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Original Article

Muscle-specific changes of lower extremities in the early period after total knee arthroplasty: Insight from tensiomyography

Armin H. Paravlic[1], **Rado Pisot**[1,2], **Bostjan Simunic**[1]

[1]Science and Research Centre, Institute for Kinesiology Research, Koper, Slovenia;
[2]Faculty of Sport, University of Ljubljana, Slovenia

Abstract

Objective: This study aimed to evaluate changes in i) muscle contractile properties of both lower extremities by using tensiomyography (TMG); ii) patients' physical function, and iii) electromechanical efficiency (EME) of the gastrocnemius medialis muscle in total knee arthroplasty (TKA) patients from before to one-month after TKA. **Methods:** Twenty-six patients scheduled for TKA were included. **Results:** The significant muscle*time interaction was found for sustain time and maximal radial displacement (Dm) ($\eta^2\geq0.219$) only, whereas time*leg interaction was found for time delay and Dm ($\eta^2\geq0.254$) only. Post hoc analysis showed a significant decrease of Dm of vastus medialis and increase in contraction time (Tc) of both the vastus lateralis and rectus femoris muscles of the involved leg, respectively. Furthermore, reduction of knee extensors (-55.4%) and flexors (-22.2%) strength, timed up and go (-26.9%), 30s chair stand (-28.9%) and EME (-38.2%) was observed. **Conclusion:** TKA treatment altered physical function as well as contractile properties of the main skeletal muscles surrounding the involved joint in the early period after surgery; however, alterations showed to be both limb and muscle-specific. This might provide clinicians and physiotherapist with additional information on how to adapt rehabilitation to the needs of an individual patient.

Keywords: Muscle Stiffness, Physical Function, Skeletal Muscle, TMG, Total Knee Replacement

Introduction

Osteoarthritis (OA) though to be the most prevalent among musculoskeletal diseases[1,2] and thus, the most-frequent occurring cause of locomotor disability in older adults[3]. In particular, the knee joint disease represents the common pathological site[2] leading to impaired quality of life4, due pain and reduced neuromuscular function[5,6]. The neuromuscular characteristics of OA patients who were submitted for total knee arthroplasty (TKA) have been widely investigated in the last two decades[7-9]. These studies have mainly focused on the assessment of the knee extensors and flexors muscle strength[10,11], voluntary activation of quadriceps muscle[8,9], changes in muscle structure[8-10], electromyography readings[12,13] and gait[14]. Accordingly, the quadriceps strength is marked as a significant determinant of patients general physical function following TKA[5,15,16]. The weakness of the quadriceps persists over a long period of time[17] and may not achieve preoperative levels[18] of the involved leg up to six months post-surgery[19,20]. TKA represents an invasive surgery that mechanically stresses knee joint and its surrounding tissue. Whiles in the long term it reliefs pain and improves patients' physical function and overall quality of life[9,21,22], early days after surgery are marked with great pain and impaired mobility. Although different technologies were used to assess these changes, to the best of our knowledge, there is no single study that assessed responses of individual muscles surrounding knee joint from pre-to-post TKA.

In recent years, tensiomyography (TMG) has been extensively used to measure adaptations of contractile properties of individual skeletal muscles[23] following muscle disuse[24], training processes[25-27], fatiguing

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Corresponding author: Armin H. Paravlic, Science and Research Centre, Institute for Kinesiology Research, Garibaldijeva 1, 6000 Koper, Slovenia
E-mail: armin.paravlic@zrs-kp.si

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Table 1. Participants' characteristics at baseline with between group comparison.

