Myofascial force transmission in the humans; a systematic scoping review of in-vivo studies

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ABSTRACT Background: The fascial system provides an environment that enables all body systems to operate in an integrated manner and is capable of modifying its tensional state in response to the stress applied to it. Recent in vitro, animal and cadaveric studies have shown that "myofascial force transfer" (MFT) has the potential to play a major role in musculoskeletal function and dysfunction. Objective: Human evidence for the existence of invivo MFT is scarce. This scoping review attempts to gather and analyse the available evidence of the in-vivo human MFT studies in order to sustain and facilitate further research and evidence based practice in this field. Methods: A search of most major databases was conducted with relevant keywords that yielded 238 articles as of August 2020. A qualitative analysis of the studies was conducted after rating it with Oxford's Center for Evidence –based Medicine (CEBM) scale. Result: Nineteen studies ranging from randomized controlled trials to case studies covering 540 patients were included in this review. The analyzed studies were highly heterogeneous and of lower methodological quality meddling with the quantitative analysis. Ten studies are confirming a 'most likely' existence of MFT, eight studies confirming it as 'likely' and one study couldn't confirm any MFT existence in this review. Conclusion: Findings from in vivo human studies supports the animal and cadaveric studies claiming the existence of MFT which need to be corroborated by the future high-quality studies. Forthcoming studies on MFT may give answers and solutions to many of the human musculoskeletal mysteries ordysfunctions.

INDEX TERMS *Fascia; Myofascial force transfer; epimuscular force transfer*

INTRODUCTION

Musculoskeletal pain and dysfunction are among the main reasons for visiting doctors, physiotherapists and osteopaths all over the world; it is also the most common cause of chronic long-term pain that affects countless people around the world (Woolf and Pfleger, 2003). As the prevalence of musculoskeletal pain increases with longevity in the sedentary population, we need to identify more justifiable causal relationships that may lead to the development and evaluation of new ways of managing these patients.

Fascia may simply be defined as a network of fibrous tissues that pervades the whole body and supports, surrounds, suspends, protects, connects and divides the musculoskeletal and visceral components of an organism (Kumka & Bonar, 2012). Recent research has shown that fascia is the most innervated structure after the skin (Fede et al., 2020) and is extensively innervated by free nerve endings and post-ganglionic sympathetic fibers (Mense 2019). Besides possessing a potential role in proprioception and pain perception (Wilke et al., 2017), fascia has been demonstrated to connect mechanically the muscles of the human body (Huijing 2007; Yucesoy 2010), which challenges the classical concept of muscles as being morphologically independent actuators (single muscle theory) (Wilke et al., 2018). Many researchers have found the role of fascia of interest and importance in musculoskeletal disorders, due to its potential to influence muscle activity and continuity. (Ajimsha et al., 2020). Studies have already demonstrated the role of fascia as a connecting link between the skeletal muscles throughout the body that are linked to each other by fascial tissue forming a network with some specific patterns (Luomala and Pihlman, 2016; Wilke et al., 2016a) that can undergo dysfunction and pain if under or over used (Ajimsha et al 2020).

The fascial system provides an environment that enables all body systems to operate in an integrated manner (Adstrum et al., 2017) and is capable of modifying its tensional situation in response to the stress applied to it (Bordoni and Simonelli, 2018; Wilke et al., 2017b) and it is believed that strain or force transmission could occur in certain directions in response to changes in muscle activity or length (Luomala and Pihlman, 2016; Norton-Old et al., 2013; Krause et al., 2016). It has been proposed that myofascial force transfer may play a major role in musculoskeletal function and dysfunction (Ajimsha et al., 2020).

Traditional anatomical descriptions usually do not consider the structural continuity of the connective tissue but recent in vitro and animal studies have shown that muscle forces not only transmitted to the tendons longitudinally (for example, in myotendinous junctions), but laterally to or between adjacent muscles by intermuscular mechanical interactions through collagen linkages between muscles and adjacent connective tissues and often referred to as ''epimuscular myofascial force transmission (EMFT)''. (Huijing, 1999; Yucesoy, 2010; Ajimsha & Shenoy 2019). These connective tissues can be endomysium, perimysium, epimysium, tendons, joint capsules, neurovascular tracts, fascia or even the viscera since fascia is ubiquitous across the body (Huijing, 2009; Karakuzu et al., 2017; Ajimsha et al., 2020). More simply EMFT refers to the transmission of muscle forces to the bone via pathways other than the classic muscle origin and insertion. (Maas & Sandercock, 2010). Fascia connects muscle fibers to each other, muscle to another muscle and muscles to periarticular tissues, allowing intramuscular (through the muscle), intermuscular (force transmission between adjacent muscles via the connective tissue at their interface) and extramuscular (between the epimysium and the adjacent non-muscular structures) force transmission (Maas & Sandercock, 2010; Huijing et al., 1998; Huijing & Baan, 2003). Apart from the invasive animal studies that have proven the existence of myofascial force transmission, human cadaveric studies have also examined the potential force transmission between the components of myofascial chains (Krause et al., 2016). Although the experimental methods vary considerably, most of the studies are concluding that force applied to a local structure can substantially affect neighboring connective tissues and muscles (Wilke et al., 2016a).

Data gathered from animal studies do not necessarily translatable to human bipedal biomechanics. Force transmission studies from cadavers cannot be justifiable to in-vivo human myofascial force transmission as it may be influenced by a multitude of factors, including (but not limited to) force production, transmission, soft tissue length–tension relationships, muscular tone, connective tissue stiffness, neural factors and so on. Most of the research on cadavers has been carried out using cadavers from the elderly, (Krause et al., 2016), another factor which may alter the results of the study on force transmission. In contrast, in vivo studies conducted in clinical settings could provide valuable hints regarding the relative contribution of myofascial force transmission to the proper functioning of the movement system and it is the only reliable evidence that we can utilize for future clinical applications. Evidences from the emerging in vivo studies are really encouraging and pointing towards the existence of the myofascial force transmission in humans. (Marinho et al., 2017; Huijing et al., 2011; Pamuk et al., 2016; Pamuk and Yucesoy, 2015; Yaman et al., 2013). This scoping review attempts to gather and analyze available evidence for myofascial force transmission in humans to support and facilitate further research in this area.

METHODS

We searched the following electronic databases with no date limitations: MEDLINE, CINAHL, Academic Search Premier (ASP), Cochrane library, PEDro databases and Google Scholar for original research, including clinical trials, Systematic reviews, cohort studies, reviews, and case studies published in the English language. The search strategy was formulated using the term myofascial force transmission and epimuscular force transmission. The inclusion criteria were decided as any in vivo human studies analysing the key words. Studies on animal or cadaveric models were excluded as well as in vitro studies. Articles published in the form of editorials, expert opinions, informative articles or articles that do not contain sufficient information to complement an analysis have also been excluded. The relevant studies were identified, selected after screening the abstract, and saved as full text for further review. Two experienced reviewers performed the independent searches in April 2020 which was later updated in August 2020 and four reviewers completed the review process. No grey literature was included. The reference lists of the eligible publications and articles were screened for additional eligible publications. The lists were compared, and articles identified by both reviewers were collected in full text. A total of 238 artcles were found to be relevant by both examiners.

In order to rank the study quality, we have applied the Oxford's Center for Evidence –based Medicine (CEBM) scale (Oxford CEBM 2009) which categories the

studies at various levels of evidence by assessing the quality based on the study design, which categorize the studies in a scale ranging from 1 to 5 with further subdivision for each. Systemic reviews with homogeneity of RCTs are classified at the highest levels, whereas expert opinions are the lowest. It has been decided that all the RCTs will be evaluated using the PEDro scale (Blobaum 2006), which evaluates methodological quality and consists of a checklist of 11 criteria, 10 of which are rated. In this review, studies with PEDro scores of 6 to 10 were considered to be of high quality, 4 to 5 were considered to be of moderate quality and 0 to 3 were considered to be of poor quality (Ajimsha et al., 2015).

