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Case Report

Modulation of Vastus Medialis Corticomotor Excitability Following Sensorimotor Perturbation Training after Total Knee Arthroplasty using Transcranial Magnetic Stimulation: A Case Report

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ABSTRACT

Total knee replacement is a treatment for end-stage knee osteoarthritis that reduces pain and restores function, but is often limited by plateaued neuromuscular function, such as reduced corticomotor excitability, which may have long-term implications for health and Quality of Life (QoL). Sensorimotor training along perturbation exercises is a relatively new technique of neurophysiological rehabilitation which can stimulate the activity of the cortex and motor control. Although the quadriceps functions as a muscle group, the vastus medialis was specifically assessed because it is highly affected by arthrogenic muscle inhibition after Total Knee Arthroplasty (TKA) and plays a key role in knee stability. The present case report examined the effects of sensorimotor training along perturbation exercises on the vastus medialis corticomotor excitability of a patient with a TKA. In the present report the objective and the subjective outcome measures were used. After unilateral TKA, a 58-year-old female patient expressed pain in knee {Numeric Pain Rating Scale (NPRS) 4/10}, stiffness of knee, and difficulty climbing stairs and standing long, 4 weeks after surgery. The clinical results were knee flexion being 95°, extension lag 10° and quadriceps strength was 3/5 on Medical Research Council (MRC) scale. The initial examination revealed a lower level of corticomotor excitability; Motor Evoked Potential (MEP) amplitude was 0.42 mV, Resting Motor Threshold (RMT) was 65%, Timed Up and Go (TUG) time was 15.1 s, NPRS score was 4/10, knee Range of Motion (ROM) was 0-95°, extension lag was 10°, and quadriceps strength was MRC grade 3/5. The Knee Injury and Osteoarthritis Outcome Score (KOOS) subscale scores were out of 100; 54 for pain, 55 for symptoms, 56 for Activities of Daily Living (ADL), 50 for sports/recreation, and 52 for QoL. The patient received a sensorimotor training along perturbation exercises was administered three times weekly for four weeks (12 sessions), with each 45-minute session comprising a 10-minute warm-up, 30-minute training period, and 5-minute cool-down. Conventional exercises and home advice were provided on non treatment days. The post-intervention results showed that significant changes in the corticomotor excitability and functional performance were observed. MEP amplitude increased by 0.43 mV (0.42 to 0.85 mV) and RMT decreased by 11 (65% to 54%). TUG time decreased by 4.9 s (15.1 to 10.2 s), NPRS score decreased by three points (4/10 to 1/10), knee ROM increased by 20° (0-95° to 0-115°), extension lag reduced by 8° (10° to 2°), and quadriceps strength improved from MRC grade 3/5 to 4/5. KOOS subscale scores improved by 28 points for pain (54 to 85), 27 points for symptoms (55 to 82), 31 points for ADL (54 to 85), 30 points for sports/recreation (50 to 80), and 31 points for QoL (52 to 83). The findings of the present case report suggests that sensorimotor training along perturbation exercises may serve as an adjunct to conventional rehabilitation strategies to promote corticomotor excitability and functional activities following TKA. However, further controlled trials are needed to prove its effectiveness.

Keywords: Activities of daily living, Exercise therapy, Knee, Osteoarthritis, Quality of life