Demographic Characteristics	Total sample (n=26)	MIp group (n=13)	Control group (n=13)	P value
Age (years)	61.12 ± 5.34	61.69 ± 5.19	58.85 ± 5.24	0.177
Sex (men/women)	14/12	7/6	7/6	
Body mass index (kg/m^2)	30.06 ± 3.17	30.54 ± 4.03	30.15 ± 1.8	0.753
Total knee arthroplasty, (right side, n)	15/26	8/13	7/13	
Days of hospital stay	8.50 ± 1.71	8.77 ± 1.74	8.23 ± 1.83	.450
MIp - motor imagery practice group				

exercises[28,29] and rehabilitation treatment[30]. TMG represents a relatively novel technology designed to assess evoked twitch contractions of individual superficial skeletal muscles non-invasively. Thus, from TMG response a several muscle contractile parameters could be derived of which contraction time (Tc) and radial displacement (Dm) of muscle belly were found to be the most reliable[23], and clinically relevant[24,30]. Specifically, Tc was found to be correlated to muscle fibre type composition at least in vastus lateralis (VL)[31], where Dm is correlated to anatomical muscle atrophy[24] as well as early atrophic processes[32].

TMG assessment from pre-to post-surgery might give more insight about individual muscles changes during the rehabilitation period. Thus, this might provide clinicians and physiotherapist with additional information about adaptations of physical rehabilitation to the needs of an individual patient, based on TMG screening. Besides TMG, our research group has developed a novel sensor that measures electromechanical efficiency (EME) index of individual skeletal muscles, which represents the dissociation between the mechanomyographic and electromyographic amplitudes[33]. It was commonly used in clinical settings to assess muscle disease[34,35], atrophy[36] and evaluate muscle adaptations following exercise[37]. Accordingly, it is proposed as a valuable tool to assess the effects of injury and/or to monitor the rehabilitation process related to injury or surgery[37], which remains to be investigated[33].

Therefore, the present study aimed to evaluate individual muscle contraction properties of lower extremities using TMG, as well as general patients' physical function and EME of the gastrocnemius muscle, before and one month after TKA surgery.

Materials and methods

Design

This was a randomised controlled parallel-group designed study conducted to investigate the mechanical characteristics of extensor and flexor muscles of knee joint in patients submitted to primary unilateral TKA for the treatment of knee OA. Patients were initially assigned into motor imagery (MI) practice group and control group as previously described[11]. However, because there were no significant differences in TMG parameters between treatment conditions, results from this study were presented based on the pooled sample. Patients were assessed 1 day before (PRE) and one month after (POST) surgery, respectively, at the Valdoltra Orthopedic Hospital (Ankaran, Slovenia). Informed consent was obtained from all participants. All procedures were carried out in accordance with the ethical standards of the 1964 Declaration of Helsinki and were approved by the Ethics Committee of Valdoltra Orthopaedic Hospital (approval No: 16/2016). The clinical trial protocol was registered on ClinicalTrials.gov, Identifier: NCT03684148.

Patients

Patients who underwent a primary unilateral TKA by 3 orthopaedic surgeons at the Valdoltra Orthopedic Hospital (Ankaran, Slovenia) were consecutively recruited from general Hospital database between August 2017 and June 2018. All patients underwent a tricompartmental, cemented TKA with a medial parapatellar surgical approach. Patients were included if they were aged 50 to 85 years, were scheduled for unilateral TKA due to end-stage OA, who were free from OA or other musculoskeletal problems on the contralateral side. Finally, 26 patients (14 males) completed both PRE and POST measurements (Table 1). Exclusion criteria were participants who had a previous history of TKA on the same side as the surgery; body mass index (BMI) of 40 kg/m^2 or higher; bilateral TKA's; uncontrolled hypertension, diabetes mellitus, patients with a history of any neurological disorder including Cerebral Vascular Attack, Multiple Sclerosis, or Parkinson's disease; patients with Rheumatoid Arthritis or active cancer; thrombose; contralateral knee OA (as defined by pain greater than 4/10 with activity), or other unstable lower-extremity orthopaedic conditions such as bleeding after surgery.

