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Is there a role for deep friction massage in the management of patellar tendinopathy? Technique characterization and short-term clinical outcomes.

Paula Maria Dias Chaves

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KEY-WORDS: TENDON; MANUAL THERAPY; CYRIAX; PAIN; MANUAL PRESSURE

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RESUMO

O objetivo do presente trabalho foi o de caracterizar e analisar os parâmetros de aplicação da Massagem Transversa Profunda (MTP) na prática clínica de fisioterapia, nomeadamente a pressão aplicada e a sua influência na sintomatologia da tendinopatia patelar. Inicialmente foi analisada a literatura relativamente à descrição e fundamentação da MTP. Posteriormente foi realizado um estudo observacional, transversal e analítico, com fisioterapeutas portugueses, selecionados por amostragem de bola de neve, com um questionário *online*. Assim, determinou-se a prevalência do uso de MTP na prática clínica e caracterizaram-se os parâmetros de aplicação utilizados. Foi ainda realizado um estudo observacional, transversal e analítico, com uma amostra de conveniência, com o objetivo de determinar a pressão cutânea mínima necessária para promover a deformação macroscópica do tendão patelar. De seguida, com o objetivo de determinar se existia relação entre a pressão aplicada durante a MTP e o tempo de início da analgesia, no tendão patelar, caracterizou-se numa primeira fase, através de um estudo observacional, transversal e analítico, a pressão média aplicada pelos fisioterapeutas durante a MTP; posteriormente, com base na pressão obtida, realizou-se um estudo randomizado, controlado, cruzado e transversal com o qual se estudou o efeito de diferentes pressões utilizadas durante a MTP no tempo até a analgesia. Por fim, foi realizado um estudo randomizado, controlado, cruzado em atletas com tendinopatia patelar, cujo objetivo foi avaliar se a pressão aplicada durante a MTP tem impacto em *outcomes* clínicos, nomeadamente na dor, força muscular e amplitude de movimento. Concluiu-se que a MTP é altamente utilizada pelos fisioterapeutas portugueses, com uma alta heterogeneidade e variabilidade nos parâmetros de aplicação escolhidos. Durante a aplicação da técnica, é aplicada uma pressão local de 2.3 kg/cm^2 (1.02; 4.16), que se encontra acima da necessária para promover a deformação macroscópica do tendão patelar (1.1 $\pm$ 0.37 kg/cm^2), independentemente das caraterísticas do indivíduo. Concluiu-se ainda que a MTP promove uma redução imediata da dor, independentemente da intensidade da pressão aplicada.

PALAVRAS-CHAVE: TENDÃO; TERAPIA MANUAL; CYRIAX; DOR; PRESSÃO MANUAL

ABSTRACT

The aim of this work was to characterize and analyze the parameters of application of deep friction massage (DFM) in physiotherapy clinical practice, namely the pressure applied and its influence on the symptoms of patellar tendinopathy. First, it was analyzed the literature regarding DFM description and grounding. Next, an observational, cross-sectional and analytical study was conducted, with Portuguese physiotherapists selected through a snow-ball sampling method, that completed an online questionnaire. This allowed to determine the prevalence of DFM utilization in clinical practice and characterize the application parameters used. It was also performed an observational, cross-sectional and analytical study with a convenience sample, aiming to determine the minimum skin pressure necessary to promote a macroscopic deformation of the patellar tendon. To determine if a dose-response relationship exists between the pressure applied during DFM and time to onset of analgesia, in the patellar tendon, a two-phase study was performed, where firstly, through an observational, cross-sectional and analytical study, it was characterized the mean pressure applied by physiotherapists during DFM; after this, the pressure observed in the previous study was used in a randomized, controlled, cross-over and cross-sectional trial evaluating the effect of different DFM pressures in the time to onset of analgesia. At last, a randomized, controlled and cross-over trial with athletes with patellar tendinopathy was performed, whose objective was to assess whether the pressure applied during DFM impacts on clinical outcomes, namely pain, muscle strength and range of motion. With the results of this work, it was concluded that DFM is highly used by Portuguese physiotherapists, which present a high heterogeneity and variability in the application parameters chosen. They applied a pressure 2.3 kg/cm^2 (1.02; 4.16), which is above the average skin pressure needed to promote the macroscopic deformation of the patellar tendon (1.1 $\pm$ 0.37 kg/cm^2), regardless of the characteristics of the individual. It was also concluded that DFM induces an immediate reduction of pain, irrespectively of the intensity of pressure applied.

KEY-WORDS: TENDON; MANUAL THERAPY; CYRIAX; PAIN; MANUAL PRESSURE

List of Abbreviations

DFM	[Deep friction massage]
adjOR	[Adjusted odds ratios]
BIC	[Bayesian information criterion]
BMI	[Body mass index]
CI	[Confidence interval]
LCA	[Latent class analysis]
MeSH	[Medical subject heading]
OR	[Odds ratios]
P25	[Percentile 25]
P75	[Percentile 75]
SD	[Standard deviation]
SPSS	[Statistical package for the social sciences]
VISA-P	[Victorian institute of sport assessment questionnaire patellar tendon]

CHAPTER 1

INTRODUCTION

Deep friction massage (DFM) was empirically developed and proposed by James Cyriax as a therapeutic resource for the specific treatment of connective tissue (Atkins, Kerr, & Goodlad, 2010; Brosseau et al., 2002; Chamberlain, 1982; Joseph, Taft, Moskwa, & Denegar, 2012; Loew et al., 2014). This manual therapy approach aims to passively mobilize soft-tissues, favouring its regeneration process and restoring the mobility of the affected tissue and its components (Atkins et al., 2010; Brosseau et al., 2002; Loew et al., 2014; Prabhakar, Kage, & Anap, 2013; Stasinopoulos & Johnson, 2004).

The specificities of this massage technique, regarding the characteristic of its application procedures (transversal and deep), aim to foster fibroblastic activity, break disorganized and dysfunctional intermolecular cross-links (adherences) between the collagen fibres, and favour the realignment and elongation of the collagen fibres, while not compromising the regeneration process (Atkins et al., 2010; Brosseau et al., 2002; Chamberlain, 1982; Davidson et al., 1997; Gehlsen, Ganion, & Helfst, 1999; Joseph et al., 2012; Loew et al., 2014; Prabhakar et al., 2013; Stasinopoulos & Johnson, 2004). Clinically, this technique aims to decrease pain and improve function (Begovic, Zhou, Schuster, & Zheng, 2016; Brosseau et al., 2002; Chamberlain, 1982; Cyriax & Cyriax, 1993; Joseph et al., 2012; Loew et al., 2014; Stasinopoulos & Johnson, 2004). For this, it is frequently used in the treatment of muscle tears, tenosynovitis and mainly tendinopathies (Chaves et al., 2017; Joseph et al., 2012).

In order to achieve success in the application of DFM, its author defined a set of adequate and precise assessment procedures and highlighted the importance of accuracy when identifying and locating the injured structure as well as the precise location of the lesion, which is confirmed through palpation (Atkins et al., 2010; Chamberlain, 1982; Cyriax & Cyriax, 1993). He also defined a set of basic application principles to ensure an effective procedure that should be adjusted according to the stage, irritability and patient feedback (Chamberlain, 1982; Cyriax & Cyriax, 1993; Stasinopoulos & Johnson, 2004).

Even though the positive effects of DFM in the tendinopathy treatment shown by individual studies, the conclusions of the systematic reviews were that DFM is not more effective than any other therapeutic resource indicated for this condition (Brosseau et al., 2002; Joseph et al., 2012; Loew et al., 2014). These results may be explained by the fact that DFM was not sufficiently studied in isolation, being part of different treatment protocols on each of the studies included in the above-mentioned systematic reviews. Notwithstanding, when analysed the description of DFM procedures provided in the clinical studies assessing its effectiveness, one can verify that although the technique is referred to as "Cyriax DFM" there is incoherence and absence of clarification in the applied procedures, which results in a lack of standardization of the applied protocols (Blackwood & Ghazi, 2012; Cooil & Gahzi, 2010; Croisier, Foidart-Dessalle, Tinant, Crielaard, & Forthomme, 2007; Fathy, 2015; Hassan, Hafez, Seif, & Kachanathu, 2016; Nagrale, Herd, Ganvir, & Ramteke, 2009; Olaussen, Holmedal, Mdala, Brage, & Lindbæk, 2015; Pellecchia, Hamel, & Behnke, 1994; Senbursa, Baltaci, & Atay, 2007; Senbursa, Baltaci, & Atay, 2011; Stasinopoulos & Stasinopoulos, 2004, 2006; Stratford, Levy, Gauldie, Miseferi, & Levy, 1989; Vasseljen, Hoeg, Kjeldstad, Johnsson, & Larsen, 1992; Verhaar, Walenkamp, Mameren, Kester, & Linden, 1996; Viswas, Ramachandran, & Korde Anantkumar, 2012). Moreover, there is also a huge methodological variability concerning the study designs, instruments and methods of assessment of the studied outcomes (pain and function).

Having this in mind and before conducting further studies regarding DFM, it seems important to revise the foundations of the technique in order to ascertain whether DFM is being used by the physiotherapists and how it is executed, aiming not only the standardization of its clinical use and application, but also to contribute to a better outlining of future studies.

Beyond the characteristics of DFM application (pressure and frequency), duration and number of treatment sessions performed, Loew et al. (2014) also identified as possible confounding variables the characteristics of the physiotherapist, which may contribute to the lack of clarification about the real therapeutic effects of this technique over the tendinous structure.

Taking into account the above-mentioned limitations, and once these may influence the results of clinical trials, it seems reasonable to question whether this lack of consensus observed in research studies is also found in daily clinical practice. Consequently, it is important to know whether the physiotherapists use a standardized DFM procedure and are following the principles of application described by Dr. James Cyriax, since non-compliance with those guidelines may interfere with the technique's effectiveness. Thus, it is required to know how DFM is really used in clinical practice, in which situations, and which application procedures are being followed.

The effectiveness of DFM as a single technique in the treatment of tendinopathy is not clear, and beyond its empirical grounding it is not known the real morphological and histological effects of its application in the human tendinous structure (Brosseau et al., 2002; Joseph et al., 2012; Loew et al., 2014). This lack of knowledge may be attributed not only to limitations of data regarding the repairing process of the tendinous tissue, but also the lack of control over DFM application procedures (Brosseau et al., 2002; Loew et al., 2014).

In respect to the repairing process of the tendinous structures, there is a difficulty to create an experimental model that encompasses all phases and characteristics of tendinopathy (Cook, Rio, Purdam, & Docking, 2016; Snedeker & Foolen, 2017). According with Medical Subject Heading (MeSH), tendinopathy is defined as a clinical syndrome describing overuse tendon injuries characterized by a combination of pain, diffuse or localized swelling, and impaired performance (NIH - U.S. National Library of Medicine, 2017). The lack of clarification concerning this condition is due not only to the complexity of normal tendon structure, the multifaceted nature and magnitude of the tendon's response to injury but also to the difficulty in creating an experimental animal model that mirrors the human load-related tendon pathology (Cook et al., 2016; Snedeker & Foolen, 2017). It has been described an increasing prevalence of tendinopathy, both sports and work related, with lower extremity tendinopathy being the most reported in literature (Albers, Zwerver, Diercks, Dekker, & Van den Akker-Scheek, 2016; Cassel et al., 2014; Svensson, Praxitelous, & Ackermann, 2017). Patellar tendinopathy, also known as jumper's knee, is one of the most common lesions among athletes practicing jumping sports as well as sports that require repetitive impact forces and sudden direction changes (Blackwood & Ghazi, 2012; Cassel et al., 2014; Everhart et al., 2017; Gaida & Cook, 2011; Lian, Engebretsen, & Bahr, 2005; Malliaras, Cook, Purdam, & Rio, 2015; Zwerver, Bredeweg, & van den Akker-Scheek, 2011). So, this is a condition related with the overload of knee extensors system and pain in the anterior region of the knee is usually the first symptom referred by the subject. The diagnosis is essentially clinical, based on pain upon palpation and functional deficit (Blackwood & Ghazi, 2012; Cook & Purdam, 2009; Cook et al., 2016; Malliaras et al., 2015; Rees, Maffulli, & Cook, 2009; Rudavsky & Cook, 2014).

Regarding the lack of control over DFM application procedures, it is known that within the principles of application described by Cyriax (Atkins et al., 2010; Chamberlain, 1982; Cyriax & Cyriax, 1993; Stasinopoulos & Johnson, 2004), the main variables concerning technical execution and that the physiotherapist should take into account are the direction of the massage, that should be performed in a transverse orientation and the pressure performed, that should be "deep enough" (Atkins et al., 2010; Brosseau et al., 2002; Chamberlain, 1982; Cyriax & Cyriax, 1993; Loew et al., 2014). While the transverse direction, needed to prevent or break the cross-links between the collagen fibres (Chamberlain, 1982; Goats, 1994; Gregory, Deane, & Mars, 2003; Joseph et al., 2012; Stasinopoulos & Johnson, 2004), may be controlled by the knowledge of the anatomical orientation of the tendon; the required pressure has only been described qualitatively as "deep enough" to reach the target tissue, while the transverse movement to the fibres is applied (Atkins et al., 2010; Chamberlain, 1982; Gregory et al., 2003; Loew et al., 2014; Sterns, 1940).

Studies performed in the animal model (Davidson et al., 1997; Gehlsen et al., 1999) have shown that a variation in the magnitude of the pressure applied during the mobilization of soft tissues reflects in a directly proportional variation of the recruitment and activation of the fibroblasts. Notwithstanding, it is not known whether these effects are also present in the human tissue. Additionally, it is not known how the amount of pressure applied may influence the other effects attributed to the technique, namely the analgesic response and functional outcomes. There are several hypotheses that may explain the mechanisms regarding DFM effects on pain reduction, as: 1) induction of hyperaemia produced by mechanical stimulus, that may result in an increased blood flow to local tissue, with a possible increase of histamine release, resulting in an increase in the speed of destruction of P Lewis substance (which, when present at high concentrations causes ischemia and pain) (Atkins et al., 2010; Chamberlain, 1982; Goats, 1994; Gregory et al., 2003; Stasinopoulos & Johnson, 2004); 2) modulation of nociceptive impulses at the spinal cord ("gate control theory"), where the mechanical stimulus of DFM will lead to the activation of low-threshold A-α and A-β fibres that inhibit nociceptive input from A-δ and C afferent fibres, that are responsible for nociceptive conduction at the dorsal horn of the spinal cord (De Bruijn, 1984; Goats, 1994; Gregory et al., 2003; Hassan et al., 2016; Stasinopoulos & Johnson, 2004; Viswas et al., 2012), and 3) the descending mechanisms of pain modulation, wherein neurotransmitters like serotonin and endogenous opioids have been shown to modulate nociceptive circuits and pain output by acting on structures such as the rostral ventromedial medulla and periaqueductal grey (Atkins et al., 2010; Bialosky, Bishop, Price, Robinson, & George, 2009; Goats, 1994; Llorca-Torralba, Borges, Neto, Mico, & Berrocoso, 2016; Pud, Granovsky, & Yarnitsky, 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015).

Regarding function, evidence has shown that pain may affect both range of movement and strength of the affected joint (Graven-Nielsen & Arendt-Nielsen, 2008; Lund, Donga, Widmer, & Stohler, 1991), presumably as a reaction to enhance protection of the painful tissue, at least in the short term (Hodges & Tucker, 2011; Lund et al., 1991; Struyf et al., 2014). This may be explained by the impairment caused by nociception on motor output through central mechanisms (motor cortex inhibition) and by peripheral sensitization (Farina, Tinazzi, Le Pera, & Valeriani, 2003; Farina et al., 2001; Struyf et al., 2014). Furthermore, it is described that pain might interfere with muscle strength once the individual may perform the contraction with reduced force due to fear of injury (Struyf et al., 2014).

Taking into account that the qualitative management of the pressure applied during DFM may be responsible for triggering the analgesic response, it is not known if the pressure performed is enough to promote the advocated biomechanical effects. This is, the pressure applied aims to produce a shear movement over the tendinous fibres, ensuring the morphological and histological effects, empirically attributed to DFM (Atkins et al., 2010; Chamberlain, 1982; Davidson et al., 1997; Gehlsen et al., 1999; Gregory et al., 2003; Sterns, 1940).This biological response, only demonstrated in the animal model, leads to an alteration of the biomechanical properties of the tendon (morphological and functional) promoting an effective and organized repair of the injured tissue (Atkins et al., 2010; Chamberlain, 1982; Davidson et al., 1997; Gehlsen et al., 1999; Gregory et al., 2003; Sterns, 1940). Beside the need of further enlightening these effects in the human tissue, it is also fundamental to ascertain what is the minimum magnitude of skin pressure necessary to induce a macroscopic deformation of the patellar tendon.

Considering the lack of consensus in the literature regarding the procedures of DFM described and acknowledging that the physiotherapist performance may be constrained by lack of mastering Cyriax's assumptions, as well as the hypothesis that its effects may be influenced by the amount of pressure applied, the main aim of this work was to characterize and analyze the parameters of application of DFM in physiotherapy clinical practice, namely the pressure applied and its influence on the symptoms of patellar tendinopathy. Taking this into account, the following specific objectives were defined:

1. To analyse and summarize the literature regarding the application of deep friction massage, as described by Cyriax, in tendinopathy.
2. To determine the prevalence of DFM use in clinical practice in Portugal, characterizing the parameters used by physiotherapists during DFM application and identifying empirical model-based patterns of DFM application adequacy in degenerative tendinopathy.

3. To determine the skin pressure needed to promote the macroscopic deformation of the asymptomatic patellar tendon and to verify if the pressure is influenced by the individual's characteristics.
4. To determine if a dose-response relationship exists between the pressure applied during DFM and time to onset of analgesia, in the asymptomatic patellar tendon.
5. To assess whether the immediate effects of DFM on clinical outcomes, namely pain (pain intensity and time to onset of analgesia), muscle strength and range of motion, are dependent on the pressure applied during DFM application in athletes with patellar tendinopathy.

The present document is structured according to the Scandinavian model and is divided in six chapters.

The first chapter concerns the introduction to DFM, where the rational to perform this work is presented. This chapter ends with the objectives of the research project. The second chapter, entitled "State of the Art" encompasses a published book chapter regarding DFM as a rehabilitation strategy for the treatment of tendinopathy. The third chapter, entitled "Original research manuscripts", comprises the experimental part of this work being composed by four original studies aiming to answer the proposed objectives. In the fourth chapter, the "Discussion" chapter, a general and integrated discussion regarding the methodology and the results of the original studies is presented. The fifth chapter encompasses the main conclusions of the thesis and perspectives for future research. The last chapter presents the bibliographic references that support the first and fourth chapters.

CHAPTER 2

STATE OF THE ART

STATE OF THE ART

Deep Friction Massage as an Effective Rehabilitation Strategy to Treat Tendinopathy.