CASE REPORT

A 58-year-old female patient came to the Outpatient Physiotherapy, four weeks after undergoing TKA for the right knee for end-stage knee osteoarthritis, before initiation of the study written informed consent was obtained from the patient for participation and for publication of clinical data and images, ensuring confidentiality and adherence to ethical standards. The patient reported the onset of knee pain and stiffness from the first postoperative day following surgery. At the time of presentation (4 weeks postoperatively; the pain intensity was 4/10 on the NPRS. She also had problems with walking, climbing up and down stairs, and with being able to move around. She had been a known case of type 2 diabetes mellitus and hypertension for the past 10 years which was well controlled by regular medications. At the time of assessment, glycated Haemoglobin (HbA1c) was 6.8%, indicating satisfactory glycaemic control, and resting blood pressure was 128/82 mmHg. Clinical assessment showed the limitation of active knee flexion to 95°, loss of extension to 10°, and weakness of quadriceps of 3/5 on the MRC scale with atrophy of the affected limb evident [1]. The vastus medialis muscle was evaluated separately through clinical palpation during isometric quadriceps contraction and by assessing selective activation using surface electromyography electrode placement during Transcranial Magnetic Stimulation (TMS) procedures. Reduced activation and weakness of the vastus medialis were observed, supporting its inclusion as the target muscle for corticomotor excitability assessment and rehabilitation. The main outcomes in this study are: Corticomotor excitability assessed by TMS with Surface Electromyography (sEMG) surface to assess (MEP and RMT) [2,3] and functional performance KOOS and TUG test [4]. The secondary outcomes are pain using NPRS, knee ROM and extension lag using Goniometer, Muscle strength using MRC grade. The overall aim of the present case study was to evaluate the effect of sensorimotor training along perturbation exercises on vastus medialis corticomotor excitability in subject with post TKA using Transcranial magnetic stimulation with Surface electromyography. TMS can be delivered as single-pulse, paired-pulse, or repetitive TMS (rTMS). Single-pulse TMS was chosen because the aim of this study was to assess corticomotor excitability through MEP amplitude and RMT. In contrast, rTMS is primarily used as a therapeutic neuromodulatory intervention and could have confounded the effects of Sensorimotor training along perturbation exercises. Surface electromyography was used in conjunction with single-pulse transcranial magnetic stimulation to assess corticomotor excitability of the vastus medialis muscle. Following skin preparation, surface EMG electrodes were placed over the vastus medialis according to Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) recommendations, The electrodes were positioned at 80% of the line connecting the anterior superior iliac spine and the joint space anterior to the medial collateral ligament, aligned parallel to the muscle fibers at approximately 55° to the femoral axis, with an inter-electrode distance of 20 mm. A reference electrode was placed over a bony prominence to minimise noise. The participant was seated comfortably with the lower limb relaxed. Transcranial Magnetic Stimulation was performed using the ALTMS Magnetic Stimulation Therapy System/Advanced Transcranial Magnetic Stimulation (REMED Co., Ltd.) Daejeon, Republic of Korea (South Korea), imported and marketed by Cnergy Incorporation, Chennai, India. A figure-of-eight coil connected to the ALTMS stimulator was positioned over the primary motor cortex corresponding to the vastus medialis representation area. Single pulses were delivered while the coil was systematically adjusted to identify the optimal hotspot that elicited the largest and most consistent motor evoked potentials. Resting motor threshold was determined as the minimum stimulus intensity required to evoke MEPs of at least 50 μV in five out of ten consecutive trials with the muscle at rest. Subsequently, single pulses were administered at the desired stimulation intensity with an inter stimulus interval of 5-8 seconds, and ten MEP responses were recorded from the vastus medialis using NATUS surface electromyography (sEMG) system. MEP amplitude was measured as the peak-to-peak amplitude of the EMG waveform, and the average of the ten trials was used for analysis of corticomotor excitability. The amplitude of the MEPs was 0.42 mV, and the RMT was 65%. In functional performance, The KOOS subscale scores were 54 for pain, 55 for symptoms, 56 for ADL, 50 for sports/recreation and 52 for QoL [5], TUG time was 15.1 seconds [6].

After baseline assessment, the patient received a 4-week structured sensorimotor training along perturbation exercises as part of the post-TKA physiotherapy. Sensorimotor training along perturbation exercises was administered by a licensed physiotherapist with postgraduate training and clinical experience in musculoskeletal rehabilitation. TMS assessments were performed under the supervision of an experienced neurologist trained in neurophysiological techniques, ensuring safe and accurate acquisition of corticomotor excitability measures. Sensorimotor training along perturbation exercises was performed using a foam surface (185 cm×92.5 cm; density 7 kg/m³), a circular MDF wobble board (diameter 39.5 cm, height 8 cm, top board thickness 1.75 cm, weight 1.7 kg), a balance board (60 cm×40 cm, height 15-18 cm, top board thickness 1.5-2 cm), and a lightweight therapy ball for dynamic catch-and-toss activities. Therapist perturbations were advanced clinically based on the subject's tolerance and balance performance and further categorised qualitatively as mild, moderate, and greater magnitude. The lack of specialised instrumentation rendered an objective quantification of any perturbation force, displacement or velocity impossible. The intervention followed the Frequency, Intensity, Time, and Type (FIIT) principle Sessions were conducted three times weekly on non-consecutive days for four weeks (12 sessions). Exercise intensity progressed from low-to-moderate in weeks 1-2 to moderate-to-high in weeks 3-4, while remaining within pain-free limits. Each 45-minute session comprised a 10-minute warm-up, 30-minute sensorimotor training along perturbation exercises, and a 5-minute cool-down. The warm-up included active-assisted knee movements, heel slides, ankle pumps, short-duration pain-free ambulation, and sit-to-stand exercises, with 30-60 s rest between exercises.