RESULTS

Of the 238 studies identified in the original search, 19 were eligible according to the inclusion criteria (Fig. 1). The Rayyan QCRI web application was used by the authors to collaborate on the selection of studies and decision-making as part of this scoping review. The frame work recommended by Arksey and O' Malley (2005) and Levac et al., (2010) was used to conduct this review and PRISMA extension for scoping reviews (PRSIMA-ScR) (Tricco et al., 2018) was used as the reporting tool. Figure 1 illustrates the decision-making flow chart for this review. The selected articles were reviewed and the details like study design, study participants, aims, myofascial force experiment, region studied, intervention dose, outcome measures used and specific results were tabulated. The corresponding authors of the articles were communicated if there were missing data or for any kind of verification. The key characteristics and methodological details of the included studies are provided in Table 1.

DATA SYNTHESIS

de Bruin et al., 2011 conducted a clinical trial (CEBM=4) with 15 cerebral palsy patients with an objective to determine whether Flexor Carpi Ulnaris (FCU) muscle influences wrist torque even after tenotomy of its distal tendon. The maximum wrist torque was determined in vivo for patients with hemiplegic cerebral palsy in three conditions: 1) with the arm and the muscle intact; 2) after tenotomy of the FCU just proximal to the pisiform bone; and 3) after dissection of the belly of the muscle from its fascial surroundings. Following FCU muscle tenotomy, the maximum wrist torque decreased by 18% and muscle dissection led to an additional 18% decrease. The authors concluded that, despite the tenotomy of its distal tendon, FCU still contributes to the flexion torque at the wrist and attribute this to the transmission of extramuscular

myofascial force. The study is having its own methodological and sampling issues (selection, performance and detection biases) that could seriously interfere with its generalizability but appreciable for its innovativeness.

In 2012, Tiane et al., Conducted an experimental trial (CEBM=4) to determine to what extent passive changes in the length of the Gastrocnemius muscle, induced by knee motion, affect adjacent Soleus muscle tension. Simultaneous ultrasound imaging of the gastrocnemius and soleus muscles was obtained during passive knee flexion (0–90°), while maintaining the ankle angle of 70° or 115° in 15 healthy volunteers. Image correlation analysis was applied to quantify muscle fascicle lengths in both muscles. This study concluded that there was a certain intermuscular force transmission between the medial Gastrocnemius muscle and the Soleus muscle during passive knee extension. The authors explain that this phenomenon by means of force transfer due to shortening of the distal Achilles tendon and a direct epimuscular force transmission via the connective tissues between the medial Gastrocnemius muscle and the Soleus muscle. Again, the small sample size and a non-randomized study methodology limits its generalizability.

In 2013, Yaman et al., conducted a clinical trial (CEBM=4) in five healthy individuals to investigate the hypothesis that changes in overall length of the Gastrocnemius muscles in vivo will result in significant and heterogeneous local tension within in all lower limb muscles in humans. They placed the subjects in the prone position with the ankle attached at 90 degrees with the help of the AFO, allowing the hip and knee to move (Δ knee angle $\approx 25^0$) within a high resolution 3D MRI scanner. The movement of the hip and knee caused significant and heterogeneous local tension not only to the Gastrocnemius muscle, but also within the synergistic and antagonistic muscle, although it was kept at a constant muscular tendon complex length. Despite its inherent methodological limitations, this study is a good starting point for future high-quality studies to verify the existence of in vivo epimuscular myofascial force transmission.

The transmission of myofascial force from Latissimus Dorsi (LD) to contralateral Gluteus Maximus (GMax) through Tensor Fascia Lata (TFL) was an interesting study led by do Carmo Carvalhais et al., in 2013 with 37 healthy volunteers attached to an isokinetic dynamometer (CEBM=3b). The objective was to assess if the active or passive tension of the LD resulted in an increase in the passive tension of the contralateral GMax, indexed by changes in hip rest position (RP) or passive

stiffness. This study revealed that forces had been transmitted from the LD to the contra lateral GMax modifying the hip PR, which supported the hypothesis. The author also reported that the functional relationship between the GMax and the hip joint was responsible for the observed effects after LD tensioning and proposed future studies which can verify the magnitude of force transmission between the LD and GMax along with the TLF stiffness. Again, the study was of low quality because of methodological flaws and the small sample size limiting its acceptance.

Inspiring from the above study, Joseph et al., in 2014 conducted an experimental matched controlled trial (CEBM=3b) with 40 participants, to investigate the effect of sacroiliac joint dysfunction (SJD) on contralateral Glenohumeral joint (GHJ) and found that SJD contributes to excessive anterior translation of humeral head (ATHH) in the contralateral GHJ. The investigators used a translational force of a push-pull dynamometer at the posterior part of the humeral head to passively translate the humeral head to the point of end feel while using a real-time ultrasound to evaluate this translation. This study confirmed the existence of an association between the sacroiliac joints and the contralateral GHJ. The authors are justifying the result by means of myofascial force transmission and mentioning it as "oblique sling muscles". They concluded that the sacroiliac joint should be assessed for any contralateral shoulder joint malfunction and vice versa. Given the small sample size, selection, performance and detection biases, the study results cannot be generalized. The author did not take into account the level of physical activity of the participants (both groups) that can affect the outcome.

In 2015, Grieve et al., investigated the immediate effect of a single application of Self Myofascial Release (SMR) on the plantar aspect of the foot on hamstring and lumbar spine flexibility. A pilot single-blind RCT (CEBM=2b; Pedro= 4/10) was conducted on 24 healthy volunteers. They observed a significant increase in hamstring and lumbar spine flexibility when compared to the control group, with a large effect-size as measured with a sit and reach test done by evaluators blinded to the group allocation. He suggested that flexibility interventions based on myofascial chains, in particular the superficial back line (SBL), induce the transmission of force along the myofascial chain resulting in non-local effects. This study used appropriate methods of randomization and concealment, but did not blind participants and presents problems of generalization because of the small sample

size, the use of healthy participants and a less reliable outcome measure.

Cruz-Montecinos et al., in 2015 conducted a clinical trial (CEBM=4) on 17 asymptomatic, sedentary young male individuals to assess the relationship between pelvic motion and deep fascia displacement in the medial gastrocnemius (MG), when seated with an extended dominant limb while doing pelvic anteversion. The displacement of the MG deep fascia was evaluated through automatic tracking with an ultrasound while angular variation of the pelvis with a 2D kinematic analyzer. The study found a positive relationship between pelvic movement and MG fascia displacement. The results reaffirm the concepts of myofascial force transmission by synergistic muscle groups and the role of fascia in restricting movement in far-flung areas. This study, while lacking methodological rigour, has led to a futuristic result that can be explored in greater depth.

In 2016, Wilke et al., evaluated the remote effects of lower limb stretching on cervical range of motion (ROM) and found that lower limb stretching leads to improvements in cervical ROM and provides some insight into the existence of myofascial force transmission in vivo. It was a pilot study with 26 healthy participants in a matched-pair comparison model (CEBM = 3b) with an experimental group (n = 13) undertaking a single session of static stretching for the Gastrocnemius and the Hamstrings to an age- and sex-matched control waiting list group (n = 13). They measured the pre- and post-intervention, maximal cervical flexion / extension ROM and found substantial changes in the experimental group's cervical ROM relative to control. The authors pointed to this finding as evidence of tension transfer along the myofascial channels. Since the result is obtained from a non-randomized small group analysis, it is prudent to generalize the result. As a continuation of the same, Wilke et al., in 2017, conducted a medium quality (CEBM=2b; PEDro= 6/10) randomized controlled study on sixty-three healthy participants to compare the same, but with three groups, remote stretching of the lower limb (LLS), local stretching of the cervical spine (CSS) and inactive control (CON) groups. Both LLS and CSS increased cervical ROM compared to the control group in all movement planes and at all measurements (P < .05). Between LLS and CSS, no significant changes were observed (P > .05). Methodological flaws and inadequate power hinders the study's generalizability. The authors have been cautious in the interpretation section as "the effects achieved do not appear to be specific to the direction, further research is required to provide evidence-based recommendations."