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Chapter 1

Deep Friction Massage as an Effective Rehabilitation Strategy to Treat Tendinopathy

Paula Chaves*[1]*, Maria Paço*[1]*, Francisco Pinho*[1]*,
***José Alberto Duarte*[2] *and Fernando Ribeiro*[3,*]**
[1]CESPU, CRL, Polytechnic Health Institute of the North,
Gandra PRD, Portugal
[2]University of Porto, Faculty of Sport,
Research Centre in Physical Activity,
Health and Leisure, Porto, Portugal
[3]School of Health Sciences, University of Aveiro,
Aveiro, Portugal

Abstract

Tendon tissue degeneration is described as a condition resulting in disorganized and fibrous tissue, where several morphometric, histological and biomechanical changes can be found. Several approaches have been proposed in the rehabilitation of chronicle tendinopathies, from surgery to

[*] Corresponding author's email: Fernando Ribeiro, School of Health Sciences, University of Aveiro, Edifício 30, Agras do Crasto - Campus Universitário de Santiago, 3810-193 Aveiro, Portugal. Email: fernando.ribeiro@ua.pt.

conservative treatment by physical exercise and physiotherapy. Physiotherapy is often advocated as an effective conservative treatment, encompassing eccentric exercise, physical agents and manual therapy. Concerning manual therapy, the deep friction massage proposed by Dr. James Cyriax is one of the most used techniques. The benefits promoted by the passive tissue mobilization resulting from deep friction massage include fostering fibroblastic activity and alignment of new collagen fibers on the regenerative tissue, as well as the acceleration of the healing process in the mobilized tissue. Deep friction massage is executed in a transverse plane, which is advocated to facilitate the breaking down of tissue adherences and of the disorganized and dysfunctional pattern between the collagen fibers without compromising the longitudinal regenerative process, as well as favoring the fibers' realignment and elongation. In general, the literature has highlighted the pertinence of using deep friction massage, combined with other physiotherapy techniques, in the treatment of tendinopathies.

Keywords: Manual therapy, collagen, degeneration, soft tissue, physiotherapy

1. Introduction

Tendon tissue degeneration is described as a condition resulting in disorganized and fibrous tissue, wherein several morphometric, histological and biomechanical changes can be observed [2, 3, 7, 14, 21, 25, 28, 31, 43, 46, 47, 49, 54]. Several approaches have been proposed in the rehabilitation of chronic tendinopathies, from surgery to conservative treatment by physical exercise and physiotherapy [2, 5, 7, 20, 25, 27, 42]. Physiotherapy is often advocated as an effective conservative treatment, encompassing eccentric exercise, physical agents [2, 22, 37, 42] and manual therapy [2, 5, 12, 20, 39, 42, 49, 56, 57]. Within manual therapy, one of the most used techniques is deep friction massage.

Deep friction massage is a specific type of intervention used in the rehabilitation of soft tissue structures such as tendons, ligaments and muscles [49]. This technique was empirically developed and proposed by Dr. James Cyriax in 1975, and is still frequently used today in clinical practice for rehabilitation of degenerative tendinopathy [9, 36, 45, 49-51, 58]. The benefits promoted by the passive tissue mobilization resulting from deep friction massage include fostering fibroblastic activity and alignment of new collagen fibers on the regenerative tissue, as well as acceleration of the healing process in the mobilized tissue.

In a time where the main challenge for research is to strengthen the clinical evidence with scientific evidence, the study of different modalities and therapeutic approaches in physiopathological and functional rehabilitation is critical. In this sense, this chapter aims to provide a critical review of the literature evaluating the efficacy of deep friction massage for treating tendinopathy.

2. Degenerative Tendinopathy

Degenerative tendinopathy has a multifactorial etiology and is thought to be a maladjustement to the mechanical load [3, 20, 21, 25, 54], and results from a failure in the tendon healing response [29]. This tendon pathology was initially termed tendinitis, though physiopathological research failed to demonstrate the presence of inflammatory cells (macrophages, lymphocytes and neutrophils) in the affected tissues, leading to the more recent designation of tendinopathy [14, 21, 25, 31, 46, 47, 59].

In this clinical condition, the degenerated tendon tissue is described as a disorganized and fibrous tissue, where different morphometric, histological and biomechanical changes can be observed [2, 3, 7, 14, 21, 25, 28, 31, 43, 46, 47, 49, 54]. These changes include abnormal alignment of collagen fibers, vascular hyperplasia, increased number of fibroblasts, extracellular matrix degeneration, increased production of type III collagen and reduction of maximal stretching threshold [2, 3, 7, 14, 21, 25, 28, 31, 43, 46, 47, 49].

Diagnosis is considered to be simple and can be confirmed through ultrasound or MRI [8, 59]. Notwithstanding, in clinical practice the diagnosis is usually achieved through a subjective and physical examination, which should include observation, palpation and clinical tests that allow the clinician to perform a differential diagnosis [12, 23, 59].

Tendinopathy is commonly related to activities requiring repetitive movements, and a symptomatic clinical presentation is characterized by the presence of pain associated with the activity and/or palpation, and also by functional impairment [31, 34, 46].

This pathology affects mainly the Achilles tendon [20, 24, 44], patellar tendon [20, 26, 44, 62], epicondylian muscles tendon [1, 20, 40, 44] and rotator cuff tendon [20, 44]. The Achilles tendon is the lower-limb structure most commonly affected, with an incidence around 6% in the inactive population and 50% in elite athletes [20, 24, 44], followed by the patellar tendon, with 12% of elite athletes affected. However, when the incidence of patellar tendinopathy is analysed specifically in sports asociated with jumping (for instance, basketball or volleyball) this percentage may increase to 40% in elite athletes and around 14% in non-elite athletes [20, 26, 44, 62]. In the upper limb, tendinopathy at the wrist extensors has a global incidence of 1% to 3% in the general population, being associated with specific professional [54] and sports movements [20, 40, 44, 54]. In tennis, the incidence has been reported as 35% to 51% [1, 54] among non-professional athletes and 9% to 35% among professional/elite players [20, 40, 44]. In relation to the shoulder, research has shown that athletes demanding specific shoulder movements, as throwing movements, tennis or swimming, are more susceptible to rotator cuff injury, with the supraspinatus muscle being the most commonly affected. The incidence of this has been reported as 24% in high-level tennis athletes aged between 12 and 19 years, and increasing with age [44].

3. Physiotherapy Treatment for Tendinopathy

The literature describes and proposes several therapeutic options to treat tendinopathy, with different theoretical mechanisms of action, but with the common aim of reducing pain and improving function [21, 25, 27, 42, 49].

Several treatment options have been presented, from surgery to conservative treatment, which includes exercise and physiotherapy [2, 5, 7, 20, 25, 27, 42]. However scientific evidence regarding the techniques' efficacy, both in isolation and combined, remains unclear, so there is no technique considered to be the ideal treatment [2, 5, 7, 20, 25, 27, 42, 61]. Physiotherapy, as a conservative treatment to tendinopathy, commonly employs eccentric exercise [2, 27, 35, 42, 61]; physical agents such as thermotherapy, cryoterapy, iontophoresis and shockwave therapy [2, 22, 37, 42]; and manual therapy including mobilization with movement, stretching and deep friction massage [2, 5, 12, 20, 39, 42, 49, 56, 57].

Some studies have shown that a gradual and controlled eccentric exercise load stimulates fibroblast activity, promotes new collagen formation and assists in the recovery of the parallel alignment of collagen fibers [2, 10, 11, 21, 25, 27, 29, 34, 38, 43, 46, 48]. Such results suggest that this type of exercise is favourable to the recovery process for degenerative tendinopathy in the body of the tendon [2, 10, 11, 21, 25, 27, 29, 34, 38, 43, 48].

Other therapeutic modalities widely accepted in clinical practice are the physical agents, theoretically for triggering a specific physiological response at the site of lesion, thus leading to injury recovery. Various physical agents induce an increase in local temperature, with the purpose of increasing the blood flow in order to enhance the tissue extensibility capacity and reduce pain [19, 22, 25, 33]. In the recovery process, induced hyperemia may increase the cellular metabolism, allowing for a large removal of waste products, new collagen synthesis and an increase in fibroblasts production [8, 19]. Theoretically, the use of this modality can influence the pathology's evolution, and it is not known how it affects rehabilitation results [2, 33]. This lack of insight about the effects of heat in tendinopathy reflects the scarcity of controlled trials studying different thermic approaches in this clinical condition.

There are also approaches intended to decrease local temperature; however, the physiological effects triggered by cold on the tendon will be dependent on the time of exposure. In the situation of a short exposure (about 15 minutes), a decrease in the tissue's temperature is expected, resulting in vasoconstriction and consequent reduction in blood flow, cellular metabolism, pain, tissue extensibility and nervous conduction velocity [19, 43]. There is no consensus in the literature regarding the efficacy or even the relevance of using cryotherapy [8]. Clinical evidence has been supporting its use to control inflammatory processes and after acute lesions [19]. In tendinopathy, due the lack of knowledge about its application, judicious use of cryotherapy is recommended only in situations where there is an associated inflammatory process of paratendon [19, 21].

Electrotherapy aims to generate an action potential in the excitable tissue, and offers three options regarding the type of current—continuous, alternating or pulsed—depending on the intended effect [2, 22, 53]. Continuous current implies an uninterrupted flow of ions of a given load and a specific direction, and may also be used, beyond its electroestimulation effect, to introduce different types of drugs transcutaneously through a process called iontophoresis [2, 22, 53]. This process uses the ionic charge of the current, associated with the ionic charge of the therapeutic product, in order to induce localized absorption of the drugs in soft tissues through attraction-repulsion forces. The efficacy of iontophoresis' effect on tendinopathy is still questionable [2, 22, 53].

Shockwave therapy is usually performed using low doses of energy or high-energy waves, which are transmitted to soft tissue through an ultrasound environment [29, 43]. Possible physiological effects are the disintegration of calcifications, as well as cellular and circulatory changes associated with the process of tendon regeneration, promoting the regeneration and inhibition of pain receptors [29, 43]. Studies evaluating the effects of this therapeutic resource in tendinopathy have shown controversial results, and more evidence is necessary to justify its use, due to the large variability of the results and protocols used [2, 27, 33].

Several techniques are employed for rehabilitation through manual therapy, including stretching, mobilization with movement and deep friction massage, among others [2, 5, 12, 20, 39, 42, 49, 56, 57]. Despite the different approaches, their general objective is functionality by re-establishment of range of movement, neuromuscular control and strength [2, 5, 12, 20, 25, 39, 42, 49, 56, 57].

Stretching is often used as a manual therapy technique for managing tendinopathy [32, 42, 60]. This technique results in an increase in the elongation capability of the tendon, which seems to favour its repair [42]. Among the different stretching techniques, those most frequently used to treat tendinopathies are static and ballistic stretching [32, 42, 60]. The literature is not conclusive about the efficacy of this technique; however, it assumes that both stretching techniques may be used as complementary treatments and should be included in a multi-modal treatment program [32, 60].

Mobilization with movement consists of the application of a manual, sustained force (usually a joint glide) on a motion segment while a previously impaired sign is performed [57]. This technique has been used in the treatment of lateral epicondylalgia and has shown positive effects regarding pain, maximum grip strength, pain-free grip force, and pressure pain threshold [39, 57]. The mechanisms underlying its positive results are not yet clear. A biomechanical hypothesis was proposed suggesting that mobilization with movement reverses positional faults; more recently it was suggested that the neurophysiologic mechanisms also play an important role in the amelioration of symptoms [57]. Notwithstanding, further research is required in order to understand the underlying mechanisms of mobilization with movement on lateral epicondylalgia.

3.1. Deep Friction Massage

The deep friction massage proposed by Dr. James Cyriax uses passive mobilization of soft tissue as a facilitating strategy to restore the injured tissue and its microstructures, favoring its regeneration [6, 12, 20, 49]. Dr. Cyriax described several different effects that justify the option for deep friction massage, including decrease of pain and improvement of function (Table 1).

Table 1. Deep friction massage effects according to Dr. Cyriax [6, 12, 20]

Effects of deep friction massage
• Decrease of pain (Gate Control Theory) • Favoring of the healing process (Development and orientation of the collagen fibers) • Hyperemia • Function improvement (through decrease of pain)

Although until today there has been no definitive scientific evidence to clearly ascertain the efficacy of this therapeutic technique on connective tissue, what is known is that this remains one of the techniques of choice for physiotherapists [20, 41, 49]. This technique seems not to be based only on the empirical grounds of the author who proposed it, or on the clinical evidence demonstrating some positive results in those patients treated with it. Rather, increasing knowledge about the anatomy and physiology of the regeneration process of tissue may be the justification for its continued use. Thus, the use of deep friction massage as a strategy favoring the development, orientation and repair of connective tissue may be explained by different physiopathologic and/or biomechanical factors.

Different aspects may explain the immediate effects of deep friction massage [5, 6, 12, 18, 20]. First, the decrease in pain might be due to nociceptive pulses' modulation on the spinal cord ("Gate Control Theory"), where afferent conduction to dorsal horns' nociceptive receptor is inhibited by concomitant activity of the mechanoreceptor stimulated by the massage, located in the same structure [16-18, 49]. Second, another possibility is the effect induced by traumatic hyperemia, which would result in an increased blood flow to local tissue, with a possible increase of histamine release, resulting in an increase in the speed of destruction of P Lewis substance (which, when present at high concentrations causes ischemia and pain) [6, 12, 17, 49]. Third, it has also been suggested that 10 minutes of deep friction massage in a localized area may cause a lasting peripheral disturbance on the nervous system, with a local anesthetic effect as well as the induction of endogenous opiates [17, 49].

Concerning the need for movement in order to achieve an effective and organized cicatrization of muscular tissue, ligament and tendon, Dr. Cyriax based his reasoning on the work of Stearns who, in 1940, found that the organization of collagen fibers in the healing and regeneration process of connective tissue may also be favored by external factors, such as mobilization [6, 12, 18, 19, 46, 52]. Also, Chamberlain, in 1982, tried to provide reasons for Cyriax's principles to use deep friction massage based on the development, orientation and repair of connective tissue [6, 46, 49].

The lesion of soft tissue involves changes in cellular matrix [21, 25, 46, 47] during the regeneration process. In fact, during the remodeling phase, the fibroblasts play a significant role in the synthesis of collagen, proteoglicans and proteins, which is essential in the development of a normal/healthy cellular matrix [13, 25, 30, 46]. Performed deep friction massage in a transversal direction to the fibers seems to prevent or break disorganized and dysfunctional intermolecular cross-links (adherences) among the collagen fibers, whereas the longitudinal regeneration process is not compromised, and its realignment and elongation are favored [6, 12, 17, 18, 20, 49].

In addition, it seems that the type of load/movement and stress placed on the tissue during the healing process [25] also contribute to the efficacy of deep friction massage. Some authors highlight the importance of load/pressure control, where the optimal load may effectively induce the production of the fibroblasts and specific proteins necessary for tendon regeneration [15, 20, 25].

3.1. Principles of Application

In order to maximize the effects of deep friction massage, beyond the requirement of accuracy in the identification and determination of injured tissue, there is a set of basic principles of application that should be adjusted depending on the severity or condition of the injury [6, 12, 49]. Table 2 lists the principles for application of deep friction massage.

As noted in the deep friction massage application principles, the frequency and duration of sessions may vary according to the severity and type of lesion (Table 3). Thus, in an acute phase, the deep friction massage should be performed daily, respecting all the application principles, but with a softer intensity and shorter duration (about 10 movements after analgesia) [6, 12, 49]. In a chronic phase, the intensity should be strong and applied for a longer duration (10 minutes after analgesia). The deep friction massage in this phase will have a more traumatic effect, which restricts its application to alternate days [6, 12, 49].

Table 2. Principles for application of deep friction massage on tendons [6, 12, 49]

Deep friction massage application principles (tendons)
• Massage should be applied and confined to the exact area of injury; • The direction of movement should be transverse to the orientation of the affected fibers; • The depth and range of the transverse movement should be enough to ensure the digital compression and friction in the whole affected area/structure; • The beginning of the application should be slow and gradual, so as to respect the initial discomfort caused, until analgesia (it is important for the physiotherapist to distinguish discomfort from pain); • The degree of depth is dependent on the phase of the condition, the irritability of the situation and the patient's feedback (it might be initially uncomfortable, but should not be painful, and if correctly applied quickly reaches analgesia); • The duration of the treatment ranges from 6 to 12 sessions, with the frequency and duration of sessions adapted to the phase and type of lesion; • Patient should be comfortably positioned, relaxed yet accessible, to ensure biomechanical advantage during application (pressure control and direction of movement); • The injured tissue's its accessibility must fulfill the principles that benefit the application and the goals of the massage. Thus, if the lesion is at the body of the tendon or its transitions (tendon-bone or tendon-muscle), it should be in a position without tension, except in tendons with sheaths (in this situation, the tendon should be placed in tension/elongation); • The technique should be performed with the "tip" (distal phalanx) of one or two fingers, where the distal interphalangeal joints should be in flexion and can be reinforced by other fingers while applying pressure; • In most situations, the fingers, hand and forearm of the physiotherapist must perform coupled movements parallel to the movement performed, as if it was a single segment; • There should be no gliding between the cutaneous surface of the physiotherapist's fingers and the treatment area, to avoid lesions resulting from the friction/rubbing (to prevent lesions from friction and/or by sliding/sweating, the physiotherapist can use a cloth between the two skin surfaces).

Table 3. Frequency, duration and intensity of deep friction massage application [6, 12, 49]

Temporal Phase	Intensity	Frequency	Duration
ACUTE	Soft	Daily	Until analgesia + 10 movements
CHRONIC	Strong	Alternate days	10 minutes after analgesia

Table 4. Contraindications to the application of deep friction massage on tendons [12, 49]

Contraindications
• Bursitis • Calcifications • Skin diseases or fragility in the area to be treated • Disease of the blood vessels (mostly trombophlebitis and deep vein thrombosis in the area to be treated) • Neoplasia or tuberculosis in the area to be treated or in its vicinity • Bacterial infections in the area to be treated or in its vicinity • Neurological disturbances (loss of sensibility) • Anti-coagulant therapy

The softer deep friction massage, performed in recent lesions, has as a mechanical goal the maintenance of the mobility of affected structures, preventing the formation of adherences (cross-links). The soft and transversal movement performed promotes the alignment, realignment and elongation of the new fibers, thereby facilitating the regeneration process [6, 12].

The deep friction massage applied with a stronger intensity aims, among other objectives, to restore the mobility of the affected structures by the destruction of adherences [6, 12].

As in the selection of any therapeutic approach, deep transverse massage also faces some restrictions and contraindications to its use (Table 4) [12, 49].

3.2. Evidence Regarding the Effects of Deep Friction Massage

Several studies have been performed to determine the relevance of using deep friction massage, alone or combined with other techniques, in the treatment of tendinopathy [4, 5, 9, 36, 41, 45, 49-51, 55, 58].

Table 5. Summary of studies evaluating the effects of deep friction massage on degenerative tendinopathy

Study	Tendinopathy	Study Design	Outcome Measures	Main Results
Verhaar et al. [55]	Wrist extensors	RCT N = 106 G1 = 53 (corticosteroids injection) G2 = 53 (DFM + Mill's maneuver) µ age (both groups) = 43 ± 9 years	Verhaar Score: Pain Dynamometer: pain free grip strength Verhaar Questionnaire: Patient's satisfaction	G1 had better immediate results. After 1 year there were no significant differences.
Stasinopoulos and Stasinopoulos [51]	Wrist extensors	RCT N = 75 G1 = 25 (eccentric exercise + static stretching) µ age = 40.4 ±5.6 years G2 = 25 (DFM + Mill's maneuver) µ age = 40.4 ± 5.6 years G3 = 25 (Bioptron light) µ age = 40.1 ± 6.2 years	VAS: pain VAS: function Dynamometer: pain free grip strength	G1 had better results on pain and function
Nagrale et al. [36]	Wrist extensors	RCT N = 60 G1 = 30 (phonophoresis + eccentric exercise + static stretching) µ age = 32 ± 5.3 years G2 = 30 (10 min DFM+Mill's maneuver) µ age = 38 ± 6.2 years	VAS: pain Dynamometer: pain free grip strength TEFS	G1 and G2 improved pain, strength and function. The improvements were higher on G2.

