was well tolerated. In several studies there was less than optimal compliance with treatments due to the frequency/duration of use required by the research protocol. In these cases, participants did not cite discomfort or other side effects as the reason for incomplete compliance. Overall, this review demonstrates that NMES can be tolerated in a pediatric population ranging from infancy to young adulthood.

Eight included studies were RCTs and were considered level II evidence because of their relatively small sample sizes. Numerous RCTs and systematic reviews have been performed in patients with CP receiving NMES,[6,59,60] with many studies indicating efficacy of NMES to improve motor function, but in children with motor impairment from other conditions, there is limited high-quality evidence to explore the benefit of NMES. Though the RCTs included in this scoping review show promise for the role of NMES in improving motor function in conditions including SCI, scoliosis, clubfoot, and brachial plexus injury, no further conclusions can be made about the efficacy of NMES in these conditions until additional large studies with streamlined outcome measures are performed in each of the specific pediatric conditions.

Stroke

In pediatric patients with stroke (n=21, across seven studies), NMES was used often in conjunction with traditional physical therapy methods to address hemiparesis and hyperkinesis. The majority of the studies focused on hand function, as measured by muscle strength, wrist/elbow/shoulder range of motion, coordination, and ability to complete daily tasks requiring the upper extremity. The most commonly used scales were the Fugl-Meyer Scale, the Box and Block Test, and the Assisting Hand Assessment (each used in two studies). Interventions with NMES were offered both in the acute poststroke setting, such as in the Onigbinde[28] and Zhao et al.[30] case reports, but also at time points as remote as 17 years poststroke, such as in the Boyne et al.[24] case report. As demonstrated in studies on NMES in adults after stroke, NMES has the potential to aid motor recovery and can be delivered at higher doses than traditional physical therapy alone, as it does not require the constant presence of a therapist.[8] To address motor impairments associated with pediatric stroke, a multifaceted approach to rehabilitation using traditional and innovative therapy strategies including NMES will likely offer the most robust recovery, but more pediatric-specific research is needed.

SCI

In patients with SCI (n=131, including 71 unique participants, across nine studies), numerous techniques have been employed to integrate NMES into exercise and strengthening programs. Three RCTs[34–36] and two case series[32,33] examined the use of the RT300-P FES bike for active stimulation and the Empi 300PV for passive stimulation and association with a variety of metrics related to musculoskeletal health and strength in children with SCI. The RCTs used three groups to compare FES during a cycling task versus passive NMES versus regular cycling without electrical stimulation. Outcome measures included hip migration index; quadriceps and hamstring strength and volume; and hip, distal femur, and proximal tibia bone mineral density. All three interventions occurred in the home setting and patients received their respective therapy for 1 hour per day, 3 days per week, for 6 months. Johnston et al.[34] found no significant change in the pre- versus postintervention hip migration index across the three groups and Lauer et al.[36] found improvements in all bone mineral density measurements in the three groups, without significant differences between groups. Lack of significant difference may either be due to insufficient power or true lack of differential benefit from the FES versus NMES versus routine cycling therapy. Johnston et al.[35] showed significantly more improvement in quadriceps strength in the FES group compared to the other groups and a significantly greater increase in quadriceps volume in the NMES group compared to other groups. To further characterize the potential differences in FES cycling versus passive stimulation on muscle strength in children with SCI, larger studies are warranted. However, both types of stimulation show promise in improving lower extremity bone mineral density and strength and may prevent hip migration.

The remainder of studies on SCI were case series and case reports and primarily focused on lower extremity function, though one by Martin et al. used the Empi 300PV (also used in the SCI RCTs) during grasping exercises to augment traditional therapy for hand function.[37] Given the severity of motor impairment often seen in SCI, particularly in complete SCI, high-dose, multifaceted therapies are needed to improve outcomes, and NMES may offer an additional option to assist with motor recovery. Additional large studies on NMES use in pediatric SCI are warranted based on promising preliminary evidence.

