

Review Article

Acupuncture and related needling in sports-related knee rehabilitation: a narrative review of neurophysiological mechanisms and assessment methods

Guan Fu^{1*}, Haimeng Liu^{2*}, Zihao Sun³, Wei Li², Fangming Liu⁴

¹School of Acupuncture-Moxibustion and Tuina, Shandong University of Traditional Chinese Medicine, Ji'nan 250355, Shandong, China; ²Department of Rehabilitation Medicine, Shandong Medical and Pharmaceutical University Hospital, Binzhou 256603, Shandong, China; ³Rehabilitation Medicine and Physical Therapy, Shandong Medical and Pharmaceutical University, Yantai 264003, Shandong, China; ⁴Department of Pain Medicine, The First Affiliated Hospital of Shandong First Medical University (Shandong Provincial Qianfoshan Hospital), Ji'nan 250014, Shandong, China. *Equal contributors and co-first authors.

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Abstract: Sports-related knee injuries, including anterior cruciate ligament (ACL) rupture, patellofemoral pain (PFP), meniscal injury, and post-traumatic knee osteoarthritis (KOA), are not only problems of local tissue damage. They can alter joint afferent input, quadriceps activation, cortical control, confidence during return-to-sport, and long-term function. For this reason, knee rehabilitation in athletes need to consider both tissue healing and neurophysiological recovery. Manual acupuncture, electroacupuncture (EA), and trigger point dry needling (DN) have been investigated as adjunctive therapies for knee pain and rehabilitation. Manual acupuncture and EA are needle-based interventions derived from traditional Chinese medicine. DN is included here because of its relevance to musculoskeletal rehabilitation, rather than as a traditional Chinese medicine intervention. Clinical studies suggest possible improvements in pain, swelling, range of motion, self-reported function, and neuromuscular performance. Mechanistic studies also suggest effects on cortical hemodynamics, sensorimotor oscillations, descending pain modulation, spinal excitability, muscle activity, and arthrogenic muscle inhibition (AMI). However, direct evidence specifically in sports-related knee injury populations remains limited. This review discusses evidence from functional near-infrared spectroscopy (fNIRS), electroencephalography (EEG), transcranial magnetic stimulation (TMS), electromyography (EMG), clinical acupuncture research, and sports rehabilitation. We group the possible mechanisms into cortical intended, corticospinal or spinal-reflexive, and peripheral muscular levels. This framework is intended to guide future research rather than to imply established causality. Given the limited direct evidence currently available in sports-related knee populations, this review is intentionally hypothesis-generating in nature. Its primary value lies in synthesizing indirect evidence from related fields, constructing a testable mechanistic framework, and proposing concrete experimental designs to inform future research.

Keywords: Acupuncture, electroacupuncture, dry needling, needling modalities, knee injury, anterior cruciate ligament, neuroplasticity, fNIRS, EEG, electromyography, rehabilitation, traditional Chinese medicine, arthrogenic muscle inhibition

Introduction

Sports-related knee injuries are prevalent among active populations and impose a substantial economic burden. Anterior cruciate ligament (ACL) injury is especially prevalent in sports involve pivoting, jumping, and cutting. Non-contact mechanisms are a common cause of these injuries [1-3]. In the United States, outpatient arthroscopic ACL reconstruction ge-

nerates considerable direct medical cost. Registry studies from Scandinavia also show that ACL reconstruction patterns vary by sex, sport exposure, and national practice [4, 5]. PFP is also common. A systematic review reported a point prevalence of 7.2% in adolescents and 22.7% specifically in female adolescent athletes (not in the general population) [6]. Meniscal injuries are common in young athletes and often coexist with ligament trau-

ma, which can complicate rehabilitation and long-term joint health [7].

Even after surgery and rehabilitation, outcomes after knee injury are not always ideal. Approximately 55% of athletes return to competitive sport after ACL reconstruction, and younger athletes have a substantial risk of a second ACL injury after return-to-sport [8, 9]. ACL and meniscal injuries also increase the risk of post-traumatic knee osteoarthritis [10, 11]. Rehabilitation therefore needs to address symptoms, quadriceps function, movement quality, confidence, and joint loading over time. Return-to-sport criteria and reinjury prediction remain debated because strength, hop tests, confidence, movement quality, and sport exposure all affect risk [12, 13].

Given the limited direct evidence in sports-related knee populations—a point we acknowledge throughout this review—it is important to clarify the scope and objectives of this review. This review does not intend to provide definitive clinical recommendations nor to assert that acupuncture/needling definitively reverses the neurophysiological sequelae of knee injury. Rather, its core contribution is threefold: (1) to systematically synthesize available but fragmented neurophysiological evidence on needling interventions across the spectrum of knee conditions (from animal models to healthy volunteers to chronic pain populations to, where available, athletes); (2) to organize this evidence into a coherent three-level mechanistic framework (cortical, corticospinal/spinal-reflexive, and peripheral muscular) that can guide hypothesis-driven research in sports knee rehabilitation; and (3) to explicitly identify critical evidence gaps and translate them into concrete, multimodal study designs, including specific recommendations for participant selection, outcome measures, and trial parameters—that can be directly implemented in future investigations. In this sense, the review is intentionally hypothesis-generating and framework-building, rather than conclusion-driven or practice-changing at this stage.