Rehabilitation program

During a hospitalisation period, all patients underwent the standardised functional exercise-based rehabilitation program that was focused on improving overall mobility, reducing knee swelling and pain. At first, patients were subjected to one daily continuous passive motion session that lasted for 45 min on average. Following that, patients were subjected to more functional exercises including walking training, learning how to use walking aids, the transition from a sitting to standing position, walking up and down the stairs, weight-bearing exercise, knee extensor muscles strengthening. Briefly, the exercise program consisted of one-to-one therapy of 60 minutes in duration on average, including warm-up and cool-down routine of 5 to 10 minutes in duration, consisting of passive and active stretching of lower limbs muscle groups; knee flexion (heel sledge in bed); plantar flexion of ankles (supine); hip abduction and adduction (supine); supine straight leg raises (for the operated leg - the patients used the help of the healthy leg); walking with aids, sit-to-stand from chairs of various heights (exercises was adopted based on injured knee flexion range of motion and level of pain); sitting and standing calf raises; standing hip flexion and extension; walking up and down the stairs (using crutches and/or handrail), arm raises and shoulder mobility. An experienced and licenced physiotherapist supervised all exercise sessions.

In addition to routine physical therapy, MI practice group received MI training as an adjunct therapy. In brief, they had been advised to imagine maximal isometric contraction, without executing the actual movement. Similarly to routine physical practice sessions, MI practice was designed progressively, wherein the beginning the patients imagined two sets of 25 repetitions with 2 minutes of inter-set rest periods, for two weeks, where 10 additional trials were added during third and fourth weeks, respectively. Each imagined contraction was mentally sustained for 5 seconds, followed by a 5-seconds of the inter-repetition rest period. Further, after every fifth contraction, the participants had 20 seconds of rest.

After hospital discharge patients were supplied with exercise program booklet consisting of the similar exercises that were performed in a hospital in order to continue with an exercise program at home. Each patient was called by the phone to monitor their adherence and keep their motivation on an optimal level. A detailed description of the exercise program might be found at registered protocol at ClinicalTrials.gov, Identifier: NCT03684148.

Tensiomyography assessment

The non-invasive tensiomyography method was used to assess the contractile properties of selected muscles. Measurements on the vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) were performed supine at rest at a knee angle set at 30° knee flexion, where 0° represents extended joint. Measurements on the biceps femoris (BF) and gastrocnemius medialis (GM) were performed prone at rest at a knee angle set at 5° knee flexion. Foam pads were used for leg support. The oscillations of the muscle belly in response to an electrically induced twitch were recorded at the skin surface using a sensitive digital displacement sensor (TMG-BMC, Ljubljana, Slovenia). The sensor was set perpendicular to the skin normal plane above the muscle belly: at 30% of femur length above the patella on the lateral side of the VL muscle; four fingerbreadths on the VM obliques, proximal to the superior-medial angle of the patella; at the midway between the superior border of the patella and the anterior superior iliac spine on the RF; at the midpoint of the line between the fibula head and the ischial tuberosity on the BF and one handbreadth below the popliteal crease on the medial mass of the calf for GM as recommended by the anatomic guide for electromyographer[38]. The rounded (5-cm diameter) self-adhesive cathode and anode (Axelgaard, Aarhus, Denmark) were set 5 cm distally and 5 cm proximally to the measuring point, on all muscles assessed. Electrical stimulation was applied through a TMG-100 System electro stimulator (TMG-BMC d.o.o., Ljubljana, Slovenia) with a pulse of 1 ms and an initial amplitude of 30 mA. During each testing session, the amplitude was progressively increased by 10 mA increments until there was no further increase in Dm or maximal stimulator output (i.e., 110 mA). Rest periods of minimum 10 s were given between each stimulus to minimise the effects of fatigue and potentiation. Testing procedures were previously described elsewhere[23,33].

Also, EME was measured in GM muscle of involved leg only. GM muscle was chosen based on the pilot study, where with current equipment which is still in the process of development, we were not able to elicit M-wave in the quadriceps muscle without uncomfortable feeling reported by the patients (data from the pilot unpublished study). It was calculated as the ratio of Dm and maximal M-wave (M_{ptp}). Testing procedures were previously described in detailed[33].

