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Functional Electrical Stimulation (FES)

Functional electrical stimulation (FES) is an established neurophysiological technique that selectively activates muscles or nerves using electrical impulses. The database reveals a substantial number of controlled human studies. The most notable finding: research focuses primarily on the **musculoskeletal system**, yet the methodological diversity—ranging from meta-analyses to proof-of-concept studies—exposes gaps in standardisation and long-term evaluation.

964

STUDIES IN
TOTAL

719

IN HUMANS

306

OF WHICH
CONTROLLED

2

IN ANIMALS

0

IN THE LAB

Figures from the IHR study database · Last updated 2026-10-16

How to Read This Dossier

ESTABLISHED

measured in humans, with a comparison group

PLAUSIBLE

supported by mechanism, animal studies or observation

HYPOTHESIS

a likely connection that still needs to be tested

Functional Electrical Stimulation (FES) at a Glance

ORIGIN:
Functional electrical stimulation (FES) is a neurophysiological therapeutic method that induces targeted muscle contractions through low-frequency electrical impulses (20–50 Hz). Developed in the 1960s for the rehabilitation of paralysis, FES is now used in neurology, orthopaedics, and sports medicine, with the coupling of stimulation and functional task being crucial for neuronal plasticity.

EVIDENCE BASE:
964 evaluated studies · 306 controlled human trials · 413 observational studies · 39 review articles · 2 animal studies · 0 cell culture studies

- STRONGEST EVIDENCE:**
- Gait rehabilitation after stroke: A randomised controlled trial (1997) demonstrated a 20.5% increase in walking speed in chronic hemiplegia patients using FES combined with physiotherapy, compared to 5.2% in the control group.
 - Upper extremity after stroke: A meta-analysis (2017) indicated consistent effects of FES on arm function, though with high heterogeneity among the included studies.
 - Subacute stroke patients: A pilot study (2008) found that electromechanical gait training combined with FES showed improvements in mobility scales and walking speed, but the contribution of FES alone remains unclear.
 - FES-induced cycling training: A randomised study (2011) showed significant improvements in the Motricity Index and walking speed in post-acute hemiparetic patients, with sustained effects over 3–5 months.
 - Safety and tolerability: Multiple controlled studies document the safety of FES, particularly with non-invasive application via surface electrodes.

- LIMITATIONS:**
- Standardisation: Stimulation protocols (frequency, pulse duration, electrode placement) vary widely, complicating direct comparisons and limiting practical applicability.
 - Long-term effects: Most studies conclude with the end of therapy; follow-ups over months or years are lacking, leaving sustained effects unclear.
 - Patient selection: Studies often include motivated patients with mild impairments, while severely affected or multimorbid patients are underrepresented.

CLASSIFICATION:
Functional electrical stimulation is an established but methodologically heterogeneous therapeutic approach for the rehabilitation of motor deficits, whose sustained effects and optimal application have yet to be conclusively determined.

1. What Functional Electrical Stimulation Is

Functional electrical stimulation (FES) is a **therapeutic method** in which electrical impulses are delivered via skin electrodes or implanted systems to nerves or muscles to induce targeted muscle contractions. Developed in the 1960s for the rehabilitation of paralysis, FES is now used in neurology, orthopaedics, and sports medicine. The technique employs **low-frequency currents** (typically 20–50 Hz), applied via surface electrodes, percutaneous needles, or implanted neuroprostheses. Typical applications include **cyclic stimulation** (e.g., during cycling), **functional stimulation** (e.g., for grasping movements), or **hybrid approaches** combining robotics or brain-computer interfaces. Implementation requires precise electrode placement, individual adjustment of stimulation parameters (amplitude, pulse duration, frequency), and often integration with conventional physiotherapy.

The critical factor across all studies is the **coupling of stimulation with a functional task**. FES does not act in isolation but through **neuronal plasticity**, which is stimulated by repeated, task-specific muscle activation. Stimulation may be **peripheral** (directly to the muscle) or **central** (via nerve roots or the spinal cord), with the choice of approach influencing effectiveness and side effects. Surface electrodes are non-invasive but prone to skin irritation and imprecise stimulation of deeper muscles. Implants allow more precise control but carry surgical risks. A key methodological challenge is the **variability of stimulation protocols**: duration, intensity, and combination with other therapies (e.g., treadmill training) differ significantly between studies, complicating direct comparisons. Additionally, **measuring therapeutic success** is heterogeneous—ranging from motor scales (e.g., Fugl-Meyer) to activities of daily living (e.g., walking speed).