Methods and scope

This article is a narrative review. This format was chosen because the evidence comes from different fields and cannot be reduced to one pooled effect estimate [14]. The review focused

on the following topics: sports knee injury, ACL injury or reconstruction, PFP, meniscal injury, KOA, acupuncture, EA, DN, fNIRS, EEG, TMS, EMG, AML, and neuromuscular rehabilitation. As a narrative review rather than a systematic or scoping review, PRISMA-ScR and PRISMA 2020 were not used as formal reporting templates, nor should this article be judged against their checklists [15, 16]. However, we drew on the general principles of systematic searching, including using multiple databases, defining search terms a priori, and checking reference lists, to ensure comprehensive coverage of the relevant literature. These practices were adopted to enhance transparency and do not imply that this review follows PRISMA methodology or meets the standards of a systematic review.

Targeted searches were conducted in PubMed, Web of Science, Scopus, and Google Scholar from database inception to 20 May 2026. Search terms included acupuncture, electroacupuncture, dry needling, needling, knee injury, anterior cruciate ligament, ACL reconstruction, patellofemoral pain, meniscal injury, knee osteoarthritis, fNIRS, functional near-infrared spectroscopy, EEG, electromyography, TMS, arthrogenic muscle inhibition, quadriceps activation, neuromuscular control, and rehabilitation. Reference lists of relevant reviews and clinical trials were also checked.

The review gave priority to peer-reviewed studies that linked knee injury, or needling interventions, with measurable central or peripheral neurophysiological outcomes. Evidence from sports-related knee injury populations was considered most directly relevant. Evidence from KOA, chronic pain, healthy volunteers, or animal studies was used to support hypotheses, not as direct proof for injured athletes. DN was included due to its use in musculoskeletal rehabilitation and the availability of EMG-relevant evidence in PFP. DN was not treated as a traditional Chinese medicine intervention.

The mechanistic profiles of dry needling (DN) and acupuncture/electroacupuncture are often conflated in the literature, warranting a conceptual clarification.

All three modalities share a common biophysical starting point: the insertion of a fine needle into soft tissue generates afferent signals from

A- δ and C fibers, which can influence spinal segmental excitability and, under certain conditions, engage supraspinal and descending modulatory pathways. This shared foundation justifies their inclusion within a unified neurophysiological framework.

However, the predominant sites and pathways of action differ substantially. Dry needling primarily targets myofascial trigger points - hyperirritable loci within taut muscle bands-and its effects are largely mediated through peripheral and segmental mechanisms: local twitch responses, disruption of dysfunctional endplate activity, alteration of the local biochemical milieu (e.g., substance P, cytokines), and modulation of spinal reflex excitability. Evidence for supraspinal effects of DN remains limited, and its observed improvements in VMO:VL coordination are most parsimoniously explained by segmental reflex modulation rather than cortical reorganization.

By contrast, manual acupuncture and electroacupuncture engage a broader range of peripheral and central mechanisms. Manual acupuncture, particularly when deqi sensation is elicited, modulates activity in sensorimotor and limbic networks (as evidenced by fNIRS, EEG, and fMRI studies) and influences descending pain pathways via endogenous opioid, serotonergic, and noradrenergic systems. Electroacupuncture adds a frequency-dependent dimension: low-frequency (2-10 Hz) EA preferentially engages enkephalin and endorphin pathways, while high-frequency (50-100 Hz) EA involves dynorphin and spinal-segmentally mediated mechanisms, with effects extending to autonomic and immunomodulatory pathways.

Thus, while dry needling and acupuncture/EA share a common needle-based interface and some overlapping spinal mechanisms, they are not mechanistically equivalent. Dry needling operates predominantly at peripheral and segmental levels, whereas acupuncture/EA recruit additional supraspinal and corticolimbic networks. In this review, we discuss them within the same framework not because their mechanisms are identical, but because they represent a continuum of needling-based neuromuscular interventions-from primarily peripheral (DN) to mixed peripheral-central (manual acupuncture) to frequency-controlled peripher-

al-central with specific neurochemical signatures (EA). This continuum provides a useful heuristic for designing comparative studies and for selecting the appropriate modality based on the target mechanism of interest. For instance, if the target mechanism is cortical sensorimotor reorganization, manual acupuncture or EA may be more appropriate than DN; if the target is peripheral trigger point deactivation, DN may be the preferred choice.

Central and peripheral adaptations following sports-related knee injury

Cortical reorganization after ACL injury

Neuroimaging and neurophysiological studies suggest that ligamentous knee injury is associated with changes in brain function. Functional magnetic resonance imaging (fMRI) work in ACL-deficient participants showed altered brain activation during knee movement, including changes in sensorimotor regions and greater involvement of visual areas [17]. Subsequent rehabilitation studies proposed that ACL injury may shift motor control toward greater reliance on visual and attentional processes [18]. Reviews of EEG, TMS, fMRI, diffusion tensor imaging (DTI), and fNIRS studies support persistent changes in sensorimotor activation, corticospinal excitability, and brain organization after ACL injury or reconstruction [19-22].

Corticolimbic and structural cortical findings are also relevant. ACLR patients often exhibit altered activity in corticolimbic regions during imagery tasks, and these responses correlate with kinesiophobia and readiness to return-to-sport [23, 24]. More recent work has linked cortical morphology, corticospinal excitability, corticomotor representation, and quadriceps strength after ACL injury [25]. These findings suggest that persistent weakness is not solely a peripheral muscle issue.