Knee extensor and flexor muscles strength

For measurement of maximal voluntary isometric contraction (MViC), the adjustable isometric dynamometer was used. During both knee extension and flexion strength assessment, hip and knee joints were fixed at 110° and 60° of flexion. The force transducer was secured around the lower leg approximately 2 cm above the lateral malleolus. Knee extensor strength was measured by a superimposed double-twitch technique like previously reported[39]. In brief, for warm-up routine, each subject has two submaximal repetitions that were gradually increased in intensity (approximately 50% and 75% of their self-perceived maximum effort), and one maximal contraction lasting for 3 seconds each. Following three minutes of rest, subjects were instructed to perform maximal isometric knee extensions, contracting as fast and forcefully as possible, after which they were advised to maintain maximal force exertion until a plateau in force production was reached. Approximately two seconds into the contraction a “supramaximal” double twitch stimulation was manually delivered by the stimulator. The trial with the highest superimposed peak force was selected as representative

Table 2. Main effects of TMG parameters studied with General linear model for repeated measures for muscle (VM, VL, RF, BF, and GM), leg (involved or uninvolved) and time (PRE and POST) as within factors.

TMG parameters	Main effects			Interactions		
	Muscle	Time	Leg	Muscle*time	Muscle*leg	Time*leg
	p value; [η^2]	p value; [η^2]	p value; [η^2]	p value; [η^2]	p value; [η^2]	p value; [η^2]
Td	**<0.001; [0.732]**	**0.032; [0.231]**	**0.001; [0.448]**	0.251; [0.071]	0.359; [0.058]	**0.013; [0.300]**
Tc	**<0.001; [0.758]**	0.081; [0.159]	0.397; [0.040]	0.426; [0.051]	0.051; [0.121]	0.480; [0.028]
Ts	**<0.001; [0.616]**	**0.004; [0.371]**	0.097; [0.146]	**<0.001; [0.332]**	**<0.001; [0.289]**	0.253; [0.072]
Tr	**<0.001; [0.523]**	**0.009; [0.325]**	0.579; [0.017]	0.432; [0.051]	0.220; [0.075]	0.220; [0.082]
Dm	**<0.001; [0.449]**	0.056; [0.189]	0.944; [0.00]	**0.001; [0.219]**	**0.005; [0.183]**	**0.024; [0.254]**

TMG - Tensiomyography; Td - time delay; Tc - contraction time; Ts - sustain time; Dm - maximal radial displacement amplitude; ***Bolded value*** *- significant effect (p<0.05).*

MViC. Each subject had three maximal trials on average, during which they have been provided with strong verbal encouragement and visual feedback. Following an assessment of knee extension strength, the knee flexion strength was measured using the same protocol, however without using the superimposed double-twitch technique.

In addition, timed up and go test (TUG), 30-second chair sit-to-stand test (STS) and self-perceived pain assessed by visual analogue scale (VAS) were measured by standardized protocols as reported elsewhere[40-42].

Statistical analysis

All data are presented as mean ± SD. All statistical analysis was done with SPSS statistical software (version 19.0, IBM Inc, Chicago, USA). Descriptive statistics were used to summarize demographic characteristics of patients and outcomes as well. Normality was confirmed by visual inspection and using the Shapiro-Wilk test, while the homogeneity of variances was tested using Levene's test for all dependent variables. Sphericity (homogeneity of covariance) was verified by the Mauchly's test. When the assumption of sphericity was not met, the significance of the F-ratios was adjusted according to the Greenhouse-Geisser procedure. Main effects were studied with a repeated-measures General linear model with muscle (VM, VL, RF, BF, and GM), leg (involved or uninvolved) and time (PRE and POST) as within factor. Where significant effects were found for muscle, leg or time effects or 2-way interactions (three-way interactions were excluded from the analysis), pairwise comparisons were used to address significant PRE-to-POST differences for each variable independently. For variables with normal distribution, a Student's t-test for unpaired samples was used to compare the involved and uninvolved leg for all TMG parameters.