Table 5. (Continued)

Study	Tendinopathy	Study Design	Outcome Measures	Main Results
Viswas et al. [58]	Wrist extensors	RCT N = 20 G1 = 10 (eccentric exercise + static stretching) μ age = 37.4 ± 4.9 years G2 = 10 (10 min DFM+Mill's maneuver) μ age = 38.2 ± 4.3 years	VAS: pain TEFS	G1 and G2 improved pain and function. The improvements were higher on G1.
Prabhakar and Kage [41]	Wrist extensors	Uncontrolled experimental trial N = 20 (US + Exercise + DFM + Mill's maneuver) μ age = 41.2 ± 7.7 years	VAS: pain Dynamometer: grip strength PRFEQ	All the outcomes improved.
Stasinopoulos and Stasinopoulos [50]	Patellar tendon	RCT N = 30 G1 = 10 (Eccentric exercise + static stretching) μ age = 28.1 ± 2.0 years G2 = 10 (pulsed US) μ age = 29.2 ± 3,8 years G3 = 10 (DFM) μ age = 26.2 ± 4.2 years	Ordinal scale to classify pain	G1 improved pain.
Blackwood and Ghazi [4]	Patellar tendon	Pilot study N = 14 G1 = 6 (Eccentric exercise + proprioception) μ age = 43 years G2 = 8 (DFM + Eccentric exercise + proprioception) μ age = 38 years	VAS: pain VISA-P: patellar function	G1 and G2 improved pain and function. The improvements were higher on G2.

Study	Tendinopathy	Study Design	Outcome Measures	Main Results
Senbursa et al. [45]	Supraspinatus tendon	RCT N = 77 G1 = 25 (Supervised exercise program) μ age = 48.2 ± 7.9 years G2 = 30 (Supervised exercise program + joint mobilization + DFM) μ age = 50.5 ± 10.6 years G3 = 22 (Home-based rehabilitation program) μ age = 48.0 ± 9.0 years	VAS: pain Goniometer: ROM MASES: Muscular Testing	All groups had positive results on all the outcomes studied. The improvements were higher on G2.
Cooil and Gahzi [9]	Supraspinatus tendon	Pilot study N = 23 G1 = 11 (Exercise + DFM) μ age = 53,56 ± 11,21 years G2 = 12 (Exercise + DFM + US) μ age = 53.2 ± 8.8 years	SPADI	Both groups showed similar and positive results.

DFM: Deep Friction Massage; US: Ultrasounds; VAS: Visual Analogue Scale; TEFS: Tennis Elbow Function Scale; PREFQ: Patient-Rated Forearm Evaluation Questionnaire; MASES: Modified American Shoulder and Elbow Surgery; SPADI: Shoulder Pain and Disability Index; μ: mean.

Most of the studies observed the effects of deep friction massage in the treatment of epicondylians tendinopathy [36, 41, 51, 55, 58], patellar tendinopathy [4, 50] and in clinical situations where the supraspinatus muscle tendon was compromised [9, 45]. Table 5 summarizes six randomized controlled trials, four evaluating the efficacy of deep friction massage on the epicondylian tendinopathy [36, 51, 55, 58], one on the patellar tendon [50] and one on the supraspinatus tendon [45], and two pilot studies [4, 9] and one non-randomized clinical trial [41], one for each one of the tendinopathies previously mentioned.

The majority of the RCTs on epicondylians tendinopathy did not observe better outcomes regarding pain, function and grip strength free from pain when using deep friction massage in comparison with other therapeutic interventions (corticosteroids injection, eccentric exercise and static stretching, polarized polychromatic non-coherent light, phonophoresis). Only Nagrale, Herd, Ganvir and Ramteke (2009), who compared deep friction massage associated with Mill's maneuver to phonophoresis associated with eccentric exercise and static stretching, showed better results on pain and pain free grip strength in the deep friction massage group.

Deep friction massage could be useful in the treatment of patellar tendinopathy in combination with eccentric and proprioceptive exercises. This observation arises from the results of two pilot studies [4, 50], which observed that deep friction massage presented positive results when associated with other therapeutic approaches, a positive result that is higher than that observed by each technique alone.

The same results were observed in the supraspinatus tendinopathy [9, 45], i.e., when deep friction massage was associated with other therapeutic techniques, it showed favorable results and acted as a result enhancer when compared to therapeutic interventions without deep friction massage addition.

A recent systematic review summarizing the research assessing the efficacy of deep friction massage in the treatment of tendinopathy in humans [20] concluded that the present evidence, while scarce, shows some benefits, namely at the elbow in combination with a Mills manipulation, and with supraspinatus tendinopathy in the presence of outlet impingement and along with joint mobilization. These systematic reviews [20] included four randomized controlled studies, three at the extensor carpi radialis brevis and one with supraspinatus outlet tendinopathy; two nonrandomized controlled studies at the extensor carpi radialis brevis; and three uncontrolled experimental trials at the supraspinatus, extensor carpi radialis brevis, and

Achilles tendons. The outcomes assessed were pain, function and muscle strength.

As previously mentioned, the combined analysis of the selected studies seems to provide evidence for the effectiveness of deep friction massage in treatment of tendinopathy treatment, although no evidence was found of deep friction massage being more effective than any other technique usually used to treat this pathology. Notwithstanding, one cannot neglect the fact that it is virtually impossible to determine the efficacy of deep friction massage, due to the fact that this technique was not studied in isolation but always used in combination with other treatment modalities [20].

Additionally, there is a great heterogeneity regarding the characteristics of the patients, the location of the structures involved, the outcomes and assessment tools, and deep friction massage treatment protocols [20]. The evidence to recommend the use of deep friction massage arises from the fact that when protocols including deep friction massage are compared with those that do not include deep friction massage, the results of the first group are more favorable to the patients' rehabilitation [20].

Although the empirical foundations for the use of deep friction massage are strong, the scientific rationale to fully justify its efficacy is still lacking. Once the evolution of knowledge about tendon pathology, regarding its etiopathogenesis, changed the existing paradigm about its pathological clinical presentation (clarifying the absence of inflammatory factors in the tendon tissue), some of the intuitive grounding to use deep friction massage may be called into question [20].

There is a need to clarify the anatomophysiological and biomechanical effects of deep friction massage. However, it is difficult to study anatomophysiological and biomechanical effects in the human model. There are already some attempts to search for evidence of the effects of soft tissue mobilization in the animal model, where it has been shown that soft tissue mobilization in the tendon stimulates tissue adaptations on a cellular level consistent with regeneration. By the late 90s, Davidson et al. [13] and Gehlsen et al. [15], targeting the analysis of effects on the cellular and extracellular matrix response of augmented soft tissue mobilization (a type of deep massage), used an animal model (rats) of tendinopathy induced by colagenase in the Achilles tendon. Both authors showed an increase in the number of fibroblasts, proportional to the pressure used.

Conclusion

In general, the investigation conducted so far highlights the pertinence of using deep friction massage, specifically combined with other modalities, in the treatment of tendinopathies. Nevertheless, the current literature does not provide a conclusive picture to allow claiming the use of deep friction massage as a single modality of treatment.

Analysis of the research performed further highlights the absence of studies illustrating the anatomophysiologic and histologic effects of deep friction massage, which would allow the study of the mechanisms responsible for the hypothetical beneficial effect of deep friction massage in the treatment of tendinopathies.

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CHAPTER 3

ORIGINAL RESEARCH MANUSCRIPTS

STUDY I

Cyriax's Deep Friction Massage application parameters: evidence from a cross-sectional study with physiotherapists

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Original article

Cyriax's deep friction massage application parameters: Evidence from a cross-sectional study with physiotherapists

Paula Chaves [a,*], Daniela Simões [a,b], Maria Paço [a], Francisco Pinho [a,c,d], José Alberto Duarte [e], Fernando Ribeiro [d,f]

[a] CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, Gandra, Paredes, Portugal
[b] Santa Maria Health School, Porto, Portugal
[c] Algoritmi – Universidade do Minho, Guimarães, Portugal
[d] School of Health Sciences, University of Aveiro, Aveiro, Portugal
[e] University of Porto, Faculty of Sport, Research Centre in Physical Activity, Health and Leisure, Porto, Portugal
[f] Institute of Biomedicine - iBiMED, University of Aveiro, Aveiro, Portugal

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A B S T R A C T

Background: Deep friction massage is one of several physiotherapy interventions suggested for the management of tendinopathy.
Objectives: To determine the prevalence of deep friction massage use in clinical practice, to characterize the application parameters used by physiotherapists, and to identify empirical model-based patterns of deep friction massage application in degenerative tendinopathy.
Design: observational, analytical, cross-sectional and national web-based survey.
Methods: 478 physiotherapists were selected through snow-ball sampling method. The participants completed an online questionnaire about personal and professional characteristics as well as specific questions regarding the use of deep friction massage. Characterization of deep friction massage parameters used by physiotherapists were presented as counts and proportions. Latent class analysis was used to identify the empirical model-based patterns. Crude and adjusted odds ratios and 95% confidence intervals were computed.
Results: The use of deep friction massage was reported by 88.1% of the participants; tendinopathy was the clinical condition where it was most frequently used (84.9%) and, from these, 55.9% reported its use in degenerative tendinopathy. The "duration of application" parameters in chronic phase and "frequency of application" in acute and chronic phases are those that diverge most from those recommended by the author of deep friction massage.
Conclusion: We found a high prevalence of deep friction massage use, namely in degenerative tendinopathy. Our results have shown that the application parameters are heterogeneous and diverse. This is reflected by the identification of two application patterns, although none is in complete agreement with Cyriax's description.

1. Introduction

For decades, deep friction massage (DFM) has been one of the physiotherapy interventions suggested for the management of tendinopathy (Andres and Murrell, 2008; Joseph et al., 2012; Loew et al., 2014). The current understanding of tendinopathy still provides rationale for its use, nonetheless the systematic reviews report that the addition of DFM to other physiotherapy interventions does not promote additional clinically important benefits on pain, strength, and function (Brosseau et al., 2002; Joseph et al., 2012; Loew et al., 2014). The conclusions of these systematic reviews are limited by the small number of randomized controlled studies, the small sample sizes as well as several methodological limitations of the included studies, such as the lack of standardization of the DFM protocol (Joseph et al., 2012; Loew

* Corresponding author. CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, Rua Central de Gandra, 1317, 4585-116 Gandra, Paredes, Portugal.
E-mail address: paulamchaves@gmail.com (P. Chaves).

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et al., 2014). In this regard, Loew et al. (2014) suggested as potential confounding variables the experience of the physiotherapist, the characteristics of DFM application (pressure and frequency), duration and number of treatment sessions, among others. Taking into account these limitations, it is important to know whether the physiotherapists use a standardized DFM procedure and are following the principles of application described by Dr. James Cyriax, since non-compliance with them may compromise the technique's effectiveness. Before conducting new randomized controlled studies assessing the effectiveness of the DFM, we need to revise the foundations of the technique in order to know if DFM is really used in clinical practice, in which situations, and which application protocols/procedures are being followed. In order to make the results of the clinical studies comparable and reliable, it is fundamental to standardize the application procedures and to know whether the clinicians are performing DFM as advocated by Dr. Cyriax or are applying a different protocol without a clear rationale.

DFM was empirically developed by Dr. Cyriax, as a way to facilitate the regeneration process of the soft tissues, including tendinous tissue (Brosseau et al., 2002; Stasinopoulos and Johnson, 2004; Atkins et al., 2010; Prabhakar et al., 2013; Loew et al., 2014).

DFM uses passive mobilization of soft tissues to foster fibroblastic activity, break disorganized and dysfunctional intermolecular cross-links (adherences) between the collagen fibres, and favour the realignment and elongation of the collagen fibres, whereas the longitudinal regeneration process is not compromised (Brosseau et al., 2002; Stasinopoulos and Johnson, 2004; Atkins et al., 2010; Prabhakar et al., 2013; Loew et al., 2014). This technique aims to decrease pain, improve function and favour the cicatrization and the repair process by promoting the development and orientation of the collagen fibres, and re-establishing the blood flow supply (Chamberlain, 1982; Cyriax and Cyriax, 1993; Davidson et al., 1997; Gehlsen et al., 1999; Brosseau et al., 2002; Stasinopoulos and Johnson, 2004; Atkins et al., 2010; Joseph et al., 2012; Begovic et al., 2016).

In order to maximize the effects of DFM, its author highlighted the importance of a set of basic application principles that should be adjusted depending on the severity, type and local of the injury (Chamberlain, 1982; Stasinopoulos and Johnson, 2004; Atkins et al., 2010).

Hence, in order to ascertain if physiotherapists are applying DFM accordingly with the principles of application described by Dr. Cyriax, the primary aim of the present study was to determine the prevalence of DFM use in clinical practice in Portugal and characterize the parameters used by physiotherapists during DFM application. Second, our aim was to identify empirical model-based patterns of DFM application adequacy in degenerative tendinopathy.

2. Materials and methods

2.1. Study design

This is an observational, analytical, cross-sectional, national survey design carried out from November 2015 to May 2016 in Portugal. A snow-ball sampling method was applied and intended to voluntarily recruit physiotherapists, both sexes, that were in clinical practice. Ethical approval was guaranteed by the Ethics Committee of the Faculty of Sports, University of Porto (Process CEFADE 34.2014). This study follows the STROBE guidelines for reporting the results of observational studies.

2.2. Procedures

A questionnaire about personal and professional characteristics as well as specific questions regarding the use of DFM, was developed and sent to three physiotherapy experts on musculoskeletal and manual therapy, asking for comments on layout and content. Some amends were made in light of their comments. The questionnaire was then completed by five physiotherapists, and final modifications were then made to layout and wording. Finally, the questionnaire was built in an online survey software (Google-Forms©) and the link to the survey was sent to e-mail lists, through the Portuguese Association of Physiotherapists database and through online social and professional networks, asking every participant to invite others to participate in the study (by sharing the link to the questionnaire).

The questionnaire began with the description of the objective of the study, as well as ethical considerations concerning anonymity and confidentiality of data. The questions were divided into two main groups. The first group referred to the sample characterization with questions regarding personal characteristics (demographic, anthropometric) and professional profile, intending to obtain information about educational degree, years of clinical practice, professional context, dominant area of intervention, weekly workload and number of patients treated per day. The second group of questions asked about the utilization or not of DFM in their clinical practice. There were questions about the clinical conditions in which it was used and if it was a technique selected for treating degenerative tendinopathy. In case of a negative response their participation in the survey would end. In case of a positive response, the participant was further asked about DFM application. There were questions concerning the frequency of application and the number of cases treated in the last year. In respect to the application protocol, the participants were asked about the time of application according with the stage of the condition (acute or chronic), the positioning of different tendons during DFM application (with or without tension), the treatment frequency as well as the criteria they use to decide the pressure performed during DFM (such as size and location of the tendon, stage of lesion - acute or chronic -, type of lesion, pain or any other factor that they considered important). The questionnaire was written in Portuguese and could be made available on request (please contact the corresponding author).

2.3. Statistical analysis

Sample characteristics are presented as counts and proportions for all variables. First, we performed a latent class analysis (LCA) to identify unmeasured class membership among the participants in order to categorize the physiotherapists based on their DFM application behaviours (observations) into different types of DFM users (latent classes) (Alice and Anne, 2017). LCA is used to uncover, from a given sample, distinct groups of individuals that are homogeneous within the group, assuming that the performance of an individual on a set of items is explained by a categorical latent variable with K classes, commonly called ‘latent classes’ (Vermunt and Magindson, 2002). Interpretation of the model is usually based on item profiles in each category, obtained from the probabilities of endorsing each item response, conditional on class membership.

In this study, the number of latent classes (also referred to as patterns) was selected among those with the lowest Bayesian Information Criterion (BIC). Starting from a single class and increasing one class at each step, an optimal solution was selected among the LCA models with the lowest BIC, when further increase in the number of classes did not lead to substantial changes in BIC. Seven parameters of correct application of DFM were used in the LCA, which was fitted using the package poLCA from R language and software environment for statistical computation (V.3.1.0; R Foundation for Statistic Computing, Austria).

Crude and adjusted odds ratios (OR and adjOR) with 95% confidence intervals (95% CI) were computed to test the relation between empirical model-based patterns of DFM application and physiotherapists sociodemographic and professional characteristics. All OR were computed using logistic regression and statistical analyses other than latent class analysis were performed using SPSS version 24.0 (Chicago, IL, USA).

3. Results

Overall, 478 participants (mean age: 32.1 ± 7.99 years, females: 67.2%) participated in this study. Table 1 summarizes participants' professional characteristics.

Four-hundred and twenty-one subjects (88.1%) reported the use of DFM in clinical practice. DFM was used most frequently in tendinopathies (n = 406; 84.9%), followed by muscle tear (n = 174; 36.4%), and tenosynovitis (n = 160; 33.5%). Although most physiotherapists reported the utilization of DFM in tendinopathy, only 267 subjects (55.9%) reported the application of DFM in degenerative tendinopathy. The main reasons for not applying DFM in this clinical condition were the perception of the lack of clinical effects (n = 108; 51.2%) and the technique as highly stressful for the patient (n = 77; 36.5%).

Similar number of physiotherapists reported the application of DFM with or without stretching in patellar tendon (Table 2). However, the majority of the physiotherapists reported the application of DFM with stretching in Achilles tendon (59.0%) and without stretching in epicondyle tendon (60.1%). Most of the physiotherapists apply DFM once in two days, regardless the chronicity (Table 2). A median of 5 min was the duration of DFM application, found in the chronic situation (Table 2).

Additionally, physiotherapists were inquired about the subjective parameters that allow them to define and adjust the pressure applied during DFM. Presence of pain (81.6%), tendon depth (57.7%), injury duration (50.2%), type of injury (46.8%), patient characteristics (44.6%), tendon size (39.7%) and tendon location (39.0%) were the parameters reported.

Table 1
Professional characteristics of the sample (n = 478).

	Final Sample	
	n	%
Academic Degree		
Physiotherapy Degree	368	77.0
Master or PhD	110	23.0
Clinical area		
Musculoskeletal	380	79.5
Neurological	53	11.1
Cardiorespiratory	19	4.0
Paediatric	8	1.7
Other [a]	18	3.8
Patients per hour		
≤2	206	43.1
3 - 4	182	38.1
≥5	90	18.8
Work Intensity, hour per week		
≤35	166	34.7
36–40	160	33.5
≥41	152	31.8
Experience, years		
≤4	170	35.6
5–10	178	37.2
≥11	130	27.2

[a] Oncology, Mental Health, Community interventions.

Table 2
Characterization of deep friction massage application in degenerative tendinopathy (n = 267).

	Final Sample	
	n	%
Position patellar tendon [a]		
With stretching	126	49.0
Without stretching	131	51.0
Position Achilles tendon [a]		
With stretching	151	59.0
Without stretching	105	41.0
Position epicondyle tendon [a]		
With stretching	105	39.9
Without stretching	158	60.1
Frequency in acute situation [a]		
Once a day	35	13.4
Once every two days	147	56.1
Twice a week	79	30.2
Other – Less frequent	1	0.4
Frequency in chronic situation [a]		
Once a day	82	31.1
Once every two days	114	43.2
Twice a week	66	25.0
Other – Less frequent	2	0.8
	Median (P25; P75)	
Duration in acute situation (minutes)	4.0 (2.0; 5.0)	
Duration in chronic situation (minutes)	5.0 (4.0; 10.0)	

P25 – percentile 25. P75 – percentile 75.
[a] Presence of missing values.

