Changes in Maximal Isometric Quadriceps Strength after the Application of Ultrasound-Guided Percutaneous Neuromodulation of the Femoral Nerve: A Case Series

Cambios en la fuerza máxima isométrica del cuádriceps tras la aplicación de neuromodulación percutánea ecoguiada del nervio femoral: serie de casos

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Abstract

Introduction For those individuals who have suffered an injury to the knee or undergone a surgical intervention, the early recovery of the muscle strength contraction properties of the quadriceps is essential for a favorable recovery and for a return to the activities of daily living and other work- or sports-related activities.

Objectives To evaluate the changes in maximal isometric strength (MIS) of the quadriceps muscle after the application of ultrasound-guided percutaneous neuromodulation (US-guided PNM) on the femoral nerve.

Materials and Methods A case series involving subjects who had previously presented unilateral knee pathology and were in the stage of recovery of quadriceps strength. The subjects were pain-free at the time of the dynamometry measurements, which were performed before and after the application of the US-guided PNM technique. The isometric measurement was performed using the KINEO dynamometry system, performing a preintervention measurement of the mean maximal isometric strength (mMIS) based on 3 repetitions (3 seconds contraction and 6 seconds relaxation). The US-guided PNM technique was performed on the femoral nerve, using the Physio Invasiva CE0120 device (Prim Physio, Madrid, Spain) and a GE Logiq e R7 ultrasound (GE Healthcare, Chicago, IL, USA).

Results In total, 13 subjects participated in the present study. Significant changes were obtained ($p < 0.001$) in the mMIS of the quadriceps of the affected knee, which progressed from a mean strength of 25.91 kg (standard deviation [SD]: 7.17 kg) to a mean strength of 29.98 kg (SD: 9.06 kg).

Discussion In subjects with knee pathology, the quadriceps muscle is inhibited despite being pain-free during the strength measurements. This process of inhibition can improve with the application of low frequency percutaneous electrical stimulation on the femoral nerve. This technique represents a complementary strategy for the recovery of the normal strength values in pathological knees with or without prior surgery.

Keywords
- ultrasound-guided percutaneous neuromodulation
- invasive physical therapy
- dynamometer
- femoral nerve
- isometric contraction

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Conclusions Ultrasound-guided PNM is an effective technique for the reestablishment of quadriceps strength in inhibited muscles.

Resumen

Introducción La restauración temprana de las propiedades en la fuerza muscular del cuádriceps en sujetos que han sufrido una lesión de la articulación de la rodilla o han sido intervenidos quirúrgicamente es esencial para la correcta recuperación e incorporación a las actividades de la vida diaria, laboral y/o deportiva.
Objetivos Valorar los cambios de fuerza isométrica máxima (FIM) en el músculo cuádriceps tras la aplicación de la técnica de Neuromodulación Percutánea Ecoguiada (NMP-e) sobre el nervio femoral.
Material y Métodos Serie de casos en sujetos que presentaban patología previa unilateral de rodilla y que se encontraban en la fase de recuperación de la fuerza del cuádriceps. Los sujetos se encontraban sin dolor en el momento de las mediciones dinamométricas y se les aplicó la técnica de NMP-e tomando mediciones antes y después de la misma. La medición isométrica se llevó a cabo mediante el sistema de dinamometría KINEO (GLOBUS, Codognè, Italia) realizando una medición pre-intervención de la fuerza máxima isométrica media (FMIm) de 3 repeticiones (3 segundos de contracción y 6 segundos de relajación). La técnica de NMP-e se realizó en el nervio femoral usando para ello el dispositivo Physio Invasiva® CE0120 (Prim Fisioterapia y Rehabilitación, Madrid, España) y un ecógrafo GE Logic R7(GE Healthcare, Chicago, IL, EEUU).
Resultados En el estudio participaron 13 sujetos. Se obtuvieron cambios significativos ($p < 0,001$) en la fuerza isométrica máxima media (FIMm) del cuádriceps de la rodilla afectada, que pasó de una media de 25,91 kg (DE 7,17 kg) a una media de 29,98 kg (DE 9,06 kg).
Discusión Existe un proceso de inhibición de la fuerza muscular del cuádriceps en sujetos con patología de rodilla a pesar de permanecer sin dolor durante la medición de fuerzas. Ese proceso de inhibición puede mejorar con la aplicación de estímulos eléctricos percutáneos de baja frecuencia en el nervio femoral, estableciendo así una estrategia más para la recuperación de los valores normales de fuerza en rodillas patológicas con o sin cirugía previa.
Conclusiones La NMP-e es una técnica eficaz para el restablecimiento de la fuerza del cuádriceps en músculos inhibidos.