Conversely, a Mann-Whitney test was used for comparison of variables not following a normal distribution. Statistical significance was accepted at p<0.05. Additionally, the effect size for dependent variables was reported as partial eta-squared (η^2).

Results

At first, the validity of TMG measurements was confirmed by showing that the Tc was highest at BF, followed by RF, GM, VM, and VL. There were no significant baseline differences between involved and uninvolved leg for all assessed TMG parameters. When compared to the uninvolved leg, the involved leg has weaker knee extensors MViC (-15.9%; p=0.001), experienced more knee pain (371.3%; p<0.001), whereas knee flexors MViC was not significantly different (p=0.184).

There was main effect on muscle for all assessed TMG variables as follows (Table 2): Td (p<0.001; η^2=0.732), Tc (p=<0.001; η^2=0.758), Ts (p=<0.001; η^2=0.616), Tr (p=<0.001; η^2=0.523) and Dm (p=<0.001; η^2=0.449) (Table 2). Time effect was detected for Td (p=0.032; η^2=0.231), Ts (p=0.004; η^2=0.0371) and Tr (p=0.009; η^2=0.325). Main effect of leg was detected for Td (p=0.001; η^2=0.448) only. Further, significant muscle*time interaction was found for Ts (p=<0.001; η^2=0.332) and Dm (p=0.001; η^2=0.219), whereas time*leg interaction was found for Td (p=0.013; η^2=0.300) and Dm (p=0.024; η^2=0.254). Moreover, muscle*leg interaction was found for Ts (p=<0.001; η^2=0.289) and Dm (p=0.005; η^2=0.183). Further details of post hoc analysis is evident from Table 3 that shows the comparison between PRE and POST values of selected TMG parameters for all included muscles of both legs.

In addition, results of the comparison from PRE to POST of the knee extension and knee flexion, TUG, STS, VAS and EME index (EMEi) of GM muscle are shown in Table 4. To summarise, at POST when compared to PRE: a) at least one TMG parameter was altered in all assessed muscles in involved leg, whereas in uninvolved leg VL was only unaltered muscle; b) ratio between involved and uninvolved leg showed to be altered in VM for Dm (p=0.028), and in VL for Td (p=0.001) and Tc (p<0.001), respectively; c) decrease of -55.4% of the involved knee extension and flexion -22.2% strength (both p<0.001) was shown, respectively, whereas uninvolved leg strength was unaltered (both p≥0.209); d) performance

Table 3. Post.hoc pairwise comparison of preoperative and postoperative tensiomyographic characteristics between involved and uninvolved leg muscles.