Changes in length in the muscle fibre direction, provide essential information for the characterising muscle function. Pamuk et al., (2016) used a combination of magnetic resonance (MR) imaging based deformation analyses and diffusion tensor (DT) imaging based tractography, to assess muscle fibre direction and local tissue deformations within the human medial gastrocnemius (GM) muscle (CEBM=4). Five healthy female subjects were placed in prone position inside the MR scanner in a relaxed state with the ankle angle set at 90^0, knees flexed at 140^0 and then to an extended position. High-resolution 3D MRI and DT image sets were acquired in these two positions, allowing local deformations to be computed along the muscle fascicles. The results suggest that the mean deformation errors are much lower than the mean direction strains of the fiber. Moreover, shortening and lengthening occurred at the same time along individual fascicles despite imposing GM lengthening. The presence of large amounts of shear between the fascicles was confirmed by shear strains along the fibres, and the authors suggested that an inhomogeneity of the fibre strain was indicative of transmission of epimuscular myofascial force. The study is not without limitations though, such as a very small sample size, the tracts obtained are representative of muscle fascicles and not individual muscle fibres, and measurements performed in a passive state of muscle. Nevertheless, this study provides a powerful tool for quantifying deformation along human muscle fibers in vivo which can help to get a much better understanding of normal and pathological muscle function and mechanisms of treatment techniques.

Karakuzu et al., 2017 conducted a small-group experimental study (CEBM=4) to investigate inter-muscular mechanical interactions (strain transfer) of human medial Gastrocnemius (GM) using combined magnetic resonance and diffusion tensor imaging. The purpose was to examine the hypothesis that submaximal plantar flexion activity at 15 % maximal voluntary capacity (MVC) causes heterogeneous length changes along the fascicles of human GM muscle of healthy female subjects (five). The authors found that the proximal route segments were shortened and the distal portions of GM were lengthened with heterogeneity in the mean fibre directions. There is inter-subject variability in the magnitude and distribution of fascicles strain. The authors concluded that sub-aximal activation of GM in the extended knee position causes heterogeneous deformation distributions, including local elongation that supports the theory of functionally dependent invivo muscle mechanics. More studies are needed to determine the cause of this heterogeneity (e.g.:-

transmission of epimuscular force). According to the authors, this was the first study of this type that quantified local deformities along the human skeletal muscle by sustained sub-aximal activation. The study result cannot be generalizable due to its inherent limitations posed from the study methodology, sample size, anatomical variations including Inter-subject variability of fascicle strain, issues with joint positions, muscle activation levels, complexity and individual differences of the epimuscluar connections, but can be an ideal starting point to introduce high quality future trials in this direction.

Finni et al, in 2017 conducted an in vivo experimental study (CEBM=4) among 11 healthy volunteers to examine whether activation could alter the shear between the soleus (SOL) and lateral gastrocnemius (LG) muscles in vivo in order to determine the norm 'the lateral connections between muscles provides pathways for myofascial force transmission'. They investigated whether the activation of the SOL and LG muscles could modify the shear between the two. The participants underwent a series of knee joint manipulations to obtain the plantar flexion force, LG, and SOL muscle fascicle lengths and relative displacement of aponeuroses between the muscles. The data was acquired over the entire range of passive movement, a 20° stretch of knee extension in both passive and active phases created by selective electrical stimulation of the LG. During active stretching, the plantar flexion force was 22 % higher and the relative movement of the aponeurosis was smaller than during passive stretching. The changes in soleus length did not differ between passive and active stretches, but the LG fascicles stretched less in the active state than in the passive state when the stretch began at 70° and 90° knee flexion. The activity-induced diminution in the relative displacement of SOL and LG suggests stiffer connectivity between the two muscles, at least at flexed knee joint angles, attributable to myofascial force transmission. It is invariably difficult to conclude and generalize results from smaller, low methodological quality studies as it can create super realization biases and even can lead to faulty assumptions, but appreciable as 'proof of concepts'.

Several researchers have already demonstrated the effects of human myofascial force transmission in vivo in terms of strain, but no force, with some exceptions, such as research by do Carmo Carvalhais et al., in 2013 demonstrating force transmission in vivo, through changes in joint kinetic variables. The study of Marinho et al., (2017) was designed to test how simultaneous changes in knee and hip positions change the resting position of the ankle and the passive torque (CEBM=4). They recruited 37

subjects that underwent an isokinetic assessment of ankle passive torque. They carried out these measurements under three test conditions: 0^0 at knee and 0^0 at hip; 90^0 at knee and $90°$ at hip; and 135^0 at knee and 120^0 at hip. The results demonstrated that the ankle resting position moved towards dorsiflexion when knee/hip position changed from $0^0/0^0$ to $90^0/90^0$ and moved towards plantar flexion when knee/hip position changed from $90^0/90^0$ to $135^0/120^0$, attaining values closer to the position of $0^0/0^0$. Similarly, passive torque diminished when knee/hip position changed from $0^0/0^0$ to $90^0/90^0$, but it enlarged when knee/hip position changed from $90^0/90^0$ to $135^0/120^0$. The action of isolated two joint muscle-tendon units crossing both the knee and ankle would not support the reversion of resting position and the passive torque behaviour when knee/hip position changed $90^0/90^0$ to $135^0/120^0$. Consequently, forces originated from continuous structures crossing the hip, knee and ankle potentially contributed to this outcome.

While Marinho et al., experimented the influence of proximal joint positions on distal joint resting position and passive torque, another researcher Yoshitake et al., in 2018, experimented the existence of epimuscular myofascial force transmission in human upper extremity (CEBM=4). They examined whether manipulating the angle of a joint to stretch the muscle can alter the shear modulus of an adjacent muscle at rest, and whether there are regional differences in this response. They selected two neighbouring muscles, Biceps brachii (BB: manipulated muscle) and Brachialis (BRA: resting adjacent muscle), because they had independent tendons attached to different bones. The study was conducted with 13 healthy young men and measured BB and BRA shear modulus with shear wave elastography to proximal and distal muscle regions with forearm supine, Neutral and pronation while maintaining the elbow joint at 100^0 or 160^0 angle. The authors added that the observed alteration of the adjacent resting muscle shear modulus may be due to the EMFT in the upper limb, and suggested that this force transmission could be facilitated by muscle at its stretched lengths. Although the study is of low methodological quality, the clinical implication of these findings may be attributed to the efficacy of interventions such as myofascial release techniques which aim to mechanically release intermuscular mechanical interactions.

In 2018, Ateş et al., conducted an experimental analysis (CEBM=4) to quantify the localized changes in the shear modulus of the lateral gastrocnemius (GL), monoarticular dorsi- and plantar-flexor muscles induced by a change in knee angle. Two experimental sessions were performed in this study. The experiment one (n= 11)

assessed the effect of knee angle on shear modulus on GL and soleus (SOL) muscle. Experiment two (n=10) evaluated the effect of knee angle on the shear module on the GL muscle, Peroneus Longus (PERL) and Tibialis Anteroir (TA). Participants underwent slow, passive ankle rotations at the following two knee positions: knee flexed at 90^0 and knee fully extended. Ultrasound shear wave elastography was used to assess the muscle shear modulus of the GL, SOL [SOL-proximal and SOL-distal], PERL, and TA. A comparison was made of the shear modulus of each muscle between the two knee positions. This study provides evidence for significant intermuscular mechanical interaction or force transfer between human leg muscles during passive ankle rotations. The limitation reported in this study was that myoelectric activity had not been evaluated to ensure that muscle activity remained passive. As has been mentioned in other studies, we need high quality randomized trials to ascertain these findings.