Neuromuscular control deficits and arthrogenic muscle inhibition

AMI is a clinically significant consequence of knee injury. It refers to the failure to fully activate the quadriceps despite voluntary effort. Proposed mechanisms include altered joint afferent discharge, presynaptic inhibition, gamma-loop dysfunction, spinal reflex changes, and supraspinal influences [26-28]. Meta-

Table 1. Main neurophysiological techniques and their applications in acupuncture/dry needling research

Technique	Measured entity	Temporal resolution	Spatial resolution	Relevant applications in this review
fNIRS	Cortical hemoglobin changes	Medium (~1 Hz)	Low-medium	Acupuncture modulation of DLPFC/M1/S1
EEG	Postsynaptic oscillatory activity	High (ms range)	Low	Mu rhythm, beta oscillations, motor preparation
TMS	Cortical excitability/plasticity	High (ms range)	Medium	Motor evoked potential (MEP), SICI/ICF
EMG	Muscle electrical activity	High (ms range)	Very low	VMO: VL ratio, onset timing, AMI

Abbreviation: fNIRS, functional near-infrared spectroscopy; EEG, electroencephalography; TMS, transcranial magnetic stimulation; EMG, electromyography; DLPFC, dorsolateral prefrontal cortex; M1, primary motor cortex; S1, primary somatosensory cortex; MEP, motor-evoked potential; SICI, short-interval intracortical inhibition; ICF, intracortical facilitation; VMO, vastus medialis obliquus; VL, vastus lateralis; AMI, arthrogenic muscle inhibition.

analytic evidence shows that quadriceps strength and voluntary activation deficits can persist after ACL reconstruction. Bilateral activation deficits may be missed when only limb symmetry is examined [29].

Experimental and clinical studies support a reflexive component of AMI. Knee joint effusion can suppress quadriceps H-reflex amplitude and motoneuron pool excitability, and these responses are partly mediated by joint afferent input [30, 31]. Reviews suggest that cryotherapy, exercise, neuromuscular stimulation, and eccentric strengthening may reduce AMI or improve quadriceps recovery, although the mechanisms are not fully settled [32-34].

Patellofemoral and meniscal conditions

PFPP presents a distinct yet related neuromuscular profile. Studies have reported delayed onset or altered activation of vastus medialis obliquus relative to vastus lateralis in PFPP. Consensus statements emphasize exercise therapy, education, load management, and individualized adjunctive care [35-39]. Meniscal injury has a different structural basis, but the meniscus contributes to load distribution and joint function. Meniscal lesions are also associated with later osteoarthritis risk in some populations [40, 41]. Clinical outcomes such as the KOOS and IKDC subjective knee form remain useful when symptoms and function are compared with mechanistic measures [42, 43].

fNIRS evidence: acupuncture modulation of cortical hemodynamics

Before reviewing the fNIRS evidence, **Table 1** provides an overview of the main neurophysiological techniques used in acupuncture and

needling research, including their temporal and spatial resolution characteristics.

Technical and methodological considerations

fNIRS measures changes in oxygenated and deoxygenated hemoglobin in superficial cortical tissue using near-infrared light. It is portable, relatively quiet, more tolerant of movement than fMRI, and usable during several rehabilitation tasks [44-48]. However, its limits should be considered. Depth sensitivity is restricted, short-separation correction can be important, and motion artifacts or systemic physiology can affect the signal [49-51].

fNIRS evidence in knee conditions and acupuncture

Direct fNIRS evidence in athletic knee populations remains limited. One near-infrared study during stair ascent after ACL reconstruction found different cortical activation patterns between ACLR patients and healthy controls. The findings suggested altered activation of premotor, supplementary motor, and somatosensory areas during a functional task [52]. In KOA, fNIRS has been used to show changes in prefrontal activation after exercise treatment. This supports its use for studying pain and rehabilitation-related cortical responses [53].

fNIRS studies of acupuncture in healthy volunteers and simulated clinical settings show changes in prefrontal and sensorimotor hemodynamics. Manual acupuncture with deqi altered hemodynamic response and functional connectivity in a prefrontal-motor network. Different reinforcing-reducing manipulations produced distinct dorsolateral prefrontal cortex (DLPFC)-primary somatosensory cortex (S1)

activation and connectivity patterns [54, 55]. Pilot and hyperscanning studies also show that fNIRS can be used to study acupuncturist-patient interaction and central responses to acupuncture stimulation [56, 57]. These studies provide a rationale for direct fNIRS trials in ACLR or PFP populations, but they do not substitute for such trials.

EEG evidence: sensorimotor oscillation modulation by acupuncture

Sensorimotor rhythms and knee injury

EEG offers high temporal resolution, making it useful for studying motor preparation, execution, and sensory processing. Mu rhythms are often discussed in relation to sensorimotor engagement, while beta activity is linked with movement preparation, execution, and post-movement rebound [58, 59]. Event-related synchronization and desynchronization help describe how motor and sensory systems are engaged during movement [60, 61]. In ACLR populations, EEG studies have reported higher frontal theta and altered alpha activity during joint position or force-control tasks. These findings suggest greater attentional demand and altered sensorimotor processing even when task performance appears similar [62, 63].

Acupuncture effects on oscillatory and brain-network activity

Acupuncture and related stimulation methods can modulate oscillatory activity in sensorimotor and pain networks. Magnetoencephalography (MEG) beamforming work found reduced beta-band power in contralateral somatosensory cortex during manual acupuncture. EEG evidence also suggests that acupuncture analgesia can involve gamma oscillation and changes in cortical connectivity [64, 65]. Studies comparing acupressure and electroacupuncture report different cortical responses. This supports separating manual, electrical, and pressure-based stimulation in future trials [66].