3.1. Patterns of deep friction massage application

From the 267 subjects that reported the application of DFM in degenerative tendinopathy, only 232 were included in the LCA analysis, due to missing data. The 2-class solution had the lowest BIC value (1-class solution BIC: 1995.088; 2-class solution BIC: 1983.492, 1-class solution BIC: 2006.101) and the best pattern interpretation. The 2-class model solution was characterized by the following item profiles: individuals assigned to pattern 1 (labelled "Similar to Cyriax's recommendations") had the highest probability of performing DFM with the tendon in the correct position, as well as the correct duration in acute situations; pattern 2 (labelled "Different from Cyriax's recommendations") included subjects with the lowest probability of performing DFM with the tendon in the right position and with the correct weekly frequency, but had the highest probability of using the right duration in acute situations

Table 3
Marginal percentage of physiotherapists that adequately apply each parameter of deep friction massage application in degenerative tendinopathy in each assigned latent class (pattern) to predict class membership (n = 232).

	Deep Friction Massage Application in Degenerative Tendinopathy Adequacy Pattern (%)		
	Total	Pattern 1	Pattern 2
Total		47.0	53.0
Duration in acute situation	80.2	78.6	81.4
Duration in chronic situation	31.0	34.6	28.3
Position patellar tendon	51.7	87.0	24.4
Position Achilles tendon	40.1	73.5	14.3
Position epicondyle tendon	60.8	82.6	43.9
Frequency in acute situation	12.5	12.6	12.4
Frequency in chronic situation	44.8	41.4	47.5

(Table 3 and Fig. 1). The correct duration of DFM in acute situations was highly prevalent in both patterns, while the application of the correct duration in chronic situations and the treatment frequency in both acute and chronic conditions was weakly prevalent in both patterns. The main differences between patterns were related to the tendon position during DFM.

The pattern 1 was not significantly associated to physiotherapists professional characteristics, when compared to pattern 2 (Table 4). Those with a master or PhD degree, more than 11 years of clinical experience, working 36–40 h per week and having 3 or more patients per hour, have a tendency to belong to pattern 1 ("similar to Cyriax's recommendations").

4. Discussion

The main aims of the present study were to determine the prevalence of DFM use in clinical practice and to characterize the parameters used by physiotherapists during DFM application. Concerning the prevalence of DFM use, our results showed that most of the physiotherapists (88.1%) use this technique as a therapeutic resource, from these, 84.9% use this procedure in tendinopathy and about half (55.9%) use it in degenerative tendinopathy. Regarding the characterization of the parameters used, less than 43% perform the recommended frequency in chronic and only 13% in acute conditions; the duration of DFM in chronic conditions was 5 min, which is half the recommended time; the position of the tendon was correct in average 50% of our sample.

The high prevalence of DFM use observed in our study is according with the literature that claims that Cyriax's DFM is one of the main therapeutic resources used in the management of tendinopathy (Stasinopoulos and Johnson, 2004; Joseph et al., 2012; Prabhakar et al., 2013).

In our sample the parameters "frequency of application" in both acute and chronic phases and "duration of application" in a chronic phase are the ones that are further apart from Cyriax's recommendations. The application of DFM in chronic conditions with a frequency different from that recommended, which is alternate days (Chamberlain, 1982; Cyriax and Cyriax, 1993; Stasinopoulos and Johnson, 2004; Atkins et al., 2010), may influence the results of the technique. When DFM is performed daily, as seen in about one third of our sample, the traumatic mechanical effect may interfere with the regeneration process, generating an excessive stimulation of fibroblasts proliferation as well as the recruitment of inflammatory cells (Davidson et al., 1997; Sharma and Maffulli, 2005, 2006). On the other hand, when DFM is performed only twice a week or less, as reported by 25.8% of the participants, the timing of the histologic and morphologic response may be different. Several authors reported that the lack of movement during the repair process of the connective tissue leads to a perturbation in the balance between collagen synthesis and degradation, an increase of cross-links in an intermolecular level, a decrease in the water content of the extracellular matrix and also an increase in the number and thickness of the collagen fibres, thus promoting anarchic cicatricial tissue formation and increased pain

Table 4
Association between patterns of deep friction massage application adequacy in degenerative tendinopathy and physiotherapists professional characteristics.

	Pattern 1 [a]	Pattern 1 [a]
	OR (95% CI)	adjOR [b] (95% CI)
Academic Degree		
Physiotherapy Degree	1.0	1.0
Master or PhD	1.70 (0.89; 3.24)	1.56 (0.73; 3.34)
Clinical area		
Musculoskeletal	1.0	1.0
Others	0.75 (0.39; 1.44)	0.72 (0.36; 1,45)
Patients per hour		
≤ 2	1.0	1.0
3–4	1.29 (0.73; 2.30)	1.14 (0.62; 2.09)
≥ 5	1.18 (0.58; 2.42)	1.31 (0.62; 2.76)
Work Intensity, hour per week		
≤ 35	1.0	1.0
36–40	1.34 (0.71; 2.52)	1.71 (0.86; 3.39)
≥ 41	0.70 (0.38; 1.32)	0.74 (0.39; 1.42)
Experience, years		
≤ 4	1.0	1.0
5–10	0.56 (0.30; 1.03)	**0.48 (0.25; 0.91)**
≥ 11	1.56 (0.80; 3.04)	1.30 (0.61; 2.77)

OR = Odds ratio; 95% CI = 95% confidence interval.
[a] Pattern 2 was used as the reference category.
[b] OR adjusted to the other professional characteristics. Bold represents the adjusted OR that is statistically significant.

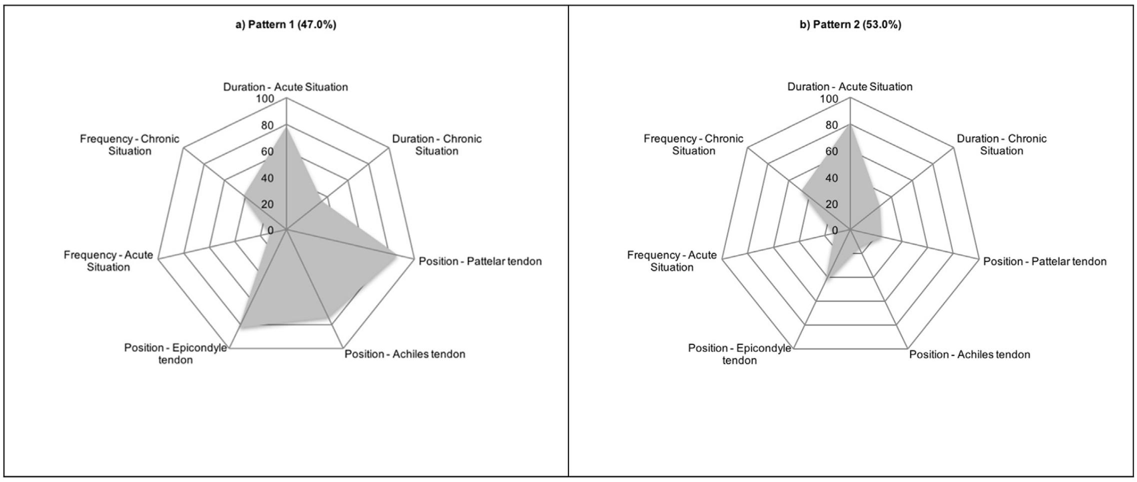

Fig. 1. Marginal percentage of physiotherapists that adequately apply each parameter of deep friction massage application in degenerative tendinopathy in each assigned latent class (pattern) to predict class membership (n = 232).

(Akeson et al., 1977; Chamberlain, 1982; Sharma and Maffulli, 2006; Atkins et al., 2010).

Concerning duration of application, our results have shown that it was lower than the advocated (Chamberlain, 1982; Cyriax and Cyriax, 1993; Stasinopoulos and Johnson, 2004; Atkins et al., 2010), which may influence the structural changes induced to the connective tissue as well as the pain modulation mechanisms (De Bruijn, 1984; Bialosky et al., 2009; Viswas et al., 2012; Vigotsky and Bruhns, 2015; Hassan et al., 2016; Llorca-Torralba et al., 2016). Interestingly, the majority of studies conducted so far only mentioned that Cyriax's principles were followed, but fail to mention the duration of DFM application (Verhaar et al., 1996; Senbursa et al. , 2007; Cooil and Gahzi, 2010; Senbursa et al., 2011; Blackwood and Ghazi, 2012) and the position of the tendon (Verhaar et al., 1996; Stasinopoulos and Stasinopoulos, 2004; Cooil and Gahzi, 2010; Senbursa et al., 2011; Blackwood and Ghazi, 2012; Hassan et al., 2016).

This diversity of parameters found allowed us to find two distinct patterns of DFM application, although none of the patterns were in complete agreement with Cyriax's description. Notwithstanding, pattern 1 is closer to the procedures defined by the technique's author as being effective (Chamberlain, 1982; Cyriax and Cyriax, 1993; Stasinopoulos and Johnson, 2004). It is important to acknowledge that the results found in our study were analysed considering the parameters described and empirically developed by Dr. Cyriax.

Some limitations need to be acknowledged. The reader should take into account the possible cultural differences regarding the frequency of DFM use in clinical practice; this study was carried out in Portugal, so our results cannot be extrapolated to other countries with different cultural and professional. Furthermore, all data were collected from a self-administered questionnaire, that relied on memory and self-reporting of the participants. Having this in mind, the authors recognize that there might have been incorrect answers to the questions, but the high rate of response showed the interest in participating in the study, which narrows the impact of the possible bias associated with self-reported questionnaires.

It is also important to bear in mind that we have used a cross-sectional design to identify performance patterns, which means that the results do not clarify the process and pathways leading to the choice of the different parameters. Although this study provides data about the prevalence and characterization of DFM application, other parameters such as the pressure performed during its application, should be further evaluated, to understand if pressure influences the effectiveness of the technique. The present study did not intent to determine whether the application of DFM according to the description of Dr. Cyriax is more effective than other application procedures (with different frequency, application time or tendon positioning). Future studies might help to understand if any of these patterns are associated with better outcomes.

5. Conclusion

The results of the present study have shown a high prevalence of DFM use by Portuguese physiotherapists. We have also observed a high heterogeneity and variability in the application parameters chosen by physiotherapists, namely the position of the tendon, the frequency in both acute and chronic conditions and the duration of DFM application in the chronic phase. This diversity enabled the identification of two patterns, although none is in complete agreement with Cyriax's description of the technique.

Conflict of interest

All authors have declared that no conflict of interest exists.

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STUDY II

Deep friction massage: the minimum skin pressure required to promote a macroscopic deformation of the patellar tendon.

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Deep friction massage: the minimum skin pressure required to promote a macroscopic deformation of the patellar tendon

Paula Chaves[1], Daniela Simões[1,2], Maria Paço[1], Francisco Pinho[1,3,4], José Alberto Duarte[5], Fernando Ribeiro[6]

[1] CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, Gandra - Paredes, Portugal.

[2] Santa Maria Health School, Porto, Portugal.

[3] Algoritmi – Universidade do Minho, Guimarães, Portugal.

[4] School of Health Sciences, University of Aveiro, Aveiro, Portugal.

[5] University of Porto, Faculty of Sport, Research Centre in Physical Activity, Health and Leisure, Porto, Portugal.

[6] School of Health Sciences and Institute of Biomedicine - iBiMED, University of Aveiro, Aveiro, Portugal.

Corresponding author:

Paula Chaves

CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, R. Central de Gandra, 1317, 4585-116 Gandra PRD, Portugal.

paulamchaves@gmail.com

ABSTRACT

Objective: To determine the skin pressure needed to promote the macroscopic deformation of the asymptomatic patellar tendon and to verify if the pressure is associated with the individual's characteristics.

Methods: A descriptive laboratory study was performed with a convenience sample of 18 young, voluntary and asymptomatic individuals of both sexes. A progressively increasing pressure was applied on the skin over the patellar tendon, through an instrument designed to perform and control the pressure upon an ultrasound probe; data was recorded and analysed by two blind investigators. All statistical analyses were conducted considering $\alpha=0.05$.

Results: The average pressure needed to promote a macroscopic deformation of the patellar tendon was 1.12 ± 0.37 kg/cm^2. Female sex and age were inversely but not significantly associated with the pressure performed. Sports practice, weight, height, BMI, muscle mass and subcutaneous thickness were positively but not significantly associated with the pressure executed.

Conclusion: The average pressure needed to promote the macroscopic deformation of the patellar tendon was 1.12 ± 0.37 kg/cm^2, which was not influenced by the characteristics of the participants.

KEYWORDS: PHYSICAL THERAPY; MANUAL THERAPY; MASSAGE; TENDON ACCESSIBILITY.

INTRODUCTION

Deep friction massage (DFM) is a widely-used intervention aiming to promote the regeneration process, through the passive mobilization of soft tissues [1-6], by inducing an increase in fibroblastic activity, break disorganized intermolecular cross-links and favour the realignment and elongation of the collagen fibres [1-4,7-12]. Its relevance in the treatment of tendinopathy is not clear, and so far, it is not known the real morphological and histological effects of its application in the tendinous structure [2,11].

The pressure performed seems to be crucial to elicit the advocated morphological and histological effects [1,4,9,10,13,14] and this fundamental parameter of the technique has only been described qualitatively as "deep enough" to mobilize the tendinous fibres [2,4,6,14], which may account for the lack of control over DFM application procedures reported in the literature [2,3]. Taking into account the importance of the pressure in the technique's execution, there is a need to define the pressure needed to apply during DFM in order to ensure that the tendon is in fact reached, assisting the physiotherapist in the quantitative management of this parameter, constituting a fundamental basis for the study of the mechanical effects of the technique.

Hence, we have performed an observational, cross-sectional and analytical study, aiming to determine the skin pressure needed to promote the macroscopic deformation of the asymptomatic patellar tendon and to verify if the pressure needed to deform the tendon is influenced by the individual's characteristics.

METHODS

SAMPLE RECRUITMENT

A convenience sample of 18 young and healthy individuals from both sexes was recruited through printed advertisements on notice boards at various sites of our institution. Inclusion criteria: age between 18 and 30 years old; asymptomatic patellar tendon. Exclusion criteria: history of previous injury of the lower limbs.

Ethical approval was guaranteed by the Ethics Committee of the Faculty of Sports, University of Porto (ref. 15.2017). All participants signed an informed consent according to the Declaration of Helsinki.

PROCEDURES

After the anthropometric measurements, in a laboratory with the temperature controlled and set at 24ºC, it was determined the skin pressure needed to promote the macroscopic deformation of the patellar tendon. To guarantee the standardization of the assessment procedure, we used a system comprised by four major components: the ultrasonography fixation ring; the sensors; a stepper motor; and a structure where all the parts come together. It was 3D printed a special component where the ultrasonography probe was fixed in the centre, and the two sensors attached in opposite directions. Those two sensors, each composed by a bar (50 kg-max load) load cell, were then attached to the structure (Figure 1).

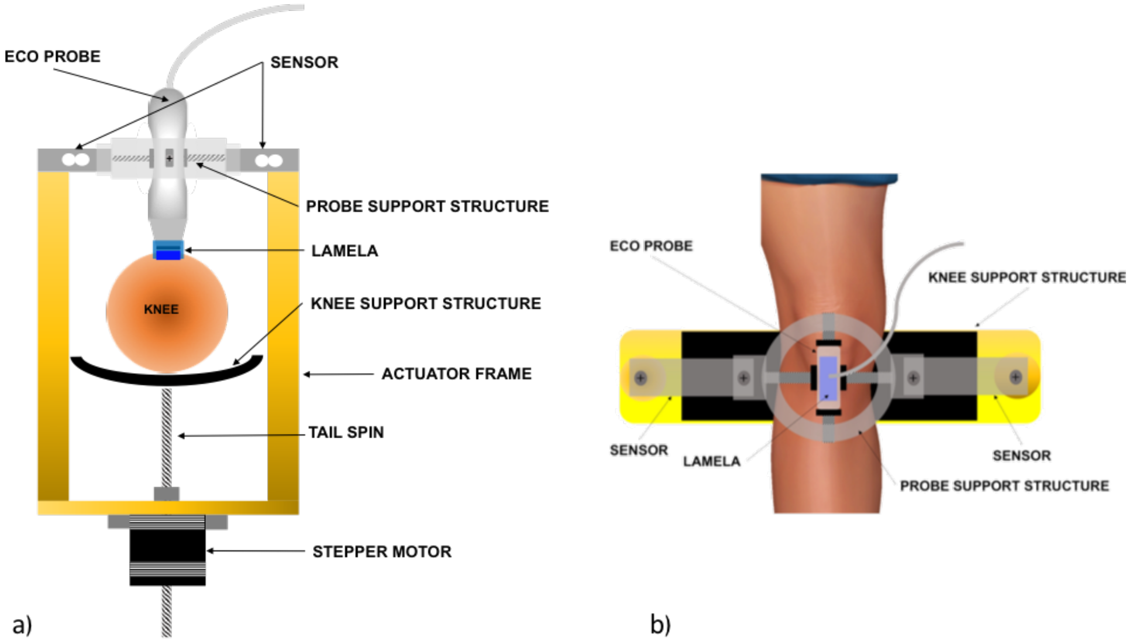

Figure 1. Developed pressure measurement system: a) constitution parts; b) superior view when applied.

Each participant was in seated position, with the knee positioned in 45º of flexion and in the centre of the developed mainframe; the ultrasonography probe was positioned to contact the skin over the patellar tendon at 1 cm below the patellar apex (Figure 2). Next, the pressure was progressively applied over the tendon at a constant speed (0.5 mm/s) and the ultrasound images as well as the values from the pressure device were recorded (Figure 2).

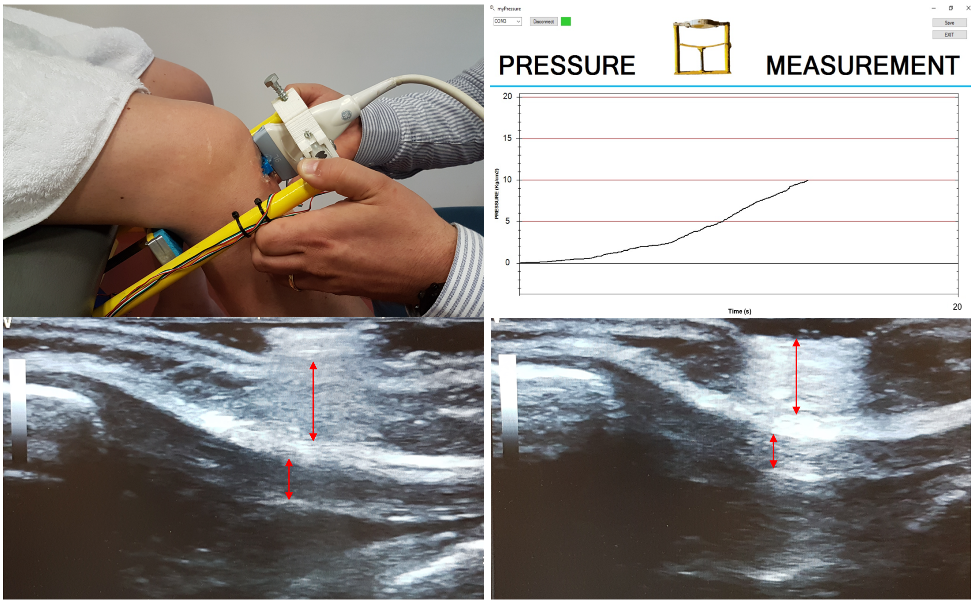

Figure 2. Laboratory setting for data collection

Once data was collected, two blind investigators analysed the video images, and identified and recorded the moment when the tendon was macroscopically deformed, by changing its position regarding the adjacent structures, being the pressure applied over the skin for that specific moment recorded. Additionally, the distance between the skin and the tendon (subcutaneous thickness) was also evaluated through the ultrasound image. The assessment procedure was repeated three consecutive times in each lower limb (dominant and non-dominant), and the average of these was used.