Wilke et al., (2019) performed an experimental regression study (CEBM=3b), which looked into the age dependency of remote exercises on MFT. Using a pre- post regression method, the authors analyzed the influence of age on MFT in 168 healthy individuals between the ages of 13 and 87. Participants were asked to perform a single 120-second SMR of the plantar fascia in the standing position and then to test the extensibility of the hamstring measured using a sit-and-reach test. Multinomial regression analysis found that SMR improved the hamstring extensibility by 10.1 percent with 58.9 percent of participants attaining a clinically significant improvement. The authors concluded that only the age and baseline flexibility predicted changes in the extensibility of the hamstring and that no relationship to sex, amount of physical activity, size, BMI, time of the day, etc. had been observed. The research has its limits on the outcome measures used and deserves physiological, morphological and functional tests to categorize and explain these unique results (neuronal, psychological, etc.). The authors expressed concern about the quality of the study and the confounding factors that might affect the outcome, and suggested high quality RCTs to verify these results.

Diong et.al. (2019) was the first to measure the magnitude and direction of changes in force resulting from passive Intermuscular force transfer between human Flexor Pollicis Longus (FPL) and the index finger part of Flexor Digitorum Profundus (FDP) in humans. To investigate this, they compared finger flexion force produced by passive thumb flexion in fifteen healthy subjects after one of the

three conditioning protocols: passive thumb flexion-extension cycling, thumb flexion maximal voluntary contraction (MVC), and thumb extension stretch (CEBM=4). Finger flexion force soared after all three conditions. In comparison to passive thumb flexion-extension cycling, change in finger flexion force was less after thumb extension stretch, but not after thumb flexion. According to the authors, as muscle conditioning altered finger flexion force caused by passive thumb flexion, the change in force is likely due to intermuscular force transmission. They cited that their findings need to be interpreted in context of methodological limitations. First, passive force in FPL in vivo was not known and cannot be directly measured in humans except during invasive surgical procedures. Similarly, activity in the deep FDP may have contributed to index finger force. Unfortunately, activity in these muscles were not recorded. Also this study could not explain why faster thumb motion during cycling did not cause larger intermuscular force transmission compared to MVC. Not knowing or unable to explain how thumb motion influences index finger force or motion of FPL can be considered as a major limitation of this study.

Freitas et al., in 2019 conducted an in vivo experimental study (CEBM=3b) with 12 healthy and recreationally active male individuals to examine the existence of epimuscular myofascial force transmission between the quadriceps muscles during passive knee flexion. They compared the shear modulus of Vastus Medialis (VM), Vastus Lateralis (VL) with the hip flexors at two lengths by manipulating the hip position (flexed at 80^0 and in neutral. This study showed no difference between hip positions in VM and VL shear modulus. This study also reported that the VL exhibits the highest shear modulus when the hip is flexed and it was highest in rectus femoris (RF) when the hip was in neutral position. The authors concluded that (i)changes in force may only occur at a connective tissue level surrounding the muscles and do not achieve the muscle bellies, (ii) the force transmission among the quadriceps muscles during passive stretching in healthy people is negligible, regardless of the degree of muscle lengthening and (iii) It cannot be concluded that the possibility that there is epimuscular myofascial force transmission between the quadriceps closer to patellar tendon, as the aponeurosis from the quadricep muscle components merge onto patellar tendon. The author has also mentioned about the confounding factors like stiffness difference between the synergistic muscle depending upon the type of population (trained or untrained, athletes or clinical population) and proposed that future studies should examine if the epimuscular myofascial force transmission

during a passive stretching condition mainly occurs at a connective tissue level, and only occur within the muscle belly for higher levels of myofascial stretch (e.g., by evoking greater knee flexion).

Wilke et al., in 2020, published findings from an experimental study (CEBM=4) which for the first time visualized the MFT between serially connected skeletal muscles objectively. The purpose of this trial was to examine the impact of ankle motion on soft tissue displacement of the dorsal thigh. Eleven healthy active individuals, in prone position and with the knee extended, underwent passive calf stretches (ankle dorsal extension) imposed by an isokinetic dynamometer. High-resolution ultrasound was used to simultaneously capture the displacement of the semimembranosus muscle, which was quantified by means of cross-correlation analysis. Inactivity of the leg muscles was controlled using surface electromyography (EMG) and found that ankle dorsal extension induced substantial caudal muscle displacements ($p < 0.0001$) and found a strong association between maximal dorsal extension and semimembranosus motion. This study confirms mechanical force transmission between serially connected skeletal muscles. The authors are relating this findings to the earlier studies showing remote exercises effects. (Grieve et al., 2015; Wilke et al., 2016, 2017, 2019). Again this study need to be replicated with a sound methodological study to establish the presence of MFT.

DISCUSSION

Nineteen studies covering 540 patients were included in this review. The included studies ranged from randomized controlled trials to case studies. The sample size varied from 5 to 168 with an average of 28 (SD 36). The analyzed studies were highly heterogeneous and of lower methodological quality, ranging from 2b (individual cohort studies and low quality RCTs) to 4 (poor quality cohort, case control studies and case series or poor or studies with non-independent reference standards) as per the Oxford's Center for Evidence –based Medicine (CEBM) grading scale. Twelve out of nineteen studies were of the grade of four. Five studies were of grade 3b (individual case control studies/ nonconsecutive studies including cohort of very limited population, analysis based on limited alternatives), and two studies of grade 2b (individual cohort studies and low quality RCTs). The reason for this low grading could be that, the most of the studies obtained were either a hypothesis tester or a proof of the concept trial. (Table 1). This implies that the deriving evidences from the current quality of studies or generalization into the existence of MFT is almost

impossible with the current level of trials. At this point, a meaningful quantitative analysis is impractical and the review need depends more on the qualitative interpretations of the findings and hence, the reviewers decided to proceed the study as a 'scoping review'.

The included studies were spanning from the year 2011 to 2020 with two RCTs, one each case control, matched-pair and regression analyses and, 14 single group pilot experimental studies. Out of 540 participants across all the studies, 87 participants were from the RCTs and the rest of all (453 participants) were from the remaining study groups (17 trials). Most of the trial participants were healthy individuals except two trails, one of which had 20 participants with sacroiliac dysfunction (Joseph et al., 2014) and the other one had 15 cerebral palsy males (de Bruin et al., 2011) as the participants.

Out of the 19 trials, nine studies were focusing the MFT of the lower extremities and three of them on the upper extremities. The extremity studies were focused mainly on the EMFT concept. Seven trials were testing the serial distribution of the MFT across the muscle (longitudinal MFT). Five among them were analyzing the existence of MFT through the posterior fascial connectivity and two studies were focusing the MFT through the trunk with the oblique connectivity of upper & lower extremities. Most of the studies were using ultrasound as the outcome measure while some were using MRI based technologies and only a few used musculoskeletal techniques as the outcome measures.

In order to draw a conclusion from such studies we have used a simple grading system ranging from 'less likely, likely to most likely' to explain the findings of the studies. The term 'less likely' represents a lack of evidence for MFT and 'most likely' represents a significant study confirmation of the MFT existence. The analysis revealed ten studies are confirming the existence of MFT as 'most likely', eight studies confirming it as 'likely' and one study couldn't confirm the existence of MFT (less likely). The results of the studies were encouraging, particularly with the studies utilizing objective outcome measures including high quality ultrasounds and real time radiological tracking of the MFT.