2. What the Studies Show in Detail

The pivotal human studies and key reviews—organised by application, population, duration, intervention, outcome measures, and results as reported in the original publications. Numbers are included only where explicitly stated in the studies.

Distribution of **controlled human studies** by application area — the numbers are not additive, as a single study may be assigned to multiple areas:

APPLICATION AREA	CONTROLLED STUDIES
Musculoskeletal system	225
Safety and tolerability	56
Fatigue and stress	23
Metabolism	21

APPLICATION AREA	CONTROLLED STUDIES
Cognition and mental health	18
Inflammatory processes	14
Bone and joints	13
Cardiovascular system	9

Gait Rehabilitation After Stroke and Spinal Cord Injury

A randomised controlled trial (1997) involving 32 chronic hemiplegia patients (at least six months post-stroke) investigated the effect of the *Odstock Dropped Foot Stimulator* (ODFS), a peroneal nerve stimulator, on walking speed and physiological cost index (PCI). The intervention group (n=16) received functional electrical stimulation (FES) combined with physiotherapy, while the control group (n=16) received physiotherapy alone. Over 12 weeks, the FES group showed a 20.5% increase in walking speed (when using the stimulator) compared to 5.2% in the control group. The PCI decreased by 24.9% in the FES group, whereas the control group showed only a 1% reduction. Without the stimulator, the FES group exhibited no improvement, indicating a purely orthotic effect. The study thus demonstrates a significant improvement in walking ability through FES, but without sustained training effects ¹.

A systematic review (2004) analysed eight studies on the orthotic effect of FES in stroke patients with foot drop. The methodological quality of the included studies ranged from 8 to 18 out of 19 points. Six studies measured walking speed, with a pooled improvement of 0.13 m/s (95% CI: 0.07–0.2) or 38% (95% CI: 22.18–53.8). The results suggest a positive orthotic effect of FES, though the data are primarily based on non-randomised studies, limiting their conclusiveness ⁴.

A randomised controlled pilot study (2008) involving 54 subacute stroke patients (within six weeks of the event) compared three intervention groups: conventional gait therapy (n=21), electromechanical gait training (GT, n=17), and GT combined with FES (GT-FES, n=16). Therapy consisted of 20-minute sessions, five days per week, over four weeks. Primary endpoints included the *Elderly Mobility Scale* (EMS), *Functional Ambulatory Category* (FAC), and walking speed over five metres. After four weeks, significant improvements were observed in EMS (Wilks’ Lambda=0.743, p=0.005), FAC (Wilks’ Lambda=0.744, p=0.005), and walking speed (Wilks’ Lambda=0.658, p<0.0001). Post-hoc analyses revealed that GT and GT-FES were superior to conventional therapy, with GT-FES tending to yield better results. A six-month follow-up was not feasible, leaving long-term effects unclear ¹⁰.

A randomised controlled trial (2011) involving 35 post-acute hemiparetic patients examined the effect of FES-induced cycling training compared to placebo FES. The intervention group received 20 sessions of 25 minutes each over four weeks. Primary endpoints were the *Motricity Index* (leg subscale) and walking speed over 50 metres. The FES group showed significant improvements in the *Motricity Index* (p<0.05), *Trunk Control Test*, *Upright Motor Control Test*, and walking speed, both post-intervention and at the 3–5 month follow-up. The placebo group exhibited no significant improvements. The study suggests that FES-induced cycling training promotes motor recovery and walking ability, though comparisons with other active therapies are lacking ¹².

HYPOTHESIS The available studies indicate that FES in gait rehabilitation primarily achieves orthotic effects, while sustained training effects (without stimulation) are less frequently demonstrated. Combining FES with electromechanical gait training or cycling may have synergistic effects, but direct comparisons with other active therapies (e.g., treadmill training) remain insufficiently explored. It remains unclear whether FES in the subacute phase promotes long-term neuronal plasticity or merely supports compensation for motor deficits.

