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Selective Electrical Muscle Stimulation of the Vastus Medialis in a Patient With Knee Osteoarthritis, With Changes in Muscle Quality, Symptoms, and Physical Activity: A Case Report

Authors' Contribution:

Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
Literature Search F
Funds Collection G

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Patient: Male, 77-year-old
Final Diagnosis: Osteoarthritis of the knee
Symptoms: Decrease in physical activity • knee joint pain
Clinical Procedure: —
Specialty: Rehabilitation

Objective: Unusual or unexpected effect of treatment
Background: Fat accumulation in the vastus medialis has been associated with the progression of knee osteoarthritis. Electrical muscle stimulation may reduce intramuscular fat accumulation by inducing contractions of the targeted muscle. We hypothesized that electrical stimulation of the vastus medialis would be associated with a reduction in intramuscular fat and improvement in self-reported symptoms during the observation period in a patient with knee osteoarthritis.

Case Report: The patient was a 77-year-old man with Kellgren-Lawrence grade 2 right knee osteoarthritis. Because he also had hypertension and hyperlipidemia, he had maintained regular exercise habits, including aquatic walking; however, he discontinued these activities because of knee pain. Electrical stimulation was applied to the vastus medialis for 30 minutes per session, 3 times per week, for 4 weeks. Ultrasound echo intensity, an indirect indicator of intramuscular fat, and the Knee Injury and Osteoarthritis Outcome Score were assessed before and after the intervention. Compared with the pre-intervention value, vastus medialis echo intensity decreased by 13.7 arbitrary units (25.3%), and knee symptoms improved during the observation period. He resumed aquatic walking 2 weeks after electrical stimulation was initiated.

Conclusions: During the observation period, vastus medialis echo intensity decreased, Knee Injury and Osteoarthritis Outcome Score scores improved, and he resumed aquatic walking. However, because this was a single uncontrolled case and physical activity resumed during the intervention, these changes cannot be attributed to electrical stimulation alone; spontaneous improvement, behavioral reactivation, or a combination of these factors remain plausible. Controlled studies across different levels of disease severity are needed.

Keywords: Activities of Daily Living • Case Reports • Electric Stimulation • Osteoarthritis, Knee • Quadriceps Muscle • Ultrasonography

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Introduction

The incidence of knee osteoarthritis (KOA) is increasing worldwide [1]. KOA can lead many individuals to reduce their physical activity levels, which may contribute to a shorter healthy life expectancy. Although many factors contribute to the progression of KOA, one such factor is fat accumulation in the quadriceps femoris [2,3]. Among the quadriceps muscles, the vastus medialis (VM) has attracted particular attention [4-6]. Longitudinal studies have reported associations between increased intramuscular fat (IMF) in the VM and meniscal tears, articular cartilage loss, bone marrow lesion progression, symptoms, and physical dysfunction [4-6]. However, whether IMF accumulation in the VM occurs specifically as part of KOA pathophysiology or results from reduced physical activity caused by KOA-related pain, limited range of motion, and muscle weakness remains unclear. Investigating whether changes in VM IMF are accompanied by changes in KOA symptoms and physical activity may contribute to the development of new treatment approaches for patients with KOA.

Muscle contraction is important for reducing IMF, and electrical muscle stimulation (EMS) can induce muscle contraction [7]. EMS has been investigated as a potential treatment for painful joint conditions such as KOA. Because no previous reports have documented whether EMS applied to the VM is associated with reduced IMF in patients with KOA, we previously investigated whether VM-targeted EMS could reduce IMF in healthy adults using ultrasound echo intensity (EI), an indicator of IMF [8]. The results showed that 30-minute EMS sessions performed 3 times per week for 4 weeks reduced EI in the VM [9]. Based on these findings, we considered applying EMS to the VM in a patient with KOA. However, because patients diagnosed with KOA typically receive orthopedic treatment, pharmacotherapy, or physical therapy, determining changes associated specifically with EMS under such circumstances is difficult.

We hypothesized that, in this patient with KOA who had discontinued treatment, VM-targeted EMS would be associated with a reduction in VM EI and improvement in patient-reported symptoms during the observation period. We therefore applied EMS to the VM and documented the clinical course. We present this case report in accordance with the CARE guidelines [10].

