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Dissertação submetida à Escola Superior de Saúde para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Fisioterapia – Opção Desporto, realizada sob a orientação científica do Professor Doutor Paulo de Carvalho, Professor da Área Técnico-Científica de Fisioterapia da Escola Superior de Saúde – Instituto Politécnico do Porto.

dezembro de 2018

Ultrasound assessment of deep fascia sliding mobility *in vivo*. A scoping review

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Abstract

Background: Failure of fascial sliding may occur in cases of excessive or inappropriate use, trauma or surgery, resulting in local inflammation, pain, sensitization and potential dysfunction. Therefore, the mechanical properties of fascial tissues, including their mobility, have been evaluated *in vivo* by ultrasound (US) imaging. However, this seems to be a method that is not yet properly standardized nor validated.

Objectives: To identify, synthesize and collate the key methodological principles that have been described in the literature for US evaluation of deep fascia sliding mobility *in vivo* in human subjects, and to analyse its reliability.

Methods: A systematic literature search was conducted on ScienceDirect, PubMed (Medline), Web of Science and B-On databases, according to the PRISMA Extension for Scoping Reviews (PRISMA-ScR) guidelines**.** The review design followed three main stages: (1) identifying the question and relevant literature; (2) selecting the literature; and (3) collating, charting and summarizing the data.

Eligibility criteria: Studies were included if they used US imaging to assess deep fascia sliding *in vivo* in human subjects, using either the term "sliding" or another with a similar meaning. Studies were excluded if they were not: reported in a peer-reviewed journal; available in English, Portuguese or Spanish; full-text accessible.

Results: From a total of 104 full-text articles retrieved and assessed for eligibility, 18 papers were included, evaluating the deep fasciae of the thoraco-lumbar (n=4), abdominal (n=7), femoral (n=4) and crural (n=3) regions. These studies addressed either diagnosis (n=11) and treatment benefits (n=7) questions, and presented levels of evidence ranging from II to IV. Various terms were used to describe the outcome measures representing the fascial sliding. Several subjects positioning, procedures to induce fascial sliding and US devices features were also used. The US analysis methods included the comparison of start and end frames and the use of cross-correlation software techniques through automated tracking algorithms. These methods had proven to be reliable on measuring sliding between TLF, TrA muscle-fascia junctions, fascia lata and crural fascia and the adjacent epimysial fasciae. However, the included papers presented heterogeneous terminologies, research questions, populations and methodologies. High quality research to determine the reliability of the current methods to assess other fasciae and evaluate the influence of age, sex-related characteristics, body composition or specific clinical conditions is lacking.

Conclusion: The US methods used to evaluate deep fascia sliding mobility *in vivo* in human subjects include the comparison of start and end frames and the use of cross-correlation software techniques through automated tracking algorithms. These seem reliable methods to measure sliding of some fasciae, but literature is needed to confirm its reliability for others. Moreover, specific standardized protocols are needed to assess each anatomical region so that US assessment of fascial sliding in vivo can be used properly in research and clinical practice.

Key words: Ultrasound imaging, fascia, sliding, mobility, scoping review.

Resumo

Introdução: A falha do deslizamento fascial pode ocorrer em casos de uso excessivo ou inadequado, trauma ou cirurgia, resultando em inflamação local, dor, sensibilização e potencial disfunção. As propriedades mecânicas dos tecidos fasciais, incluindo a sua mobilidade, têm sido avaliadas *in vivo* através de ecografia. No entanto, este parece ser um método que ainda não está devidamente padronizado nem validado.

Objetivos: Identificar, sintetizar e comparar os princípios metodológicos da investigação científica que utilizou a avaliação ecográfica do deslizamento da fáscia profunda em humanos *in vivo*, e avaliar a sua fiabilidade.

Métodos: Realizou-se uma pesquisa sistemática da literatura nas bases de dados ScienceDirect, PubMed (Medline), Web of Science e B-On, de acordo com as diretrizes PRISMA Extension for Scoping Reviews (PRISMA-ScR). A revisão seguiu três etapas principais: (1) identificação da questão e da literatura relevante; (2) seleção da literatura; e (3) agrupamento, mapeamento e resumo dos dados.