STATISTICAL ANALYSIS

Descriptive statistics comprised absolute and relative frequencies for categorical variables, and mean with standard deviation for numeric variables. The normality of data distribution was tested with the Shapiro–Wilk test, Q-plots and histograms. All continuous data followed a normal distribution. To compare the mean pressure performed on dominant vs. non-dominant limb, the paired sample *t*-test was used. Crude Beta (β) and respective 95% confidence intervals (95% CI) were used to estimate the relation between pressure performed on dominant limb and participant's characteristics. All statistical analyses were conducted considering an α=0.05 and were 2 tailed. Analyses were performed on IBM® SPSS® Statistics version 24.0 (Chicago, IL, USA).

RESULTS

The participants age was 23.0 ± 4.56 years, most of them were female (n=11, 61.1%), and half of them were engaged in a sport (n=9, 50.0%); their body mass index was 22.5 ± 3.86 kg/m^2 (weight: 64.5 ± 11.28 kg, height: 1.7 ± 0.09 m, muscle mass: 45.2 ± 10.82 kg).

The average pressure needed to promote a macroscopic deformation of the patellar tendon was 1.12 ± 0.37 kg/cm^2. When compared the dominant limb with the non-dominant limb, no statistically significant differences were found (p=0.100).

Table 1 shows the association between DFM pressure and participants' demographic, anthropometric and body composition characteristics. Female sex and age were inversely but not significantly associated with DFM pressure. Sports practice, weight, height, body mass index (BMI), muscle mass and subcutaneous thickness were positively but not significantly associated with DFM pressure.

Table 1. Association between the skin pressure performed during DFM (kg / cm^2) and participant's characteristics

	Pressure performed Dominant Side *Crude β* *(95% CI)*
Sex	
Female	-0.226 (-0.595; 0.143)
Male	0
Sports Practice	
Yes	0.105 (-0.269; 0.479)
No	0
Age, years	-0.006 (-0.049; 0.036)
Weight, kg	0.015 (-0.001; 0.030)
Height, m	1.341 (-0.694; 3.376)
BMI, kg/m^2	0.024 (-0.025; 0.072)
Muscle Mass, kg	0.011 (-0.006; 0.028)
Subcutaneous Thickness, mm	0.700 (-0.658; 2.059)

DISCUSSION

The aim of the present study was to characterize the skin pressure needed to promote macroscopic deformation of the asymptomatic patellar tendon and to verify if the characteristics of the participants were associated with the pressure. Our results have shown that on average, the minimum skin pressure needed to promote the macroscopic deformation of the patellar tendon was 1.12 ± 0.37 kg/cm^2 and also that there was no association between the required pressure and the characteristics of the participants.

To our best knowledge, this is the first study that objectively analysed the pressure needed to macroscopically deform of a tendinous structure through a mechanical pressure mimicking a therapeutic procedure. This information may be useful as reference for therapeutic interventions based on mechanical deformation of the tendon, such as DFM.

The objective quantification of the pressure needed to promote the macroscopic deformation of the patellar tendon may help to clarify the qualitative description of this parameter (“deep enough”), acting as a guide and allowing a better control over the application procedures of the DFM.

Taking this into account, this study may represent a basis for future research targeting the enlightening about the relevance of DFM application in the treatment of tendinopathy and further study the histological and morphological effects attributed to the technique and found in the animal model. Our results bring an important clarification about the minimum pressure needed to promote deformation of the patellar tendon, allowing to provide a basis for the histological and morphological effects to occur. Thus, if the pressure performed during DFM is inferior to the pressure we have found, the physiotherapist should be aware that the mechanical effects attributed to the technique may not be elicited.

LIMITATIONS

The reader should take into account that this study was performed in asymptomatic individuals. However, once our aim was to evaluate the minimum skin pressure necessary to promote the macroscopic deformation of the patellar tendon, this variable could be limited and/or conditioned by pain, if the participants presented a symptomatic patellar tendon. Moreover, there is no grounding to consider that symptomatic individuals may have alterations in the subcutaneous tissues. Although our sample is in the age group with the highest prevalence of patellar tendinopathy and even though our results have shown that there was no association between the individuals’ characteristics and the pressure performed, the authors acknowledge that the sample size as well as its characteristics may constitute a limitation of the study.

CONCLUSION

The average skin pressure needed to promote the macroscopic deformation of the patellar tendon was 1.12 ± 0.37 kg/cm^2 and there was no association between the pressure needed and the characteristics of the participants.

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STUDY III

Pressure applied during deep friction massage: characterization and relationship with time to onset of analgesia

Under Review in

Musculoskeletal Science and Practice

Pressure applied during deep friction massage: characterization and relationship with time to onset of analgesia

Paula Chaves[1], Daniela Simões[1,2], Maria Paço[1], Francisco Pinho[1,3,4], Mário Correia[1], Francisco Ferreira[1], José Alberto Duarte[5], Fernando Ribeiro[6]

[1] CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, Gandra - Paredes, Portugal.

[2] Santa Maria Health School, Porto, Portugal.

[3] Algoritmi – Universidade do Minho, Guimarães, Portugal.

[4] School of Health Sciences, University of Aveiro, Aveiro, Portugal.

[5] University of Porto, Faculty of Sport, Research Centre in Physical Activity, Health and Leisure, Porto, Portugal.

[6] School of Health Sciences and Institute of Biomedicine - iBiMED, University of Aveiro, Aveiro, Portugal.

Corresponding author:

Paula Chaves

CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, R. Central de Gandra, 1317, 4585-116 Gandra PRD, Portugal.

paulamchaves@gmail.com

ABSTRACT

Objective: To determine if a dose-response relationship exists between the pressure applied during deep friction massage (DFM) and time to onset of analgesia, in the asymptomatic patellar tendon. For this, it was firstly characterized the pressure applied by physiotherapists during DFM (study 1) and then, based on these pressures, it was assessed the effect of different DFM pressures, on the time to onset of analgesia (study 2).

Methods: First, the mean pressure applied by 40 physiotherapists, during a DFM session was assessed with a pressure sensor, through an observational, cross-sectional and analytical study. Next, the effects of different pressure intensities (median, percentiles 25 and 75 of the mean pressure obtained in study 1) were studied in a randomized, controlled and cross-over trial enrolling 30 participants with asymptomatic patellar tendon. A pressure sensor was used to register the pressure applied during DFM.

Results: A wide variation of the pressure applied was found [median of (mean pressure: 2.3 kg/cm^2 (1.02; 4.16), median pressure: 2.1 kg/cm^2 (0.92; 4.05), minimum pressure: 0.7 kg/cm^2 (0.49; 1.49) maximum pressure: 5.4 kg/cm^2 (2.56; 9.40)]. It was also shown that higher pressures have lower times to onset of analgesia [1 kg/cm^2: 84.5 seconds (67.00; 113.50), 2.3 kg/cm^2: 73.5 seconds (59.00; 87.30), 4.2 kg/cm^2: 54.0 seconds (37.80; 62.00)], ($p \leq 0.001$).

Conclusion: The DFM pressure obtained by physiotherapists was 2.3 kg/cm^2 (1.02; 4.16). Higher pressures of DFM result in lower time to onset of analgesia.

Keywords: CYRIAX; PAIN; PATELLAR TENDON; MANUAL THERAPY; PHYSIOTHERAPY

INTRODUCTION

Deep friction massage (DFM) is a therapeutic resource used in the treatment of tendon injuries based on its positive potential effects on function and pain (Brosseau et al., 2002; Childress & Beutler, 2013; Cook & Purdam, 2009; De Bruijn, 1984; Goats, 1994b; Leadbetter, 2005; Loppini & Maffulli, 2011; Maffulli, Longo, & Denaro, 2010; Rees, Maffulli, & Cook, 2009; Stasinopoulos & Johnson, 2004).

Clinically, its' effect on pain is confirmed by the immediate feedback of the patient with tendinopathy, which describes an analgesic effect during and immediately after the application of the technique (Atkins, Kerr, & Goodlad, 2010; Stasinopoulos & Johnson, 2004). The positive effects of DFM on pain are often explained by the induction of hyperaemia produced by mechanical stimulus (Atkins et al., 2010; Chamberlain, 1982; Goats, 1994b; Gregory, Deane, & Mars, 2003; Stasinopoulos & Johnson, 2004), the modulation of nociceptive impulses at the spinal cord ("gate control theory") (De Bruijn, 1984; Goats, 1994b; Gregory et al., 2003; Hassan, Hafez, Seif, & Kachanathu, 2016; Stasinopoulos & Johnson, 2004; Viswas, Ramachandran, & Korde Anantkumar, 2012), and also the descending mechanisms of pain modulation (Atkins et al., 2010; Bialosky, Bishop, Price, Robinson, & George, 2009; Goats, 1994b; Llorca-Torralba, Borges, Neto, Mico, & Berrocoso, 2016; Pud, Granovsky, & Yarnitsky, 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015). Notwithstanding, regardless the mechanism beyond the analgesic effect of DFM, the mechanical stimulus seems to be the common trigger of this response (Bialosky et al., 2009), which in DFM corresponds to the pressure applied during the technique execution.

The principles of DFM application are quite vague in respect to pressure, once it is described as "deep enough". During DFM the intensity of the pressure is managed according to the feedback of the patient and clinically the physiotherapist grades the intensity of the pressure by asking the patient to report whether pain is bearable (Atkins et al., 2010; Brosseau et al., 2002; Chamberlain, 1982; Cyriax & Cyriax, 1993; Loew et al., 2014). The pressure aims to guarantee indirect access to the target tissue, which may lead to an alteration of the morphological properties of the tendon and influence pain modulation (Atkins et al., 2010; Chamberlain, 1982; Davidson et al., 1997; Gehlsen, Ganion, & Helfst, 1999; Gregory et al., 2003; Loew et al., 2014; Sterns, 1940).

It has been suggested that the lack of standardization of the DFM protocol, namely the pressure applied, may be one of the potential confounding variables concerning DFM's effectiveness (Loew et al., 2014). Notwithstanding, taking into account that pain is a symptom used by the physiotherapist as a reference for the management of the pressure applied, the authors question if the standardization claimed for this technique is possible or even useful. So, despite DFM being a widely-used technique (Chaves et al., 2017; Joseph, Taft, Moskwa, & Denegar, 2012; Prabhakar, Kage, & Anap, 2013; Stasinopoulos & Johnson, 2004), there is no study characterizing the pressure applied during DFM, remaining it at the discretion of the physiotherapist. Additionally, it is not known how the amount of pressure applied may influence the above-mentioned mechanisms and, consequently, how it affects the time needed to promote an analgesic response. Before further mechanistic or clinical studies are undertaken, it is important to accurately describe the pressure application conditions that elicit an analgesic effect, further enlightening if the standardization of the pressure applied may add clinical value. The purpose of this study was, therefore, to determine if a dose-response relationship exists between the pressure applied during DFM and time to onset of analgesia, in the asymptomatic patellar tendon. In order to accomplish this, we firstly characterized the pressure applied during DFM, describing the mean pressure applied by physiotherapists and determining if it was applied uniformly during the DFM execution (study 1). Because pressure may influence the effects of DFM, namely on pain, we further studied the effect of different pressures, based on the mean pressure found in study 1, applied during DFM on the time to onset of analgesia (study 2).

METHODS

STUDY DESIGN AND PARTICIPANTS

The characterization of the pressure applied during DFM (study 1) was determined in an observational, cross-sectional and analytical study enrolling 40 physiotherapists. The recruitment was through direct invitation to physiotherapists that use DFM as a therapeutic resource in the treatment of degenerative tendinopathy. Those with any physical constraint that prevented or restrained the application of the technique or that did not use DFM in the last six months were excluded. Next, after determining the pressure applied by physiotherapists during DFM, the effects of different pressure intensities (median, percentile 25 and percentile 75 of the pressure obtained in the study 1) on the time to onset of analgesia were studied in order to ascertain whether a dose-response relationship exists between pressure and time to onset of analgesia (study 2). For this, a randomized, controlled, cross-over trial was performed with 30 healthy individuals, both sexes, that were recruited through printed advertisements on notice boards at various sites of our institution. In order to be included, the participants should have had an asymptomatic patellar tendon. Exclusion criteria: history of previous injury of the lower limbs, intake of medication that could interfere with pain mechanisms, and presence of any factors or conditions that could interfere with the tendinous tissue as well as with the awareness and sensibility to pain or with the neurophysiological response expected.

In both studies, height and weight were measured using a stadiometer (Seca®, Bodymeter 206, Hamburg, Germany) and a scale, respectively (Tanita BC-545, Tanita®, Tokyo, Japan), and body mass index (BMI) (kg/m^2) was calculated. Both studies obtained ethical approval by the Ethics Committee of the Faculty of Sports, University of Porto (Process CEFADE 15.2017). All participants provided written informed consent and all procedures were conducted according to the Declaration of Helsinki.

ASSESSMENT AND MONITORING OF THE PRESSURE INTENSITY DURING DFM

In order to quantify the amount of pressure performed by the physiotherapist while executing DFM, an instrument that monitors and records the pressure applied was used (Figure 1). This consists of a piezo-resistive sensor provided by Tekscan^{TM} A201 FlexiForce^{TM} (Tekscan^{TM}, Inc.South Boston, MA, USA) with an active area of 9.53 mm^2 in a pressure range of 0-445N. The sensor was connected according to the respective datasheet specifications to achieve the stated linear error of 3% under full scale and a repeatability error of 2.5%. To acquire the pressure data, a microcontroller based platform (Teensy 3.2, PJRC^{TM}, OR, USA) was programmed for 100 sps sampling frequency. This device runs on a 96 MHz clock with 16 bits resolution for analog-to-digital conversion. The microcontroller was coupled a Bluetooth 2.1+EDR module for wireless data transmission at 230400 bps. Under these specifications, the sensor full scale bandwidth from 0-3.3V achieves a resolution of 0.0068 N (680 micrograms). For data recording and real-time visualization, a Windows^{TM}, (Microsoft^{TM}, Albuquerque, New Mexico, USA) based application was used (Figure 1). Before each acquisition, the sensor was properly calibrated with two standard weights. The recorded data was processed under Matlab_R2016a (MathWorks^{TM}, Inc., Natick, Massachusetts, USA). Data was first 5 Hz low-pass filtered through a 4Th order Hamming window FIR (Finite Impulse-Response).

Figure 1. Instrument to monitor and register the pressure

STUDY 1

The participants were invited to come to the laboratory of our institution and to perform DFM as they usually do in their clinical practice (regarding duration, pressure, positioning of patient and physiotherapist) using the above-mentioned instrument. They were allowed to adapt themselves to the instrument before the data collection; all the procedures were supervised by an investigator. In order to ensure their blinding concerning the pressure performed, there was no feedback from the instrument. The physiotherapists were instructed to position themselves, adjust the table height, select the hand position and perform DFM according to their usual execution (in real context) in one treatment session, including the total time of application. In order to control any intrinsic variability of the targeted tissue that could influence the intensity of the pressure applied by the participants, DFM was always applied in the same asymptomatic patellar tendon. Furthermore, the position of the subject receiving the DFM and the local of application of DFM were standardized by positioning the knee with 15º of flexion (controlled by a standard goniometer - Baseline®, New York, NY, USA) and setting the application point of DFM at 1 cm below the inferior border of the patella. After the DFM application, the following pressure variables were extracted: mean pressure, median pressure, minimum and maximum pressure as well as standard deviation. The total time of DFM application was measured by the investigator using a chronometer (NIKE, Inc., Beaverton, OR, USA).

STUDY 2

In this study, the instrument previously described was used along with the Windows based application to allow the physiotherapist to have real-time visualization (feedback) of the pressure applied during DFM. The measured pressure was plotted in real time to give visual and auditory feedback to the physiotherapist applying DFM (Figure 1), hence keeping the pressure constant during all the procedure. The DFM procedure was always performed by the same physiotherapist, that was previously trained in the use of the device. The 30 healthy participants were invited to come to the lab during three days, 48 hours apart from each other; in each day, the participants received DFM with a different pressure. The three different pressures used in this study were the percentile 25, the median, and the percentile 75 of the pressure registered in the study 1, which corresponded to P1 = 1.0 kg/cm^2, P2 = 2.3 kg/cm^2 and P3 = 4.2 kg/cm^2, respectively. The order of application was defined by a simple randomization process (Figure 2), using a random sequence generator (www.random.org). The participants were positioned lying supine, with 15º of knee flexion (controlled by a standard goniometer - Baseline®, New York, NY, USA) and the application point of DFM was set at 1 cm below the inferior border of the patella, at the patellar tendon. Taking into account that DFM is performed through a manual pressure that should elicit a bearable pain, the subjects were asked to report analgesia to the investigator as soon as they stop feeling discomfort or pain. The time to onset of analgesia was measured by the investigator using a chronometer (NIKE, Inc., Beaverton, OR, USA).

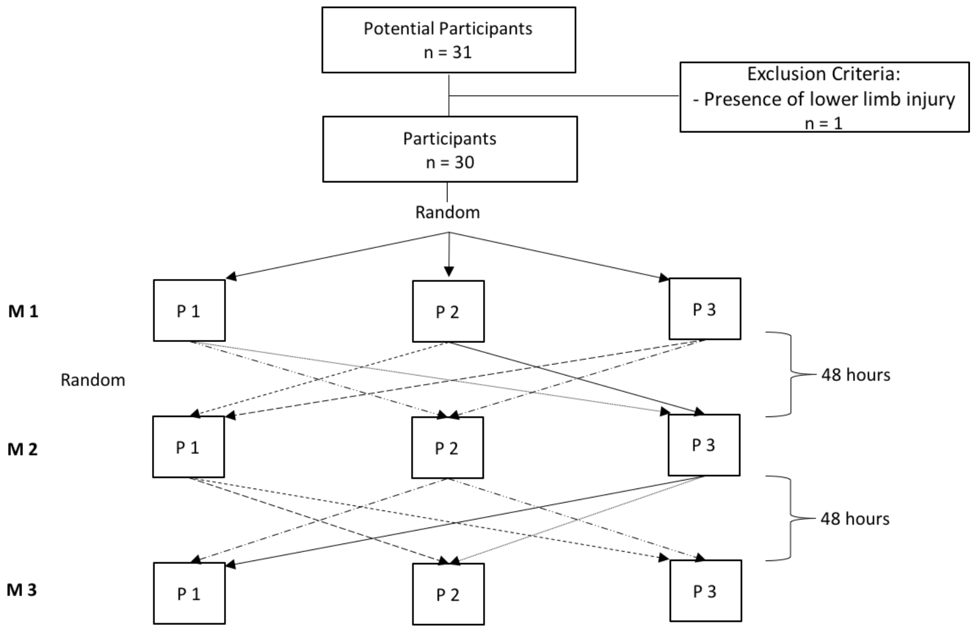

Figure 2. Study 2 flow diagram.
The order of the pressure (P) applied in each moment (M) was randomly determined.

