The acute effect of common peroneal nerve electrical stimulation on quadriceps maximum activity failure in patient with knee osteo arthritis after ten physiotherapy sessions

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Abstract---Introduction: Knee osteoarthritis (OA) is the most prevalent OA worldwide, particularly in the USA. Studies show that knee OA leads to functional limitations, including problems with weight tolerance during walking, climbing stairs, household activities, and lightweight package transport. Since the quadriceps muscles play a critical role in weight tolerance throughout the knee joint, weakness in these muscles diminishes the capacity to protect the knee and results in knee susceptibility to more physical stress and developed structural injuries. Abnormal quadriceps muscle functioning that often manifests into weakness is part of a movement disorder presumably due to certain neurological conditions such as Parkinson's disease (PD), stroke, etc., or knee injuries after surgery, arthritis, traumatic injuries, and more. This weakness can originate from atrophy or neural inhibition that prevents maximal activation of the quadriceps muscle. This condition is called arthrogenic muscle inhibition (AMI), which Hopkins first introduced in 1990. AMI is associated with several causes, including swelling, inflammation, pain, joint stiffness, and structural damage, though the importance of these causes remains unclear. Consistently, this phenomenon is caused by discharging the sensory receptors in the damaged knee joint. Hence, AMI of the quadriceps muscle has troubled therapists and can lead to atrophy and delay or even impede the proper rehabilitation process.

Methods: This study investigated 15 patients with grades 2 and 3 OA (BMI class 2 and 3; mean age of 7.52 years; mean pain intensity of 7.46). Participants were selected based on the VAS scale by the simple non-probability sampling method. In two stages, the quadriceps muscle activation capacity was recorded using the quadriceps muscle extensor torque parameter. The maximum autonomic effort to activate the maximum quadriceps muscle was also recorded. After resting for five minutes, synchronizing the electrical stimulation of the common peroneal nerve with the maximum autonomic effort of the individual to maximize the quadriceps muscle was investigated.

Results: Quadriceps muscle extensor torque was significantly increased ($p < 0.05$) upon synchronizing electrical stimulation of the common peroneal nerve with a maximal autonomic effort to activate quadriceps muscle, compared to synchronizing electrical stimulation of quadriceps muscle with the maximal autonomic attempt to activate the quadriceps muscle. Conclusion: The defect of maximal quadriceps muscle activity, which, as a protective mechanism in the early stages of knee joint injury, hinders the maximal movement of this muscle, can be diminished by stimulating the common peroneal nerve at the fibula head with low intensity, which leads to an arousal reflex between the pretibial and quadriceps muscles.

Keywords---inhibition, quadriceps, knee joint injury, functional defect, common peroneal nerve, knee osteoarthritis.
Introduction and goals

Knee osteoarthritis (OA) is the most prevalent type of OA worldwide, particularly in the USA [1-2]. According to reports, knee OA leads to functional limitations, including problems with weight tolerance during walking, climbing stairs, household activities, and lightweight package transport [3]. Since the quadriceps muscles play a critical role in weight tolerance throughout the knee joint, weakness in these muscles reduces the capacity to protect the knee and results in knee susceptibility to more physical stress and developed structural injury [4]. As mentioned above, weakness in quadriceps muscles directly contributes to knee pain and may influence postural balance and oscillation in patients with knee OA [3, 4]. According to studies, weakness in quadriceps muscles could exert many adverse effects on physical function and inability over time in patients with knee OA [5]. However, according to Slemenda et al., some OA patients have weakness in their quadriceps femoris muscle even if they do not develop pain or atrophy [6, 7]. This finding indicates that pain and disuse atrophy alone fail to weaken the quadriceps femoris muscle in individuals with knee OA, and other mechanisms in patients with knee OA may contribute to quadriceps muscle weakness. In a study by Hurley and Newham, some patients with knee OA were fully disabled in activating their quadriceps muscles, a condition is known as a quadriceps activity failure (QAF) [8].

In another study, when applying QAF, the autonomic reduction of the maximum isometric output of the quadriceps muscle torque was observed. This result was compared with the isometric output of the quadriceps muscle contraction produced by the superimposition provided by the electrical device. Although QAF is associated with joint effusion in patients with knee injuries, according to researchers, some patients with knee OA who develop QAF do not manifest joint effusion symptoms [10]. Kristen et al. reported that degenerative changes in the knee joint OA structure might originate from changes in sensory information from the joint mechanoreceptor, where the quadriceps muscle activation capacity may be reduced. In a study on patients with knee OA who develop QAFs, compared with controls in terms of gender, age, and activity, QAF was associated with more quadriceps muscle dysfunction with reduced strength and reduced physical performance and functions [11, 12].