Case Report

The patient was a 77-year-old man whose chief concern was “sharp knee pain during walking”.

Approximately 1.5 weeks before the EMS intervention, he began experiencing pain in the medial compartment of his

right knee, which interfered with weight-bearing activities. Consequently, he was unable to continue his regular exercise routine, which included aquatic and outdoor walking, leading to reduced physical activity. After visiting an orthopedic clinic near his home, he was diagnosed with Kellgren-Lawrence (KL) grade 2 right KOA based on radiographic findings [11]. He was prescribed oral nonsteroidal anti-inflammatory drugs (NSAIDs; loxoprofen sodium), a loxoprofen sodium patch, and physical therapy. However, after taking the oral medication twice and undergoing 2 physical therapy sessions, he discontinued both treatments of his own volition. Additionally, he did not wear a knee brace or other support device in his daily life.

He had been receiving pharmacotherapy for hypertension and hyperlipidemia for approximately 30 years. Believing that exercise was also necessary, he engaged in aquatic walking for 30 minutes 3 to 4 times per week and consciously sought to walk regularly. His current medications included a long-acting calcium channel blocker (nifedipine) and an angiotensin II receptor blocker (azilsartan) for hypertension, as well as a fibrate (bezafibrate extended-release tablets) and a hydroxymethylglutaryl-CoA reductase inhibitor (rosuvastatin calcium tablets) for hyperlipidemia. Additionally, he had no history of muscle-related conditions, such as autoimmune myopathy.

Weight-bearing pain was localized to the medial joint space of the right knee and was confirmed by tenderness on palpation. The patellar ballotement test result was negative, and no joint effusion was observed on physical examination. Knee range of motion ranged from 0° of extension to 135° of flexion, with no notable restriction. Muscle strength was not tested, because of concerns related to his hypertension.

Regarding activities of daily living, his Barthel Index score was 100 [12]. However, the Japanese Knee Injury and Osteoarthritis Outcome Score (KOOS) [13] subscale scores were as follows: Symptoms, 75.0; Pain, 75.0; Activities of Daily Living, 77.9; Sport/Recreation, 58.3; and Quality of Life, 31.3 (Table 1). Right knee pain intensity was 75 mm on the visual analog scale.

Approximately 1 week after the initial visit, he consented to undergo EMS targeting the VM. EMS was then performed for 30 minutes per session, 3 times per week, for 4 weeks.

To document changes during the intervention and follow-up period, ultrasound EI of the VM and body composition were assessed before EMS and 2 weeks after EMS completion. Ultrasound EI was measured 2 weeks after EMS completion because previous studies have indicated that EI decreases at this time point and that histological changes in muscle immediately after EMS may affect EI values [9]. The KOOS was completed before EMS, at 2 and 4 weeks after EMS initiation, and at 2 and 12 weeks after EMS completion (Figure 1).

Table 1. Knee Injury and Osteoarthritis Outcome Score (KOOS) subscale scores before and after electrical muscle stimulation (EMS).

	Before EMS	2 weeks after EMS initiation	4 weeks after EMS initiation	2 weeks after EMS completion	12 weeks after EMS completion
Symptoms	75.0	92.9	96.4	89.3	100.0
Pain	75.0	80.6	83.3	91.7	100.0
Activities of daily living	77.9	97.1	97.1	100.0	100.0
Sports/recreation	58.3	75.0	75.0	93.8	100.0
Quality of life	31.3	56.3	68.8	81.3	93.8