Critérios de elegibilidade: Foram incluídos os artigos que usaram a ecografia para avaliar o deslizamento da fáscia profunda em seres humanos *in vivo*, usando o termo "*sliding*" ou outro com significado semelhante. Foram excluídos os estudos: não disponíveis em publicações revistas por partes, não disponíveis em inglês, português ou espanhol ou cujo texto completo não se encontrava acessível.

Resultados: De um total de 104 artigos completos avaliados para elegibilidade, foram incluídos 18 artigos que avaliaram as fáscias profundas das regiões toracolombar (n=4), abdominal (n=7), femoral (n=4) e crural (n=3). Estes estudos abordaram questões de diagnóstico (n=11) e benefícios terapêuticos (n=7) e apresentaram níveis de evidência entre II e IV. Foram usados vários termos para descrever as medidas de resultados correspondentes ao deslizamento fascial. Foram usados diversos posicionamentos dos participantes, procedimentos para induzir o deslizamento fascial e características dos dispositivos de ecografia. Os métodos de análise do deslizamento fascial incluíram a comparação de imagens ecográficas inicial (estado de repouso) e final (estado alvo) e o uso de técnicas de software de correlação-cruzada através de algoritmos de rastreamento automatizado. Estes métodos mostraram-se fiáveis para medir o deslizamento entre a fáscia toracolombar, as junções músculo-fasciais do transverso abdominal, a fáscia lata e a fáscia crural e as fáscias epimisiais adjacentes. No entanto, os artigos incluídos apresentaram terminologias, questões de investigação, populações participantes e metodologias heterogéneas. É escassa a investigação de alta qualidade para determinar a fiabilidade dos métodos atuais para analisar outras fáscias e avaliar a influência da idade, de características relacionadas com o género, composição corporal ou condições clínicas específicas nas medidas de deslizamento fascial.

Conclusão: Os métodos ecográficos de medição do deslizamento fascial incluem a comparação entre *frames* inicial e final de uma gravação de vídeo de ultrassom e a análise de relação cruzada através de algoritmos de rastreamento automatizado. Estes métodos parecem ser fiáveis para medir o deslizamento de algumas fáscias, mas é necessária literatura para confirmar a sua fiabilidade para outras. Além disso, são necessários protocolos de avaliação específicos e padronizados para cada região anatómica, de modo que a avaliação ecográfica do deslizamento fascial *in vivo* possa ser usada adequadamente na investigação e na prática clínica.

Palavras-chave: ecografia, fáscia, deslizamento, mobilidade, revisão.

1. INTRODUCTION

The fascial system builds a “three-dimensional continuum of soft, collagen containing, loose and dense fibrous connective tissues that permeate the body” and incorporates elements such as “adipose tissue, adventitiae and neurovascular sheaths, aponeuroses, deep and superficial fasciae, epineurium, joint capsules, ligaments, membranes, meninges, myofascial expansions, periostea, retinacula, septa, tendons, visceral fasciae, and all the intramuscular and intermuscular connective tissues including endo-/peri-/epimysium” (Stecco et al. 2018). This system “surrounds, interweaves between, and interpenetrates all organs, muscles, bones and nerve fibers, endowing the body with a functional structure, and providing an environment that enables all body systems to operate in an integrated manner" (Stecco et al. 2018). Beyond this broader and more functional definition of the “fascial system”, a narrower anatomical definition states that "a fascia is a sheath, a sheet, or any other dissectible aggregations of connective tissue that forms beneath the skin to attach, enclose, and separate muscles and other internal organs” (Adstrum et al. 2017).

Deep fasciae (also known as muscular fasciae) are elements of the fascial system that correspond to all the well-organized, dense, fibrous layers that interact with the muscles, connect different elements of the musculoskeletal system and transmit muscular force over a distance (Stecco 2015; Stecco et al. 2018). There are two main types of deep muscular fasciae – the aponeurotic and the epimysial fasciae. The aponeurotic fasciae (e.g. fascia lata, crural fascia, brachial fascia, antebrachial fascia, thoracolumbar fascia and the rectus sheath) consist of two or three layers of parallel collagen fibre bundles orientated along different directions, separated from the underlying muscles and able to transmit muscular forces over a distance (Stecco 2015). This multi-layered structure of aponeurotic fasciae differentiates it from aponeurosis (or flat tendon) that contains unidirectional collagen fibres (Stecco 2015). The epimysial fasciae (e.g. the epimysium of the muscles of the limbs and the deep fascia of some trunk muscles) consist of three thin and well-organized superimposed fibrous layers that ensheath a specific muscle and define its form and structure, provide insertions for muscle fibres, transmit muscular forces and connect adjacent synergistic muscular fibre bundles (Stecco 2015).