What Is Missing: Long-term studies with follow-up assessments after at least twelve months, systematically evaluating the sustained benefits of FES in gait rehabilitation compared to other therapeutic approaches (e.g., body-weight-supported treadmill training).

Overall Picture

FES as Standard Therapy? The Limits of the Evidence

FES is increasingly recommended in guidelines for **stroke rehabilitation** and **spinal cord injuries**, yet the evidence base is **not uniformly robust**. The most frequently cited controlled studies (e.g., the 1997 work on peroneal stimulation) show **improvements in walking ability**, but many of these studies are **small and methodologically limited**. A key issue is the **lack of standardisation**: stimulation parameters (frequency, pulse duration, electrode placement) vary widely, complicating direct comparisons. Additionally, **control groups** are often suboptimal—many studies compare FES with **no therapy** rather than an active control intervention (e.g., robotics or conventional physiotherapy). The **2017 meta-analysis** on the upper extremity after stroke demonstrates significant effects, but the **heterogeneity of the included studies** is high. Another shortcoming is the **lack of blinding**: since patients and therapists can feel the stimulation, placebo controls are nearly impossible, compromising **internal validity**.

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CRITICAL POINT is the **transferability of results** to clinical practice. Many studies are conducted under **controlled conditions** (e.g., with close supervision), whereas **real-world implementation** is often less structured. Furthermore, **long-term data** are lacking: most studies conclude with the end of therapy, while follow-ups over months or years are rare. Another issue is **patient selection**: many studies include only **motivated patients** with mild impairments, while severely affected or multimorbid patients are underrepresented. The **cost-benefit assessment** of FES is also unclear—although the technique appears **non-invasive and cost-effective**, the **initial costs for equipment** and the **training required for therapists** are high. While **basic research** (e.g., on muscle biology) shows that FES can influence **muscle atrophy** and **neuronal degeneration** in the studied areas, the **clinical benefit** of these effects remains insufficiently established.

3. How Robust Is the Research?

Research on FES is broad in scope, with a clear focus on the **musculoskeletal system**: Controlled human studies investigate its applications in **stroke**, **spinal cord injuries**, or **peripheral nerve damage** among other interventions. The most frequently cited works (e.g., the 2017 meta-analysis on the upper extremity post-stroke) demonstrate that FES has been studied for the **restoration of grip function** and **gait pattern** within rehabilitation research. Additional areas, such as **fatigue syndromes**, **metabolic parameters**, and **cognitive functions**, are often explored in studies covering multiple therapies, where FES is one of several interventions examined. **Safety** of FES is well-documented through a series of controlled studies, while other fields like **oncology** or **intestinal function** remain understudied. The distribution of study types reveals a **strong clinical orientation**: Observational studies and controlled human trials together form the majority, reflecting a practice-focused approach across rehabilitation methods.

The **reliability of the evidence** varies significantly across applications. The **highest methodological quality** is found in meta-analyses and systematic reviews (e.g., the 2017 study on the upper extremity), which show consistent effects on **gait speed** and **arm function** post-stroke. However, many of the controlled studies are **small and heterogeneous**: Stimulation protocols, comparator groups (e.g., sham stimulation vs. no therapy), and outcome measures differ substantially. Another issue is the **lack of blinding**—both patients and therapists are often unblinded, which may introduce bias. The **long-term effects** of FES are scarcely investigated: Most studies conclude with the end of therapy, while follow-up assessments are rare. Furthermore, **dose-response analyses** are frequently absent, leaving unanswered how intensity and duration of stimulation could be optimised. While **basic research** (e.g., on the biology of denervated muscles) provides mechanistic explanations, the translation into clinical practice often remains unclear.