Research has revealed that the severity of the quadriceps muscle contraction can significantly affect the reaction's incidence, so the reaction is inhibited during the rest of the muscle where there is no contraction. Given the critical quadriceps femoris muscle role in weight tolerance, minimizing the activation of this muscle is among the most significant and primary rehabilitation goals [13, 23, 15]. By underscoring central activation mechanisms, this study proposes a new method to evaluate and treat this problem via a deep understanding of this phenomenon, the nervous mechanisms involved, and the proposed therapeutic interventions.

Materials and Methods

This study investigated 15 randomly selected volunteers affected by knee OA, including nine (66.7%) males and six (33.3%) females. OA has affected the right leg in 60% of patients and the left leg in 40%. The mean age of participants was...
50.53 years (SD = 12.31). All participants had knee OA referred to the physiotherapy clinic affiliated with the Rehabilitation School, Shahid Beheshti University of Medical Sciences. Exclusion criteria were having skeletal-musculoskeletal abnormality that limits the motor ability of lower limbs, neuromuscular abnormality, cardiovascular abnormality, a history of certain neurological condition, and not having regular professional exercise in the past year. Participants' height, weight, and body mass index (BMI) were measured, and median, standard deviation (SD), age range, and demographic characteristics were checked and recorded.

The electrical nerve stimulator used was a separate dual-channel stimulator model P710 (NOVIN medical engineering Co.). The rectangular stimulation wave was applied with a pulse duration of 100 μs at 40 Hz. The electrodes were monopolar and spontaneously attached to the skin. The quadriceps muscle was stimulated by placing the active electrode (cathode) on the muscle bulk and the anode on the femoral nerve direction proximal to the cathode. The common peroneal nerve was stimulated by a 3.2 cm in thickness cathode at the fibula head. The larger electrode (anode) was rectangular and placed nearly 2 cm distal to the cathode.

The cathode electrode was placed on the skin to allow desired deep peroneal nerve stimulation. This can be achieved by dislocating the electrode to create the most minor motor threshold for innervated muscles (tibialis anterior muscle, extensor digitorum muscle, extensor pollicis longus muscle, peroneus tertius). This stimulation leads to dorsiflexion of the ankle. The electrical stimulation intensity required to stimulate the common peroneal nerve is defined based on the motor threshold of the tibialis anterior muscle. In all tests, the aim is to achieve the highest reflex in distinct hip and knee joint positions, which often occurs at the last 15° of knee extension and 110° of hip flexion. The desired stimulation intensity to achieve the highest reflex was two times the motor threshold. Notably, motor threshold changes with each sudden foot movement, which can be due to dislocation of the cathode electrode and the movement of muscles under the electrodes.

An eight-channel surface electromyography device (Data log, Biometrics, UK) was used to record participants' generated force (kg). The dynamometer was set on one of the channels of the electromyographic device, and the rate of power generated by the quadriceps muscle was observed and recorded at various stages of the test. Participants' information, including height (measured by a measuring tape), weight (measured by a scale), age, BMI, and other demographic information, were calculated and recorded in the relevant forms.

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<th>Table 1. Statistical indices of the background variables (n = 15)</th>
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Participants were then seated on a chair designed to assess the extensor torque of the knee (Figure 1). This device was first tested by Rezasoltani et al. in the biomechanics laboratory at the Faculty of Rehabilitation Sciences [16] (Sws ≤ 9.1 N, ICCs ≥ 0.90). This study was conducted in two stages, each under particular conditions. Before any intervention, the motor threshold of the tibialis anterior muscle and the intensity required to make the most tolerable contraction of the quadriceps muscle (pain threshold) were estimated for each individual. The output of the devices was then switched off for each current.

Then, to warm up the quadriceps muscle and get informed of the test conditions, each participant performed 20 contractions with the submaximal intensity while sitting on a chair, i.e., the last 15° of knee extension and 110° hip joint flexion (Figure 1).

Data were analyzed at a significance level of $\alpha=0.05$. The study used a paired t-test (for normally distributed data) and its non-parametric equivalent Wilcoxon signed-rank test (for non-normally distributed data) to compare the maximum muscle torque before and after the common peroneal nerve electrical stimulation. The normality of data distribution was investigated using the Shapiro–Wilk test. Descriptive statistical methods such as tables, graphs, and statistical indicators were also employed. Graphs were drawn in Excel 2010 software, and results were extracted in SPSS18.

**Results**

Table 2 indicates the normal distribution of data on the maximum extensor torque of the quadriceps muscle obtained using the Shapiro–Wilk test. According to the Shapiro–Wilk test data, the paired t-test was employed to measure the data
obtained from different study stages. Table 3 compares data from different stages of the study based on the paired t-test. The highest extensor torque of the quadriceps muscle synchronized with electrical stimulation of the common peroneal nerve in patients with knee OA was significantly high compared to the highest extensor torque of the quadriceps muscle synchronized with electrical stimulation of the quadriceps femoris muscle \((p = 0.023)\).