Each deep fascial layer is separated by thin layers of loose connective tissue (LCT) that allows the sliding movements of adjacent fascial layers between each other and in relation to other structures such as muscles and organs, reducing friction and facilitating movement (Cowman et al. 2015; Roman et al. 2013; Stecco 2015; Stecco et al. 2009;

Stecco, Stern, et al. 2011). This ability to slide involves the presence of a lubricating substance – hyaluronic acid (HA), which is abundantly distributed between the sub-layers of aponeurotic fascia, between the epimysial fascia and the underlying muscles, in the perimysium and endomysium and also in the visceral, perivascular and perineural fascia (Cowman et al. 2015; Roman et al. 2013; Stecco 2015; Stecco et al. 2009; Stecco, Stern, et al. 2011). Increasing HA levels leads to greater lubrication between fascial planes and viscera or muscles, or between dense fascial layers, improving the sliding system and encouraging a more efficient function (Roman et al. 2013). LCT is an important water and salts reservoir for the surrounding tissues, and may also accumulate a variety of residual products; an abnormal accumulation of these products over time, as well as stasis or dehydration, can alter the mechanical properties of the LCT and, particularly, the normal sliding of the collagen layers; this failure of LCT sliding may occur in cases of excessive or inappropriate use, trauma or surgery, processes in which occurs fat infiltration, decrease in the amount of HA, increase of acidification and viscosity, reduced sliding and hyper-activation of free nerve endings, resulting in local inflammation, pain, sensitization and potential dysfunction (L. Chaitow 2014a, 2014b; Stecco 2015).

Fascia has been forgotten and devalued by the scientific community for many years due to its ubiquitous and apparently disordered nature and, mainly, to the lack of adequate assessment tools (Klinger, W., & Schleip 2015; Stecco, Macchi, et al. 2011). Recent evolution of histology and US imaging evaluation led to a considerable increase in fascia-related research (Chaitow, L., & Schleip 2012), especially regarding its role in muscular force transmission (Krause et al. 2016; Wilke et al. 2016), movement perception and coordination (Schleip et al. 2012; Stecco, Macchi, et al. 2011; Turrina, Martínez-González, and Stecco 2013), aetiology of pain (Wells et al. 2013), as well as the therapeutic modalities that aim to restore the normal functioning of the fascial system (Ajimsha, Al-Mudahka, and Al-Madzhar 2015; Beardsley and Škarabot 2015; Mauntel, Clark, and Padua 2014; McKenney et al. 2013; Webb et al. 2015; Webb and Rajendran 2016).

On this subject, several recently conducted systematic reviews report that myofascial techniques are emerging as solid evidence base strategies (Ajimsha et al. 2015) that increase range of motion (ROM) (Mauntel et al. 2014; Webb and Rajendran 2016) and flexibility (Beardsley and Škarabot 2015) without decreasing muscle function (Mauntel et al. 2014); decrease pain perception (Webb and Rajendran 2016) and improve muscle performance (Webb et al. 2015) and recovery (Beardsley and Škarabot 2015),

which results in increased movement efficiency and reduced risk of injury (Mauntel et al. 2014); these techniques may be used in athletes and in the general population (Beardsley and Škarabot 2015) before rehabilitation and physical activity (Webb et al. 2015). Although, great heterogeneity in quality, methods and results is highlighted among studies (Ajimsha et al. 2015; McKenney et al. 2013; Webb et al. 2015; Webb and Rajendran 2016). These studies used several outcome measures (and respective evaluation instruments) such as ROM (goniometry and functional tests), pain perception (visual analogue scale, questionnaires and algometry), flexibility and performance (functional tests and scales), pulmonary function (spirometry), variability of heart rate and blood pressure (sphygmomanometry), postural stability (stabilometry), muscle activation (electromyography), production of muscle strength (dynamometry), among others. Emphasis should be given to the fact that only one of the studies (Tozzi, Bongiorno, and Vitturini 2011) included in one of the reviews (Ajimsha et al. 2015) assessed the fascial mobility (of visceral fasciae) by using "dynamic US topographic anatomical evaluation".