Palabras clave
► neuromodulación percutánea ecoguiada
► fisioterapia invasiva
► dinamometría
► nervio femoral
► contracción isométrica

Introduction

Weakness of the quadriceps muscle after either an injury to the knee or knee surgery is a common impairment described in the literature.[1–3] This weakness is defined as muscle inhibition of articular origin.[4–6] The early restoration of the muscle contraction properties of the quadriceps is essential to ensure appropriate recovery and facilitate the return to the activities of daily living, as well as to work and/or sports activities.[7–9]

Among the various types of muscle contraction, maximal isometric strength (MIS, or maximal isometric voluntary contraction [MIVC]), is an essential parameter of strength for the correct functioning of the muscle motor unit.[10–12] Conditioned muscle inhibition can effectively decrease this variable.

Furthermore, a correlation exists between MIS and maximal concentric and eccentric strength.[13,14] Several studies have found that MIS is vital during the performance of functional activities, such as jumping, cycling or running.[15,16] Therefore, MIS is an essential variable in neuromuscular assessments.

The electrical stimulation of the peripheral nervous system is a therapeutic strategy that has been primarily used for the treatment of chronic pain for the past 50 years.[17,18] This stimulation produces a modification of the input to the central nervous system, known as neuromodulation[19–22].

Currently, various neuromodulation procedures have been described in the health sciences,[23] such as brain stimulation, spinal cord stimulation, and peripheral stimulation. Ultrasound-guided percutaneous neuromodulation (US-guided PNM) is a recently developed invasive physical therapy technique used for neurofunctional improvement and for the treatment of pain.[23] To date, no studies have related this technique with muscle stimulation and dynamometry changes. Dynamometric tests with devices that enable the calculation of variables related with isometric movement are another form of functional assessment tools.[24,25]

The aim of the present study was to evaluate changes in isometric strength measured using dynamometry, after the application of US-guided PNM in the femoral nerve.

Materials and Methods

Design

A quasi-experimental study with a single intervention group, in which the mean maximal isometric strength (mMIS) was measured, using dynamometry, before and after an intervention with PNM at the level of the femoral nerve of both quadriceps muscles.

Sample

The study subjects were voluntary participants > 18 years old recruited among patients of the Fisiocéano clinic (Móstoles, Madrid, Spain). The inclusion criteria were: subjects with previous pathology in one of their knees but without pain at the time of study, with variation coefficients[26] $< 15\%$ and who were in the stage of quadriceps muscle recovery. Subjects with pathologies that caused pain during the measurements and for whom dynamometry was contraindicated were excluded (acute muscle injuries, important joint instability, or acute joint inflammation, among others). For the use of US-guided PNM, the main contraindications were needle phobia, epilepsy, pacemaker, and pregnancy. All of the subjects signed the corresponding informed consent form to participate in the study.

Measurements Performed

An expert on dynamometry, external to the physiotherapist who performed the intervention, performed the measurements and collected the strength data for statistical analysis. An isometric measurement of the quadriceps muscle was performed using the KINEO (GLOBUS, Codognè, Italia) dynamometry system. The assessment protocol consisted of a preintervention measurement of the mMIS (3 seconds contraction and 6 seconds relaxation, for a total of 3 repetitions) of both quadriceps muscles, and a postintervention measurement of the mMIS of the quadriceps on the side of the pathological knee. The assessment position was 90° of hip flexion and 45° of knee flexion, without straps and with manual grips on lateral supports. The lever arm was placed 2 cm from the malleolus on the ventral aspect of the ankle, without straps.[10]