Neuroimaging studies also support central effects of acupuncture. fMRI studies and reviews have linked acupuncture to limbic, brainstem, somatosensory, and pain-modulatory networks, although study designs and control conditions vary widely [67-72]. For sports knee rehabilitation, these data are best considered

hypothesis-generating. They do not prove that acupuncture reverses ACL-related cortical reorganization.

EMG and spinal-level evidence: neuromuscular effects of acupuncture and needling

Dry needling and EMG-measured motor control

The most direct EMG evidence for needling modalities comes from PFP. In a randomized controlled trial, Ma et al. found that quadriceps trigger point DN improved pain, function, and VMO:VL neuromuscular performance compared with sham needling plus stretching (*a component of therapeutic exercise*) [73]. A systematic review and meta-analysis reported low-to-moderate evidence that DN may reduce pain and disability in knee pain syndromes, especially when it is combined with exercise [74].

DN may act through both local and central mechanisms. Myofascial trigger points are associated with altered endplate activity, local biochemical changes, the release of pain mediators, and impaired motor control [75-79]. Systematic reviews of dry needling for musculoskeletal pain support short-term effects in some body regions, but effects vary by population, comparator, dose, and co-interventions [80-83]. DN should therefore be viewed as a possible neuromuscular adjunct, not as a stand-alone treatment for knee rehabilitation.

Electroacupuncture and spinal motoneuron excitability

EA may affect spinal and supraspinal pathways through electrically driven afferent input. In an animal model of spinal cord compression injury, EA improved locomotor outcomes and altered H-reflex and ventral root potentials. This animal evidence suggests that electrical needle stimulation can influence spinal excitability under certain conditions; however, direct translation to injured athletes requires human studies [84]. Studies of acupuncture analgesia suggest that EA effects depend partly on stimulation frequency and involve endogenous opioids, serotonin, norepinephrine, and descending pain modulation [85-92].

Local tissue responses may also contribute to acupuncture effects. Needle rotation can pro-

duce measurable biomechanical responses in connective tissue. Experimental studies have reported acupuncture-related fibroblast remodeling, adenosine signaling, and autonomic-immune mechanisms [93-99]. These findings help form hypotheses, but they do not show that acupuncture resolves AMI after ACL reconstruction.

Clinical evidence across knee conditions

Chronic knee pain and knee osteoarthritis

The strongest clinical evidence for acupuncture is in chronic pain and knee osteoarthritis, rather than in sports injury. Individual patient data meta-analysis supports acupuncture over sham and no-acupuncture controls for chronic pain, including osteoarthritis. Some effects may persist after treatment [100, 101]. Cochrane and network meta-analytic evidence also supports a role for acupuncture in osteoarthritis pain, although effect size and clinical relevance vary by comparator and study design [102, 103].

Large randomized trials in knee osteoarthritis have produced mixed results. The largest of these, the German Acupuncture Trials (GERAC; n=1,002), found that both verum and sham acupuncture produced clinically meaningful improvements in WOMAC pain and function scores at 26 weeks compared with usual care, with no significant difference between the two groups [104]. Similarly, a US multi-center trial (n=570) reported that acupuncture as adjunctive therapy produced modest but statistically significant improvements in WOMAC pain (mean difference -3.4, 95% CI -5.4 to -1.4) and function scores compared with sham acupuncture at 23 weeks, although the clinical significance of this effect size has been debated [105]. In contrast, a more recent Australian trial (n=282) found no clinically important difference between acupuncture and sham acupuncture when both were added to advice and exercise, suggesting a smaller added benefit of acupuncture over credible sham than previously thought [106]. Neuroimaging studies in KOA suggest that acupuncture can modulate cortical thickness and resting-state connectivity in regions involved in pain modulation [107, 108]. This may help explain clinical effects in chronic knee pain, but the evidence is not specific to injured athletes. Thus, while the KOA

evidence provides valuable mechanistic and clinical insights, its direct applicability to athletic populations requires caution, as the underlying pathophysiology and functional demands differ substantially. Nevertheless, we include it here because it represents the highest-quality clinical evidence currently available for acupuncture/EA in knee pain, and it forms the evidentiary foundation upon which future sports-specific trials should be built.

Recent systematic reviews support a cautious interpretation. One review found post-treatment improvements in pain and function in KOA, but it also found no clear added benefit of combining acupuncture with exercise-based physical therapy in some comparisons [109]. A network meta-analysis showed that the apparent effect of sham acupuncture may differ depending on whether sham needles are placed at the same points as verum acupuncture or at different points [110]. Recent reviews of electrical acupoint stimulation and acupuncture combined with moxibustion report possible benefit, but they also note heterogeneity, low certainty for some outcomes, and the need for better standardized trials [111, 112].

ACL reconstruction, post-surgical knee rehabilitation, and related TCM evidence

Direct evidence specifically in ACLR populations is limited. A systematic review of TCM after ACL reconstruction reported improvements in pain, Lysholm score, range of motion, and swelling when TCM was combined with conventional rehabilitation, but many included trials were small or had methodological weaknesses [113]. A Chinese randomized trial reported that EA combined with routine rehabilitation significantly improved pain, swelling, range of motion, and IKDC and Lysholm score after ACL reconstruction [114]. A small prospective study, published in a complementary medicine journal, suggested that EA combined with growth hormone may reduce quadriceps atrophy after ACL reconstruction [115]. The independent effect of EA remains unclear and needs separate testing.