The ten studies confirming the existence of MFT are heterogeneous and varies from RCT to simple experimental trials with 221 participants at an average of 22 (SD 18). This includes an RCT (CEBM=2b), a matched pair intervention (CEBM=3b), and rest all (eight studies) were experimental studies without a control or comparison group (CEBM=4). Even though the studies are confirming highly significant MFT existence, the methodological under

quality limits its generalizability and should practice caution in its interpretation. The RCT that confirms the MFT existence was a medium methodological quality trial (CEBM: 2b; PEDro: 6/10) from Wilke et al., (2017), completed with sixty-three healthy participants and found 'most likely' existence of MFT through the posterior fascial connectivity using a real time ultrasonic 3D movement analysis. This RCT was an extension of Wilke et al., 2016 study which was testing the same by means of a controlled, matched-pairs analysis. Cruz-Montecinos et al., (2015) and Wilke et al., (2020) had visualized longitudinal and remote effect of MFT in the lower extremities and claimed that local alterations of the mechanical tissue properties may modify flexibility in the neighboring joints. do Carmo Carvalhais et al., in 2013, confirmed longitudinal MFT between the latissimus dorsi (LD) and contra lateral gluteus maximus (GMax) through TFL by using an isokinetic dynamometer on 37 individuals. Experimental trials by Yaman et al., (2013); Pamuk et al., (2016); Marinho et al., (2017); Karakuzu et al., (2017) were highlighting 'most likely' existence of EMFT on the lower extremities while Diong et al., (2019) confirms the same between the thumb and the index finger.

Eight studies concluded the 'likely' existence of MFT, including a pilot RCT (CEBM= 2b; PEDro: 4/10)), a regression (CEBM= 3b) and a case control trial (CEBM= 3b). The rest were of single group experimental analysis (CEBM=4). The pilot RCT by Grieve et al., 2015, suggested 'likely' existence of MFT through posterior fascial connectivity when assessed post self myofascial release (SMR) with a sit and reach test compared to a control. In 2019, Wlike et al., has done a similar study on 168 healthy individuals using a regression analysis supported the 'likely' occurrence of MFT through the posterior fascial connection and by using same outcome measure. The case control study by Joseph et al., 2014 was pointing towards the likelihood of altered myofascial force transmission between Sacroiliac joint and contralateral GHJ in individuals who are having sacroiliac joint dysfunction. The studies by Tian et al., (2012); Finni et al., (2017); Ateş et al., (2018) were proposing the probability of MFT especially EMFT on the lower extremities while Yoshitake et al., (2018) and de Bruin et al., (2011) were proposing the same in the upper extremities. Freitas et al., 2019, with a small number of population studied the shear modulus of Quadriceps using shear wave elastography and reported 'no change' in the shear modulus between two hip positions during passive knee flexion and stated that EMFT (at a muscle belly level) does not occur between the quadriceps muscles when passively flexing the knee until 90 but

suggested further studies to examine the occurrence of EMFT with greater muscle stretches and with different hip and knee positions.

It seems sensible that in the authors' qualitative synthesis, the best evidence would be derived from the existing higher quality studies, which probably have the less biased results. Unfortunately, there is a dearth of such studies at present. Even though the levels of evidence in this review may be considered arbitrary, it seems unlikely that a different review approach or grading system would have resulted in a different conclusion (Ajimsha et al., 2020). Although efforts were made to gather most of the published studies, some relevant trials might have been missed. Due to resource and language constraints, only publications in the English language were considered in this review and no effort was made to identify any unpublished trials. The included studies were very heterogeneous in terms of the MFT definition, study design, trial procedures, body regions, movements, protocols, sampling, outcome measures, and/or the presentation of data. Even though the majority of the studies were given positive evidence regarding the existence of MFT, one can't confidently claim the occurrence MFT nor can generalize the present findings. The current data can only be pooled as an 'emerging evidence' of the in vivo existence of MFT in humans that need to be established by future quality studies.

It is impossible to actively encourage the utilization of the available positive results of MFT to justify the clinical practice because of the limited capacity of health systems to absorb the new evidence and implement the necessary measures to do away with the obstacles hampering translation of the results of theory into practice. With underpowered sample sizes and the heterogeneity of the studies, we cannot argue that the MFT is the reason of many musculoskeletal mysteries but only suggest that there is 'some initial positive' findings of the MFT existence.

Clinician may use the concept of MFT as a justifiable aspect of their managements, but they should be aware that the functional implications are yet to be studied (Wilke et al., 2016). Currently, an increasing number of researchers and manual practitioners show continued interest and enthusiasm on the subject of myofascia and its force transmission, hence we can expect that high quality future studies with strong evidences might ascertain the existence of MFT. The objective reality of MFT might serve as a breakthrough in explaining several phenomena that lack a clear understanding of their etiology or pathophysiology even today. Clinicians may use the MFT as a way to rationalize the phenomenon's like referred and nonspecific

pains which are often difficult to explain, and even can use as a concept to explain their treatment effectiveness. Even if we can explain such musculoskeletal dysfunctions and pain with strong evidence of MFT, we need to practice caution in generalizing it, as for example mobilizing fascia on the left leg decreases pain in the right leg (Sj, Aboodarda et al., 2015; Wiewelhove et al., 2019). Fascial research is moving forward into a level of acquiring new perspectives and horizons and we should believe that the technological advancement can explore much more in this field so that many of the bodily disorders and derangements can be demystified.

To have the high quality evidence, we need to appraise and organize the studies with good quality designs. Participants should be randomized, the design should be double blinded (Ajimsha and Shenoy, 2019). Usage of a-priori calculated sample sizes; adequate power; limiting the sources of bias; appropriate levels of significance; assessing the threats to statistical validity; appropriate registration and the usage of technologies and radiological outcome measures may revolutionize the future of this field of research. We need to abstain from reporting within group differences as evidence of effectiveness (Matthews and Altman, 1996; KF Schulz et al., 2010). One should understand that a systematic review or meta-analysis isn't essentially higher than a well-conducted RCT, and not all RCTs are essentially greater than observational trials of sound methodological quality (Ajimsha and Shenoy, 2019). Practitioners should utilize their critical appraisal skills to decipher any research findings before applying it to clinical practice. These recommendations would support inferences of clinically meaningful results and facilitate future meta-analyses and recommendations in this field. In all clinical trials, we support the current appeals for transparency and advocate journal adherence to the reporting guidelines. (Hoffmann et al., 2014; Chan et al., 2014).

LIMITATIONS OF THE STUDY

In spite of our best efforts to perform this review, it has several limitations that are inherent to any scoping review such as paucity of methodological rigor and a higher level of critical appraisal. Scoping review is a valuable tool in the ever-increasing collections of evidence synthesis methods, and we agree that it is an ideal method when it comes to finding new knowledge, gaps, scoping a body of literature, clarifying concepts, or investigating a research (Munn et al., 2018). We believe the following limitations may have some impact on the outcome of the review. Firstly, we had limited our search to human in-vivo studies having specified keywords only, as stated in the

methodology. This was necessary to set fixed key words for the literature search in order to remain focused. It may however be possible that a few studies on MFT research would have become available with the input of a different set of keywords. Nevertheless, to our knowledge, there are no other known keywords available that is defining the concept of MFT. Secondly, exclusion of grey literature and non-English studies could have some impact on the results. Due to heterogeneity, methodological diversity and under quality, other scoring scales for methodological quality and biases couldn't be used. The majority of the studies analyzed involved a single group of cross sectional type experimental trials with a point of measure and results, and it is difficult to establish causal relationships based on these outcomes. Only an estimation of the prevalence of the process or phenomenon can be obtained by analyzing such studies (Setia 2016). Adherence to the qualitative appraisal always has its own limitations, including interpretation and social biases. We believe, usage of multiple reviewers might have reduced the "reviewer biases" to a keen extent. We encourage readers to critically appraise the research evidence prior to their application to clinical practice.