Physiotherapy Interventions

The US-guided PNM intervention consisted specifically of the application of a biphasic asymmetric electrical current compensated with a rectangular positive phase and a negative triangular phase, with a frequency of 10 Hz, a pulse width of 240 µs, and maximal tolerated intensity. This was in order to provoke a pain-free maximal muscle

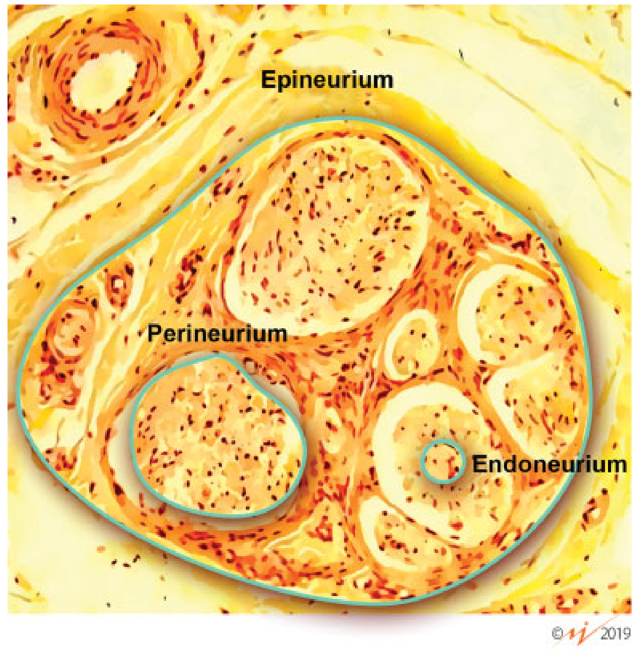

Fig. 1 Microscopic image of the transverse section of a peripheral nerve. Note the epineurium, the perineurium and the endoneurium (Reproduced with permission from MVClinic Institute).

contraction, according to the following protocol: 10 stimulations with a duration of 10 seconds, with a 10-second rest period between each stimulation, as proposed by Minaya et al.[23] The certified device employed for the percutaneous application of the electrical current was the Physio Invasiva® CE0120 (Prim Fisioterapia y Rehabilitación, Madrid, Spain) using the PES modality, with 0.30 mm × 40 mm Physio Invasiva® needles (Prim Fisioterapia y Rehabilitación, Madrid, Spain). The femoral nerve was located over the femoral triangle, using the GE Logic R7 US machine (GE Healthcare, Chicago, IL, USA) with a 12L linear probe, in a transverse section. The needle was inserted using an inplane approach, with an angle of 45° to the skin surface, until reaching the epineurium of the femoral nerve at its lower and lateral aspect (►**Fig. 1**). The axonal topography described for this nerve[27] shows how, at this site, the greater part of the motor axons of the quadriceps muscle are located (►**Fig. 2**). Prior to the insertion of the needle, the skin was cleaned using isopropyl alcohol and chlorhexidine (Lainco® 2% antiseptic for clean skin). The intervention was performed by a physiotherapist with > 10 years of experience in invasive procedures and US assessments.

Statistical Analysis

A descriptive analysis was performed by calculating the mean, the median and the mode of the characteristics of the dependent and independent variables. Inferential statistics were performed via the comparison of the means using the Student-t test ($\alpha = 0.05$) for related samples, after considering the normality of the sample and the distribution of