STATISTICAL ANALYSIS

Descriptive statistics comprised absolute and relative frequencies for categorical variables, and mean with standard deviation (SD) or median with percentiles 25 and 75 (P25, P75) for numerical data, in accordance to data distribution. The normality of data distribution was previously assessed with the Shapiro-Wilk test. The comparisons of DFM pressure parameters between execution modes (thumb *vs.* index finger) were performed using Mann-Whitney test, once these variables did not present a normal distribution. The influence of DFM pressure sequence on time to onset of analgesia was tested using Kruskal-Wallis test. The comparison of the time to onset of analgesia in each DFM pressure, was tested using Wilcoxon test. All statistical analyses were conducted considering an $\alpha=0.05$. Analyses were performed on IBM® SPSS® Statistics version 24.0 (IBM Corp, Armonk, NY, USA).

RESULTS

CHARACTERIZATION OF THE PRESSURE APPLIED DURING DFM (STUDY 1)

Most of the 40 physiotherapists were female and worked in private practice (table 1). Table 1 summarizes participants' personal and professional characteristics. The results show a wide variation (figure 3) on the pressure performed by the physiotherapists [mean pressure: 2.3 kg/cm^2 (1.02; 4.16), median pressure: 2.1 kg/cm^2 (0.92; 4.05), minimum pressure: 0.7 kg/cm^2 (0.49; 1.49), maximum pressure: 5.4 kg/cm^2 (2.56; 9.40)] and a moderate oscillation over time within physiotherapists' execution [standard deviation: 0.97 kg/cm^2 (0.38; 1.83)]. The median time of DFM execution was 206.5 seconds (170.0; 349.25).

Most of the subjects chose the thumb to perform the DFM in the patellar tendon (52.5%) and no statistically significant differences were found in the DFM pressure parameters between thumb and index finger execution (all $p>0.05$).

Table 1. Personal and professional characteristics of the sample

	Final Sample	
	n	%
Sex		
Female	29	72.5
Male	11	27.5
Academic Degree		
Physiotherapy Degree	34	85.0
Master Degree	6	15.0
Workplace		
Public hospital	2	5.0
Private hospital	1	2.5
Private practice, National Health Service	28	70.0
Private practice, others	9	22.5
	Mean (standard deviation)	
Age (years)	30.5 (6.10)	
Weight (kg)	63.6 (9.90)	
Height (cm)	168.7 (7.24)	
BMI (kg/m^2)	22.3 (3.02)	
	Median (P25; P75)	
Clinical Experience (years)	7.0 (1.00; 10.00)	
Work Intensity (hour per week)	40.0 (30.00; 40.00)	
Number of Patients Treated (N per hour)	4.0 (3.00; 4.75)	

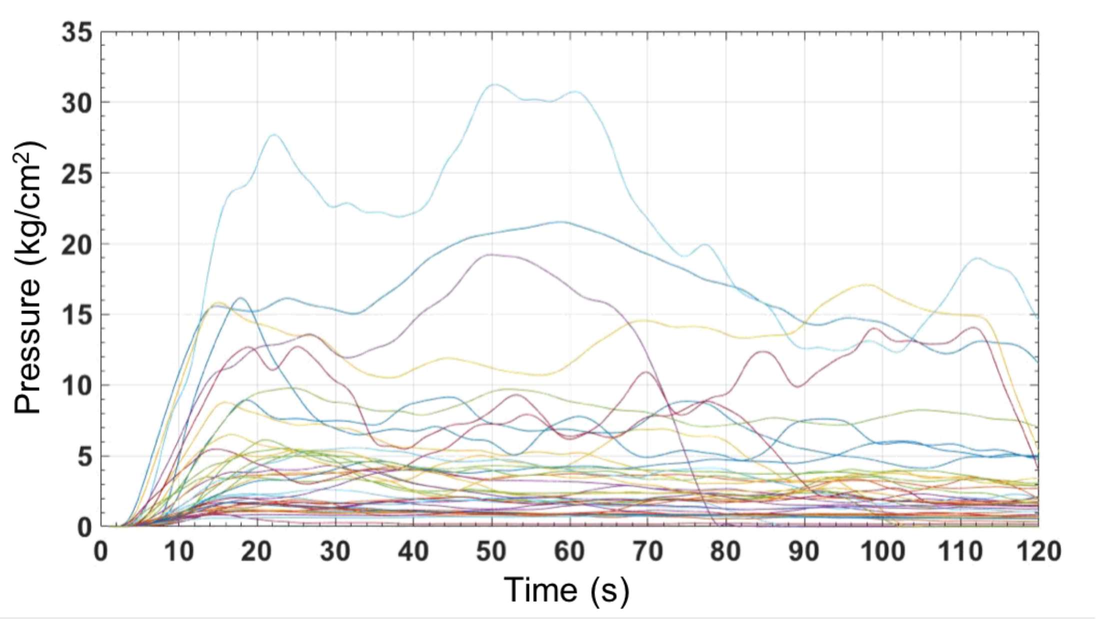

Figure 3. Variation of the pressure performed during DFM by the physiotherapists

EFFECTS OF DIFFERENT DFM PRESSURES ON TIME TO ANALGESIA (STUDY 2)

This study comprised 30 healthy subjects, most of them female (n = 21, 70.0%). Participants mean age was 21.8 ± 1.55 years old, weight was 65.1 ± 8.01 kg, height was 1.7 ± 0.08 m, and mean BMI was 23.3 ± 2.02 kg/cm^2.

Time to onset of analgesia in each DFM pressure is presented in figure 4. The results show a dose-response and inverse relationship between DFM pressure and time to onset of analgesia, i.e. when the DFM pressure increases the time to onset of analgesia significantly decreases [1 kg/cm^2: 84.5 seconds (67.00; 113.50), 2.3 kg/cm^2: 73.5 seconds (59.00; 87.25), 4.2 kg/cm^2: 54.0 seconds (37.75; 62.00)], ($p \leq 0.001$); being the difference in the time to reach analgesia between the lowest and the highest pressure applied of 30 seconds.

In order to manage the cumulative effect, the DFM pressures were applied in a randomized sequence. No statistically significant differences were found in the time to onset of analgesia according to the pressure sequence (all $p > 0.05$).

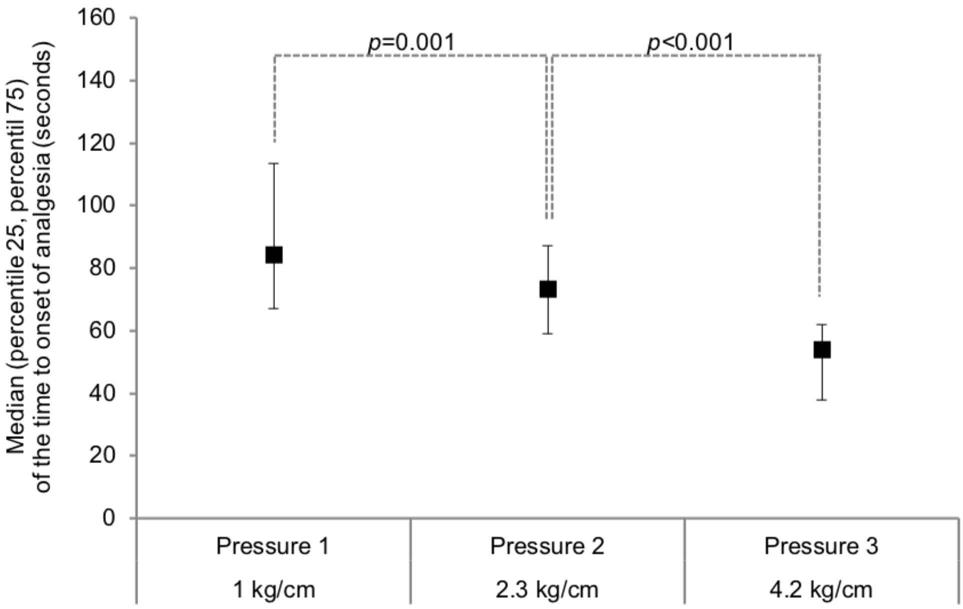

Figure 4. Deep friction massage pressure and corresponding median (percentile 25; percentile 75) of the time to onset of analgesia

DISCUSSION

The aim of the present study was to characterize the pressure applied during DFM and to determine if a dose-response relationship exists between the pressure applied during DFM and time to onset of analgesia in the asymptomatic patellar tendon. Our results indicate that the pressure used by physiotherapists during DFM is 2.3 kg/cm^2 (1.02; 4.16) and higher the pressure of DFM the lower the time to onset of analgesia. Nonetheless, the difference between the lowest and the highest pressure on the time to reach analgesia was 30 seconds.

To our best knowledge, this study is the first quantifying and analysing the intensity of the manual pressure applied by physiotherapists during DFM application. The literature regarding DFM only described the pressure in a qualitative and subjective way as sufficient and constant (Atkins et al., 2010; Chamberlain, 1982); this is reflected in the results of study 1, that showed a wide variation on the pressure performed by the physiotherapists. Previous studies have shown that the intensity of the applied pressure has a directly proportional increase in the response of recruitment and activation of fibroblasts (Davidson et al., 1997; Gehlsen et al., 1999). The pressures described by those authors ranged between 5.1 kg/cm^2 and 15.3 kg/cm^2, which are much higher than those observed in our study. However, these studies only refer to morphological and histological effects, and the technique was applied longitudinally to the tendinous fibres with an instrument, i.e. the technique was not manual. Furthermore, it should be taken into account that these studies were carried out in the animal model (Davidson et al., 1997; Gehlsen et al., 1999). Regarding the influence of the application of different pressures in time to onset of analgesia (study 2), our results showed that a higher pressure of DFM led to a decrease in the time to onset of analgesia which may reflect a faster response of the pre-synaptic modulation mechanisms. Thus, a higher intensity of the mechanical stimulus (DFM pressure) will lead to a higher and faster activation of low-threshold A-α and A-β fibers that inhibit the nociceptive input from A-δ and C afferent fibers, that are responsible for nociceptive conduction at the dorsal horn of the spinal cord (Blackwood & Ghazi, 2012; De Bruijn, 1984; Goats, 1994a, 1994b; Gregory et al., 2003; Hassan et al., 2016; Stasinopoulos & Johnson, 2004; Viswas et al., 2012).

The pressure performed during DFM execution may act as a noxious stimulus, often called counter irritant which is used as a conditioning stimulus to induce reduction in the perception of pain – conditioned pain modulation (Vigotsky & Bruhns, 2015; Yarnitsky, 2010). This mechanism induces analgesia through descending pain modulatory systems, wherein neurotransmitters like serotonin and endogenous opioids have been shown to modulate nociceptive circuits and pain output by acting on structures such as the rostral ventromedial medulla and periaqueductal grey (Atkins et al., 2010; Bialosky et al., 2009; De Bruijn, 1984; Goats, 1994b; Pud et al., 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015; Wright & Sluka, 2001). Notwithstanding, the present study used a sample of asymptomatic individuals and it has been suggested that in conditions of "no pain" the descending noradrenergic system that originates in *Locus Coeruleus* has little influence, playing a minor role in basal pain sensitivity (Llorca-Torralba et al., 2016; Pertovaara, 2013). However, the reader should take into account the fact that the highest pressure only reduced the time to onset of analgesia by 30 seconds (comparison between the lowest and the highest pressures), which raises the question about the clinical relevance of such difference.

Some limitations should be acknowledged. First, it is important to point out that both studies were performed in asymptomatic individuals, which may interfere not only with the pressure applied by physiotherapists (study 1) but also interfere with pain modulation mechanisms (study 2). However, once it was not our objective to study nor draw any conclusions about the mechanisms underlying DFM effects' on pain, further considerations about the specific underlying mechanisms cannot be made. We also acknowledge that once study 1 was conducted in a laboratorial environment, this could have conditioned the physiotherapists' performance during DFM. Notwithstanding, the conditions related to personal adjustments regarding the position of the physiotherapist and the hand position chosen was not imposed to the participant, so they performed the technique as in real context.

Future studies assessing the long-term effects of DFM in clinical populations should take these results into account by providing a mean to deliver a standardize pressure during DFM application. Thus, it is important to assess what is the manual pressure necessary to develop the effects intended and attributed to the technique (morphological, histological and functional) (Atkins et al., 2010; Chamberlain, 1982), determining if different pressures influence the clinical outcomes.

CONCLUSION

The present study was the first to objectively document the pressure applied by physiotherapists during DFM application which was 2.3 kg/cm^2 (1.02; 4.16). A wide variation on the pressure performed by the physiotherapists was found as well as a moderate oscillation over time within physiotherapists execution. Moreover, our results have shown that higher pressures of DFM result in lower time to onset of analgesia.

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STUDY IV

Deep friction massage in the management of patellar tendinopathy, in athletes: short term clinical outcomes.

Submitted in

Physical Therapy in Sport

Deep friction massage in the management of patellar tendinopathy, in athletes: short term clinical outcomes.

Paula Chaves[a], Maria Paço[a], Daniela Simões[b], Sandra Silva[a], Francisco Pinho[a,c,e], José Alberto Duarte[d], Fernando Ribeiro[e]

[a] CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, R. Central de Gandra, 1317, 4585-116 Gandra PRD, Portugal.

[b] Santa Maria Health School, Travessa Antero de Quental, 173, 4049-024 Porto, Portugal.

[c] Algoritmi – Escola de Engenharia da Universidade do Minho, Campus Azurém, 4800-058 Guimarães, Portugal.

[d] University of Porto, Faculty of Sport, Research Centre in Physical Activity, Health and Leisure, Rua Dr. Plácido Costa, 91, 4200-450 Porto, Portugal.

[e] School of Health Sciences and Institute of Biomedicine - iBiMED, University of Aveiro, Edifício 30, Agras do Crasto, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal.

Corresponding author:

Paula Chaves
CESPU, Institute of Research and Advanced Training in Health Sciences and Technologies, R. Central de Gandra, 1317, 4585-116 Gandra PRD, Portugal.
paulamchaves@gmail.com

ABSTRACT

Objective: To assess whether the immediate effects of DFM on clinical outcomes, namely pain (pain intensity and time to onset of analgesia), muscle strength and range of motion, are dependent on the pressure applied during the DFM application in athletes with patellar tendinopathy.

Methods: A randomized, controlled, cross-over trial was conducted with ten athletes with diagnosis of patellar tendinopathy. All participants attended four sessions, three treatment sessions with DFM applied with different pressures (the mean pressure – which was previously determined for each participant – and the mean pressure ± 25%) and a control session, each of which was separated by 48 hours. The order of the sessions was randomly assigned. Before and immediately after each session the following outcomes were assessed: pain (intensity upon palpation and time to onset of analgesia), knee flexion passive range of motion and muscle strength of knee extensors.

Results: Pain intensity changed significantly over time ($F_{1,9}$=52.364; p<0.001; η^2_p=0.853) and among sessions ($F_{3,27}$=82.588; p<0.001; η^2_p=0.902), with a significant interaction for group X time ($F_{3,27}$=19.841; p<0.001; η^2_p=0.688). The knee extensors strength and knee flexion range of movement did not change significantly over time ($F_{1,9}$=2.240; p=0.169; η^2_p=0.199) and ($F_{1,9}$=1.370; p=0.272; η^2_p=0.132), respectively; nor in the observed interaction for session X time ($F_{3,27}$=3.276; p=0.074; η^2_p=0.267) and ($F_{3,27}$=1.992; p=0.139; η^2_p=0.181), respectively. Regardless of the pressure applied, the time to onset of analgesia was not significantly different ($F_{2,18}$=1.026; p>0.05; η^2_p=0.102).

Conclusion: The present study has shown that DFM induces an immediate reduction in pain intensity upon palpation, regardless of the pressure performed.

Keywords: CYRIAX; PATELLAR TENDON; MANUAL THERAPY; MUSCLE STRENGTH; RANGE OF MOTION; PAIN; FUNCTION

INTRODUCTION

Patellar tendinopathy, also known as jumper's knee, is a condition associated with load demands and excessive use of the patellar tendon which results in a pathologic cascade of events including neovascularization, nerve ingrowth, tendon degeneration, and, ultimately, a painful tendon (Abate et al., 2009; J. L. Cook & Purdam, 2009; Malliaras, Cook, Purdam, & Rio, 2015). Patellar tendinopathy can thus be considered a failed healing process of this structure (Abate et al., 2009; Jill L. Cook, Khan, & Purdam, 2001; D'Addona, Maffulli, Formisano, & Rosa, 2017; N. Maffulli, Longo, & Denaro, 2010). Clinically, this lesion is characterized by a combination of pain, diffuse or localized swelling, impaired proprioception and performance (Jill L. Cook et al., 2001; J. L. Cook & Purdam, 2009; Malliaras et al., 2015; Rudavsky & Cook, 2014; Torres et al., 2017).

The treatment of tendinopathy is often multifactorial and should consider the chronicity of the problem, the potential abnormal movement patterns of the athlete, and the functional and structural impairments associated with the tendon pain (M. Reinking, 2012). A panoply of physical therapy modalities is available, although some with scarce evidence to support their use, to treat tendon pain such as physical agents, deep friction massage (DFM), counterforce bracing, education and abnormal movement pattern correction, and exercise namely eccentric training (Andres & Murrell, 2008; Blackwood & Ghazi, 2012; M. Reinking, 2012). Regarding DFM, despite the lack of definitive clinical evidence to support its use in the management of chronic tendinopathy and the absence of studies describing the tissue effects of DFM, it is still one of the therapeutic resources frequently used in this condition (Blackwood & Ghazi, 2012; Brosseau et al., 2002; Chaves et al., 2017; Joseph, Taft, Moskwa, & Denegar, 2012; Loew et al., 2014; Nicola Maffulli, Sharma, & Luscombe, 2004; Prabhakar, Kage, & Anap, 2013; Rees, Maffulli, & Cook, 2009; Rees, Wilson, & Wolman, 2006; M. F. Reinking, 2016; Stasinopoulos & Johnson, 2004). DFM aims to reduce adhesions, enhance realignment of collagen fibers and improve pain (Atkins, Kerr, & Goodlad, 2010; Begovic, Zhou, Schuster, & Zheng, 2016; Brosseau et al., 2002; Chamberlain, 1982; Davidson et al., 1997; Gehlsen, Ganion, & Helfst, 1999; Joseph et al., 2012; Loew et al., 2014; Prabhakar et al., 2013; Stasinopoulos & Johnson, 2004). The pain reduction attributed to DFM seems to be triggered by the mechanical stimulus provided by the application of deep pressure during DFM (Bialosky, Bishop, Price, Robinson, & George, 2009), regardless of the mechanism involved in its reduction (Atkins et al., 2010; Bialosky et al., 2009; Gregory, Deane, & Mars, 2003; Hassan, Hafez, Seif, & Kachanathu, 2016; Llorca-Torralba, Borges, Neto, Mico, & Berrocoso, 2016; Pud, Granovsky, & Yarnitsky, 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015; Viswas, Ramachandran, & Korde Anantkumar, 2012).

The description of DFM defines that the pressure should be performed in accordance with the target tissue and taking into account the patient feedback, nonetheless it is not known if and how the intensity of the pressure applied during DFM treatment influences the technique’s effect on pain and consequently on function (J. L. Cook, Rio, Purdam, & Docking, 2016; Graven-Nielsen & Arendt-Nielsen, 2008; Silbernagel, Gustavsson, Thomee, & Karlsson, 2006). It is known that strength may be impaired by nociception, that leads to inhibition of motor cortex or even develop peripheral sensitization (Farina, Tinazzi, Le Pera, & Valeriani, 2003; Farina et al., 2001; Lund, Donga, Widmer, & Stohler, 1991; Struyf et al., 2014).