A consensus statement developed by Zügel el al. (2018) reflects the current state of knowledge regarding the role of fascial tissues in the discipline of sports medicine (Zügel et al. 2018). Imaging and non-imaging tools for diagnosis and assessment of fascial tissues are presented, including biopsy (for the assessment of histological properties including molecular analysis), bio-impedance (for hydration changes), manual palpation (for stiffness, elasticity and shearing mobility of tissues), indentometry (for stiffness and elasticity), US imaging (for thickness of layers and tendon elongation), B-mode ultrasonography (for tendon structure and mechanical/material properties), compression-based US elastography (for stiffness), shear-wave US elastography (for stiffness) and US with correlation software (for relative shearing motion of adjacent layers). Taking into account the scope of this review, it must be highlighted that the shearing mobility of fascial tissues and the relative shearing motion of adjacent fascial layers have been assessed through manual palpation and US with correlation software. Concerning these particular diagnostic methods, the authors of the aforementioned consensus explain that although manual palpation represents a cost-neutral and widely used screening method aimed at assessing viscoelastic properties, its reliability is limited; in contrast, imaging methods such as US or elastography are pointed out as reliable promising tools for explicitly quantifying the mechanical properties of fascial tissues under *in vivo* conditions (Zügel et al. 2018).

Ultrasonography is an imaging method based on the phenomenon of interaction between US and tissues that has become increasingly prevalent (Soni, N., Arntfield, R., & Kory 2015). Despite the limited literature on its use by non-medical professionals (in particular by physiotherapists), this method may be advantageous for therapeutic efficacy when used as a complement to clinical reasoning, in the management of clinical progress and in the measurement of rehabilitation outcomes (Roll, S. C., Asai, C., & Tsai 2016). US imaging allows immediate and real-time acquisition of high-resolution, multi-plane images (Erkonen, W. E., & Smith 2009; Soni, N., Arntfield, R., & Kory 2015) and dynamic visualization of tissue characteristics, behaviour and structure (L. Chaitow 2014b) in a safe, non-invasive, fast and painless manner, presenting excellent users acceptance; it is relatively portable and costs less than other imaging modalities such as computerized tomography (CT) and magnetic resonance imaging (MRI) (Erkonen, W. E., & Smith 2009; Soni, N., Arntfield, R., & Kory 2015); it is appropriate for serial follow-up, as it allows multiple sequential examinations or evaluations of a large group of individuals (Fabrikant and Park 2011; Middleton, W. D., Kurtz, A. B., & Hertzberg 2004). However, it presents a relatively limited field of vision for deep structures due to bone shading, and its diagnostic accuracy depends on the operator's technical capabilities (operator bias) (Erkonen, W. E., & Smith 2009; Soni, N., Arntfield, R., & Kory 2015), since he manually controls the transducer, so that variations in the compression pressure, orientation or direction of the probe can modify the resulting images (Drakonaki, Allen, and Wilson 2009).

Multiple US imaging modes have been developed to improve image acquisition, such as: a) two-dimensional (2D) or “brightness”-mode (B-mode) – standard mode of most US devices that provides morphological and structural data of the examined tissue; b) 3D-mode – that allows three-dimensional evaluation of tissues and is widely used in the evaluation of the fetal anatomy; c) “motion”-mode (M-Mode) – often used to analyse the movement of structures over time; d) Doppler-mode – which allows the qualitative and quantitative assessment of blood flow (Fusini et al. 2017; Soni, N., Arntfield, R., & Kory 2015); e) or elastography – modified US that is based on the principle that the US signals coming from a structure in response to an external compression (mechanical or acoustic wave) is an indirect measure of its biomechanical properties, allowing to measure, for example, the stiffness of tissues (Fusini et al. 2017).