Evidence from total knee arthroplasty is not directly generalizable to sports knee injury. It is still relevant because it involves post-surgical pain, swelling, and quadriceps recovery. Meta-analyses suggest that EA or acupuncture may

Table 2. Summary of clinical evidence on different needling interventions for sports-related knee conditions

Condition/ population	Intervention	Evidence type	Main outcomes	Strength of evidence	Limitations
Knee osteoarthritis (KOA)	Manual acupuncture/ electroacupuncture	Individual patient data meta-analysis	Pain, function	Moderate†	Non-athlete populations; sham control heterogeneity
Patellofemoral pain (PFP)	Dry needling (combined with exercise)	RCT + meta-analysis	VMO: VL ratio, pain (effects enhanced when combined with exercise)	Low-moderate†	Small sample sizes; lack of long-term follow-up
ACL reconstruction (ACLR)	Electroacupuncture	Small RCT	Pain, ROM, Lysholm score	Low†	Methodological weakness; intervention heterogeneity
ACL reconstruction (ACLR)	Traditional Chinese medicine (combined)	Systematic review	Lysholm score, swelling	Very low†	High risk of bias in most included trials

†Evidence grades are the authors' qualitative assessment, based on the strength and consistency of the available evidence, considering study design, sample size, heterogeneity, and directness to the population of interest. Grades were not derived from a formal GRADE assessment. These grades reflect the strength of direct evidence for needling interventions specifically in the sports-related knee population indicated, not the overall evidence base for acupuncture or dry needling in broader pain or neuro-modulation contexts. Abbreviation: KOA, knee osteoarthritis; PFP, patellofemoral pain; ACLR, anterior cruciate ligament reconstruction; VMO, vastus medialis obliquus; VL, vastus lateralis; ROM, range of motion; TCM, traditional Chinese medicine.

support selected rehabilitation outcomes after total knee arthroplasty, but protocol heterogeneity and trial quality remain concerns [116, 117].

Relationship to established rehabilitation interventions

Acupuncture should be studied as an adjunct to established rehabilitation, not as a replacement. Eccentric exercise, proprioceptive training, and neuromuscular electrical stimulation each have evidence supporting their use in improving neuromuscular recovery after ACL reconstruction or traumatic knee injury. These approaches provide useful comparators or co-interventions in future acupuncture trials [118-121]. A clinically informative trial should ask whether needling adds value to progressive exercise, motor learning, load management, and return-to-sport training.

The clinical evidence for needling interventions across different knee conditions is summarized in **Table 2**, highlighting the heterogeneity in study populations, intervention types, and evidence strength.

Proposed mechanisms

The evidence reviewed above can be organized into three levels. At the cortical level, manual acupuncture and electroacupuncture (EA) may modulate activity in the DLPFC, primary motor cortex (M1), S1, supplementary motor area (SMA), and pain-related networks. This level can be assessed by fNIRS, EEG, MEG, fMRI, and TMS. In sports knee injury, the main ques-

tion is whether needling reduces excessive attentional or visual dependence and supports more efficient sensorimotor control during rehabilitation tasks. The proposed three-level framework is illustrated in **Figure 1**.

At the corticospinal and spinal-reflexive level, EA may influence pain processing, descending modulation, and spinal excitability. This is relevant to AMI because quadriceps activation failure is partly mediated by altered afferent input and spinal inhibitory mechanisms. At the peripheral muscular level, DN may reduce trigger point irritability and improve quadriceps coordination. These levels may interact. Pain reduction can change cortical control, cortical control can change descending drive, and improved muscle recruitment can support better task practice. The proposed levels, along with modality-specific considerations for dry needling, manual acupuncture, and electroacupuncture, are summarized in **Table 3**.

Future research directions

Future studies should incorporate concurrent assessments of brain, muscle, and movement in the same participants. One practical design would involve recording fNIRS over DLPFC, M1, and S1, surface EMG from VMO, VL, rectus femoris, and hamstrings, and motion capture during stair negotiation or single-leg squat. This would allow investigators to test whether needling interventions (e.g., manual acupuncture, EA, or DN) change cortical activation, quadriceps coordination, and movement quality in the same rehabilitation task.