Thus, assuming the importance of the pressure during DFM, we hypothesize that the immediate effect of DFM on pain and function, namely range of motion and muscle strength, is modulated by the magnitude of pressure, with higher pressures inducing better outcomes. To test this hypothesis, this study aims to assess whether the immediate effects of DFM on clinical outcomes, namely pain (pain intensity upon palpation and time to onset of analgesia), muscle strength and range of motion, are dependent on the pressure applied during the DFM application in athletes with patellar tendinopathy.

Material and Methods

Study Design and Participants

A randomized, controlled, cross-over trial (ClinicalTrials.gov ID: NCT03255538) was conducted with a non-probabilistic convenience sample of young athletes with patellar tendinopathy. Participants were recruited among athletes of local sports clubs after direct contact with the physiotherapists working there. First, the physiotherapists were contacted and asked to refer potential participants; after that, the athletes were invited to participate in the study. Ten athletes with diagnosis of unilateral patellar tendinopathy (6 males and 4 females, 5 with tendinopathy at the left and 5 with tendinopathy at the right lower limb) with a mean age of 27.90 ± 5.24 years, weight of 73.30 ± 6.00 kg, height of 1.75 ± 0.07 m and a body mass index of 23.90 ± 1.73 kg/cm^2, volunteered to participate in the study. In order to be included, the participants should be aged 18 years old or above, have a history of training-related and/or competition-related pain in the patellar tendon, pain on palpation of the patellar tendon and symptoms persisting for more than 12 weeks. Furthermore, the participants should have never been treated with DFM and should have unilateral patellar tendon pain (Crossley et al., 2007). The exclusion criteria were: history of other injuries or pathologies to the lower limbs, intake of medication that could interfere with pain mechanisms or with strength production, active skin disease, deep vein thrombosis and the presence of any factors or conditions that could interfere with the awareness and sensibility to pain or preclude the production of maximal muscle contractions.

All participants attended five sessions: one session for basal assessment and four sessions comprising one control session and three DFM intervention sessions (applied with different pressures); separated by 48 hours to avoid any carryover effect. These four sessions were randomly assigned using a random sequence generator (www.random.org).

PROCEDURES

In the first visit to the laboratory, all the participants have performed a basal assessment, that was initiated by height measurement, through a stadiometer (Seca®, Bodymeter 206, Hamburg, Germany) as well as the evaluation of body composition through a Tanita BC-545 (Tanita®, Tokyo, Japan). Then, for each participant, the assessment of the mean pressure performed during DFM application was evaluated. This evaluation intended to mimic the use of DFM in clinical practice. Having this, the physiotherapist responsible for DFM application positioned the participant in supine lying, with the knee positioned in 15º of flexion (controlled by a goniometer) and the application point of DFM was defined according to the pain location at palpation (Atkins et al., 2010; Chamberlain, 1982; Cyriax & Cyriax, 1993) and it was registered. Then, the same physiotherapist applied pressure over the pain location, being the pressure intensity guided by the participant feedback until it was considered moderate, through the verbal descriptor scale (Peters, Patijn, & Lame, 2007). After achieving this pressure, the physiotherapist maintained it as in a regular DFM session, comprising 10 minutes of DFM after analgesia was obtained. The technique was performed with a pressure sensor placed at the tip of the physiotherapist finger, so that the intensity of the pressure applied during the DFM session was registered. DFM was performed accordingly with the execution procedures defined by Cyriax (Cyriax & Cyriax, 1993), this is, slow and rhythmic movements of small amplitude applied transversely to the orientation of the tendon fibres, maintaining a constant pressure. The time to onset of analgesia (reported by the participant) was measured by the investigator using a chronometer (NIKE, Inc., Beaverton, OR, USA).

The pressure sensor used by the physiotherapist during DFM application, was part of an instrument that monitors and records pressure variables (Figure 1). This consisted in a piezo-resistive sensor provided by Tekscan A201 FlexiForce™ with an active area of 9.53 mm^2 in a pressure range of 0-445N. The sensor was connected according to the respective datasheet specifications to achieve the stated linear error of 3% under full scale and a repeatability error of 2.5%. To acquire the pressure data, a microcontroller based platform (Teensy

3.2) was programmed for 100 sps sampling frequency. This device runs on a 96 MHz clock with 16 bits resolution for analog-to-digital conversion. The microcontroller was coupled a Bluetooth 2.1+EDR module for wireless data transmission at 230400 bps. Under these specifications, the sensor full scale bandwidth from 0-3.3 V achieves a resolution of 0.0068N (680 micrograms). For data recording and real-time visualization, a Windows™ based application was used (Figure 1).

Figure 1. Instrument to monitor and register the pressure

Before each acquisition, the sensor was properly calibrated with two standard weights. The recorded data was processed under Matlab_R2016a. Data was first 5 Hz low-pass filtered through a 4th order Hamming window FIR (Finite Impulse-Response).

The pressure variables were extracted from each signal and the mean pressure of the DFM application during the session was calculated for each participant. This value was used to determine the pressure to be applied to each participant in DFM intervention sessions.

In the following four visits to the laboratory, the participants were randomly assigned to the one of the following sessions: control session (P0), mean pressure -25% (P1), mean pressure (P2) and mean pressure +25% (P3).

All intervention sessions followed the same structure, that comprised a pre- and post intervention assessment. For the intervention, the participant was positioned in supine lying, with the knee positioned in 15º of flexion (controlled by a goniometer) and the physiotherapist applied the pressure, through a contact with the fingertip in the application point registered in the basal assessment, accordingly with the session (P1, P2 or P3) fulfilling the execution procedures of the technique.
During each intervention session, the pressure performed by the physiotherapist was continuously measured with the device previously described (Figure 1). The pressure was plotted in real time to give visual and auditory feedback to the physiotherapist, hence keeping the target pressure for each session constant during all the procedure. As in the basal assessment, in the DFM sessions, the participants were asked to report the time to onset of analgesia.

Control session (P0): This session followed the same structure as the intervention sessions, however, the intervention procedure was replaced by a rest period of 12-14 minutes (the individual time to onset of analgesia found in the basal assessment followed by 10 minutes), with the participant positioned in supine lying, with the knee positioned in 15º of flexion (controlled by a goniometer). The length of this session was defined to match the duration of the DFM sessions.

Mean pressure -25% (P1): For this intervention, the physiotherapist applied in each participant the mean pressure obtained in the basal assessment for each of the participants decremented by 25% and applied the technique accordingly with its execution procedures with a duration of 10 minutes after the onset of analgesia.

Mean pressure (P2): For this intervention, the physiotherapist applied in each participant the mean pressure obtained in the basal assessment for each of the participants and applied the technique accordingly with its execution procedures with a duration of 10 minutes after the onset of analgesia.

Mean pressure +25% (P3): For this intervention, the physiotherapist applied in each participant the mean pressure obtained in the basal assessment for each of the participants incremented by 25% and applied the technique accordingly with its execution procedures with a duration of 10 minutes after the onset of analgesia.

Outcome measures

Before and immediately after each session the following outcomes were assessed: pain intensity upon palpation, knee flexion passive range of motion and muscle strength of knee extensors. All measures were obtained by the same two examiners who were blind to the session allocation. The participants were also questioned regarding the presence of any adverse event.

Pain intensity upon palpation

A standardized pressure of 2 kg/cm^2 (controlled by the pressure device above-described), was applied over the most painful point (identified in the basal assessment), and then the participant was asked to graduate pain intensity through a 11-point numeric scale. The 11-point numeric scale is a unidimensional measure of pain intensity, in which a respondent selects a whole number (0–10 integers) that best reflects the intensity of their pain, with 0 representing one pain extreme ("no pain") and 10 representing the other pain extreme ("pain as bad as you can imagine") (Hawker, Mian, Kendzerska, & French, 2011).

Knee flexion passive range of movement

Knee flexion passive range of movement was obtained through goniometry. This is considered to be a valid and reliable tool to measure range of movement (Gogia, Braatz, Rose, & Norton, 1987; Milanese et al., 2014). Participants were positioned in supine lying for measurement of knee flexion and the measurement was performed using a standard goniometer (Baseline®, New York, NY, USA), as previously described (Norkin & White, 2003). The knee was passively mobilized into flexion by a third person until the participant referred the presence of pain. This procedure was repeated three times and the average of the range of movement obtained was used. The reliability of this assessment procedure was established in 8 individuals with the same characteristics of our sample, tested in two sessions separated by 5 days. The results demonstrated excellent test–retest reliability with intraclass correlation coefficient ($ICC_{(3,1)}$) = 0.97.

MUSCLE STRENGTH OF KNEE EXTENSORS

Knee extensors muscle strength was measured isometrically using a dynamometer (Baxtran, UCS, Vilamalla, Girona, SPAIN). Participants were seated in the plinth with hips at 90º and knees flexed at 60°, without any back support nor contact of the lower limbs with the floor. Participants were instructed to hold the side of the plinth for stabilization and the dynamometer was placed on the inferior part of the leg, proximal to the ankle joint. Then, they performed a warm-up test with two submaximal and one maximal contraction, followed by three maximal isometric tests in the extension direction (5 seconds of contraction with 120 seconds of rest between tests). All participants received the same verbal instructions and encouragement (Croisier, Foidart-Dessalle, Tinant, Crielaard, & Forthomme, 2007; Shenoy, Mishra, & Sandhu, 2011). The average of the three repetitions was used. Muscle strength (Nm) was recorded and normalized for mass ($Nm.kg^{-1}$).

STATISTICAL ANALYSIS

Descriptive statistics comprised absolute and relative frequencies for categorical variables and mean with standard deviation (SD) for numerical data. Shapiro-Wilk test was used to assess the normality of data distribution. To compare the effects of the sessions on pain, range of motion and muscle strength a Repeated Measures General Linear Model of two factors was used: session (control and 3 different pressures) and Time (pre- and post-session). A Repeated Measures General Linear Model with Bonferroni correction for pairwise comparisons was also used to compare data at baseline (pre-session) between interventions, pain intensity during DFM and time to onset of analgesia. Effect size was reported using the partial eta-squared (η^2_p) where values $0.01 \leq \eta^2_p < 0.06$ represent a small effect, values $0.06 \leq \eta^2_p$ p < 0.14 represent a medium effect, and values η^2_p

> 0.14 represent a large effect. All statistical analyses were conducted considering an α=0.05. Analyses were performed on IBM® SPSS® Statistics version 24.0 (IBM Corp, Armonk, NY, USA).

Ethical considerations

Ethical approval was guaranteed by the Ethics Committee of the Faculty of Sports, University of Porto (Process CEFADE 15.2017). All the participants agreed to participate in the study by signing an informed consent, that respects all the ethical considerations as stated in the Declaration of Helsinki.

Results

Before the interventions, no differences between sessions were observed regarding pain intensity ($F_{3,27}$=2.927; p>0.05; η^2_p=0.245), knee flexion passive range of movement ($F_{3,27}$=1.042; p>0.05; η^2_p=0.104) and muscle strength of knee extensors ($F_{3,27}$=0.144; p>0.05; η^2_p=0.016).

Pain intensity changed significantly over time ($F_{1,9}$=52.364; p<0.001; η^2_p=0.853) and among sessions ($F_{3,27}$=82.588; p<0.001; η^2_p=0.902), with a significant interaction for group X time ($F_{3,27}$=19.841; p<0.001; η^2_p=0.688) (Table 1). Despite the fact that after the DFM sessions the score of pain was constant (zero), there was a notorious decrease in pain scores after all DFM sessions, whereas in the control session there were no statistically significant differences (p>0.05). When analysed the knee extensors strength, it was observed that it did not change significantly over time ($F_{1,9}$=2.240; p=0.169; η^2_p=0.199) and there was no observed interaction for session X time ($F_{3,27}$=3.276; p=0.074; η^2_p=0.267). (Table 1). Conversely, no differences were observed in knee flexion range of movement in any group; range of movement did not change significantly over time ($F_{1,9}$=1.370; p=0.272; η^2_p=0.132) and there was no observed interaction for session X time ($F_{3,27}$=1.992; p=0.139; η^2_p=0.181).

Table 1. Immediate effects of the sessions on pain, muscle strength and range of motion

		Pre-intervention assessment Mean (SD)	Post-intervention assessment Mean (SD)
Pain intensity upon palpation (0-10)	P0: Control session	6.3 (1.57)	6.4 (2.17)
	P1: -25% of the mean pressure	4.7 (2.36)	0.0 (0.0)
	P2: Mean pressure	4.5 (2.22)	0.0 (0.0)
	P3: +25% of the mean pressure	4.9 (1.60)	0.0 (0.0)
Muscle strength (Nm.kg-1)	P0: Control session	169.0 (38.28)	170.3 (36.85)
	P1: -25% of the mean pressure	173.4 (49.89)	185.1 (50.62)
	P2: Mean pressure	179.1 (48.24)	209.2 (53.08)
	P3: +25% of the mean pressure	172.8 (81.40)	197.06 (79.16)
Range of motion (°)	P0: Control session	150.1 (7.14)	150.3 (7.93)
	P1: -25% of the mean pressure	152.1 (7.37)	153.7 (7.32)
	P2: Mean pressure	152.8 (6.41)	154.2 (6.00)
	P3: +25% of the mean pressure	152.9 (6.95)	153.3 (6.67)

The comparison of the differences between interventions (Figure 2), showed that there was only a statistically significant difference between DFM sessions and control session for pain intensity ($p<0.001$).

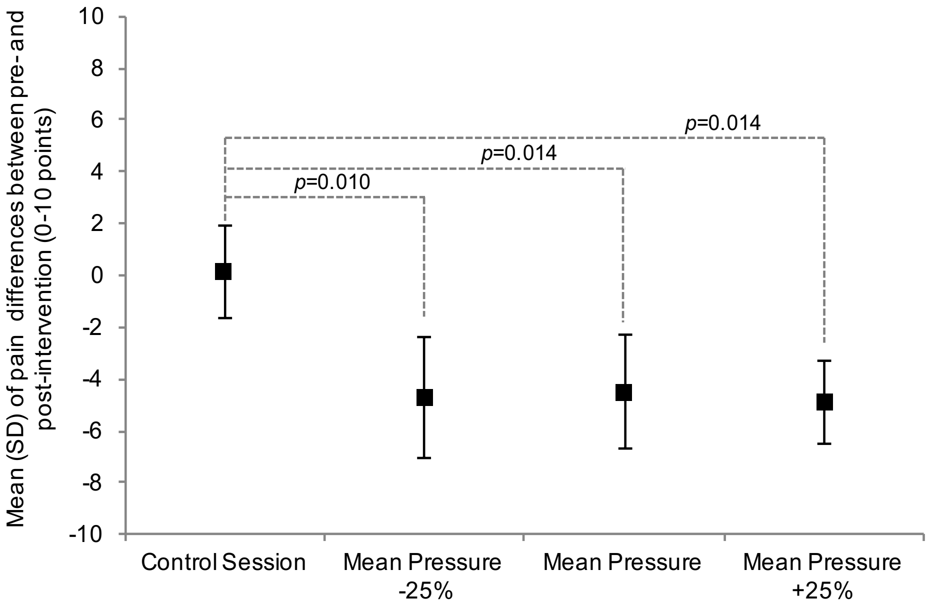

Figure 2. Mean and standard deviation (SD) of deep friction massage effect on pain

When compared the time to onset of analgesia between sessions (Figure 3), it was shown that regardless of the pressure applied, the time to onset of analgesia was not affected ($F_{2,18}$=1.026; p>0.05; η^2_p=0.102).

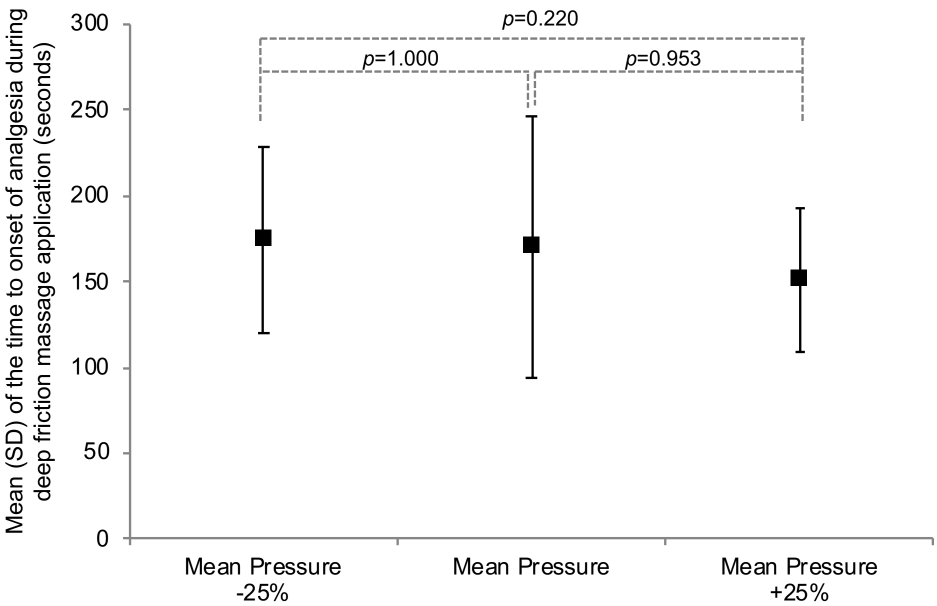

Figure 3. Mean and standard deviation (SD) of time to onset of analgesia during deep friction massage by intervention

Adverse Events

None of the participants reported the presence of any adverse event.

Discussion

The aim of the present study was to assess the immediate effect of different pressures applied during DFM in pain (pain intensity upon palpation and time to onset of analgesia during the technique), muscle strength of knee extensors and range of movement of the knee in athletes with patellar tendinopathy.

Our findings do not confirm our hypothesis, as our results showed that the immediate effects of DFM are not dependent on the pressure applied during the DFM application. Although it was shown an immediate reduction on pain intensity, regardless of the pressure applied, this fact was not verified in the time to onset of analgesia nor in the functional outcomes evaluated.

As far as the authors know, this is the first study aiming to evaluate in isolation, DFM effects' in pain and function as well as to quantify the effects of different intensities of pressure applied in the above-mentioned outcomes. Our results have shown that DFM promotes an immediate pain reduction pain. Notwithstanding, this reduction in pain intensity and time to onset of analgesia were not affected by the magnitude of the pressure used during DFM, this is, the mechanical stimulus performed during DFM seems to trigger an analgesic response independently of the pressure applied. This response may be explained by different mechanisms such as the induction of hyperaemia produced by mechanical stimulus (Atkins et al., 2010; Chamberlain, 1982; Goats, 1994; Gregory et al., 2003; Stasinopoulos & Johnson, 2004), the "gate control theory" (De Bruijn, 1984; Goats, 1994; Gregory et al., 2003; Hassan et al., 2016; Stasinopoulos & Johnson, 2004; Viswas et al., 2012), and/or the descending mechanisms of pain modulation (Atkins et al., 2010; Bialosky et al., 2009; Goats, 1994; Llorca-Torralba et al., 2016; Pud et al., 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015). Specific considerations regarding the different pain mechanisms are beyond the scope of this paper, and the readers should look for further explanations on the available literature (Atkins et al., 2010; Bialosky et al., 2009; Pud et al., 2009; Vigotsky & Bruhns, 2015).