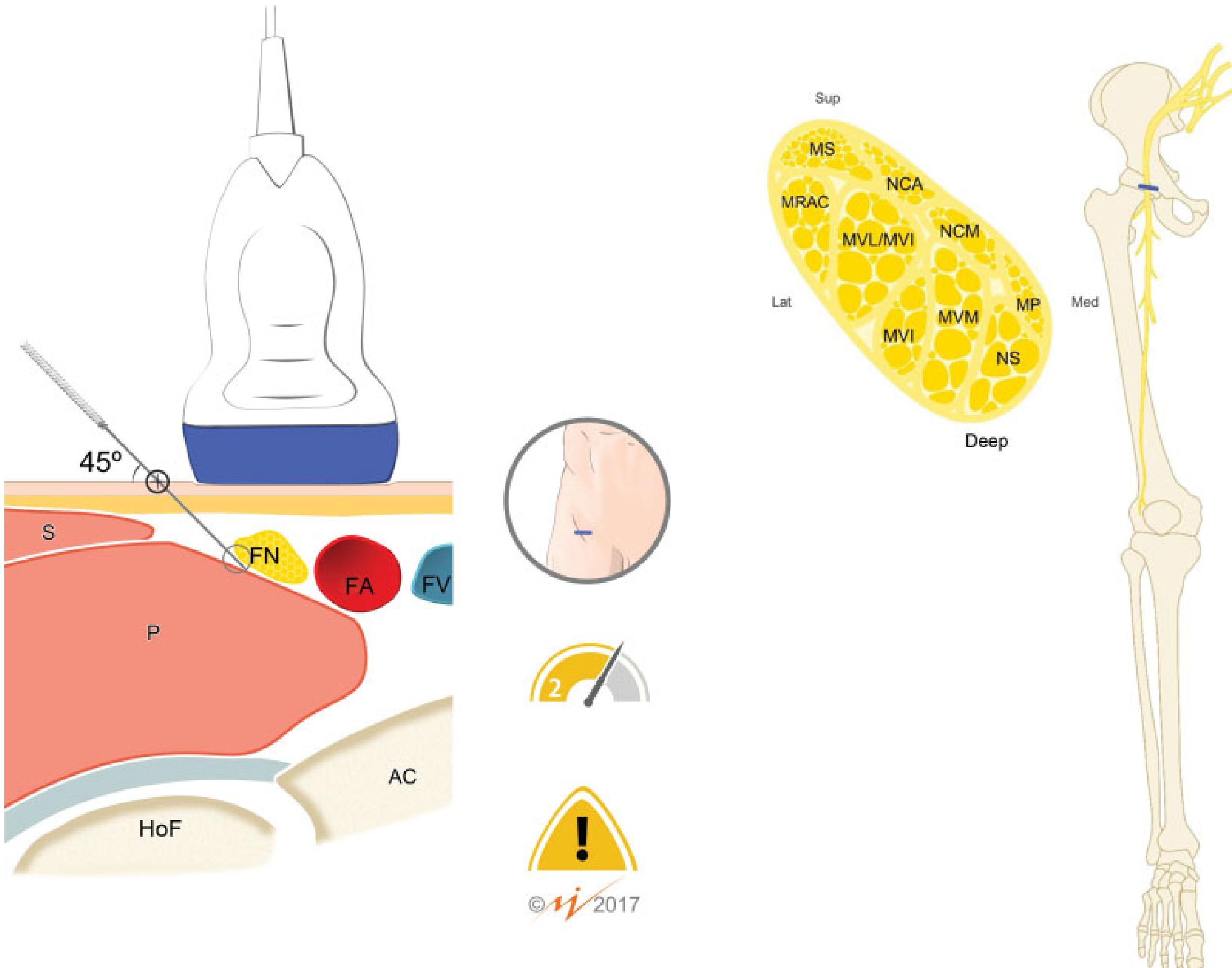

Fig. 2 Image of the therapeutic US-guided PNM procedure of the femoral nerve and explanatory image of the axonal topographic distribution of the nerve (Reproduced with permission of MVClinic Institute). Abbreviations: AC, acetabulum; FA, femoral arteri; HoF, head of femur; Lat, lateral; Med, medial; MP, pectineus muscle; MRAC, rectus femoris anterior muscle; MS, sartorius muscle; MVI, vastus intermedius muscle; MVL, vastus lateralis muscle; MVM, vastus medialis muscle; NCA, anterior cutaneous femoral nerve; NCM, medial cutaneous femoral nerve; FN, femoral nerve; NS, saphenous nerve; P, psoas; Deep, deep; S, sartorius; Sup, superficial; FV, femoral vein.

the kinetic samples assessed by dynamometry or via biomechanical systems. All of the analyses were performed using the Microsoft Excel 2013 software (Microsoft Corporation, Redmond, WA, USA).