Muscle	TMG	Involved leg			Uninvolved leg			Inv/Uni ratio	Inv/Uni ratio	
	Parameter	PRE	POST	P value	PRE	POST	P value	PRE	POST	P value
VM	Td	23.0 (2.0)	24.1 (3.0)	0.086	22.5 (2.2)	22.4 (2.2)	n.s.	1.02 (0.09)	1.08 (0.13)	0.087
	Tc	29.4 (8.2)	29.0 (7.5)	n.s.	27.2 (5.2)	28.4 (6.06)	n.s.	1.09 (0.29)	1.03 (0.15)	n.s
	Ts	235.5 (46.0)	192.3 (29.0)	↓ **<0.001**	248.1 (41.8)	221.7 (37.4)	↓ **0.003**	0.96 (0.15)	0.89 (0.19)	n.s
	Tr	84.1 (53.4)	52.1 (16.5)	↓ **0.028**	82.6 (43.6)	59.0 (15.8)	n.s.	1.08 (0.53)	0.95 (0.40)	n.s
	Dm	7.2 (1.6)	4.9 (1.6)	↓ **<0.001**	7.4 (1.8)	6.5 (1.9)	↓ **0.041**	1.01 (0.22)	0.80 (0.38)	**0.028**
VL	Td	22.4 (2.4)	24.8 (2.7)	↑ **0.001**	22.5 (2.5)	21.1 (5.0)	n.s.	1.01 (0.12)	1.15 (0.15)	**0.001**
	Tc	24.9 (6.5)	28.1 (5.3)	↑ **0.028**	23.6 (3.4)	22.8 (6.5)	n.s.	0.83 (0.15)	1.20 (0.26)	**<0.001**
	Ts	185.5 (68.1)	197.3 (47.9)	n.s.	169.2 (58.4)	188.1 (76.8)	n.s.	1.21 (0.61)	1.23 (0.92)	n.s
	Tr	133.5 (58.2)	118.0 (53.2)	n.s.	110.5 (50.7)	120.1 (78.6)	n.s.	1.38 (0.81)	1.55 (1.80)	n.s
	Dm	5.7 (1.6)	5.1 (1.4)	↓ 0.054	5.5 (1.7)	5.3 (1.8)	n.s.	1.12 (0.33)	0.97 (0.29)	n.s
RF	Td	25.9 (3.7)	27.1 (2.7)	↑ **0.033**	24.5 (2.3)	24.3 (2.9)	n.s.	1.06 (0.14)	1.13 (0.17)	0.088
	Tc	34.8 (6.2)	39.0 (7.9)	↑ **<0.001**	33.5 (7.1)	34.9 (7.1)	n.s.	1.06 (0.18)	1.14 (0.24)	n.s
	Ts	155.8 (46.0)	188.3 (40.3)	↑ **0.007**	143.7 (46.1)	147.1 (43.5)	n.s.	1.35 (1.13)	1.47 (0.82)	n.s
	Tr	89.3 (30.2)	90.1 (29.8)	n.s.	81.5 (35.6)	86.0 (38.3)	n.s.	1.51 (1.37)	1.45 (1.43)	0.088
	Dm	8.3 (2.2)	8.2 (3.0)	n.s.	8.1 (2.1)	7.2 (2.1)	↓ **0.022**	1.06 (0.26)	1.18 (0.48)	n.s
BF	Td	29.2 (4.2)	30.0 (8.5)	↑ **0.022**	29.2 (3.6)	29.5 (3.1)	n.s.	1.01 (0.12)	1.02 (0.28)	n.s
	Tc	42.9 (13.2)	43.4 (15.4)	n.s.	45.8 (13.4)	47.7 (10.0)	n.s.	0.99 (0.35)	0.94 (0.35)	n.s
	Ts	241.2 (70.4)	230.7 (46.2)	n.s.	231.7 (43.5)	209.1 (22.9)	↓ **0.011**	1.06 (0.34)	1.10 (0.19)	n.s
	Tr	96.4 (39.2)	76.7 (20.4)	n.s.	89.2 (35.7)	72.7 (23.1)	↓ **0.033**	1.26 (0.91)	1.13 (0.40)	n.s
	Dm	8.1 (3.5)	7.3 (4.8)	n.s.	6.7 (3.2)	6.7 (3.7)	n.s.	1.35 (0.73)	1.12 (0.70)	n.s
GM	Td	22.6 (2.6)	24.1 (5.1)	n.s.	22.1 (2.3)	23.0 (2.9)	n.s.	1.02 (0.11)	1.05 (0.15)	n.s
	Tc	31.6 (7.2)	31.6 (6.2)	n.s.	30.0 (5.2)	33.7 (6.9)	↑ **0.009**	1.07 (0.23)	0.97 (0.22)	n.s
	Ts	252.8 (50.4)	215.0 (28.6)	↓ **0.001**	262.2 (85.5)	218.9 (34.0)	**<0.001**	1.01 (0.22)	0.99 (0.12)	n.s
	Tr	67.5 (30.5)	60.0 (38.8)	↓ **0.014**	83.1 (78.2)	64.8 (36.9)	n.s.	1.13 (0.56)	1.03 (0.63)	n.s
	Dm	4.4 (2.0)	4.1 (1.4)	n.s.	4.4 (2.0)	5.5 (1.8)	↑ **0.009**	1.07 (0.26)	0.84 (0.46)	0.062

TMG tensiomyography; VM vastus medialis; VL vastus lateralis; RF rectus femoris; BF biceps femoris; GM gastrocnemius medialis; ↑ - increase in the POST compared to PRE; ↓ - decrease in the POST compared to PRE; Bolded value - significant difference; η^2- partial eta squared.