In weeks 1-2 of your rehabilitation training protocol, neuromuscular re-education of the quadriceps functions is practiced here. This especially involves the vastus medialis muscle. As well as low-to-moderate intensity sensorimotor training along perturbation exercises. [Table/Fig-1] shows the sequence of sensorimotor perturbation training exercises performed during this phase. A foam surface was prepared for testing Static weight shift to right to left and front to back [Table/Fig-1a], followed by a Wobble board two legs in stance [Table/Fig-1b], Then supported single leg exercises were done on unstable surfaces [Table/Fig-1c], Wobble board marching was done [Table/Fig-1d], Isometric contraction of quadriceps during unstable standing [Table/Fig-1e], Mini squats on foam surface [Table/Fig-1f], Eyes closed standing with controlled external perturbations was done for postural stability improvement [Table/Fig-1g], Step up

[Table/Fig-1]: Structured sensorimotor training integrated with perturbation-based exercises on unstable surfaces (foam surface and wobble board) during weeks 1 and 2. a) Static weight shifting on foam surface (Right -to-left and front-to- back weight shifting); b) Supported double leg stance on wobble board; c) Single leg stance on unstable surface (Foam surface); d) Supported Wobble board marching on affected limb; e) Isometric quadriceps contraction during unstable standing (Foam surface); f) Mini squats on foam surface; g) Eyes closed standing with controlled multidirectional perturbations; h) Step-up and step-down on foam surface with multidirectional perturbations.

step down on foam with mild multidirectional perturbations given by the therapist [Table/Fig-1h]. The exercises were done for 2 to 3 sets of 10 repetitions or 20 to 30 seconds holds. A 60 to 90 second rest was given between sets.

In weeks 3-4, training moved to more demanding and functional tasks aimed at improving dynamic neuromuscular control and corticomotor functioning. [Table/Fig-2] shows the advanced sensorimotor perturbation training exercises performed during this phase. Exercises included unsupported double leg stand on wobble board [Table/Fig-2a], Mini squats on unstable surfaces with external perturbations [Table/Fig-2b], perturbation-assisted lateral walking and diagonal walking [Table/Fig-2c], step-over exercises on unstable platforms [Table/Fig-2d], single-legged stance with multidirectional upper limb reaching along ball catch and toss exercises when standing on unstable platforms [Table/Fig-2e], and more advanced step-up and step-down exercises with greater magnitude and randomness [Table/Fig-2f]. These workouts were done for 2-3 sets with 30-45 seconds holds or 10-15 reps. Also, 60-90 s rest between sets. Plus, a two minutes rest between exercise categories. The cool-down consisted of quadriceps, hamstring, and calf stretching and deep breathing exercises for five minutes. On non treatment days, conventional exercises comprising quadriceps and hamstring isometrics, straight leg raises, short arc quadriceps exercises, mini squats, bridging, and clamshell exercises were performed in three sets of 10 repetitions with 30-60 seconds rest between sets, along with home advice regarding activity modification and pain-free ambulation. Other directions were to take her medicines, monitor blood glucose and Blood Pressure (BP) often, wear proper footwear, use cold therapy and take rest. The treatment was tolerated as well and no serious adverse events or treatment-related complications were observed during the 4-week physiotherapy intervention.