Myelomeningocele

Two studies assessed the role of NMES in therapy for children with myelomeningocele (n=16). Walker et al.[41] demonstrated in a before-and-after case series that patients with myelomeningocele receiving outpatient, nighttime NMES had improvements in muscle strength, gait, and bowel continence. Participants served as their own controls and interval progress was assessed in patients before and while using NMES. Despite a rigorous intervention schedule and relatively poor compliance, the patients made modest improvements while using NMES. This study, among others included in this review, suggested that home NMES is a viable option that allows for a higher dosage of NMES beyond what could be provided in a supervised physical therapy setting.

Scoliosis

Two studies assessed the role of NMES in acquired scoliosis (n=41). In the RCT by Thabet,[43] participants received either NMES or myofeedback, along with routine exercises. They reported improvement in asymmetry of plantar pressure, suggesting NMES may assist with halting the progression or even improving paraspinal muscle asymmetry in idiopathic scoliosis.

In the studies on both myelomeningocele and scoliosis, NMES was employed on the torso to address truncal stability or alignment, suggesting the versatility of NMES for motor impairments involving more than the extremities. More research is needed on the potential applications of NMES for postural support and central tone and strength, particularly in congenital and acquired SCI and scoliosis.

Clubfoot

In clubfoot (n=64, across three studies), NMES may also have potential to augment traditional methods such as foot bracing to improve musculoskeletal alignment and function. One RCT and two cohort studies were included in this review; Youssef et al.[46] and Gelfer et al.[44] used NMES in addition to the standard Ponseti method in infants, and Morales-Osorio et al.[45] used NMES in older children with a history of clubfoot to strengthen the peroneal muscle. The RCT was unable to show significant improvement with NMES compared to traditional methods, but it was likely underpowered; the two cohort studies suggested potential benefit from NMES. Notably, NMES was tolerated in infants as young as 1 week old.

Obstetric brachial plexus injury

Patients with obstetric brachial plexus injury have experienced a unilateral injury to cervical spine nerve roots related to difficult delivery that often recovers gradually with therapy and time, but many individuals are left with permanent motor impairments in the affected arm.[61] In patients with obstetric brachial plexus injury (n=60, across four studies), NMES may offer a potential adjunctive option to traditional therapy to help augment the dose of therapy provided to improve strength and function. Two included studies were small RCTs that showed greater improvements in arm strength, bone mineral density, and function in patients receiving NMES compared to conventional physical therapy.[48,49] Larger RCTs to confirm these findings will be a critical step to allow for more widespread implementation of NMES as an adjunctive therapy. Along with the studies in patients with clubfoot, these studies also demonstrated that NMES can be tolerated by infants as young as 2 weeks old.

Genetic neuromuscular disease

Three studies with a total of 15 patients assessed the potential role of NMES in Duchenne muscular dystrophy and spinal muscular atrophy. Fehlings et al.[51] performed a small RCT (n=13) in a cohort of patients with spinal muscular atrophy in which each participant served as an internal control, with one upper extremity of the patient receiving NMES and the other receiving placebo. Patients wore NMES nightly and trends in strength were compared to both preintervention strength and concurrent, contralateral strength. No improvement in strength was noted in the arm receiving nighttime stimulation compared to the control arm, suggesting either no clear benefit of NMES or insufficient power to quantify benefit. More studies are needed to further assess the role of NMES in spinal muscular atrophy and other progressive neuromuscular diseases, given the theoretical benefit without an obvious downside.

Other neuromuscular conditions

Five studies (all case reports, with a total of five patients) investigated the use of NMES in a range of other neuromuscular conditions including intensive care unit-acquired weakness due to membranoproliferative glomerulonephritis, Pelizaeus–Merzbacher disease, type VI osteogenesis imperfecta, bilateral lower extremity amputation, and forearm fracture. In all five studies, patients experienced functional motor impairments either due to acute or chronic conditions and benefitted from a multimodal approach to rehabilitation. The participants ranged from 2 to 21 years of age and received NMES in addition to routine physical therapy in either inpatient or outpatient settings. Case reports such as these help to broaden the scope of potential uses for NMES to augment routine physical therapy for recovery from both acute musculoskeletal injuries as well as chronic and/or degenerative conditions affecting strength and function.