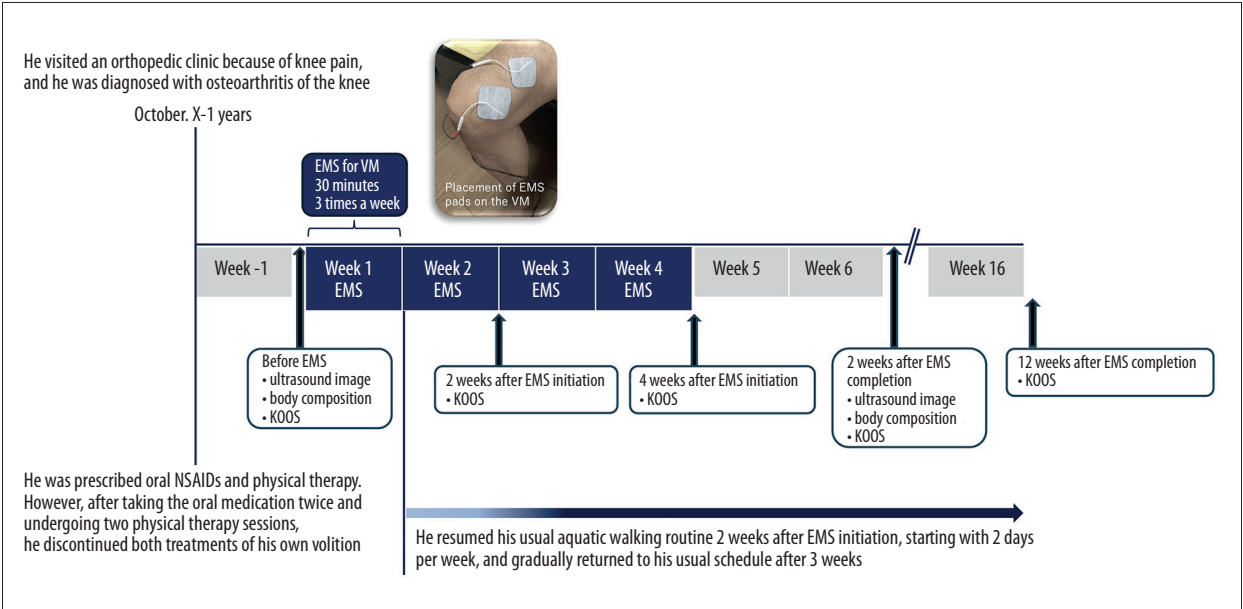


Figure 1. Timeline of the case. Abbreviations: EMS, electrical muscle stimulation; VM, vastus medialis; KOOS, Knee Injury and Osteoarthritis Outcome Score; NSAIDs, nonsteroidal anti-inflammatory drugs.

Diagnostic Assessment

Ultrasound EI and Methods of Measurement

B-mode images of the VM, vastus lateralis (VL), vastus intermedius (VI), and rectus femoris (RF) were obtained using a SONIMAGE HS1 ultrasound imaging system with an L18-4 linear probe (Konica Minolta Inc, Tokyo, Japan). Preset imaging parameters were applied to standardize the imaging conditions before measurement. Images were acquired with a probe center frequency of 18 MHz, gain of 32, dynamic range of 70, frame rate of 35, and depth of 3.5 cm.

He was seated with the hip, knee, and ankle joints flexed at 90°. To avoid compression-related changes in thigh shape at the ultrasound imaging sites, the distal two-thirds of the posterior thigh were kept off the seat. After he rested in the seated position for 5 minutes, short-axis images of the VM, VL, VI,

and RF were acquired 3 times for each muscle. Short-axis images were defined as images perpendicular to those in which muscle fibers were visualized in parallel. The imaging sites were located 5 cm proximal to the base of the patella for the VM, 10 cm proximal to the base of the patella for the VL, and 15 cm proximal to the base of the patella for the VI and RF. Each site corresponded to the point of maximal bulging of the respective muscle, as observed on the body surface.

A linear probe was coated with a water-soluble ultrasound gel (Ito Co, Ltd, Saitama, Japan), and the monitor was adjusted so that the femur showed the highest intensity. All measurements were performed by the same examiner with more than 10 years of experience in ultrasound imaging. To minimize measurement bias, during the measurements performed 2 weeks after EMS completion, the examiner was not allowed to view the ultrasound images obtained before EMS. Instead, the probe was placed on the skin at predetermined measurement

Table 2. Ultrasound echo intensity (EI) in each quadriceps femoris muscle.