Table 4. Functional and other TMG derived parameters changes from the preoperative to postoperative period.

Variables	PRE (n=26)	POST (n=26)	p value
MViC knee extension (Nm)			
Involved leg	122.1 ± 45.4	55.7 ± 31.0	**<0.001**
Uninvolved leg	145.2 ± 44.6	142.6 ± 41.9	0.405
MViC knee flexion (Nm)			
Involved leg	78.3 ± 29.0	60.9 ± 22.9	**<0.001**
Uninvolved leg	82.1 ± 30.2	85.5 ± 29.3	0.209
Timed up and go (s)	7.5 ± 1.5	9.5 ± 3.0	**0.002**
30s Chair stand test (repetitions)	10.5 ± 3.1	7.5 ± 3.1	**<0.001**
VAS (points)			
Involved leg	54.2 ± 12.9	34.4 ± 13.5	**<0.001**
Uninvolved leg	11.5 ± 11.7	4.4 ± 9.8	**<0.001**
EMEi of involved leg GM muscle (m/A)	2.0 ± 2.1	2.7 ± 2.0	0.022
GM Dm of involved leg (mm)	8.6 ± 2.9	8.2 ± 2.4	0.508
M_{ptp} of involved leg (mA)	6.6 ± 3.5	4.3 ± 2.8	**0.015**

MViC maximal voluntary isometric contraction, VAS visual analog scale, EMEi electromechanical efficiency index, VL vastus lateralis muscle, GM gastrocnemius medialis; Bolded value - significant difference.

on TUG (-26.9%) and 30s chair stand (-28.9%) tests were decreased (both $p \leq 0.002$); e) pain levels were reduced in both knees (involved -36.5%; uninvolved -61.7%; both $p \leq 0.001$;), and finally; f) decrease of M_{ptp} (-34.6%; $p=0.015$) and EMEi (-38.2%; $p=0.022$) of involved side was observed, while Dm was not altered ($p=0.508$) (Table 4).

Discussion

The main findings of the present study were that: i) TKA treatment of OA showed to have muscle-specific effects, whereas observed alterations in muscle contractile properties were greater in involved compared to uninvolved side at one-month post-surgery; ii) physical function measured as means of knee extensors muscles strength, timed up to go and 30-second sit to stand tests was significantly decreased following TKA which is in line with previous literature and iii) EMEi of the involved leg of GM muscle increased from pre-to-post TKA, meaning lower electromechanical efficiency of assessed muscle. That corresponds to early quadriceps muscle weakness that has profound functional consequences peaking at 3.5 weeks after TKA and was previously found to be associated with decreased gait speed, stair-climbing, and chair sit-to-stand performance[43].

To the best of our knowledge, there are only four[30,44-46] studies aimed to investigate contractile muscle properties of lower extremity skeletal muscles following the injury and/or surgery. However, none of these studies did use TMG to explore the effects of TKA on individual skeletal muscles surrounding the involved joint. In contrary, the aforementioned studies assessed the effects of anterior cruciate ligament (ACL) reconstruction[45,46], femoroacetabular impingement injury[44] and treatment[30] on contractile properties of main skeletal muscles surrounding the involved joint. While current study findings cannot be directly compared with previous ones regarding population being included, surgery employed and Pre-to Post time of evaluation, significant alterations of individual muscle contractile properties were detected. Given the surgical approach employed in the current study i.e., medial parapatellar, it was speculated that major changes will occur on VM. Pisot et al.[24] reported that increase in Dm correlated with the decrease in muscle thickness following bed rest and Šimunič et al.[32] found that Dm increased during bed rest much before anatomical atrophy is observed, thus indirectly showing signs of muscle atrophy and tonus loss. On the contrary, a decrease of Dm was observed in the present study, indicating higher muscle stiffness one month following surgery. This phenomenon was regularly found also in athletes and seniors after intense plyometric sports training[25,27] and after eccentric loads that provoked delayed onset muscle soreness[47]. An arthrogenic muscle inhibition (AMI) is a process following orthopaedic surgeries in which quadriceps activation failure is caused by neural inhibition. The peripheral mechanisms for this inhibition include alteration in muscle resting motor thresholds, changes in the discharge of articular sensory receptors, altered spinal reflex excitability (affecting the group I non-reciprocal (Ib) inhibitory pathway, the flexion reflex and the gamma loop)[48].