Results

In total, 13 voluntary subjects participated in the present study, with a mean age of 39.92 years old (standard deviation [SD]: 9.09), of which 2 were female and 11 were male. ►**Table 1** presents the sociodemographic and clinical characteristics of the sample.

After the application of US-guided PNM on the femoral nerve, changes were obtained for the mMIS of the quadriceps muscles that had undergone previous pathology. Prior to the intervention, the mean strength was 25.91 kg (SD: 7.17 kg) compared to a mean of 29.98 kg after the intervention (SD: 9.06 kg). The results obtained were statistically significant with a *p-value* of 0.0019.

It is also important to note that the mMIS of the quadriceps on the healthy contralateral side was 27.59 kg (SD: 7.86 kg), compared to 25.91 kg (SD: 7.17 kg) on the injured side. This finding was statistically significant ($p = 0.026$) (►**Fig. 3**). This data reveals a decrease of the maximal isometric strength on the affected side prior to the intervention. These values, as can be observed in ►**Fig. 4**, after the intervention, are equal or, in many cases, greater than the contralateral measure of the initial reference.

Discussion

To the best of our knowledge, no study has measured the mMIS of the quadriceps muscle using dynamometry after the application of US-guided PNM in the femoral nerve.

The preintervention measures gathered in the present study reveal that the mean mMIS of the pathological side was 25.91 kg, whereas the mean mMIS of the contralateral

Table 1 Description of the study population

Subject	Gender	Age	Height (cm)	Weight (Kg)	Pathological side	Type of lesion
01	F	44	166	52	L	Condropathy
02	F	28	162	64	L	Rupture anterior cruciate ligament
03	M	38	188	78	R	Meniscopathy
04	M	39	182	89	R	Meniscopathy
05	M	41	175	71	R	Condropathy
06	M	59	169	90	L	Meniscopathy
07	M	27	183	77	L	Condropathy
08	M	38	167	92	L	Arthroscopy of the meniscus
09	M	51	178	87	L	Meniscopathy
10	M	49	178	84	R	Surgery of meniscus and anterior cruciate ligament
11	M	36	173	84	L	Meniscopathy
12	M	32	174	70	R	Arthroscopy of the meniscus
13	M	37	185	83	R	Arthroscopy of the meniscus

Abbreviations: F, female; L, left; M, male; R, right.

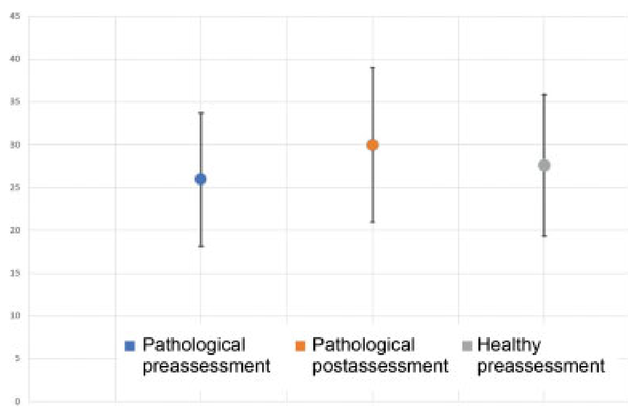

Fig. 3 Summary of dynamometry data. The graph displays the data of the mean maximum isometric strength of the quadriceps in the pathological knee. Preintervention and postintervention; and the preintervention measurements of the healthy contralateral quadriceps along with the standard deviation.