[Table/Fig-2]: Structured sensorimotor training combined with perturbation-based exercises using foam surface, wobble board, balance (tilt) board, and ball during weeks 3 and 4. a) Unsupported stance on wobble board with mild perturbations; b) Mini squats on unstable surface (foam surface) with multidirectional perturbations; c) Diagonal walking and lateral walking on foam surface with multidirectional perturbations; d) Step over exercises on foam surface with multidirectional perturbations; e) Single leg stance on balance board and double leg stance on balance board with multidirectional ball activities; f) Step up and step down exercises with multidirectional perturbations.

Post-intervention assessment demonstrated significant improvements in both primary and secondary outcome measures following Sensorimotor training along perturbation exercises [Table/Fig-3]. Primary outcomes included corticomotor excitability and functional performance. The TMS test indicated increased corticomotor excitability manifesting in a higher motor evoked potential of 0.85mV (an increase of 0.43 mV from baseline value of 0.42 mV) and a drop in resting motor threshold from 65% to 54% (a drop of 11%) [Table/Fig-4]. Functional performance measures also improved. KOOS for pain improved by 31 points (54 to 85), 27 points for symptom (55 to 82), 31 points for ADL (54 to 85), 30 points for sports/recreation (50 to 80) and 31 points for QoL (52 to 83). TUG test time shows a decrease from 15.1 seconds to 10.2 seconds, which is a decrease of 4.9 seconds [Table/Fig-5]. Clinical recovery further supported secondary outcomes. The NPRS reflected a drop in pain intensity from 4/10 to 1/10, a decrease of three points. Knee ROM assessed using goniometer improved from 0-95° to approximately to 0-115°, which means improvement of 20°. Furthermore, the extension lag was reduced from 10° measured before the intervention to 2° following the intervention, thereby representing an 8° reduction. Using MRC grading scale, muscle strength was graded 3/5 before the intervention and increased to 4/5 after the quadriceps visual feedback intervention [Table/Fig-6]. Through sensorimotor training along perturbation the aim to enhance the neuromuscular control and corticomotor activation of Vastus Medialis to improve functional mobility after TKA. The primary goal of treatment was not pain reduction but was seen as an added benefit.

Outcome type	Outcome measures		Pre test	Post-test	Improvements
Primary	Transcranial magnetic stimulation	Motor evoked potential	0.42 mV	0.85 mV	Increased 0.43 mV
		Resting motor threshold	65%	54%	Reduced 11%
	Knee injury and osteoarthritis outcome score	Pain	54/100	85/100	Increased 31 points
		Symptoms	55/100	82/100	Increased 27 points
		ADL	56/100	84/100	Increased 28 points
		Sports and recreational activities	50/100	80/100	Increased 30 points
		QoL	52/100	83/100	Increased 31 points
	Time Up and Go (TUG) test		15.1 seconds	10.2 seconds	Reduced 4.9 seconds
Secondary	Numerical Pain Rating Scale (NPRS)		4/10	1/10	Reduced 3 points
	Knee range of motion (Flexion) using goniometer		0-95°	0-115°	Increased 20°
	Knee range of motion (Extension) using goniometer		95-0°	115-0°	
	Muscle strength (MRC Grade)		3/5	4/5	Increased 1 grade
	Extension Lag using goniometer		10°	2°	Reduced 8°

[Table/Fig-3]: Overall view of pre-assessment (before the intervention) and post-assessment (immediately after completion of the 4-week intervention) changes in primary and secondary outcome measures following sensorimotor training along perturbation-based exercises in a subject with post-total knee arthroplasty.

Outcomes	Pre-test	Post-test
TMS-MEP	0.42 mV	0.85 mV
TMS-RMT	65%	54%

[Table/Fig-4]: Primary outcome measure pre and post-intervention comparison of corticomotor excitability parameters (MEP and RMT) assessed by transcranial magnetic stimulation with surface EMG.

Primary outcome measures	Pre-test	Post-test
KOOS		
Pain	54/100	85/100
Symptoms	55/100	82/100
ADL	56/100	84/100
Sports and recreational	50/100	80/100
QoL	52/100	83/100
TUG test	15.1 sec	10.2 sec

[Table/Fig-5]: Primary outcome measures pre and post-test intervention comparison of functional performance assessed by KOOS with five subscales pain, symptoms, ADL, sports and recreational activities, Quality of life (QoL) and Time Up and Go (TUG) test.