US imaging is commonly used in the musculoskeletal field to view soft tissues such as muscle, nerve, tendon, ligament and fascia (Whittaker et al. 2007). Tissue

mobility has been assessed through US, for example, to examine tendon mobility (Van Doesburg et al. 2012; Guimberteau and Bakhach n.d.; J. H. Korstanje et al. 2012) or the excursion of peripheral nerves (Kasehagen et al. 2018). Fascia can be visualized *in vivo* by CT, MRI and US (Stecco 2015). Although MRI and CT can provide a more objective view of the location and alterations of the fascial layers, US is less costly and allows measuring the thickness of the various sublayers and analysing the sliding between fascia and muscle and between the various fascial sublayers (Stecco 2015). Stecco (2015) admits that US and its elastographic variant show great promise for studying fasciae in clinical practice to complement physical assessment, support diagnosis and evaluate treatment outcomes (Stecco 2015).

In clinical practice and in scientific research, the use of diagnostic US procedures to assess deep fasciae mobility and to monitor therapeutic interventions seems to be still very incipient (Roll, S. C., Asai, C., & Tsai 2016). For researchers and clinician practitioners to have confidence to use US as an objective method of assessing the deep fasciae sliding capacity, it is necessary to know the available methods and to confirm that they have adequate levels of evidence.

Within this context, the main objective of the present scoping systematic review was to identify, synthesize and collate the key methodological principles that have been described in literature for US evaluation of deep fascia sliding mobility *in vivo* in human subjects, and to analyse its reliability. Particularly, it was intended: to identify and chart the examined fasciae and the US equipment characteristics and parameters used; to document the methodological procedures implemented to assess deep fasciae mobility through US measurements; to present, whenever available, the reliability assessment of the US measurements; and to determine the level of evidence supporting the use of US imaging to quantify fascial sliding.

2. METHODS

In contrast to systematic reviews that focus on specific questions or examine the effect of clinical interventions, scoping reviews are useful for answering broader questions and can be conducted to meet various objectives, including to examine the extent, range and nature of the evidence on a topic or question, to determine the value of undertaking a systematic review, to summarize findings from a body of knowledge that is heterogeneous in methods or discipline, or to identify gaps in the literature to aid the planning and commissioning of future research (Tricco et al. 2018)**.** The results of a

scoping review can assist in shaping priorities for future clinical advancement and research investigations, especially in a novel area of interest (Roll, S. C., Asai, C., & Tsai 2016). Despite the difference on the objectives and on the methodological approach, such as absence of risk-of-bias assessment or meta-analysis, scoping reviews employ rigorous and systematic methodology, similar to systematic reviews (Liberati et al. 2009), as shown below.

2.1. Information sources and search strategy

A systematic literature search was conducted according to the PRISMA-ScR guidelines (Tricco et al. 2018)**.** A protocol for this scoping review was drafted and revised by the research team during December 2017. The systematic search of health and science bibliographic databases, namely ScienceDirect, PubMed (Medline), Web of Science and B-On, was performed to identify potentially relevant articles for inclusion in this review published up until April 14, 2018 with no restriction on publication date. The search was carried out using a consistent search strategy across all databases (Table 1) and included key words from three main concepts: ultrasound imaging (ultrasound, ultrasonography, sonography), fascia (fascia, fascial, myofascial, neuromyofascial, connective) and sliding (slide, sliding, glide, gliding, motion, movement, mobility, mobilization, excursion, displacement). The Boolean operators "OR" and "AND" were used to link the key words from each concept and to link the concepts themselves, respectively. After article selection, a final hand search was performed of the reference lists of the included articles to identify any other potentially eligible articles.

Table 1: *Strategy for electronic database searches*

DATABASE	**SEARCH FIELDS**	**SEARCH TERMS** (database subject headings)
Sciencedirect PubMed (Medline) Web of Science B-on	Title, abstract, key words	(ultrasound OR ultrasonography OR sonography) AND (fascia OR fascial OR myofascial OR neuromyofascial OR connective) AND (slide OR sliding OR glide OR gliding OR motion OR movement OR mobility OR mobilization OR excursion OR displacement)

2.2. Eligibility criteria

The review included: quantitative studies that used US imaging to assess sliding of deep fascia (muscular fascia) – based on the Functional Atlas of the Human Fascial System (Stecco 2015); and *in vivo*, human studies, published in peer-reviewed journals, with no restriction on publication date. Studies were excluded if they: were descriptive commentaries, conference abstracts or proceedings, review articles, pre-clinical and preliminary reports; were not available in English, Portuguese or Spanish; were not available in the full-text version. Study characteristics for eligibility are detailed in Table 2, including participants, interventions, control groups, outcome measures and study design (PICOS).