4. Common Claims — and What the Data Actually Show

CLAIM	EVIDENCE BASE
FES replaces conventional physiotherapy	The studies demonstrate that FES has a complementary effect, not a substitutive one. Controlled trials typically compare FES + physiotherapy vs. physiotherapy
FES is equally effective for all forms of paralysis	The evidence is strongly dependent on the diagnosis . For stroke and spinal cord injuries , the data are robust, whereas for peripheral nerve damage or multi
More stimulation leads to better outcomes	There are no dose-response studies that clarify the optimal intensity or duration. Excessive stimulation can cause muscle fatigue or skin irritation in the exam
FES is suitable for every patient	Contraindications (e.g. pacemakers , open wounds , epilepsy) are often not systematically recorded in studies. Patient selection is a critical but under-research

5. The Most Robust Studies

Ranked by strength of evidence, not by prominence. The full evaluation includes significantly more studies; only the most reliable are listed here.

Controlled Human Studies

- ¹ The effects of common peroneal stimulation on the effort and speed of walking: a randomised controlled trial with chronic hemiplegic patients (1997)
- ² Effectiveness of upper limb functional electrical stimulation after stroke for the improvement of activities of daily living and motor function: a systematic review and meta-analysis (2017)
- ³ Comparison of robotics, functional electrical stimulation, and motor learning methods for treatment of persistent upper extremity dysfunction after stroke (2015)
- ⁴ The orthotic effect of functional electrical stimulation on the improvement of walking in stroke patients with a dropped foot: a systematic review (2004)
- ⁵ Rehabilitation of reaching and grasping function in severe hemiparetic patients using functional electrical stimulation therapy (2008)
- ⁶ Functional electrical stimulation therapy for voluntary grasping versus conventional rehabilitation alone in patients with subacute incomplete tetraplegia (2011)
- ⁷ Functional electrical stimulation enhancement of upper extremity functional recovery during stroke rehabilitation: a pilot study (2007)
- ⁸ Effects of action observation training plus brain-computer interface-based functional electrical stimulation on paretic arm motor recovery in patients (2016)
- ⁹ Recovery of coordinated gait: a randomised controlled stroke trial of functional electrical stimulation (FES) versus no FES, with weight-supported treadmill training (2011)
- ¹⁰ A pilot randomised controlled trial of gait training in subacute stroke patients with partial body-weight support and electromechanical assistance (2008)
- ¹¹ Controlled study of neuroprosthetic functional electrical stimulation in subacute post-stroke rehabilitation (2005)
- ¹² Cycling induced by electrical stimulation improves motor recovery in post-acute hemiparetic patients: a randomised controlled trial (2011)

- In-home tele-rehabilitation improves tetraplegic hand function (2011)
- A randomised study of home-based electrical stimulation of the legs versus conventional bicycle exercise training for patients with chronic heart failure (2003)
- Activity-based therapy for recovery of walking in individuals with chronic spinal cord injury: results from a randomised clinical trial (2014)
- ¹³ A randomised trial to investigate the effects of functional electrical stimulation and therapeutic exercise on walking performance in people with multiple sclerosis (2009)
- ¹⁴ The effects of peroneal nerve functional electrical stimulation versus ankle-foot orthosis in patients with chronic stroke: a randomised controlled trial (2014)
- ¹⁵ Rehabilitation of hand function in subacute tetraplegic patients based on brain-computer interface and functional electrical stimulation: a randomised pilot study (2016)
- ¹⁶ Functional electrical stimulation of dorsiflexors and plantar flexors during gait to improve walking in adults with chronic hemiplegia (2010)
- ¹⁷ Reducing the cost of transport and increasing walking distance after stroke: a randomised controlled trial of fast locomotor training combined with functional electrical stimulation (2016)
- ¹⁸ Functional electrical stimulation therapy for retraining reaching and grasping after spinal cord injury and stroke (2020)
- Comparative study of the effects of extracorporeal magnetic innervation versus electrical stimulation for urinary incontinence after radical prostatectomy (2004)
- ¹⁹ Contralaterally controlled functional electrical stimulation for upper extremity hemiplegia: an early-phase randomised clinical trial in subacute stroke (2012)
- ²⁰ Contralaterally controlled functional electrical stimulation improves hand dexterity in chronic hemiparesis: a randomised trial (2016)

6. Summary

Functional electrical stimulation (FES) is a widely used method in the rehabilitation of the musculoskeletal system, particularly following stroke and spinal cord injury. Controlled studies show improvements in gait, grasping function, and motor recovery, especially when combined with physiotherapy or electromechanical training. The evidence is most consistent for orthotic effects (e.g., peroneal stimulation for foot drop), while sustained training effects without stimulation are less frequently documented. The safety of FES is supported by numerous studies, with non-invasive applications via surface electrodes being preferred. However, the methodological quality of studies varies widely, often featuring small sample sizes, lack of blinding, and heterogeneous outcome measures. Additionally, active control groups are frequently absent, which limits the conclusiveness of the findings.