CONCLUSION

Although this scoping review gives positive results for the existence of myofascial force transfer, several aspects need to be clarified and thoroughly analyzed. We need high-quality, in vivo randomized controlled trials and biomechanical studies to ascertain the above findings, because the current studies are either in non-randomized format or with inadequate methodological quality and sample size that prevents generalizability of results. Future research should focus on determining the existence of myofascial force transmissions more objectively and reliably, which could not be fully evidenced in the work cited in this review. The upcoming studies on MFT may give answers to many of the human musculoskeletal mysteries or dysfunctions. Practitioners may use the concept of Myofascial force transmission as a compelling justification, but need to be vigilant in ensuring that its mechanism and functional implications remain to be explored.

DECLARATION OF CONFLICT OF INTEREST

The authors report no declarations of interest.

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Table 1

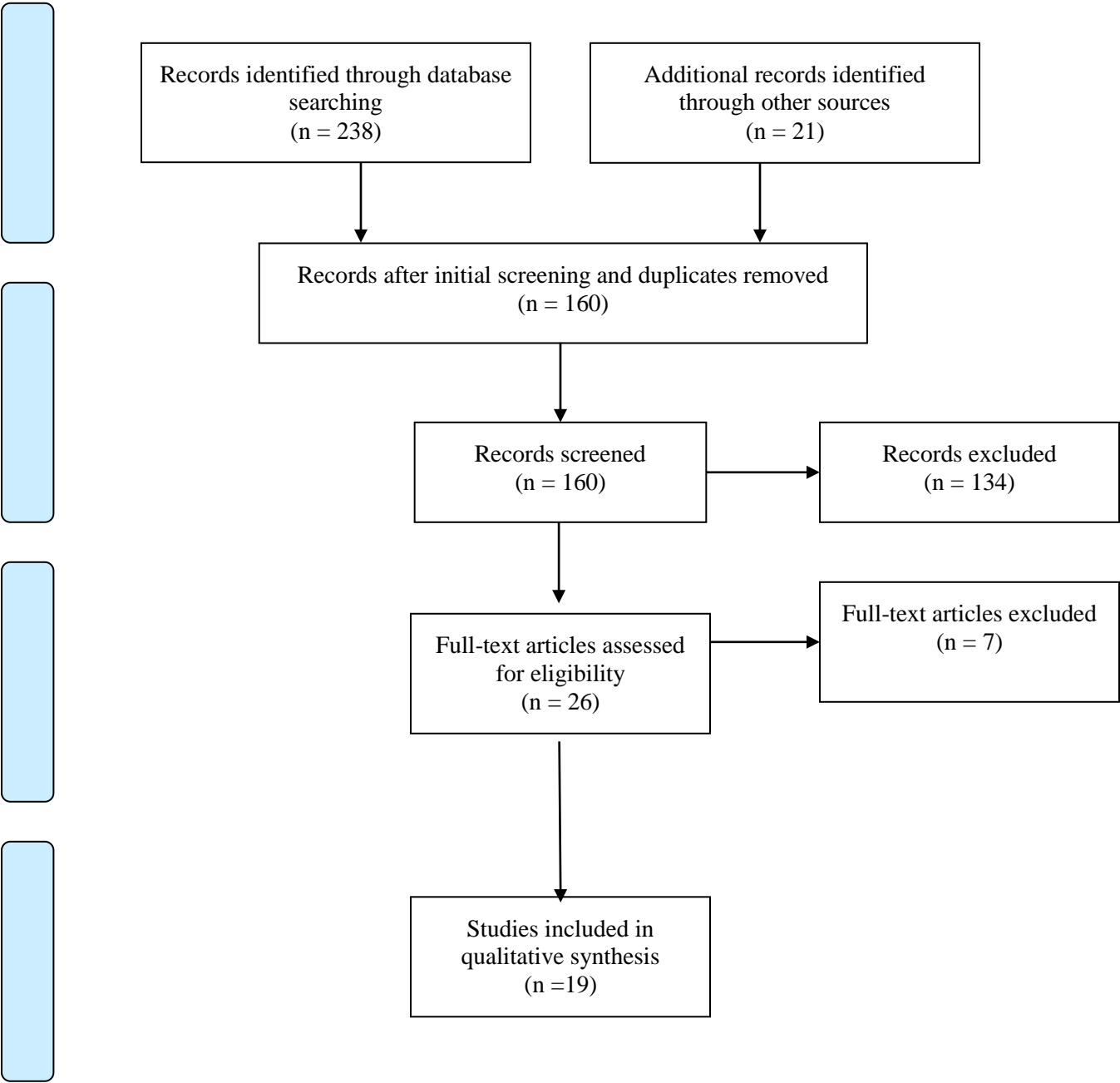| SI NO	Author/Year	Study Design	Study Objective	Population	Intervention	Comparison	Outcome Measure	Result	Study Quality (CEBM)	MFT area Identified	Result supporting MFT?
1	de Bruin et al., 2011	Clinical Trial	To determine whether Flexor carpi ulnaris muscle still influences wrist torque even after tenotomy of its distal tendon	Total = 15; CP patients Mean Age = 17 Gender =Male	Determined in vivo maximal wrist torque in hemiplegic cerebral palsy patients in three conditions: 1) with the arm and the muscle intact; 2) after tenotomy of the flexor carpi ulnaris just proximal to the pisiform bone, with complete release from its insertion; and 3) after careful dissection of the belly of the muscle from its fascial surroundings up until approximately halfway its length.	None	Wrist torque	After tenotomy of the flexor carpi ulnaris muscle, the maximal wrist torque decreased 18% whereas dissection of the muscle resulted in an additional decrease of 18%. We conclude that despite the tenotomy of its distal tendon, the flexor carpi ulnaris still contributes to the flexion torque at the wrist through myofascial force transmission	4	Muscle tendon of Flexor carpi ulnaris	Likely
2	Tian et al., 2012	Cross-sectional experimental study	To determine the degree to which passive changes in gastrocnemius muscle length, induced by knee motion, affect the tension in the adjacent soleus muscle, and to quantify the magnitude of myofascial passive force transmission between gastrocnemius and adjacent soleus.	Total = 15; Healthy pop Age = 29 ± 4 Gender not mentioned	Simultaneous ultrasound images of the gastrocnemius and soleus muscles were obtained during passive knee flexion (0 – 90°), while keeping the ankle angle fixed at either 70° or 115°.	None	Quantification muscle fascicle lengths	This study suggests there may be some intermuscular force transmission between the medial gastrocnemius muscle and soleus muscle during passive knee extension	4	Between Gastrocnemius and Soleus	Likely
3	do Carmo Carvalhais et al., 2013	Cross-sectional experimental study	To provide empirical evidence of myofascial force transmission from Latissimus dorsi (LD) to contralateral gluteus maximus (Gmax) through tensor fascia lata (TFL) in-vivo.	Total = 37; Healthy pop Age = 24.92 ± 3.21 Gender = Male = 15 Female = 22	An assessment of passive hip torque against medial rotation by means of an isokinetic dynamometer, carried out under three test conditions: (1) control, (2) passive LD tensioning and (3) active LD tensioning.	None	LD tensioning	This study suggests the evidence of intermuscular force transmission between the medial gastrocnemius muscle and soleus muscle during passive knee extension	3b	From LD to contralateral GMax through TFL in-vivo.	Most Likely
4	Yaman et al., 2013	Cross-sectional experimental study	To test whether global length changes of gastrocnemius muscle tendon complex in vivo will cause sizable and heterogenous local strains within all muscle of the human lower leg	Total = 5; Healthy pop Age = 27 ± 3 Gender = Male	Each subject was positioned prone within MRI scanner. The left leg was brought to a reference position before the patient table was moved into MRI bore. The ankle angle was 6 to 90 degree using AFO. TO keep the orientation of the lower leg contant, position of the knee cap & tip of AFO were marked on the patient table. The knee angle was 170 degree +/- 3. Sets of 3D high resolution MRI were acquired. The hip & knee joints were repositioned so that knee angle was 150 degree +/- 6 degree and took the MRI.	None	Local lengthening and local shortening of specific muscle groups at different location	MFT is a relevant mechanism in vivo confirming the study hypothesis	4	Gastrocnemius muscle tendon complex (lower extermity)	Most Likely