		Before EMS	2 weeks after EMS completion
VM	Affected	54.1 (1.2)	40.4 (0.1)
	Unaffected	49.2 (2.7)	52.9 (0.6)
VL	Affected	54.3 (1.0)	55.4 (0.2)
	Unaffected	59.2 (1.0)	61.2 (1.0)
VI	Affected	61.8 (0.8)	67.1 (0.3)
	Unaffected	66.3 (0.9)	64.6 (0.6)
RF	Affected	54.2 (0.1)	52.7 (0.6)
	Unaffected	60.3 (6.0)	57.5 (1.8)

Values are presented as means (standard deviations) in arbitrary units. Abbreviations: EI, echo intensity; EMS, electrical muscle stimulation; VM, vastus medialis; VL, vastus lateralis; VI, vastus intermedius; RF, rectus femoris.

Table 3. Changes in body composition before and after electrical muscle stimulation (EMS).

	Before EMS	2 weeks after EMS completion
Body mass (kg)	73.20	73.15
Body mass index (kg/m ²)	24.9	24.9
Body fat percentage (%)	30.5	30.5
Right lower limb fat percentage (%)	25.2	25.2
Left lower limb fat percentage (%)	24.5	24.5
Right lower limb muscle mass (kg)	5.05	5.05
Left lower limb muscle mass (kg)	5.25	5.15

sites and images were acquired while ensuring that the femur was displayed with high brightness.

For each muscle, the largest onscreen area excluding the fascia and connective tissue was defined as the region of interest. Using ImageJ software version 1.53e (National Institutes of Health, Bethesda, MD, USA), EI was quantified in arbitrary units (a.u.) on an 8-bit grayscale ranging from 0 to 255, with 0 representing black and 255 representing white. The mean of 3 measurements was used as the representative value for each site.

Before EMS, the mean ultrasound EI values (standard deviations), in a.u., for the affected and unaffected sides were as follows: VM, 54.1 (1.2)/49.2 (2.7); VL, 54.3 (1.0)/59.2 (1.0); VI, 61.8 (0.8)/66.3 (0.9); and RF, 54.2 (0.1)/60.3 (6.0) (Table 2). Only the VM showed higher EI on the affected side than on the unaffected side.

Body Composition and Methods of Measurement

Body mass, whole-body fat percentage, lower-limb fat percentage, and lower-limb muscle mass were measured using

a body composition analyzer (Body Planner DF870; Yamato Scale Co, Ltd, Hyogo, Japan). Body fat percentage and muscle mass were calculated using bioelectrical impedance analysis. Details of the measurement procedures have been described previously [9]. Body mass index (BMI) was calculated from height measured with a stadiometer and body mass obtained from the body composition analyzer.

His body composition before EMS was as follows: height, 1.715 m; body mass, 73.2 kg; BMI, 24.9 kg/m²; body fat percentage, 30.5%; lower limb fat percentage, 25.2% on the right and 24.5% on the left; and lower limb muscle mass, 5.05 kg on the right and 5.25 kg on the left (Table 3).

Therapeutic Intervention

The EMS device used was the ESPURGE (Ito Co, Ltd, Saitama, Japan). He sat in a chair with the knee flexed to 90°, and two 50 × 50 mm self-adhesive gel pads were placed to cover the entire muscle belly of the VM. The gel pads were carefully positioned to avoid covering the bellies of the adjacent RF or sartorius muscles (Figure 1).