According to Table 3, the mean torques of the quadriceps femoris muscle when synchronized with electrical stimulation of the common peroneal nerve were nearly 4.5 times greater than the mean torques of the quadriceps femoris when synchronized with electrical stimulation of the quadriceps muscle. Electrical stimulation of the common peroneal nerve seems to hold a greater capacity to increase the extensor torque of the quadriceps femoris muscles when synchronized with the most autonomic effort of participants than direct electrical stimulation of the quadriceps femoris muscle \((p = 0.023)\).

| Table 2. Normality of data (the Shapiro–Wilk test) \((n = 15)\) |
|---------------------|-----------------|-----------------|
| Sig. | Statistic | |
| First torque (*) | 0.918 | 0.182 |
| Second torque (**) | 0.918 | 0.179 |

* Extensor torque of the quadriceps femoris muscles with electric stimulation of the quadriceps femoris muscles
** Extensor torque of the quadriceps femoris muscles with electric stimulation of the common peroneal nerve

| Table 3. Measurements reliability indices \((n = 15)\) |
|---------------------|-----------------|-----------------|
| SEM | SDD | 95% CI for ICC | p-value |
| First torque (*) | | | |
| Second torque (**) | 1.751 | 1.781 | 0.712 / 8.222 | 0.023 |

 ICC: Intraclass correlation coefficient; SEM: standard error of measurement; SDD (smallest detectable difference)

* Extensor torque of the quadriceps femoris muscles with electric stimulation of the quadriceps femoris muscles
** Extensor torque of the quadriceps femoris muscles with electric stimulation of the common peroneal nerve

**Discussion**

This study investigated the prompt impact of electrical stimulation of the common peroneal nerve on the maximum activation capacity of the quadriceps femoris muscle in patients with knee OA. Neuromuscular activation failure or inhibition of the quadriceps femoris muscle, mainly caused by knee joint injuries due to trauma, knee joint surgeries, knee joint arthritis, etc., is a protective mechanism to prevent further knee joint injuries in the early stages. Such an inhibition plays a protective role in the early stages but disrupts the efficient rehabilitation
process with time. Numerous studies report a reactive relationship between the pretibial muscles and the quadriceps femoris muscle.

As a well-established theory, the inputs of the descending system stimulate this response pathway, in which the intensity of muscular activities and using motor units of the quadriceps femoris muscle increase with an increase in the power of descending inputs. In addition, the relationship between the power of descending inputs and the intensity of quadriceps femoris muscle activity is bilateral, implying that the reaction will be more effective with a rise in the autonomic activity of the quadriceps femoris muscle contraction. Furthermore, the rate and intensity of this reflex change at different angles of the knee joints, with the maximum intensity found at the end of the knee joint extension and the end of the hip joint flexion. This reaction has a low motor threshold in the excitation amplitude of the Type I movement fibers. The reaction’s low excitation threshold indicates a high excitation speed of afferents involved, confirming the role of group I afferent fibers in this reaction. These peritubular Group 1 afferents originate from the Golgi tendon organ (Ib) and the muscle spindle (Ia). However, most studies support the more prominent role of Ib group afferents in this reflex. According to studies, the quadriceps femoris muscle contraction intensity can substantially affect the incidence of this reaction so that this reaction is inhibited during resting with no contraction. Concerning the importance of the quadriceps femoris muscle during weight-tolerance activities, minimizing the activation failure of this muscle is among the most critical and primary goals of the rehabilitation phase.

The reaction’s functional role is well depicted when a person walks on a treadmill at a constant speed. The reaction approaches its maximum at the end of the swing stage and the onset of the stance stage. However, it will disappear entirely between the mid-stance and terminal swing phases. According to our study, indirect stimulation of the quadriceps femoris muscle by electrical stimulation of the common peroneal nerve (CPQ reaction activation) achieves better results than amplification by the direct electrical stimulation of the muscle bulk. This is crucial when direct electrical stimulation of the quadriceps is not achievable or when a more relevant and effective strengthening of the quadriceps femoris muscle is required. We can achieve more data on this sensory-motor dysfunction by conducting more research on the nature and structural features of the CPQ reaction. Furthermore, additional research on the reaction pathway between the peritubular and quadriceps femoris muscles can assist in studying other muscles in the body.

**Conclusion**

Studies have shown that the quadriceps femoris muscle contraction intensity can significantly affect the incidence of this reaction so that this reaction is inhibited during resting with no contraction. Concerning the importance of the quadriceps femoris muscle during weight-tolerance activities, minimizing the activation failure of this muscle is among the most critical and primary goals of the rehabilitation phase. The maximum quadriceps femoris muscle activation failure plays a protective role in the early stages, but it disrupts the effectiveness of this muscle during functional activities over time. Therefore, besides conventional
rehabilitation interventions to reduce this activation defect, electrical stimulation of the common peroneal nerve at the fibula head can reduce quadriceps femoris muscle activation failure in people with knee OA.

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