5	Joseph et al., 2014	Case control study/ clinica trial	To investigate the biomechanical effect of SJD on the contralateral GHJ	Total = 40 (20 SJD; 20 Healthy) Age - SJD = 35 ± 6.2; Healthy = 35 ± 8.1 Gender not mentioned	A translator force of 80 N using a push–pull dynamometer to the posterior part of humeral head to passively translate the humeral head anteriorly to the point of end feel. The distance between neck of scapular and the top of greater tubercle was measured for resting position of humeral head (RPHH) and anterior translation of humeral head (ATHH).	Healthy matched contols	RPHH and ATHH monitored using real time ultrasound	"Sacroiliac Joint Dysfunction (SJD) contributes to excessive anterior translation of humeral head (ATHH) in the contralateral GHJ. This may occur due to altered myofascial force transmission across oblique sling muscles."	3b	Between lumbopelvic region and contralateral glenohumeral joint through anterior and posterior oblique muscular slings	Likely
6	Cruz-Montecinos et al., 2015	Cross-sectional experimental study	To demonstrate the relationship between pelvic motion when seated with the knees extended with the displacement of the deep fascia of the Medial Gastrocnemius (MG) muscle of the dominant limb during pelvic anteversion.	Total = 17; Asymptomatic sedentary individual Age = 22.76 ± 1.8 Gender =Male	Each individual was asked to perform the exercise three times. Each task consisted of moving from maximum retroversion of the pelvis, with the hips at 80 °,knees fully extended and ankles at 0 °, to a position of pelvic anteversion. Task execution was standardized with a metronome, and the individual had to move from pelvic retroversion to anteversion within 4 s	None	Pelvic Range of Motion, displacement of MG fascia	The results reaffirm and enforce the functional concept of force transmission through synergistic muscle groups and grants new perspectives for the role of the fasciae in restricting movement in remote zones	4	Pelvic region to knee joint and MG muscle	Most Likely
7	Grieve et al., 2015	RCT (pilot)	To investigate the immediate effect of a single application of self myofascia relaese (SMR) on the plantar aspect of the foot, on hamstring and lumbar spine flexibility.	Total = 24 healthy participants (12 IG;; 12 CG) Age - = 28 ± 11.3.; Healthy Gender = 8 Male & 16 Female	Participants randomly allocated to an intervention (SMR) or control group (no therapy). Baseline and post intervention flexibility was assessed by a sit-and-reach test (SRT). Participants were instructed to roll a tennis ball on the sole of each foot from behind the metatarsal heads to the heel concentrating on the medial arch for 2 min. The Intervention procedure consisted of baseline SRT measurements, followed by 4 min of SMR (2 min per foot) and then post intervention SRT measurements.	control group (no therapy).	Hamstring and lumbar flexibility	Efficacy of SMF on one area of a proposed "anatomy train" and its global effect on proximal flexibility. This study has supplied evidence for the immediate effectiveness of SMR on the superficial Back line (SBL) and suggest that asymptomatic individuals could have an immediate increase in flexibility of the hamstrings and lumbar spine through this intervention.	CEBM=2b; PEDro= 4/10	Posterior myofascial chain (SBL)	Likely
8	Pamuk et al., 2016	Cross-sectional experimental study	To assess muscle fiber direction local tissue deformations within the human medial Gastrocnemius (GM) muscle as caused by knee angle changes	Total = 5; Healthy pop Age = 27 ± 1 Gender =Female	Participants were positioned prone with in the MR scanner in a relaxed state with the ankle angle fixed at 90 degrees . The knee was brought to f lexion (140.8 ± 3 degree) (undeformed state). Sets of 3D high resolution MR, and DT images were acquired. This protocol was repeated at extended knee joint position (117 ± 1degree) (deformed state)	None	Shear strain	In homogeneity of fiber strain indicates epimuscular myofascial force transmission. Effects of knee movement assessed indicate major strain distribution along human GM muscle fibers.	4	GM deformation with respect to Knee angle changes	Most Likely
9	Wilke et al., 2016	Pilot Clinical Trial (controlled, matched-pairs intervention study)	Aimed to address this research deficit by investigating the effectiveness of lower limb stretching to increase neck mobility.	Total = 26 healthy pop (13 EG; 13 CG) Age= 30.3 ± 6.2; Gender = 16 Male; 10 Female	One group (n = 13) performed three 30 s bouts of static stretching for the gastrocnemius and the hamstrings, respectively. An age- and sex-matched control group (CG; n = 13) remained inactive. Pre- and post-intervention, maximal cervical ROM in flexion/extension was assessed.	Age and gender matched control group (n=13)	Maximal Cervical ROM	A single session of static stretching might elicit acute flexibility increases at distant joints. Strain transfer via myofascial meridians represents a plausible explanation for this finding	3b	Myofascial chain linking lower limbs with cervical ROM	Most Likely
10	Wilke et al., 2017	RCT	Investigated the remote effectiveness vs lower limb stretching vs local cervical stretching on neck ROM	Total=63 healthy pop (36 ± 13 years, ♂32) were randomly assigned to one of three groups	Remote stretching of the lower limb (LLS), local stretching of the cervical spine (CSS) or inactive control (CON). Prior (M1), immediately post (M2) and 5 min following intervention (M3), maximal cervical ROM was assessed	Inactive controls	maximal Cervical ROM	Both LLS and CSS increased cervical ROM compared to the control group in all movement planes and at all measurements (P < .05). Between LLS and CSS, no statistical differences were found (P > .05).	CEBM=2b; PEDro= 6/10	Myofascial chain linking lower limbs with cervical ROM	Most likely