Concerning function, our results have shown that DFM did not produce significant changes in the range of movement of knee flexion, which may be due to the fact that at baseline, the participants did not present impairments in the range of movement. Likewise, when analysed the results regarding strength there were no statistically significant differences between the change induced by DFM sessions and that observed in the control session. It is known that strength may be impaired by nociception, that leads to inhibition of motor cortex or even develop peripheral sensitization (Farina et al., 2003; Farina et al., 2001; Lund et al., 1991; Struyf et al., 2014). Having this, and considering that our results have shown that when DFM was performed there was a decrease in pain intensity scores, we hypothesize that DFM have triggered an analgesic response that through the activation of descending nociceptive inhibition should have reduced the nociceptive input to the central nervous system, and consequently it would be expectable that the motor output (muscle strength) would be enhanced (Nijs et al., 2012; Struyf et al., 2014). However, the fact that our results did not present statistically significant changes in this outcome may be explained by the great inter-individual variability found (reflected in the small effect size). Furthermore, it should be noted that this study only evaluated immediate effects and from a single DFM intervention session.

Taking into account that, globally, our data indicates that higher pressure did not translate into better outcomes, the physiotherapist should take into consideration that a most distressful technique is not related with pain reduction or muscle strength improvement. However, the reader should bear in mind that the application of lower pressures may compromise the morphological changes attributed to the technique, that were not evaluated in our study.

The present study had some limitations. The lack of differences between sessions in the muscle strength change could be related with the small sample size. Only the immediate effects of the technique were measured, it is not known for how long the effects of DFM last. Future studies could overcome these limitations by assessing different time points (e.g. at 1h, 6h, 24h) after the application of the technique as well as having higher intensities of DFM pressure. Future studies should encompass larger sample sizes, follow the protocol regarding treatment frequency recommended by the author of DFM and analyze its effectiveness with a follow-up period; should also include instruments for functional outcomes (such as VISA-P).

CONCLUSION

The present study has shown that DFM induces an immediate reduction in pain intensity upon palpation, regardless of the pressure performed. Notwithstanding, further studies are needed to determine the tissue response to different pressures and determine if the repair process of the tendon is influenced by pressure.

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STUDY REGISTER

This study is registered in ClinicalTrials.gov with the ID: NCT03255538.

Conflict of interest: None declared.

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CHAPTER 4

DISCUSSION

DISCUSSION OF METHODOLOGY

The aim of this work was to characterize and analyse the parameters of application of DFM in physiotherapy clinical practice, namely the pressure applied and its influence in the technique's results for treating tendinopathies. In order to do this, we have performed different studies, whose choices regarding methods are further discussed next.

On study II and III, it was decided to recruit healthy individuals once, the assessed outcomes could not be conditioned by the presence of pain. This is, in study II, because the target pressure (minimum pressure to promote the macroscopic deformation of the patellar tendon) was unknown and could be above the pain tolerance of the symptomatic individual; in study III, the standardization of the pressure to be performed during DFM would also be constrained, if the individuals presented pain, because, once again, the pain could not be bearable to the participant and so jeopardize the achievement of the study aims. Despite this duly weighted choice, it is important to acknowledge that this should be taken into account in the extrapolation of the results.

Still refering to study II, it was used a mainframe that encompassed the ultrasonographic probe and the pressure sensors, whose aim was to manage the application of a pressure on the skin over the patellar tendon, uniform and progressively, monitoring its macroscopic deformation through ultrasonographic image. The use of ultrasonography was chosen considering the fact that this is the only method that allows real-time visualization and assessment of the tendinous structure beside the possibility of being carried out rapidly, being non-invasive and easy to use as well as the fact that the apparatus is portable and relatively inexpensive (Del Baño-Aledo et al., 2017; Gellhorn & Carlson, 2013; Gellhorn, Morgenroth, & Goldstein, 2012).

The results obtained in study II were essential to the development of study IV, once data retrieved allowed us to define the standardized pressure applied during pain upon palpation testing. So, once data analysis has shown that the maximum pressure needed to promote the macroscopic deformation of the patellar tendon was 2 kg/cm^2, this was the standardized pressure applied, in study IV, during the assessment of pain upon palpation. Another outcome assessed in this study was knee extensors strength, and, for this, it was used a dynamometer that is a portable, easily handled and low-cost device, as well as the fact that is easily used in clinical context. Also, the fact that we targeted an isometric assessment, it did not justify to use other more expensive instruments. Moreover, It is reproducible and significantly correlated with the isokinetic values, showing its usefulness when compared with expensive laboratory-based dynamometers (Kollock, Onate, & Van Lunen, 2010; Muff et al., 2016).

Still in study IV, it was also assessed the knee range of movement, that followed a protocol previously described (Norkin & White, 2003). However, when analysed the collected data regarding pre-intervention assessment, it was verified that the participants did not present range of movement limitations. This fact allowed us to reflect regarding the use of the selected protocol and hypothesize whether the use of a protocol that would impose more tension over the knee extensors, as the muscle test for *rectus femoris* length (Ely test) would allow to detect range of movement impairments (Norkin & White, 2003).

Regarding the option of the pressure applied during DFM, it was decided to mimic the clinical practice as far as possible. For this, and considering the intra-individual variability during DFM found in study III, it was calculated the mean pressure applied by the physiotherapist during a regular DFM session of each participant (performed in the basal assessment), and that was the value used to define the pressures in each of the intervention sessions (P1, P2, P3).

DISCUSSION OF RESULTS

Our results have shown that most of the physiotherapists use this technique as a therapeutic resource, but with some variation in the parameters of application per comparison to the authors' description, highlighting the lack of standardization pointed out in a systematic review (Loew et al., 2014). Having this in mind, and once the pressure applied during DFM seems to be crucial to elicit the advocated effects of the technique, we aimed to establish the minimum pressure needed to promote the deformation of the patellar tendon. It was observed that this was 1.1 ± 0.37 kg/cm^2 and there was no association between the pressure needed to promote the deformation of the tendon and the characteristics of the participants (sex, age, weight, height, BMI, muscle mass, sports practice and subcutaneous thickness). Hence, in clinical practice the physiotherapist should be aware that a DFM pressure on patellar tendon lower than 1.1 kg/cm^2 is not sufficient to promote the deformation of the tendon and so trigger the advocated effects.

Next, we have characterized the pressure applied by physiotherapists and verified whether the pressure applied during DFM was above the minimum pressure need to deform the patellar tendon and whether it is a key factor determining the time to onset of analgesia both in the healthy patellar tendon and in patellar tendinopathy. Furthermore, we have also assessed the immediate effect of different pressures applied during DFM in pain (pain intensity upon palpation and time to onset of analgesia), in the muscle strength of knee extensors and in the range of movement of knee flexion, in participants with patellar tendinopathy. Our results indicated that the pressure applied during DFM presented high variability (within and between physiotherapists), the median pressure (P25; P75) applied by physiotherapists was 2.3 kg/cm^2 (1.02; 4.16) and 1.7 ± 1.07 kg/cm^2 (mean ± SD) in the healthy patellar tendon and patellar tendinopathy, respectively. Although the mean pressure performed by physiotherapists (both in the asymptomatic and in the symptomatic patellar tendon) is superior to the minimum pressure needed to promote the macroscopic deformation of the tendon, it should be noted that during the technical execution, the minimum pressure performed by physiotherapists [0.7 kg/cm^2 (0.49; 1.49)] was inferior to the one needed to promote tendon deformation. This fact reinforces the need to follow the technique's guidelines, which indicates that the pressure should be constant during all the procedure once this may compromise the mechanical response (Atkins et al., 2010; Chamberlain, 1982).

Concerning its analgesic effect, it was shown that higher the pressure of DFM the lower the time to onset of analgesia, however, the differences were only statistically significant in the participants with healthy patellar tendon. Despite the statistical significance, the difference in the time to onset of analgesia was small (~30 seconds), being questionable its clinical relevance. Regarding immediate effects, DFM has shown to decrease pain intensity immediately after its application. This effect was not influenced by the magnitude/intensity of the pressure applied, once higher pressures did not produce a better outcome.

After a thorough analysis of the literature regarding DFM (State of the Art), we have found that this technique is sought to decrease pain, favour the repair process by promoting the development and orientation of the collagen fibres, hyperaemia and function improvement (Atkins et al., 2010; Brosseau et al., 2002; Chamberlain, 1982; Joseph et al., 2012; Loew et al., 2014; Stasinopoulos & Johnson, 2004).

In order to achieve clinical success with this technique, its author highlighted the importance of accuracy when identifying and locating the injured tissue (confirmed through palpation) as well as a set of basic application principles to ensure an effective procedure (Atkins et al., 2010; Chamberlain, 1982; Joseph et al., 2012; Stasinopoulos & Johnson, 2004).

Although the technique's lack of evidence in isolation, our results (Study I) have shown a high prevalence of DFM use (84.9%), which is according to the literature that claims Cyriax's DFM one of the main therapeutic resources used in the management of tendinopathy (Joseph et al., 2012; Prabhakar et al., 2013; Stasinopoulos & Johnson, 2004), which can be a reflex of the clinical usefulness that physiotherapists attribute to this technique.

When analyzed the application parameters chosen by a sample of Portuguese physiotherapists, we have observed that the application parameters chosen were very heterogeneous and variable, specially concerning the frequency in both acute and chronic conditions, the duration of DFM application in the chronic conditions and the position of the tendon. Although it is not known how these differences interfere with the results observed in previous clinical studies, it seems reasonable to assume that these non-compliances with Cyriax's recommendations, as seen in previous studies (Blackwood & Ghazi, 2012; Cooil & Gahzi, 2010; Hassan et al., 2016; Senbursa et al., 2007; Senbursa et al., 2011; Stasinopoulos & Stasinopoulos, 2004; Verhaar et al., 1996), may be one of the reasons explaining the lack of definite results of DFM in the treatment of tendinopathy.

According with the principles of aplication of DFM, it should be applied for six to twelve sessions and the frequency and duration of the treatment should be suitable to the type and stage of the lesion (Atkins et al., 2010; Chamberlain, 1982; Stasinopoulos & Johnson, 2004). In an acute stage, the aim is the maintenance of the mobility of the structures from the affected tissue in order to prevent the formation of cross-links, promote the alignment, realignment and elongation of the new fibres, hence facilitating the regeneration process. For these reasons, DFM should be performed daily, with a lighter intensity and shorter duration (about ten movements after analgesia) (Atkins et al., 2010; Chamberlain, 1982; Stasinopoulos & Johnson, 2004). In a chronic injury, the intensity should be higher and a longer duration is expected (ten minutes after analgesia), since the aims at this stage are to reestablish the mobility of the structures of the injured tissue, through the break of the adherences that resulted from the desorganized cicatrisation process. Considering the potential traumatic effect of the technique, it should be performed in alternate days (Atkins et al., 2010; Chamberlain, 1982; Stasinopoulos & Johnson, 2004). Our results, regarding the frequency of application of DFM in chronic conditions, have shown that the recommendation of alternate days is not complied, as about 31% of the physiotherapists reported to use the technique daily. Therefore, the traumatic mechanical effect may interfere with the regeneration process, generating an excessive stimulation of fibroblasts proliferation as well as the recruitment of inflammatory cells (Davidson et al., 1997; Sharma & Maffulli, 2005, 2006). On the other hand, when DFM is performed only twice a week or less, as reported by about 26% of the participants, the timing of the histologic and morphologic response may be lost. Several authors reported that the lack of movement during the reparative process of the connective tissue leads to a perturbation in the balance between collagen synthesis and degradation, an increase of cross-links at intermolecular level, a decrease in the water content of the extracellular matrix and also an increase in the number and thickness of the collagen fibres, thus promoting anarchic scar tissue formation and increased pain (Akeson et al., 1977; Atkins et al., 2010; Chamberlain, 1982; Sharma & Maffulli, 2006).

When analysed our results concerning the technique's duration on the chronic phase, we observed that once again the parameters described by Cyriax are not complied. The physiotherapists referred to perform a lower time of DFM (a median of 5 minutes), which may limit not only the preconized structural changes in the connective tissue, but also compromise the neurophysiological and vascular effects associated to the analgesic effect (Atkins et al., 2010; Bialosky et al., 2009; Chamberlain, 1982; De Bruijn, 1984; Goats, 1994; Gregory et al., 2003; Hassan et al., 2016; Llorca-Torralba et al., 2016; Pud et al., 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015; Viswas et al., 2012).

In respect to tendon position, the technique's author described that if the lesion is located at the body of the tendon or teno-osseous / myotendinous transitions, the tendon should be positioned without tension (except for the tendons with synovial sheath, that should be placed in a stretching position) (Atkins et al., 2010; Chamberlain, 1982; Stasinopoulos & Johnson, 2004). The non-fulfilment of these recommendations as seen in about 50% of the participants, may compromise the physiological crimp (Franchi et al., 2007; Hansen, Weiss, & Barton, 2002), which may limit a deepest and most comprehensive access to the largest number of fibres possible.

It is also described that the performance of the technique should be transverse to the orientation of the affected fibres, with a depth and range sufficient to ensure the compression of all the affected area, but taking into account the stage, irritability and patient feedback (Atkins et al., 2010; Chamberlain, 1982;

Stasinopoulos & Johnson, 2004). The pressure performed during DFM seems to be crucial to elicit the advocated morphological and histological effects (Atkins et al., 2010; Chamberlain, 1982; Davidson et al., 1997; Gehlsen et al., 1999; Gregory et al., 2003; Sterns, 1940), but this fundamental parameter has only been described qualitatively as “deep enough” to mobilize the tendinous fibres (Chamberlain, 1982; Gregory et al., 2003; Loew et al., 2014), which may account for the lack of control over DFM application procedures reported in the literature (Brosseau et al., 2002; Loew et al., 2014).

Previous studies have shown that the intensity of the pressure induces a directly proportional increase in the response of recruitment and activation of fibroblasts (Davidson et al., 1997; Gehlsen et al., 1999). The pressures described by these authors ranged between 5.1 kg/cm^2 and 15.3 kg/cm^2, which are much higher than those observed in our studies (Studies II, III and IV). However, the studies from Davidson et al. (1997) and Gehlsen et al. (1999) only refer to morphological and histological effects in the animal model.

The application of DFM should be slow and progressive, respecting the initial discomfort of the subject until reaching analgesia (Atkins et al., 2010; Chamberlain, 1982; Stasinopoulos & Johnson, 2004); this would allow the physiotherapist to get immediate effects on pain. These effects may be explained by different mechanisms such as: 1) induction of hyperaemia produced by mechanical stimulus (Atkins et al., 2010; Chamberlain, 1982; Goats, 1994; Gregory et al., 2003; Stasinopoulos & Johnson, 2004); 2) the “gate control theory” (De Bruijn, 1984; Goats, 1994; Gregory et al., 2003; Hassan et al., 2016; Stasinopoulos & Johnson, 2004; Viswas et al., 2012), and/or 3) the descending mechanisms of pain modulation (Atkins et al., 2010; Bialosky et al., 2009; Goats, 1994; Llorca-Torralba et al., 2016; Pud et al., 2009; Stasinopoulos & Johnson, 2004; Vigotsky & Bruhns, 2015).

When we studied the effects of DFM on pain intensity, our results have shown that this technique is effective to reduce pain, immediately after the technique application. Notwithstanding, regardless the intensity of the pressure applied, the obtained pain intensity score and the time to onset of analgesia was not affected by the pressure variation. Although these results contradict the dose-response relationship found in study III (higher pressures led to lower times until analgesia), it should be taken into consideration that when compared the values of the pressures used in asymptomatic and symptomatic individuals (study III and IV, respectively), these were very different. On study III the minimum, mean and maximum pressures applied were 1 kg/cm^2, 2.3 kg/cm^2 and 4.2 kg/cm^2, respectively; while on study IV these were 1.3 kg/cm^2, 1.7 kg/cm^2 and 2.2 kg/cm^2, respectively. These comparisons show that the pressures used in the symptomatic individuals were generally inferior to the ones applied in the asymptomatic individuals; moreover, the differences between the pressures applied in each session (P1, P2, P3) were also very low (in study III the differences were about 100% between sessions, while in study IV the differences were 25%), which may account for the lack of statistically significant differences in the time to onset of analgesia, in the symptomatic individuals.

Beside its effects on pain, DFM is also used in the treatment of tendon injuries based on its potential positive effects on function (Childress & Beutler, 2013; De Bruijn, 1984; Maffulli, Longo, & Denaro, 2010). It is known that function may be impaired by nociception, that leads to inhibition of motor cortex or even to the development of peripheral sensitization (Farina et al., 2003; Farina et al., 2001; Graven-Nielsen & Arendt-Nielsen, 2008; Lund et al., 1991; Struyf et al., 2014). Thus, considering that DFM would trigger an analgesic response through any of the pathways previously described, it is reasonable to expect that the reduced nociceptive input to the central nervous system would lead to an enhanced motor response (Nijs et al., 2012; Struyf et al., 2014), which was not supported by our results. However, a more detailed analysis of the results regarding knee extensors strength, shows that this outcome presented a small effect size which reflects a great inter-individual variability. Furthermore, it is not known if the fact of using pressures guided by the feedback of the participant (low pressures – moderate pain) and such low difference between sessions (25%) is contributing to the lack of statistically significant differences.

CLINICAL IMPLICATIONS

Considering that this technique aims to promote therapeutic effects and not palliative effects, it seems important to effectively promote deformation of the tendon, to allow that the preconized morphological and histological changes may occur, thus favouring the tissue repair. Having this, the management of the pressure applied by the physiotherapist during DFM, should take into account the fact that to promote the macroscopic deformation of the patellar tendon, a pressure of at least 1.1 kg/cm2 should be applied.

CHAPTER 5

CONCLUSIONS

CONCLUSIONS

Our results have shown that DFM is highly used by Portuguese physiotherapists. We have also observed a high heterogeneity and variability in the application parameters chosen by physiotherapists, namely the position of the tendon, the frequency in both acute and chronic conditions and the duration of DFM application mostly in the chronic phase. This diversity enabled the identification of two patterns, although none is in complete agreement with the description of the technique.

We have also documented the pressure applied during DFM which was 2.3 kg/cm^2 (1.02; 4.16), which is a pressure above the average pressure needed to promote the macroscopic deformation of the patellar tendon that was 1.1 ± 0.37 kg/cm^2, regardless of the characteristics of the individual. This is, when managing the pressure applied during DFM, not only in daily clinical practice but also in research settings, the physiotherapist should take into account this minimum pressure needed to macroscopically deform the tendon.

Furthermore, our results have also shown that DFM induces an immediate reduction of pain, irrespectively of the intensity of the pressure applied, in athletes with patellar tendinopathy.

FUTURE PERSPECTIVES

Future studies should encompass larger sample sizes, follow the protocol regarding treatment frequency recommended by the author of DFM and analyse its effectiveness with a longer follow-up period. Randomized controlled studies assessing the effects of DFM in the treatment of tendinopathies could also evaluate other functional outcomes using validated instruments such as the Victorian Institute of Sport Assessment Questionnaire Patellar Tendon (VISA-P). It would also be important to further study the morphological effects attributed to the technique, and reported in the animal model, as well as determine the tissue response to different pressures and if the repair process of the tendon is influenced by pressure.

Although it is reasonable to assume the need for a standardization of the procedures, it seems clear that even if some procedures are difficult to standardize, they should not be disregarded; namely, it should be assured that the tendon is deformed. All the other procedures regarding DFM application should be studied in order to highlight whether the standardization is viable and clinically useful.

CHAPTER 6

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