HYPOTHESIS The available data suggest that FES primarily serves as an adjunctive therapy rather than a replacement for conventional physiotherapy. Combining FES with other modalities (e.g., robotics or brain-computer interfaces) may yield synergistic effects, though direct comparisons with established therapies (e.g., treadmill training) are still lacking. The absence of standardised stimulation parameters and limited transferability to clinical practice constrain the practical relevance of the results. Furthermore, it remains unclear whether the positive effects are confined to specific patient subgroups (e.g., those with milder paralysis) or can also be achieved in severely affected patients.

To strengthen the evidence base, the following studies would be necessary: 1) Long-term studies with follow-up assessments after at least twelve months to systematically evaluate the sustained benefits of FES compared to other therapeutic approaches. 2) Dose-response analyses to clarify optimal stimulation parameters (intensity, duration, frequency) for different applications. 3) Randomised controlled trials with active control groups (e.g., robotics or treadmill training) to establish the superiority or equivalence of FES. 4) Investigations into patient selection to determine which subgroups (e.g., based on severity of paralysis or comorbidities) benefit most from FES. 5) Cost-effectiveness studies to assess the long-term value of FES relative to acquisition and training costs.

7. Unresolved Questions

- **Long-term effects:** It remains unclear whether FES produces **lasting improvements** after the end of therapy. Most studies conclude on the final day of stimulation.
- **Combination therapies:** There is little systematic research into which **synergies** (e.g., with robotics, virtual reality, or medications) enhance the effect.
- **Implants vs. surface electrodes:** Whether **implanted systems** (e.g., neuroprostheses) yield **better outcomes** than non-invasive methods remains an open question.

Frequently Asked Questions

Can FES be used for chronic paralysis, or is it limited to the acute phase?

Most controlled studies investigate **subacute or chronic phases** (e.g., following stroke or spinal cord injury). The **1997 study** on peroneal stimulation demonstrated that FES has been examined for the treatment of **chronic hemiplegia**, with promising results. However, **neuronal plasticity** is greater in the **acute phase**, which may enhance effects. A **2014 systematic review** on the biology of denervated muscles suggests that FES can still **preserve muscle mass** even in **long-term denervation**, albeit with **reduced effect size**. The **question of the optimal therapeutic phase**, however, remains unresolved.

How safe is FES? Are there risks or side effects that therapists should be aware of?

The **safety of FES** is well-documented in a range of controlled studies. The most common **side effects** include **skin irritation** (with surface electrodes) and **muscle fatigue** at excessive stimulation intensities. **Serious complications** (e.g., cardiac arrhythmias) are **rare** but may occur with **incorrect electrode placement** or **contraindications** (e.g., pacemakers). A **2003 study** on FES in **chronic heart failure** demonstrated that the technique has **no adverse cardiovascular effects** in the examined contexts when applied correctly. Nevertheless, an **individual risk assessment** should be conducted prior to initiation, particularly in **multimorbid patients**.

Which stimulation parameters are best supported by evidence for clinical practice?

The **stimulation parameters** vary considerably across studies, yet some **patterns** emerge. For **gait rehabilitation** (e.g., foot drop), a **frequency of 30–50 Hz** with **pulse durations of 200–400 µs** has proven effective in the examined contexts (e.g., the **2004 study** on peroneal stimulation). For the **upper extremity** (e.g., grip function), **lower frequencies (20–30 Hz)** are often used to **minimise muscle fatigue**. The **amplitude** should be individually adjusted to elicit a **visible muscle contraction** without causing pain. **Hybrid approaches** (e.g., combinations with **robotics** or **brain-computer interfaces**) show promising results in **proof-of-concept studies** (e.g., 2018), but are **not yet standardised**.

Sources

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Research, put in context. Every statement leads to the original paper; the decision in the individual case rests with the treating professional.
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