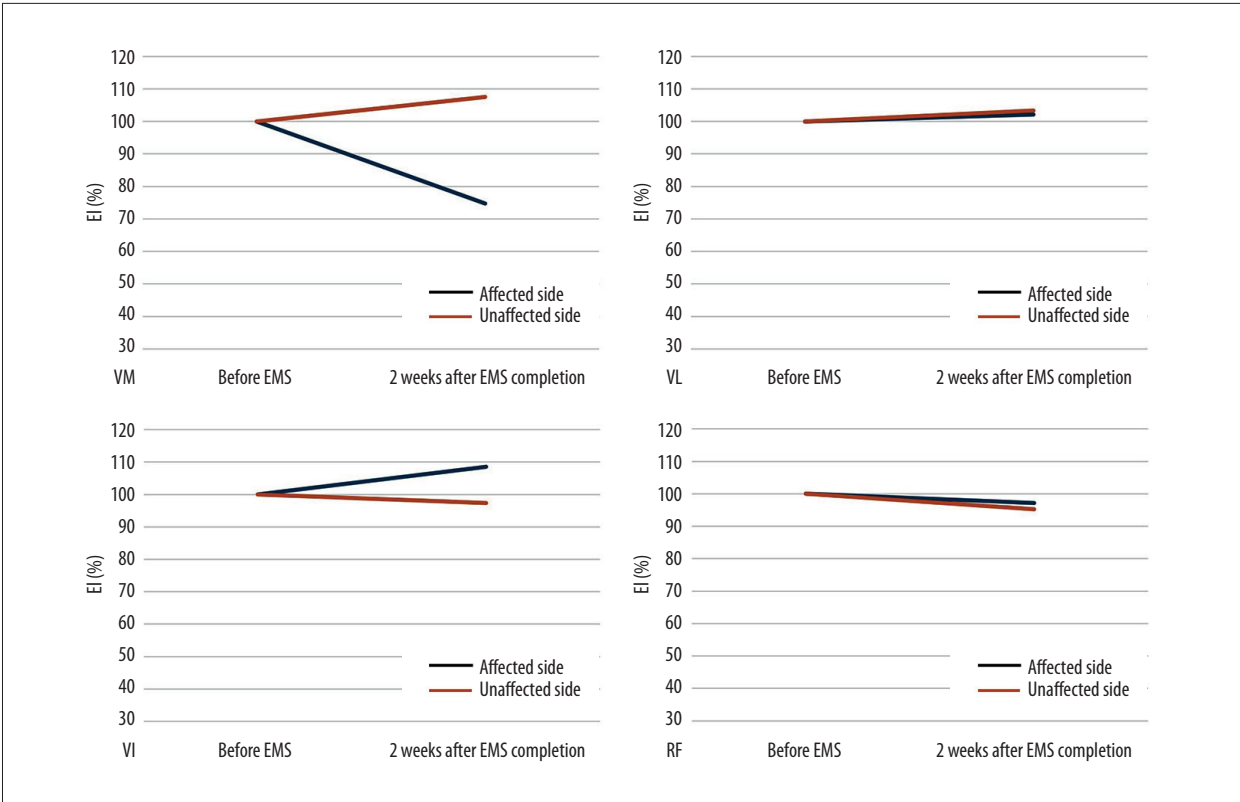


Figure 2. Rate of change in ultrasound EI in each quadriceps femoris muscle. Abbreviations: EI, echo intensity; EMS, electrical muscle stimulation; VM, vastus medialis; VL, vastus lateralis; VI, vastus intermedius; RF, rectus femoris.

The parameters for the biphasic square-wave pulses were set based on previous studies [9] and protocols reported for quadriceps femoris strengthening [14], as follows: pulse width, 300 μ s; frequency, 50 Hz; and stimulation cycle, 5 seconds on and 7 seconds off. The stimulation intensity was initially set to the level at which muscle contraction was visually confirmed and he was able to tolerate the stimulation without discomfort. As habituation to the stimulation intensity can occur during EMS, the intensity was adjusted every 5 minutes to maintain the highest tolerable intensity.

The mean current intensity was 25.7 ± 2.9 mA. This value was calculated from the current intensity recorded at the start and end of each EMS session, and the mean and standard deviation of these values are presented. Under these conditions, EMS was administered for 30 minutes per session, 3 times per week, on Mondays, Wednesdays, and Fridays, for 4 weeks. No specific time restrictions were imposed, and sessions were scheduled at times convenient for him. A physical therapist supervised each session to ensure that the self-adhesive EMS gel pads were properly applied to the VM belly and to prevent operational errors during the 5-minute intervals at which the current intensity was increased. The 4-week EMS intervention was completed without changes to the protocol established at the initial session, and no adverse events were observed.

No specific restrictions were placed on his diet or physical activity, and he was instructed to continue his usual daily routines.

Follow-Up and Outcomes

No delayed-onset muscle soreness was observed in the VM on the following day. Immediately after the first EMS session, both the patient and the supervising physical therapist perceived greater knee stability during walking, and the right stance phase appeared more stable.