Summary

In summary, across a wide variety of pediatric neuromuscular conditions, NMES shows promise as an adjunctive therapy to improve muscle health, strength, and function. Given the variety of methodologies and outcome measures in the 35 studies reviewed, it is hard to make any global conclusions on the efficacy of pediatric NMES, particularly compared to standard therapies, but it appears to be tolerated in children with a variety of ages and conditions. Furthermore, numerous small RCTs as well as cohort studies, case series, and case reports demonstrate its potential for improving recovery in a range of neuromuscular conditions. For future effective research on NMES, more standardized outcome measures with meaningful clinical correlations are needed. Patient-centric outcome measures focused on daily motor function, such as the Fugl-Meyer Assessment, Canadian Occupational Performance Measure, and the Functional Independence Measure, each used in several of the studies included in this review, may be most effective at demonstrating to clinicians the potential benefit of NMES in neuro-recovery. In addition, many questions remain regarding optimal dosage, duration, device type, and protocol for each of the conditions in which NMES may be used. This review demonstrates that a wide variety of NMES devices exist, each with different settings and dosages for electrical stimulation, and no conclusions can be made about which devices or dosages are most effective. Larger RCTs will provide higher powered evidence to either support or refute the role for NMES in pediatric rehabilitation for conditions beyond CP.

It is unclear why there is limited research on NMES use in a wide variety of pediatric conditions. One explanation may be that individuals who have adopted NMES as a tool in rehabilitation have already seen anecdotally how helpful it can be, and thus are not limited by the lack of evidence. Another possibility is that the compelling evidence in adults and children with CP is sufficient to extrapolate to other conditions. But we propose that the lack of large level I or II studies has limited the wide adoption of NMES in settings such as the pediatric intensive care unit, where the technology may have significant potential but has not been adequately studied. Additionally, the lack of supporting data limits the reimbursement for NMES, which further limits its clinical application.

Limitations

This scoping review has several limitations, most notably we identified only eight, relatively small RCTs on pediatric NMES use in conditions beyond CP. Due to this relative lack of strong evidence on pediatric NMES use in conditions other than CP, this review summarizes prior study methodology but is unable to reach conclusions about the efficacy of NMES in a variety of diagnoses. Beyond the RCTs, the remainder of the studies included in this review were level III to V evidence consisting of case–control and cohort studies, case series, and case reports. As with all scoping reviews, the aim was to include all relevant literature meeting the inclusion criteria, but it is possible that certain studies were omitted because of limitations in search techniques. Both authors screened articles at both stages of review, but given the large number of articles initially identified through the search, including articles in languages other than English, this review may underestimate the number of peer-reviewed articles on NMES, both in pediatric neuromuscular conditions and in CP.

CONCLUSION

This scoping review presents a comprehensive overview of the use of NMES in pediatric patients with acute and chronic neurological conditions beyond CP. A limited number of studies have been performed to examine the role of NMES for rehabilitation in pediatric conditions including stroke, SCI, and other congenital and acute neuromuscular conditions. To our knowledge, this is the first paper to examine the range of pediatric conditions for which NMES has been studied in patients as young as 1 week old. The 35 studies included in this review demonstrate that NMES can be tolerated in children with a wide range of ages and neuromuscular conditions. Though conclusions regarding its efficacy are unable to be reached given the limited number of large RCTs, this scoping review suggests that NMES may augment traditional therapy methods in motor recovery from acute and chronic neuromuscular conditions. Through this review we have identified gaps in the literature and advocate for future larger-scale RCTs to better understand the potential benefit of NMES on motor function in the pediatric population.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

SUPPORTING INFORMATION

The following additional material may be found online:

Figure S1: Flow chart of the study selection for the scoping review.