Secondary outcome measure	Pre-test	Post-test
NPRS	4/10	1/10
Knee ROM (Flexion)	0-95°	0-115°
Knee ROM (Extension)	0-95°	0-115°
Muscle strength	3/5	4/5
Extension Lag	10°	2°

[Table/Fig-6]: Secondary outcome measures of pre and post-test values of pain using NPRS, Knee ROM using goniometer, Muscle strength using MRC grade, extension lag using goniometer.

DISCUSSION

TKA was recommended for end-stage knee osteoarthritis for pain alleviation and restoration of functional mobility in patients who did not respond to conservative management [7,8]. Following TKA, rehabilitation strategies targeting in neurorehabilitation have been shown to improve quadriceps corticospinal excitability and motor recovery [9]. The current case report investigated sensorimotor training along perturbation exercises on the vastus medialis corticomotor excitability and functional recovery post TKA. After a four-week intervention, neurological, functional, and clinical parameters showed significant improvement. Corticomotor excitability improved, as evidenced by an increase in MEP amplitude from 0.42 mV to 0.85 mV and a reduction in RMT from 65% to 54% [10]. Moreover, we adhered to the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) recommendations for electrode placement or Hermens et al. which validate the EMG output recorded on the surface [11]. Consequently, the changes in corticomotor excitability are likely of physiological origin, as opposed to measurement error. According to Groppa S et al., resting motor threshold and MEP amplitude can be reliable measures of corticospinal excitability [12]. KOOS scores demonstrated marked improvements across all domains, including pain (54-85), symptoms (55-82), ADL (56-84), sports/recreation (50-80), and QoL (52-83). Furthermore, the magnitude of improvement exceeded commonly reported Minimal Clinically Important Difference (MCID) thresholds. The improvements in all KOOS subscales (27-31 points) exceeded the reported 3-month MCID values for patients following TKA (Symptoms: 6, Pain: 10, ADL: 6, Sport/Recreation: 8, and QOL: 10), indicating clinically meaningful functional improvement [13]. Functional mobility also improved, with the TUG test decreasing from 15.1 to 10.2 seconds (32.5% improvement). Similarly, the TUG improvement of 4.9 seconds exceeded the reported Minimal Detectable Change (MDC95) of 2.27 seconds in patients following TKA, suggesting that the observed improvement exceeded measurement error and represented a meaningful functional change [14]. Secondary outcomes included reduced pain (NPRS: 4/10 to 1/10), improved knee ROM (0-95° to 0-115°), reduced extension lag (10° to 2°), and increased quadriceps strength (MRC 3/5 to 4/5). These findings suggest that sensorimotor perturbation-based rehabilitation positively influences cortical and peripheral recovery. The comparison of the present study with other published literature has been presented in [Table/Fig-7]. Kittelson AJ et al., similarly reported reduced quadriceps corticospinal excitability in knee osteoarthritis, supporting the role of central nervous system alterations in lower-limb dysfunction [15]. Sensorimotor perturbation training may enhance corticomotor excitability through increased proprioceptive input and repeated task-specific activation. These neurophysiological changes were associated with improved quadriceps strength, KOOS scores, and TUG performance, suggesting enhanced functional recovery following TKA. Corticomotor assessment was performed according to established TMS recommendations. Cavaleri R et al., proposed that averaging MEPs across multiple trials will enhance measurement reliability and reproducibility [16]. According to Tsauo JY et al., sensorimotor training enhanced proprioception and functional performance among patients with knee osteoarthritis [17]. Fitzgerald GK et al., showed that agility and perturbation training improved pain and functional outcomes. This supports sensorimotor challenges to promote adaptations [18]. Previous research investigating the impact of sensorimotor rehabilitation on knee replacement yielded results consistent with those found in the present study. According to Moutzouri M et al., the effects of enhanced sensorimotor rehabilitation after TKA on muscle strength, activation, balance, and functional performance were studied [19]. Although spontaneous recovery, rehabilitation progression, placebo effects, and repeated TUG testing may have contributed to the observed improvements, the concurrent gains in MEP amplitude, RMT, KOOS scores, quadriceps strength, pain, and mobility suggest that the benefits were not solely due to spontaneous recovery. Similarly, Blasco JM