Table 2 shows the ultrasound EI results before EMS and 2 weeks after EMS completion. **Figure 2** shows the rate of change, and **Figure 3** shows ultrasound images of the right VM before EMS and 2 weeks after EMS completion. Right VM EI decreased by 13.7 a.u. (25.3%). Although a minimum clinically important difference for skeletal muscle EI could not be identified in our literature review, the 95% minimal detectable change (MDC₉₅) for RF EI was reported to be 6.77 a.u. when measured by the same examiner [15]. Thus, a grayscale change of approximately 7 a.u. or greater in the RF may exceed measurement error. However, because VM imaging requires the linear probe to be placed obliquely over the muscle belly rather than directly from above, the RF MDC₉₅ cannot be directly applied to the VM. The 13.7-a.u. decrease therefore exceeded the reported RF MDC₉₅,

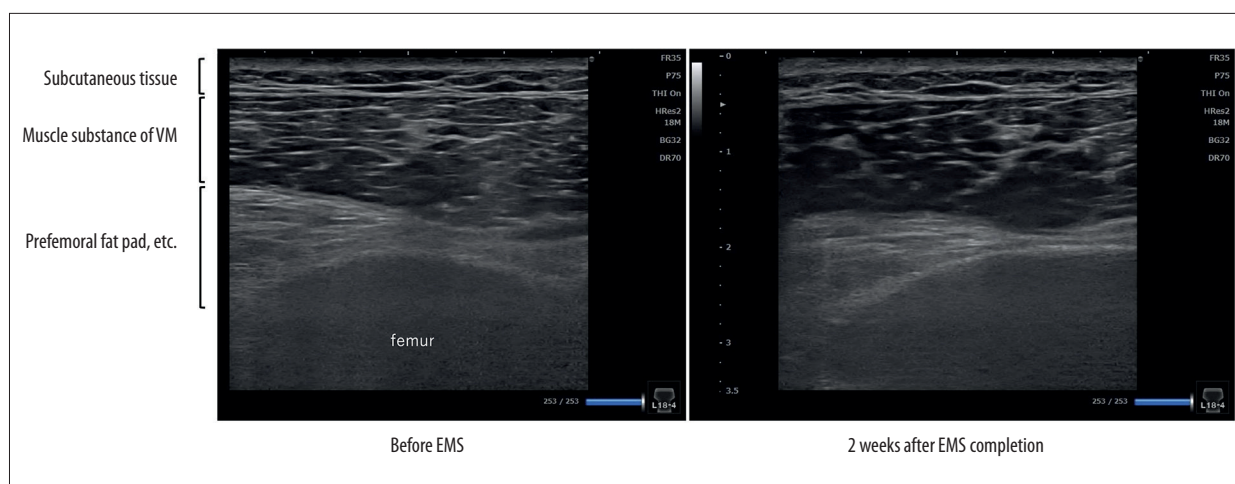


Figure 3. Ultrasound images of the vastus medialis (VM) before electrical muscle stimulation (EMS) and 2 weeks after EMS completion.

