Ultrasound, Elastosonography, Functional and Visual Evaluation of the Outcome of Repetitive Muscle Magnetic Stimulation

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Purpose

Evaluation of repetitive Muscle Magnetic Stimulation (rMMS) effects on functional status and quality of life after knee surgery. Ultrasound (US) and Elastosonography, as well as Visual Analog Scale (VAS), Maximal Voluntary Contraction (MVC) and Short Form Health Survey (SF-36) assessment were performed.
Methods and Materials

A 55 year old female patient underwent knee surgery reporting a severe quadriceps muscle (QM) group atrophy showing no improvements after 11 months of rehabilitative physiotherapy.

Patients with Knee disorders exhibit a decreased activation of quadriceps compared to the uninvolved limb suggesting that neural mechanisms contribute to the weakness of the quadriceps. Weakness of the quadriceps muscle results in important functional consequences such as decreased gait speed, balance, difficulty with stair climbing, and rising from a chair and risk of falls.

After the cessation of inconclusive therapy, a 50 minute rMMS treatment was applied to the diseased QM, 3 days a week for 7 weeks.

For the rMMS a Medtronic MagPro R100 device (Medtronic Denmark A/S, Copenhagen, Denmark) connected to elliptical RT-120 and circular MCF-125 coils was used. The performed stimulation protocol was: activation for 5 seconds from 20 to 30 pps with rise time of 0.8 sec and fall time of 0.8 sec, rest of 10 seconds. We directly stimulated the vastus lateralis muscle and rectus femoris muscle (RFM) of the QM group. Stimulation was preferably applied midway between the upper third and the remaining two thirds of the body of the muscle, at the point of maximum response.

In rMMS a current flow through a solenoid and causes a rapid change of the magnetic field, which in turn induces a depolarization of excitable tissues (muscle) such as that which is determined for the electrical stimulation. The advantage is that the current does not pass through high resistance tissues such as the skin for which the nociceptors are not activated and so it is possible to obtain a valid muscle contraction without inducing stimulation pain.

The RFM was the muscle evaluated with Ultrasound due to the fact it was the one mainly stimulated by the rMMS treatment.

B-Mode US examination and Elastosonography were performed in order to add imaging and functional evaluations to the rMMS treatment.

B-Mode US muscle structure evaluation and thickness measurement and Elastosonography color coded tissue stiffness map (MyLabAlpha, Esaote S.p.A., Florence, Italy) were evaluated before (T0) and after (T1) the rMMS treatment. VAS, MVC and SF-36 scores were also evaluated at T0 and T1.

Elastosonography is a non-invasive method to support the physician in assessing tissue elasticity. This technology provides additional information to standard B-Mode, a better definition of the lesion area, and it is suitable for diagnosis and follow-up. Moreover, it gives information on the tissue elasticity by associating different chromatic
patterns. Real-time elastosonography (ElaXto; Esaote S.p.A., Florence, Italy) is based on the concept of elastic strain: an object, subject to stress, distorts proportionally to the intensity of the applied stress and depending on the material. It is known that tissue elasticity, in different districts, is correlated to pathologies. Palpation, which is routinely used in clinical exams, is based on this assumption. In order to perform the elastosonographic exam, the user has to apply a perpendicular pressure through rhythmic movements on the tissue under exam. Thanks to the pressure given by that action, it is possible to evaluate the modification of the echo signal and thus to compute how the different tissues distort (if they are soft) or move (if they are hard) compared to the probe position. The result of this calculation, computed in real-time, is shown by a color image overlapped to the B-Mode image. The deformability degree is given by a chromatic scale. ElaXto is a qualitative analysis where the estimation of strain information is computed in relation to the surrounding tissue. The computed strain information is dependent on the tissue of the Region of Interest (ROI). To date, elastosonography was not applied on in vivo leg muscle for tissue elasticity investigations in relation to magnetic stimulation treatment assessment and follow up. Elastosonography is a relatively-quantified technology: tissues are shown harder or softer in a relative not in an absolute manner, therefore, tissues soft are softer than the average value of the tissues within the ROI while they can be hard if compared to other tissues.
Results

Transverse and longitudinal US acquisitions were performed by the same expert sonographer at T0 and T1, following the same protocol. Specifically, the right foot was always the first to be scanned and the US images were performed with the probe in both longitudinal and transversal positions. B-mode US acquisitions were performed on both legs. They were examined in the same area, in order to have a direct comparison between the injured (DX) and healthy (SX) leg.