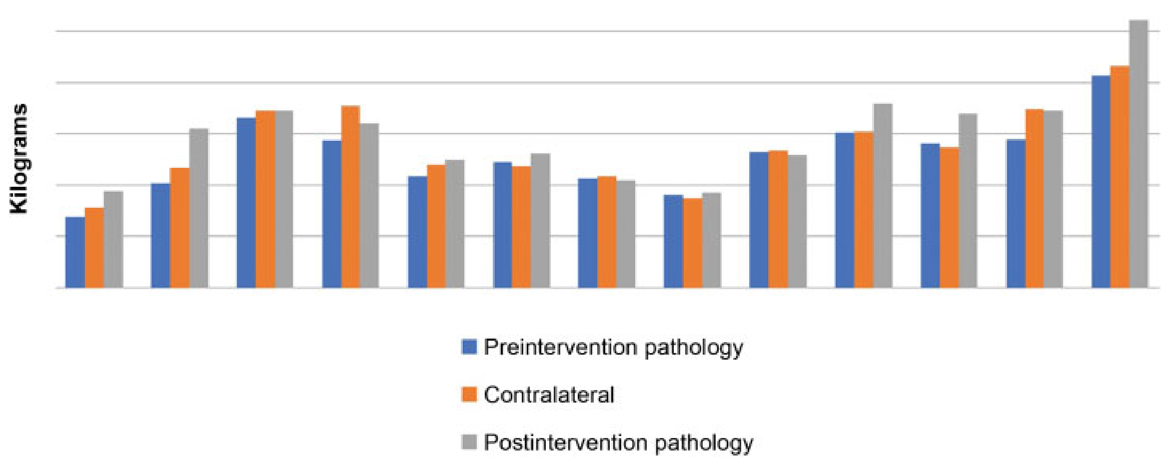

Fig. 4 In blue, the mean maximal isometric strength of the quadriceps of the knee with preintervention pathology; in orange, the contralateral side preintervention; and, in gray, the mean maximal isometric strength of the quadriceps with postintervention pathology. Note the increase of > 15% in the mean of the pre- and postintervention measurements of the quadriceps of the knee with previous pathology. It is also observed how, after the intervention, the mean maximal isometric strength of the quadriceps of the pathological knee, in many cases, was beyond the initial measurements of the mean maximal isometric strength of the contralateral healthy knee.

side was 27.59 kg. Therefore, there is evidence of weakness of the quadriceps muscle on the leg with a previous injury when compared with the contralateral leg. Nonetheless, according to a systematic review performed by Hart et al, bilateral deficiencies in quadriceps activation are common.[28] This may explain why subjects 6, 8 and 11 presented values in which the mMIS was greater in the leg with previous pathology when compared with the contralateral side.

After the intervention, there was a statistically significant improvement of the mMIS of the quadriceps on the affected side, which increased from a mean of 25.91 kg, prior to the intervention, to 29.98 kg postintervention. This indicates that the PNM was effective for increasing, or hypothetically recovering, the strength of the quadriceps muscles that were inhibited secondary to problems of the joint. The hypothesis regarding this neuromuscular inhibition is a decrease in the corticospinal excitability and/or changes in the spinal reflex.[29]

A systematic review by Sonnery-Cottet et al found moderate evidence for the effectiveness of cryotherapy and physical exercise in the management of muscle inhibition of an articular origin.[30] In contrast, Pietrosimone et al suggested that therapeutic interventions directed at eliciting changes in the voluntary activation of the quadriceps may improve the effectiveness of therapeutic exercise in strength improvements.[31] For this reason, US-guided PNM may be a suitable therapeutic procedure for use prior to exercise programs.

Furthermore, US-guided PNM is a technique that may be employed in patients immediately after either an injury or a surgical intervention, representing a physiotherapy tool that may help prevent the appearance of muscle atrophy and the establishment of neuromuscular inhibition, thus avoiding the negative consequences that may delay or hamper the return to activity of a patient.[29,32]

This new treatment concept may open new lines of research and provide both the physiotherapist and the patient with improved results regarding strength gains in these types of articular disorders.

The results of the present study reflect preliminary conclusions due to the limitation of the sample size. Future research should confirm these findings and analyze whether similar strength improvements occur in other muscle groups after neural stimulation. Additionally, it is necessary to perform both mid- and long-term assessments of strength using a dynamometer to evaluate how long these improvements are maintained over time.

Conclusions

Ultrasound-guided PNM has been found to be an effective technique for the reestablishment of isometric strength of the quadriceps in inhibited muscles.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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