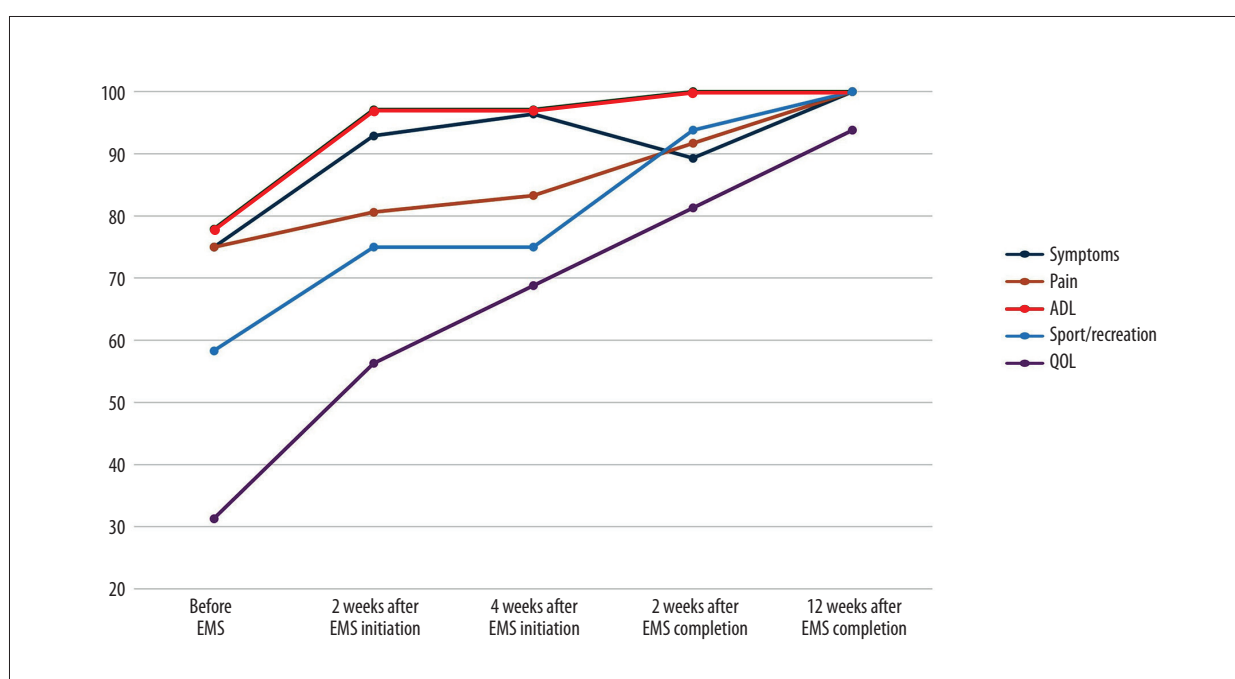


Figure 4. Temporal changes in Knee Injury and Osteoarthritis Outcome Score (KOOS). Abbreviations: EMS, electrical muscle stimulation; ADL, activities of daily living; QOL, quality of life.

but the extent to which it represents true change in the VM cannot be determined from this case alone.

BMI, body fat percentage, and lower-limb fat percentage on the EMS-treated side remained nearly unchanged (**Table 3**). Thus, the decrease in right VM EI occurred without appreciable changes in these body-composition measures; however, this does not establish that EMS caused the EI decrease. **Table 1** and **Figure 4** show the changes in KOOS subscale scores over time. Providing feedback on the KOOS scores 2 weeks after EMS initiation may have supported adherence to the program. In addition, before the EMS intervention began,

the patient was provided with a calendar detailing the scheduled sessions. He was instructed to record the initial current intensity, reassess the intensity every 5 minutes, and record the final level. This approach enabled him to continue EMS at the highest tolerable intensity within a comfortable range.

He did not use any oral or topical NSAIDs from the start of the EMS intervention until 12 weeks after its completion. Additionally, he did not wear a knee brace or other support device during this period. He resumed his usual aquatic walking routine 2 weeks after EMS initiation, starting with 2 days per week, and gradually returned to his usual schedule after 3 weeks (**Figure 1**).

Discussion

We previously conducted a pilot study in healthy participants to examine changes in VM EI and their timing during VM-targeted EMS [9]. As an extension of that study, we applied EMS to a patient with right KOA who had discontinued medication and physical therapy for personal reasons and documented his clinical course. After the 4-week EMS period, VM EI was lower than the pre-intervention value, and KOOS scores for Symptoms, Pain, Activities of Daily Living, and Quality of Life had improved during the observation period. Several limitations are important when interpreting these findings. First, this was a single uncontrolled case of KL grade 2 KOA; therefore, the observed changes cannot be generalized to other patients or attributed to EMS. Controlled studies involving patients with different KL grades are needed. Second, EMS was applied only to the VM, and no comparison condition was included. Accordingly, the specific contribution of VM stimulation cannot be determined. Symptom and functional improvements may have reflected EMS, spontaneous improvement, behavioral reactivation, or a combination of these factors.