Re-positioning of the probe in almost exactly the same scanning plane at T0 and T1 acquisitions was possible due to the use of real-time Archive visual comparison tool. A general B-Mode US overview was done, in order to check and set the correct image quality (XView, MView and Grayscale were optimized).

The location of the examined area on the RFM was measured between the knee and the ankle (Figure 1) using a tape ruler.

A large amount of US gel (Parker Aquasonic 100, Parker Laboratories, USA) was applied in order to avoid compression of the probe coupling with the leg skin. Indeed, it is known that even a small compression changes the shape and dimension of the relaxed muscle tissue. The technique adopted consisted in starting to couple the linear probe (SL1543, 3-13 MHz, Esaote S.p.A., IT) with the leg muscle tissue until complete coupling of the probe on the center part of the echographic image sector was achieved. The probe movement towards the leg muscle stopped as soon as the first tissue compression was noticed.

Regarding the B-Mode US evaluation, at T0 a difference in RFM structure between the damaged leg and the healthy one was easily visible, in terms of muscle dimensions (longitudinal view) and tissue structure. Figure 2 shows the damaged leg on the left side of the image and the healthy leg on the right side of the image.

B-Mode US T0 measurement in longitudinal and transverse view of the distance between the RFM upper and inner aponeurosis showed a difference between the injured (DX) and healthy (SX) (between 4.5 and 5mm; see Figure 3).

B-Mode US T0 measurement in longitudinal and transverse view of the distance between the RFM upper and inner aponeurosis showed a difference between the injured (DX) and healthy (SX) (between 4.5 and 5mm; see Figure 3).

T0 Elastosonography evaluation of the RFM showed a softer structure in the injured leg (DX) compared to the healthy one (SX). Elastosonography evaluation and RFM thickness measurement were carried out both in longitudinal (Figure 4) and transverse view (Figure 5).

US B-Mode evaluation performed at T1 showed a 2-mm increase in muscle thickness (Figure 6), larger presence of defined muscle structure in longitudinal (Figure 7) and transverse (Figure 8) acquisitions and a harder pattern at elastosonography assessment.
in longitudinal (Figure 9) and transverse acquisitions (Figure 10) than at T0, especially between the RFM upper aponeurosis and the muscle mid line.

At T0 it was not possible to evaluate MCV due to severe pain (VAS=10). At T1 the MCV was 25% lower than in the healthy leg. Between T0 and T1 the pain was reduced to VAS=2. Total scores of the SF-36 increased from 58% (at T0) to 83% (at T1) and physical score increased from 25% (T0) to 76% (T1) for physical function. There was a leg circumference increase of 4 cm between T0 and T1.
Images for this section:

![Image](image_url)

**Fig. 1:** measuring the location of the examined area on the RFM using a tape ruler

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**Fig. 2:** B-Mode US showing the injured RFM on the left side of the image and the healthy RFM on the right side of the image, at T0

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Fig. 3: B-Mode US showing thickness difference between injured (A) and healthy (B) RFM

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Fig. 4: T0 Elastosonography Longitudinal view injured RFM (A) and T0 Elastosonography longitudinal view healthy RFM (B)

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**Fig. 5:** T0 Elastosonography transverse view injured RFM (A) and T0 Elastosonography transverse view healthy RFM (B)

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Fig. 6: B-Mode longitudinal US showing the injured RFM (A) and the healthy RFM (B), at T1

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Fig. 7: B-Mode transverse US showing the injured RFM (A) and the healthy RFM (B), at T1

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**Fig. 8:** T1 Elastosonography longitudinal view injured RFM (A) and T1 Elastosonography longitudinal view healthy RFM (B)

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Fig. 9: T1 Elastosonography transverse view injured RFM (A) and T1 Elastosonography transverse view healthy RFM (B)

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Conclusion

rMMS has demonstrated improvements in muscle function parameters in COPD patients (Bustamante et al. 2010), but to the best of our knowledge no data are available in patients with muscle strength reduction after knee surgery. The use of rMMS was effective at providing rapid improvements in strength, knee pain and quality of life, and morphological and structural muscle changes have been documented by means of B-Mode US and elastosonography. A portable US system capable of elastosonography with a high level of image quality was used due to its transportability. Indeed, many subjects with leg injuries have limited mobility. US diagnostic technology is generally real-time, non-ionizing and cost effective, so it is also useful for repeat follow up. It is widely available within different clinical settings and portable systems are also suitable for home diagnosis. The rMMS is safe and painless compared to Neuromuscular Electrical Stimulation. Randomized controlled trials on a larger population are needed in order to confirm these preliminary results.
References


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