Author/study design	Participants with symptoms	Treatment	Outcomes	Findings
Present case/ case report	58-year-old female, 4 weeks post-TKA with Pain, stiffness, weakness	Sensorimotor training along perturbation exercises and conventional physiotherapy (4 weeks)	TMS (MEP, RMT), KOOS, TUG	Improved corticomotor excitability, function, and mobility.
Moutzouri M et al., RCT [19]	Post-TKA patients with Pain, balance deficit	Sensorimotor training and conventional rehabilitation (6 weeks)	KOOS, BBS, JPS	Improved balance, proprioception, function, and QoL.
Sadiq S et al., SB-RCT [21]	52 primary TKA patients with Pain, poor balance, proprioception	Sensorimotor training and telerehabilitation (22 weeks)	KOOS, BBS, JPS, EQ-5D-5L	Enhanced balance, proprioception, muscle thickness, function, and adherence.
Fitzgerald GK et al., RCT [18]	183 knee OA patients with pain, instability	Agility and perturbation training	WOMAC, 6MWT, SCT	Similar improvements to standard exercise; no superior functional benefit.
Rhon D et al., POCS [22]	15 symptomatic knee OA patients with Pain, stiffness	Manual therapy and perturbation exercises	WOMAC, GROC	Reduced pain and stiffness; improved function with good tolerance.
Premkumar M et al., Case report [23]	Grade II knee OA patient with pain, weakness	Perturbation and dynamic resistance training	Strength, ROM	Improved quadriceps strength and knee extension ROM.

[Table/Fig-7]: Comparison of present case and other past literature [18,19,21-23].

et al., reported that preoperative sensorimotor training improved functional outcomes, balance, and proprioception following TKA [20]. The findings, though not deriving solely from postoperative rehabilitation programs, offer some indirect evidence for the benefit of sensorimotor training in people undergoing TKA. According to the findings of the Sadiq S et al., study, patients with TKA who have MD showed improvements in functional performance, QoL, and adhere to their rehabilitation protocol [21]. Although corticomotor excitability was not evaluated, our findings extend this evidence by demonstrating improved MEP amplitude and RMT, suggesting benefits on both central and peripheral recovery mechanisms following TKA. Similarly, Rhon D et al., reported that manual therapy combined with perturbation exercises reduced pain and stiffness while improving function in knee osteoarthritis [22]. According to Premkumar M et al., those with grade-2 oestoarthritis showed improvement in quadriceps strength and knee extension ROM following perturbation combined with dynamic resistance training [23]. Taylor emphasised the muscular and dynamic stability and functional performance at the lower extremities due to perturbation based interventions [24].

The available evidence supports the use of perturbation-based sensorimotor exercises in TKA rehabilitation, consistent with the improvements observed in this case. However, as a single-case report, the findings cannot be generalised to the broader TKA population. The intervention period was limited to four weeks, and long-term follow-up was not conducted to determine the sustainability of the observed improvements. In addition, the absence of a control or comparison group limits the ability to attribute the observed changes solely to the intervention. The presence of bilateral knee osteoarthritis, with occasional symptoms in the contralateral knee, may also have influenced exercise performance and functional outcomes. Future research should include larger sample sizes and randomised controlled trials to establish the effectiveness of sensorimotor training combined with perturbation-based exercises following TKA. Long-term follow-up studies are recommended to evaluate the durability of improvements in corticomotor excitability, pain, balance, functional performance, and QoL. Further research should also determine the optimal timing, frequency, intensity, and duration of the intervention and examine its effectiveness across different stages of postoperative rehabilitation and varying severities of osteoarthritis.

CONCLUSION(S)

The current study suggests that the use of sensorimotor training with perturbation exercises along with conventional physiotherapy was associated with improvements in pain functional performance and neurophysiological parameters post TKA. The observed improvements cannot be considered solely due to sensorimotor training along perturbation exercises because of the single-case design and the simultaneous administration of traditional physiotherapy. Moreover, the presence of diabetes mellitus and hypertension may limit the extrapolation of findings. In order to determine the long-term effectiveness and optimal dosage of sensorimotor perturbation training in TKA post-rehabilitation, future studies are required to conduct properly powered randomised controlled trials, with larger samples, longer follow-up and comprehensive functional and neurophysiological outcome measures.

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