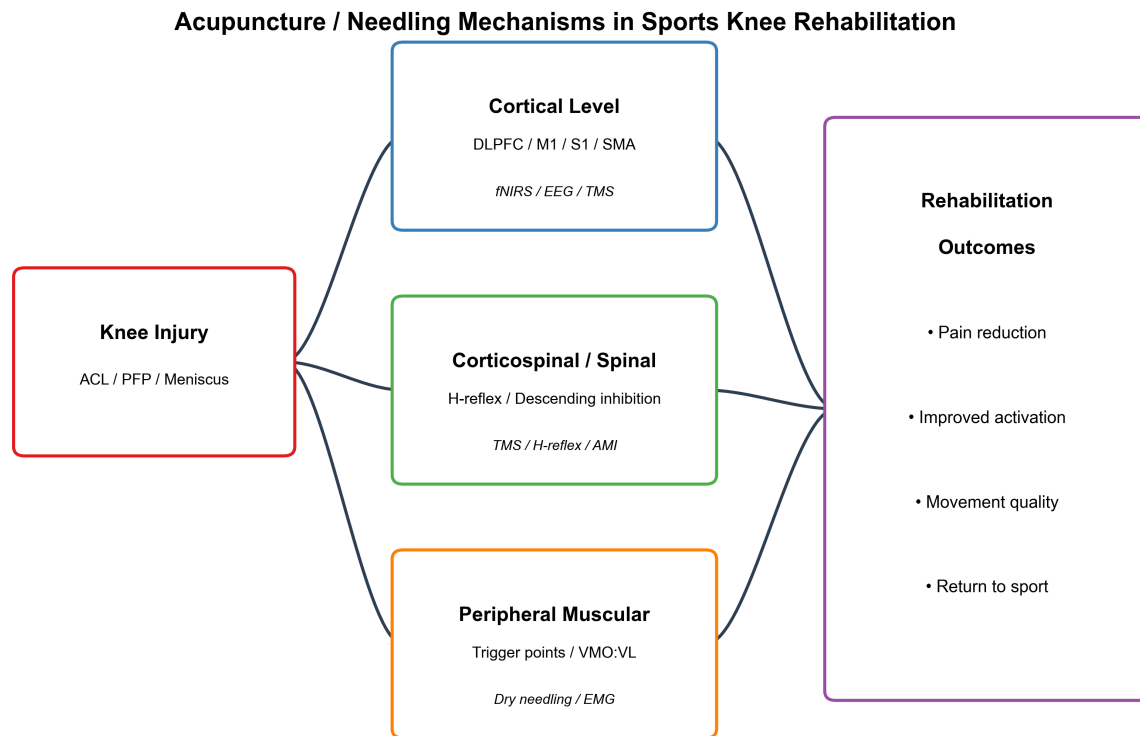


Figure 1. Proposed neurophysiological mechanisms underlying acupuncture and related needling interventions in sports-related knee rehabilitation. The diagram illustrates three levels of action: (1) cortical (DLPFC, M1, S1, SMA), assessed by fNIRS/EEG/TMS; (2) corticospinal/spinal-reflexive (H-reflex, descending inhibition, AMI), assessed by TMS/H-reflex/EMG; and (3) peripheral muscular (trigger points, VMO:VL coordination), targeted by dry needling and assessed by EMG. These levels interact and collectively contribute to improved rehabilitation outcomes, including pain reduction, improved activation, movement quality, and return-to-sport. Abbreviation: DLPFC, dorsolateral prefrontal cortex; M1, primary motor cortex; S1, primary somatosensory cortex; SMA, supplementary motor area; fNIRS, functional near-infrared spectroscopy; EEG, electroencephalography; TMS, transcranial magnetic stimulation; H-reflex, Hoffman reflex; AMI, arthrogenic muscle inhibition; EMG, electromyography; VMO, vastus medialis obliquus; VL, vastus lateralis.

Dose-response studies of EA are also needed. Current protocols vary in frequency, intensity, session duration, point selection, and treatment frequency. A factorial study could compare 2 Hz, 10 Hz, 50 Hz, and 100 Hz EA while measuring pain, H-reflex, CAR, EMG, and fNIRS outcomes. Such studies should distinguish analgesic effects from neuromuscular recovery effects.

Future ACLR trials should include neurophysiological outcomes, not only clinical scores. A three-arm trial could compare standard rehabilitation plus verum EA, standard rehabilitation plus sham EA, and standard rehabilitation alone (**Figure 2**). Outcomes could include CAR, H-reflex, VMO:VL EMG ratio, quadriceps strength, fNIRS connectivity during functional tasks, IKDC score, Lysholm score, ACL-RSI, and return-to-sport status. Trial reports should follow TIDieR, CONSORT, and STRICTA guidance

so that randomization, acupuncture parameters, comparator conditions, and rehabilitation co-interventions are clear enough to reproduce [122-124].

In addition to neurophysiological outcomes, psychological measures should also be included. Kinesiophobia and psychological readiness affect return-to-sport after ACL reconstruction. Acupuncture may influence pain, threat appraisal, and prefrontal regulation; however, this hypothesis requires direct testing. Studies that combine the Tampa Scale for Kinesiophobia (TSK-11), ACL-RSI, pain catastrophizing, EEG, and fNIRS would help determine whether clinical improvement is accompanied by neurophysiological and psychological changes.

While the proposed multimodal trial design offers a comprehensive approach, several practical considerations merit discussion. First,

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Table 3. Proposed levels of needling effects in sports knee injury rehabilitation, with modality-specific considerations