Furthermore, interesting findings were in alterations observed on RF, where uninvolved leg experienced a decrease in Dm, while the involved leg showed an increase in Tc at one month after surgery. In the first few weeks after surgery RF as the primary hip flexor of a quadriceps muscle group has an essential function in the overall mobility of TKA patients[49]. Hence, it is a common situation that healthier/uninvolved leg is used in early periods after surgery to support the function of the involved leg in hip joint movements. Therefore, observed changes are possibly evoked by changing everyday physical activity and movement patterns, which are necessary whenever the patient needs to get up from the chair and/or bed or to relocate a position of the involved leg.

In recent decades assessment of EME was used within different clinical settings for a variety of purposes. For example, it was used to distinguish between diseased and healthy skeletal muscles by comparing patients with cerebral palsy and healthy control subjects[34], while Barry et al.[35] suggested EME as a measure of muscle disease and atrophy. Accordingly, it is proposed as a valuable tool to assess the effects of injury and/or to monitor the rehabilitation process related to injury or surgery[37], which remains to be investigated[33]. The present study demonstrated significant alterations of GM EMEi of the involved leg, hence confirming the postulated theory[35,37]. However, in our study, a twitch and TMG-derived Dm was used in nominator while in other studies, a muscle sound or vibrations were recorded during voluntary contractions. As the Dm increase during and after physical inactivity in healthy young participants[24,32] yielding higher EMEi, in this study, we report EMEi for the first time in patients after surgery, that is one month after surgery in the peak arthrogenic muscle inhibition phase. However, our finding in GM was consistent as in young subjects, and the higher EMEi values could be interpreted as lower efficiency. Accordingly, studies showed that GM has a significant contribution to substantial muscle-tendon architecture power and work done by lower-limb during walking when compared to other distal muscle such as soleus and gastrocnemius laterals (GL)[50]. Moreover, in the asymptomatic population, GM electromyographic activity showed to be greater when compared to GL, indicating the importance of GM at a push off phase during walking[51]. In contrary, while similar activation level was seen between GM and GL muscles in OA patients, only GM showed reduced activity when compared to healthy control group. Observed alterations in neuromuscular control might be prescribed to protective mechanisms of shifting higher force production to lateral side in order to counteract the high medial joint loading commonly found in OA patients[52]. To conclude, our data suggesting that more attention in early post-surgery period should be made in GM muscle recovery as well. In the scope of current study limitations, further studies aimed to investigate the time course of TMG measurement improvements i.e., with longer follow up periods, including different rehabilitation protocols comparisons and different surgical approaches as well are warranted.

Conclusions

In the early post-surgery period, TKA treatment of osteoarthritic knee negatively affects the physical function of lower extremities as well as contractile properties of the main skeletal muscles surrounding the involved joint. However, alterations showed to be both the limb and muscle-specific. Mainly, the substantial aggravation of the knee extensors function was noticed, while knee flexors were not deteriorated. More specifically, employed surgical approach evoked a decrease of Dm of VM muscle, that was altered in the involved leg when compared to the healthy leg at one month after surgery. Therefore, more attention should be made in preserving the knee extensors function in general, with a special focus on reducing VM muscle stiffness in the early post-surgery rehabilitation period.

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