Because he had hypertension, maximal knee muscle strength was not measured for risk-management reasons. Decreased knee extension strength is associated with knee pain in patients with KOA [16], and the VM may play an important role in this relationship [17]. In patients with KOA, qualitative muscle changes such as IMF accumulation may occur before quantitative changes such as muscle atrophy and may be closely related to muscle strength [2]. IMF accumulation in the VM is associated with decreased knee muscle strength [18,19]. Because knee extension strength was not assessed, we could not determine whether the observed decrease in VM EI was accompanied by a change in strength. In a 3-year longitudinal study of patients with KOA that also used ultrasound EI as an indicator, Taniguchi et al [6] reported that a 1-a.u. increase in VM EI was associated with adjusted odds ratios of 1.24 for worsening functional disability and 1.13 for worsening symptoms. In the present patient, VM EI decreased by approximately 14 a.u. over a period that included both the 4-week EMS intervention and resumption of aquatic walking 2 weeks after EMS initiation. These longitudinal associations do not establish that the observed EI decrease altered disease progression in this patient.

The observed decrease in EI may reflect changes in muscle composition other than a definitive reduction in total IMF. EMS induces muscle contraction by electrically exciting muscle fibers and motor axons, and intramuscular triglyceride hydrolysis may be promoted to provide energy for contraction [20,21]. However, EI is an indirect indicator; therefore, the observed decrease does not definitively confirm a reduction in total IMF and may instead reflect changes in intramuscular triglycerides. EMS also depolarizes sensory axons and generates electrically evoked sensory

volleys that can influence central nervous system motor circuits [22]. KOOS scores had already improved 2 weeks after EMS initiation, whereas EI did not change at this time point in our previous study [9]. This temporal difference raises the possibility that mechanisms other than changes in IMF, including neural mechanisms, may have been involved in the early symptomatic changes; however, central nervous system excitability was not measured in this patient. In addition, aquatic walking was resumed 2 weeks after EMS initiation and may also have influenced subsequent symptoms, physical activity, and muscle use.

The possibility that his symptoms, pain, and physical activity would have improved without EMS cannot be ruled out. Although individual differences exist, previous studies have reported that patients with KL grade 2 KOA are less likely to show pain resolution or improvement in physical function than those with KL grade 0 or 1, and this tendency may be greater in patients who do not receive treatment for KOA [23,24]. Furthermore, because factors such as BMI and muscle strength are associated with pain improvement [23], body composition was measured at the same time as ultrasound EI to monitor factors that might influence symptoms, pain, and physical activity. Body mass, BMI, body fat percentage, lower-limb fat percentage, and lower-limb muscle mass remained nearly unchanged. Knee pain in OA is multifactorial, and psychological factors may further contribute to its complexity [24]. The greatest improvement was observed in the quality of life subscale of the KOOS. Before the EMS intervention, the patient reported persistent concern about his right knee. Reduced attention to the knee as symptoms improved may have been associated with greater motivation to exercise. However, given the single-case design, definitive treatment effects cannot be inferred, and alternative explanations, including spontaneous recovery and behavioral reactivation, remain plausible.

Finally, the clinical context of this patient should be considered when interpreting the observed course. He had KL grade 2 KOA, a Barthel Index score of 100, no notable knee range of motion restriction, and no joint effusion; muscle strength was not measured. These characteristics indicate relatively preserved function and limit the extent to which the findings can be applied to patients with more severe disease or greater functional impairment. EMS pad placement was supervised by a physical therapist throughout the intervention. Whether patients can apply the pads accurately and safely without supervision, particularly older adults or those with cognitive impairment, requires further evaluation.

Conclusions

In this patient, a 4-week VM-targeted EMS program was completed without adverse events. During the observation period,

VM ultrasound EI decreased, KOOS scores improved, and aquatic walking was resumed 2 weeks after EMS initiation. Because this was a single uncontrolled case and behavioral reactivation occurred during the intervention, these changes cannot be attributed to EMS or to a reduction in IMF. The observed temporal associations support further controlled investigation of VM-targeted EMS, including its feasibility, mechanisms, and outcomes across different levels of KOA severity.

Patient Consent

He received an explanation of the EMS procedure, its potential benefits, and the ultrasound measurements, body composition assessments, and KOOS questionnaires. We also explained that he could discontinue participation and withdraw consent at any time after the EMS intervention had begun. He provided written informed consent for both the intervention and publication of this case report, including the accompanying images.

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