Tier/Level	Assessment Tools	Main mechanism considered	Modality Specificity	Key Refs
Tier 1: Cortical	fNIRS; EEG/MEG; fMRI; TMS	Needling may change activity in DLPFC, M1, S1, SMA, visual-motor reliance, and sensorimotor oscillations. Direct testing in sports knee injury populations remains limited.	Manual acupuncture/EA (primary): Evidence supports supraspinal engagement via sensorimotor and limbic networks. DN: Minimal direct evidence for cortical effects; supraspinal actions remain speculative.	[17-25, 44-72]
Tier 2: Corticospinal/Spinal-Reflexive	H-reflex; CAR; TMS-MEP; SICl/ICF; AMI measures	EA may alter nociceptive input, descending pain pathways, presynaptic inhibition, and motoneuron pool excitability. Direct ACLR evidence is still sparse.	EA (primary): Frequency-dependent effects on spinal excitability via endogenous opioid pathways. DN (segmental): Modulates spinal reflex excitability via trigger point deactivation. Manual acupuncture: Intermediate; effects may involve both segmental and supraspinal components.	[26-32, 84-99]
Tier 3: Peripheral Muscular	sEMG; VMO: VL ratio; onset timing; dynamometry; motion capture	DN may reduce trigger point irritability and improve quadriceps recruitment and coordination, especially in PFP-related VMO/VL dysfunction.	DN (primary): Directly targets myofascial trigger points; effects mediated via local twitch responses, endplate activity modulation, and segmental reflexes. Manual acupuncture/EA (adjunctive): May complement via pain modulation and improved muscle activation, but direct peripheral effects are less well characterized.	[33-39, 73-83]
Interactions across levels	Combined fNIRS, EEG, EMG, motion capture; clinical scales	Pain relief, cortical control, spinal excitability, and muscle recruitment may act together. Direct multimodal testing is still needed.	All modalities may contribute, but through different primary pathways; combined interventions (e.g., EA + exercise) may yield synergistic effects.	[100, 101, 111-123]

Note: Mechanisms are grouped by the main level at which they are usually assessed. The levels are not independent, and the strength of evidence differs across populations and modalities. The table summarizes possible mechanisms. It does not imply that each pathway has been directly demonstrated in sports-related knee injury populations. "Modality Specificity" indicates the primary level at which each intervention has the strongest evidence; this does not exclude the possibility of effects at other levels, but reflects the current state of the literature. fNIRS, functional near-infrared spectroscopy; EEG, electroencephalography; MEG, magnetoencephalography; fMRI, functional magnetic resonance imaging; TMS, transcranial magnetic stimulation; MEP, motor-evoked potential; SICl, short-interval intracortical inhibition; ICF, intracortical facilitation; CAR, central activation ratio; VMO, vastus medialis obliquus; VL, vastus lateralis; DN, dry needling; EA, electroacupuncture; PFP, patellofemoral pain; ACLR, anterior cruciate ligament reconstruction.