Table S1: Demographics of studies included in scoping review

Table S2: Detailed summary of interventions and outcomes

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ESTIMULACIÓN ELÉCTRICA NEUROMUSCULAR PARA LA RECUPERACIÓN MOTORA EN AFECCIONES NEUROLÓGICAS PEDIÁTRICAS: UNA REVISIÓN DE ALCANCE

OBJETIVO
Explorar el alcance de condiciones y afecciones neurológicas pediátricas para las que se ha estudiado la estimulación eléctrica neuromuscular (EENM).

MÉTODO
Se realizaron búsquedas en las bases de datos (PubMed, Google Scholar, Scopus y Embase) desde 2000 hasta 2020, utilizando los términos de búsqueda 'estimulación eléctrica neuromuscular' O 'estimulación eléctrica funcional' con al menos una de las palabras 'pediátrico O niño O niños O adolescente ', y sin las palabras' disfagia O implantado O enuresis O estreñimiento '. Se excluyeron los artículos centrados en adultos o personas con parálisis cerebral (PC).

RESULTADOS
Treinta y cinco estudios cumplieron los criterios de inclusión, con un total de 353 participantes pediátricos (293 participantes únicos; edad media 7 años y 4 meses, rango 1 semana-38 años). La EENM se aplicó en una variedad de afecciones pediátricas distintas de la PC, que incluyen accidente cerebrovascular, lesión de la médula espinal, mielomeningocele, escoliosis, pie zambo congénito, lesión obstétrica del plexo braquial, enfermedades neuromusculares genéticas y otras afecciones neuromusculares que causan debilidad.

INTERPRETACIÓN
Los 35 estudios concluyeron que la EENM fue bien tolerada y la mayoría de los estudios sugirieron que la EENM podría aumentar el efecto de los métodos de terapia tradicionales para mejorar la fuerza. Las medidas de resultado fueron heterogéneas. La investigación adicional sobre EENM con estudios aleatorizados más grandes ayudará a aclarar su potencial para mejorar la fisiología y la movilidad en pacientes pediátricos con afecciones neuromusculares.

ESTIMULAÇÃO ELÉTRICA NEUROMUSCULAR PARA RECUPERAÇÃO MOTORA EM CONDIÇÕES NEUROLÓGICAS PEDIÁTRICAS: UMA REVISÃO DE ESCOPO

OBJETIVO
Explorar a amplitude das condições neurológicas pediátricas para as quais a estimulação elétrica neuromuscular (EENM) foi estudada.

MÉTODOS
As bases de dados (PubMed, Google Scholar, Scopus e Embase) foram pesquisadas de 2000 a 2020, usando os termos de busca 'neuromuscular eletroestimulação' OU 'estimulação elétrica funcional' com pelo menos uma das palavras 'pediatric OR child OR children OU teenager' , e sem as palavras 'disfagia OR implantado OR enurese OR constipação'. Foram excluídos artigos voltados para adultos ou indivíduos com paralisia cerebral (PC).

RESULTADOS
Trinta e cinco estudos preencheram os critérios de inclusão, com um total de 353 participantes pediátricos (293 participantes únicos; idade média de 7 anos e 4 meses, intervalo de 1 semana a 38 anos). A EENM foi aplicada em uma variedade de condições pediátricas além da PC, incluindo acidente vascular cerebral, lesão medular, mielomeningocele, escoliose, pé torto congênito, paralisia obstétrica do plexo braquial, doenças neuromusculares genéticas e outras condições neuromusculares que causam fraqueza.

INTERPRETAÇÃO
Todos os 35 estudos concluíram que a EENM foi bem tolerada e a maioria dos estudos sugeriu que a EENM poderia aumentar os métodos tradicionais de terapia para melhorar a força. As medidas dos resultados foram heterogêneas. Mais pesquisas sobre EENM com estudos randomizados maiores ajudarão a esclarecer seu potencial para melhorar a fisiologia e a mobilidade em pacientes pediátricos com condições neuromusculares.