11	Finni et al., 2017	Cross-sectional experimental study	To elucidate whether MFT pathways have functional roles in vivo; examined whether activation could alter the shear between the Soleus (SOL) and lateral Gastrocnemius (LG) muscles.	Total = 11; Healthy pop Age = 29 ± 6 Gender not mentioned	A series of knee joint manipulations where plantar flexion force, LG, and SOL muscle fascicle lengths and relative displacement of aponeuroses between the muscles were obtained. Data during a passive full range of motion were recorded, followed by 20° knee extension stretches in both passive conditions and with selective electrical stimulation of LG.	None	Relative displacement of SOL and LG apponeurosis	The activity-induced decrease in the relative displacement of SOL and LG suggests stronger (stiffer) connectivity between the two muscles, at least at flexed knee joint angles, which may serve to facilitate myofascial force transmission.	4	Soleus and lateral Gastronemius	Likely
12	Marinho et al., 2017	Cross-sectional experimental study	To verify how simultaneous changes on knee/hip positions modify the ankle's resting position and passive torque.	Total = 37 ; Healthy pop Age = 23.97 ± 3.48 Gender= male & female	The relationship between the absolute values of ankle passive resistance torque and the ankle angular position was used to calculate the dependent variables: ankle resting position (position in which the passive resistance torque is zero); and ankle passive torque at 0° (torque at the neutral position of the ankle in the sagittal plane). These measures were carried out under three test conditions: 0° at knee and 0° at hip (0°/0°); 90° at knee and 90°at hip (90°/90°); and, 135° at knee and 120° at hip (135°/120°).	None	Ankle passive resistance torque and the ankle angular position	The ankle mechanical behavior during changes of knee/hip positions demonstrated the existence of tissue continuity between the hip and ankle joints, in physiological conditions This result supports the existence of myofascial force transmission among lower limb joints	4	Lower limb muscles	Most Likely
13	Karakuzu et al., 2017	Cross-sectional experimental study	To test the hypothesis if submaximal plantar flexion activity causes heterogeneous length changes along the fascicles of human medial gastrocnemius (GM) muscle, in vivo MRI based deformation analyses and DTI based tractography.	5 Healthy pop; Age = 26 ± 3; Gender =Female	Each subject was positioned in a 3T clinical MR scanner in prone position. The right foot was firmly fastened to the custom-built MRI compatible foot pedal at an ankle angle of 90 degrees.In relaxed condition of the subjects, image acquisition was done (undeformed state). Subsequently, the subjects performed sustained isometric plantar flexion at 15% MVC and maintained that during a second image acquisition (deformed state). Separate sets of 3D high-resolution anatomical (MR) and diffusion images (DT) were acquired for both states.	None	Fascicle strain	Conclude that submaximal plantar flexion activity causes a heterogeneous distribution of strain within the GM fascicles	4	Medial Gastrocnemius	Most likely
14	Yoshitake et al., 2018	Cross-sectional experimental study	To examine if the shear modulus of a resting muscle is altered when joint angle is manipulated to passively stretch a neighboring muscle in the distal direction and if the effect of passive muscle stretch on shear modulus shows regional differences.	Total = 13; Healthy pop Age = 21.6 ±2.7 Gender =Male	The shear modulus of Biceps Brachii (BB) and Brachialis (BRA) was measured with shear-wave elastography at proximal and distal muscle regions for three forearm positions and with the elbow joint angle at either 100 deg or 160 deg.	None	Shear Modulus	Epimuscular myofascial force transmission may be facilitated at stretched muscle lengths.	4	Biceps Brachi and Brachialis	Likely
15	Ateş et al., 2018	Cross-sectional experimental study	To quantify the localized changes in the shear modulus of the gastrocnemius lateralis (GL), monoarticular dorsi- and plantar-flexor muscles induced by a change in knee angle.	Total = 21 healthy participants in 2 experimental groups (EG). EG1= 11 participants (Age = 26.9 ± 2.2); EG 2= 10 participants (Age = 24.6 ± 2.2) Gender both males and females	Participants underwent slow passive ankle rotations at the following two knee positions: knee flexed at 90° and knee fully extended.This was performed during two experimental sessions	Between group comparison of two different experimental conditions	Shear Modulus	As the muscle shear modulus is linearly related to passive muscle force, these results provide evidence of a nonnegligible intermuscular mechanical interaction between the human lower leg muscles during passive ankle rotations.	4	GL, soleus (proximal & distal), peroneus longus (PERL), and tibialis anterior (TA)	Likely

16	Wilke et al., 2018	Clincal trial (regression analysis trial)	To examine the age-dependency of non-local exercise effects following plantar fascia self myofascial release (SMR).	Total = 168 ; Healthy subjects Age = 45 ± 21; male & female	All participants bilaterally performed one 120s bout of SMR at the plantar foot (total treatment duration: 4 minutes). With a foam ball, they bilaterally massaged the plantar aponeurosis, rolling gently between origin and insertion in the upright standing position. Prior to and post intervention, sit and reach tests were conducted in order to estimate hamstring flexibility.	None	Hamstring flexibility	Plantar foot SMR increases hamstring extensibility, which is explained by age to a small degree. Additional research is warranted in order to delineate the substrate of remote exercise effects. Besides mechanical force transmission, also cortical adaptations might represent the driving factor.	3b	Plantar muscles and hamstring muscles	Likely
17	Freitas et al., 2019	Cross-sectional experimental study	MFT between the muscles of quadriceps during passive knee flexion	Total = 12; Healthy pop; Age = 23.7 ± 3.6. Gender = Male	Passive knee flextion with hip flexors at 2 length with hip position 80 degree and 0 degree. Twelve stretching trials for each hip position. with 1-min rest between trials, as two repetitions were performed for each muscle region (i.e., 3 muscles, 2 regions, 2 repetitions). At the end of the protocol, two 4-s maximal knee extension isometric contractions were performed (with the knee and hip fixed at 80 deg flexion) in order to normalize EMG signals.	None	Shear wave elastography - Shear modulus of Quadriceps	The in vivo shear modulus of the vastus lateralis and vastus medialis of healthy individuals remained unchanged between two hip positions during passive knee flexion up to 90 degree. Epimuscular myofascial force transmission (at a muscle belly level) does not occur between the quadriceps muscles when passively flexing the knee until 90 degrees.	3b	Between Quadriceps Muscles	Less Likely
18	Diong et al., 2019	Cross-sectional experimental study	To investigate intermuscle force transmission between human flexor pollicis longus and the index finger part of flexor digitorum profundus	15 healthy subjects Age = 44 ± 11 Gender =8 Female & 7 Male	Subjects first performed two index finger distal interphalangeal flexion MVCs against the load cell. Next, the removable post was adjusted to extend the thumb using 6 N, and the position of the post was marked before the thumb was released. Finally, the thumb interphalangeal joint was passively flexed and extended by an investigator to determine the limits of range of motion.	None	Intermuscle force transmission	Findings indicate that intermuscle force transmission occurs between the thumb and index finger muscles under passive physiological conditions	4	Flexor pollicis longus and flexor digitorum profundus	Most likely
19	Wilke et al., 2020	Cross-sectional experimental study	To examine the impact of ankle motion on soft tissue displacement of the dorsal thigh	11 healthy active individuals (26.8 ± 4.3 years; 6 Males),	Healthy active individuals in prone position and with the knee extended, underwent passive calf stretches (ankle dorsal extension) imposed by an isokinetic dynamometer. High-resolution ultrasound was used to simultaneously capture the displacement of the semimembranosus muscle, which was quantified by means of cross-correlation analysis. Inactivity of the leg muscles was controlled using surface electromyography (EMG).	None	Ultrasound recorded tissue displacement	Initial in vivo evidence for a mechanical force transmission between serially connected skeletal muscles. This means that local alterations of the mechanical tissue properties may modify flexibility in neighboring (superior or inferior) joints.	4	Posterior lower leg (hamstring and calf) - dorsal thigh (MFT across knee joint)	Most likely

Ajimsha et al., 2020

Figure 1

APPENDIX
PRISMA Flow Diagram

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┌─────────────────────────────┐     ┌─────────────────────────────┐
│ Records identified through  │     │ Additional records identified│
│ database searching          │     │ through other sources        │
│ (n = 238)                   │     │ (n = 21)                     │
└─────────────┬───────────────┘     └──────────────┬──────────────┘
              │                                     │
              └──────────────┬──────────────────────┘
                             ▼
        ┌────────────────────────────────────────────────┐
        │ Records after initial screening and duplicates │
        │ removed                                         │
        │ (n = 160)                                       │
        └───────────────────────┬────────────────────────┘
                                ▼
        ┌─────────────────────────────┐     ┌─────────────────────────────┐
        │ Records screened            │────▶│ Records excluded            │
        │ (n = 160)                   │     │ (n = 134)                   │
        └─────────────┬───────────────┘     └─────────────────────────────┘
                      ▼
        ┌─────────────────────────────┐     ┌─────────────────────────────┐
        │ Full-text articles assessed │────▶│ Full-text articles excluded │
        │ for eligibility             │     │ (n = 7)                     │
        │ (n = 26)                    │     └─────────────────────────────┘
        └─────────────┬───────────────┘
                      ▼
        ┌─────────────────────────────┐
        │ Studies included in         │
        │ qualitative synthesis       │
        │ (n =19)                     │
        └─────────────────────────────┘
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