Proposed Three-Arm Trial Design with Multimodal Assessment

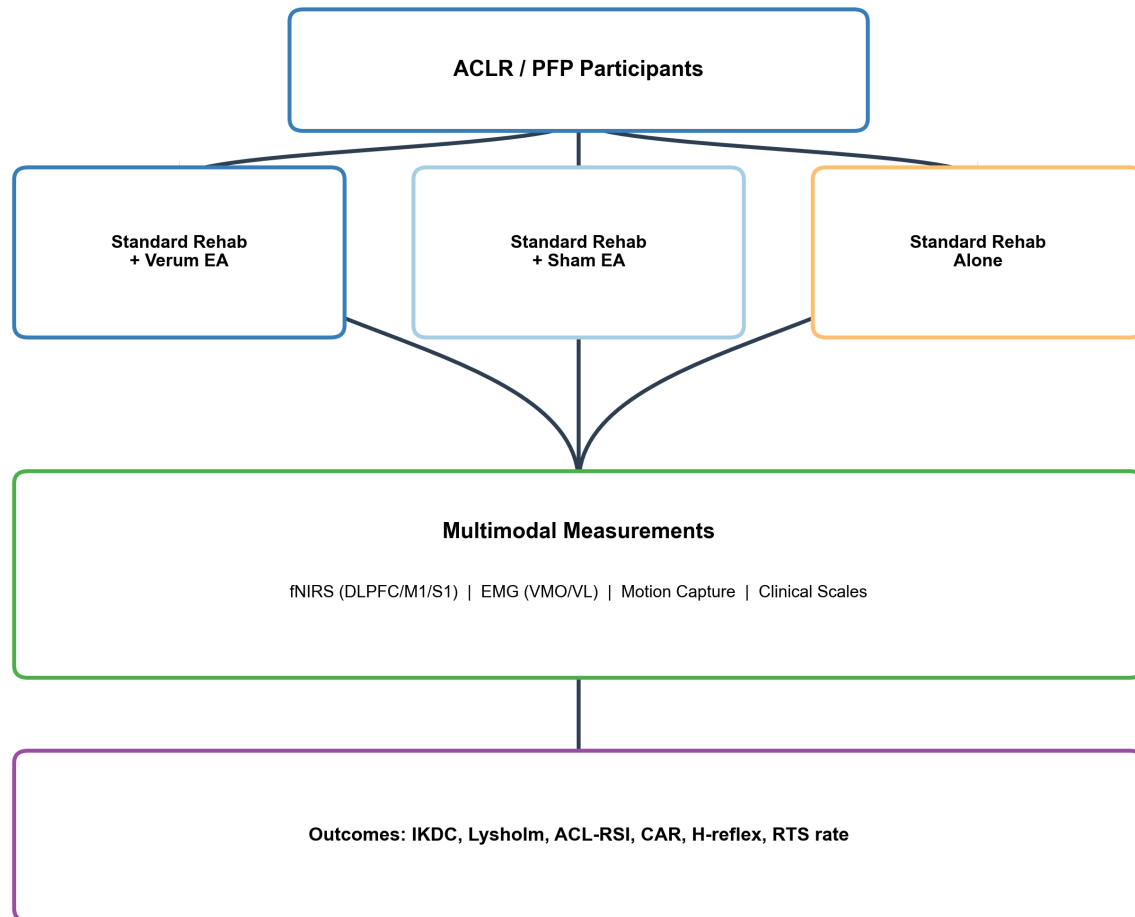


Figure 2. Proposed three-arm trial design for evaluating electroacupuncture as an adjunct to standard rehabilitation following ACL reconstruction or for patellofemoral pain. Participants are randomized to (1) standard rehabilitation plus verum electroacupuncture, (2) standard rehabilitation plus sham electroacupuncture, or (3) standard rehabilitation alone. Multimodal assessments include fNIRS (DLPFC/M1/S1), EMG (VMO/VL), motion capture, and clinical scales. Primary outcomes cover clinical scores (IKDC, Lysholm, ACL-RSI), neurophysiological measures (CAR, H-reflex), and return-to-sport rate. Abbreviation: EA, electroacupuncture; fNIRS, functional near-infrared spectroscopy; DLPFC, dorsolateral prefrontal cortex; M1, primary motor cortex; S1, primary somatosensory cortex; EMG, electromyography; VMO, vastus medialis obliquus; VL, vastus lateralis; IKDC, International Knee Documentation Committee; ACL-RSI, Anterior Cruciate Ligament Return to Sport after Injury; CAR, central activation ratio; H-reflex, Hoffman reflex.

concurrent fNIRS, EMG, and motion capture during functional tasks pose significant demands on equipment synchronization, personnel expertise, and data processing. A pragmatic alternative is a phased assessment schedule, in which fNIRS and EMG are recorded on separate sessions to reduce participant burden and data complexity. Second, sample size estimation should account for the expected effect sizes derived from existing fNIRS and EMG literature in knee conditions; based on previous

studies, an effect size of Cohen's $d \approx 0.5-0.7$ for cortical hemodynamic changes would require approximately 40-50 participants per arm (with 15-20% attrition) to achieve 80% statistical power. Third, although the acupuncturist cannot be blinded, assessors conducting neurophysiological measurements and data analysts can be blinded to group allocation; sham EA using non-penetrating sham needles and inactive stimulators should be carefully validated for credibility. These practical consid-

erations are essential for translating the proposed design into feasible, methodologically sound trials.

Limitations

This review has several limitations. First, it is a narrative review rather than a systematic review. Although the literature was organized by topic and database searches were conducted, there was no formal dual screening, risk-of-bias assessment, formal certainty grading (e.g., GRADE or Cochrane), or quantitative synthesis. However, we have provided a qualitative summary of evidence strength in **Table 2** based on the authors' assessment of study design, sample size, and consistency of findings. Second, the evidence base is heterogeneous. Studies differ in injury type, postoperative timing, acupuncture modality, stimulation parameters, control condition, rehabilitation co-interventions, and neurophysiological outcomes.

Several mechanistic links remain speculative. For example, evidence that EA modulates descending pain pathways or H-reflex behavior does not prove that it alleviates quadriceps AMI after ACL reconstruction. Similarly, evidence that DN changes trigger point irritability does not confirm restoration of sport-specific neuromuscular control. Many acupuncture studies are conducted in healthy volunteers, chronic pain populations, or animal models. These studies help build hypotheses but should not be treated as direct evidence for injured athletes.

Importantly, the limitations noted above, particularly the scarcity of direct evidence in sports knee populations and the reliance on indirect data from chronic pain, healthy volunteers, and animal models, should not be interpreted solely as weaknesses. Rather, they define the precise scope and purpose of this review: to identify what is known, what remains unknown, and how the gap between them can be bridged. By systematically mapping indirect evidence onto a mechanistic framework and proposing concrete study designs, this review serves as a hypothesis-generating resource to inform future confirmatory studies. The limitations are therefore not obstacles to the review's utility, but the very reason such a review is needed.

Conclusion

Sports-related knee injuries can disrupt neuromuscular control beyond the injured ligament, meniscus, cartilage, or periarticular tissue. Cortical reorganization, altered corticospinal excitability, AMI, pain-related changes, and abnormal muscle coordination can all influence rehabilitation. Acupuncture, EA, and related needling approaches such as DN are possible adjuncts because they may influence pain, cortical activity, spinal excitability, and muscle control. DN should be regarded as a related rehabilitation needling modality, rather than a traditional Chinese medicine intervention. Current evidence supports hypothesis generation and adjunctive use, not replacement of established rehabilitation.

Direct testing in sports knee populations is now needed. The three-level framework and the multimodal trial design proposed in this review provide a roadmap for such investigations. Studies that combine brain measures such as fNIRS or EEG, corticospinal measures such as TMS, EMG, and motion capture can test whether needling-related neurophysiological changes are associated with improvements in strength, movement quality, confidence, and return-to-sport outcomes. By synthesizing indirect evidence, identifying clear gaps, and offering testable hypotheses and study designs, this review aims to accelerate the translation of neurophysiological knowledge into hypothesis-driven rehabilitation research—even as direct evidence in athletic populations continues to accumulate.

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Disclosure of conflict of interest

None.

Address correspondence to: Fangming Liu, Department of Pain Medicine, The First Affiliated Hospital of Shandong First Medical University (Shandong Provincial Qianfoshan Hospital), No. 16766 Jingshi Road, Lixia District, Ji'nan 250014, Shandong, China. Tel: +86-0531-89268900; E-mail: liufangming8431@163.com; Wei Li, Department of

Rehabilitation Medicine, Shandong Medical and Pharmaceutical University Hospital, No. 661, Second Huanghe Road, Bincheng District, Binzhou 256603, Shandong, China. Tel: +86-15266720333; E-mail: yishengliwei@163.com

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