Table 2: *Study characteristics for review eligibility (PICOS)*

CHARACTERISTICS	INCLUSION	EXCLUSION
Participants	The study sample included human participants *in vivo* only.	Studies conducted in cadavers, animals or other models.
Intervention	US imaging was used to assess *in vivo* deep fasciae sliding.	
Control/comparator	Not applicable. No control or comparators.	
Outcome measures	Studies in which one of the outcome measures was the US measurement of deep fascia layers' sliding (using either the term "sliding" or another term with a similar meaning).	
Study design	Quantitative study designs including randomized controlled trials (RCTs), pseudo-randomized controlled trials, cohort, cross-sectional, case series, case control, or case studies.	Descriptive commentaries, conference abstracts or proceedings, review articles, pre-clinical and preliminary reports.
Publication	Peer-reviewed publications.	Articles not available in English, Portuguese or Spanish. Full text not available.

2.3. Selection of sources of evidence

One reviewer screened all titles and abstracts of the articles identified in the literature search to assess potential eligibility. Duplicates and articles that were clearly ineligible after title and/or abstract analysis were excluded during this initial screening process. Full

text was obtained of the remaining potentially eligible studies. Two reviewers independently appraised all identified studies against the inclusion and exclusion criteria to determine final eligibility. Differences in judgments were discussed with a third reviewer, who acted as an arbiter to determine the final judgment of eligibility.

2.4. Data items, data charting process and synthesis of results

A standardised data-charting form, based on the review objectives, was developed in Excel[tm] by two reviewers and discussed with the research team. One reviewer extracted the relevant information from each eligible article, discussed the results with the team members and continuously updated the data-charting form in an iterative process.

The extracted data are presented in tables described within the results. One initial table was made to give a global overview of all the included studies, collecting general data from identification, demographic characteristics, level of evidence (LoE) (OCEBM Levels of Evidence Working Group, Durieux, Pasleau, Howick, et al. 2011), study type assessment using the "decision algorithm to help define study designs" (Peinemann and Kleijnen 2015), body region and studied fascia (Stecco 2015). Consensus was reached among the review team members to organize the included articles into several groups according to the body region and respective deep fasciae analysed: thoracolumbar, abdominal, femoral and crural regions fasciae. It was agreed that the transversus abdominis (TrA) muscle fascia would be included in the group of fasciae of the abdominal region, although it constitutes an anatomical continuity with the anterior layer of the thoracolumbar fascia (TLF) (Stecco 2015). Four tables group the methodologic information retrieved from the studies of each region, including the US device characteristics (brand and transducer characteristics), US imaging procedures (imaging mode, acquisition frequency and depth, subjects positioning, transducer´s location and standardizing procedures), different fascial sliding outcome measure(s) used across the papers, description of reliability analysis for the employed US measurements, procedures used to induce fascial sliding and fascial sliding analysis methods.

2.5. Critical appraisal of individual sources of evidence

One reviewer used the OCEBM LoE to assess each clinical article. The OCEBM LoE is an easy and effective tool to evaluate the strength of results in research studies (OCEBM Levels of Evidence Working Group, Durieux, Pasleau, and Howick 2011). This classification rapidly estimates the methodological quality of each article (Howick et al.

2011). According to this system, articles were classified from level I (higher LoE) to V (lower LoE), where higher LoE means better methodological quality and lower risk of bias (Howick et al. 2011).

3. RESULTS

3.1. Selection of sources of evidence

The systematic database search (last run on April 14 2018) yielded 4282 records. After duplicates were removed, the title and abstract of the remaining 3091 articles were screened. A total of 104 full-text articles were retrieved and assessed for eligibility. Of these, 86 were excluded for the following reasons: 37 did not perform US evaluation of fascial sliding, 19 did not use a sample of human subjects *in vivo*, 20 did not study deep fasciae (muscular fasciae), 7 were review articles, 1 full text was not accessible, 1 was a descriptive documentary and 1 was a pre-clinical study. Therefore, were considered for review 18 studies, grouped into different sections according to the anatomical regions analysed. Results of the literature search, screening and selection processes are summarized in the PRISMA diagram (Moher D, Liberati A, Tetzlaff J 2009) in Figure 2.

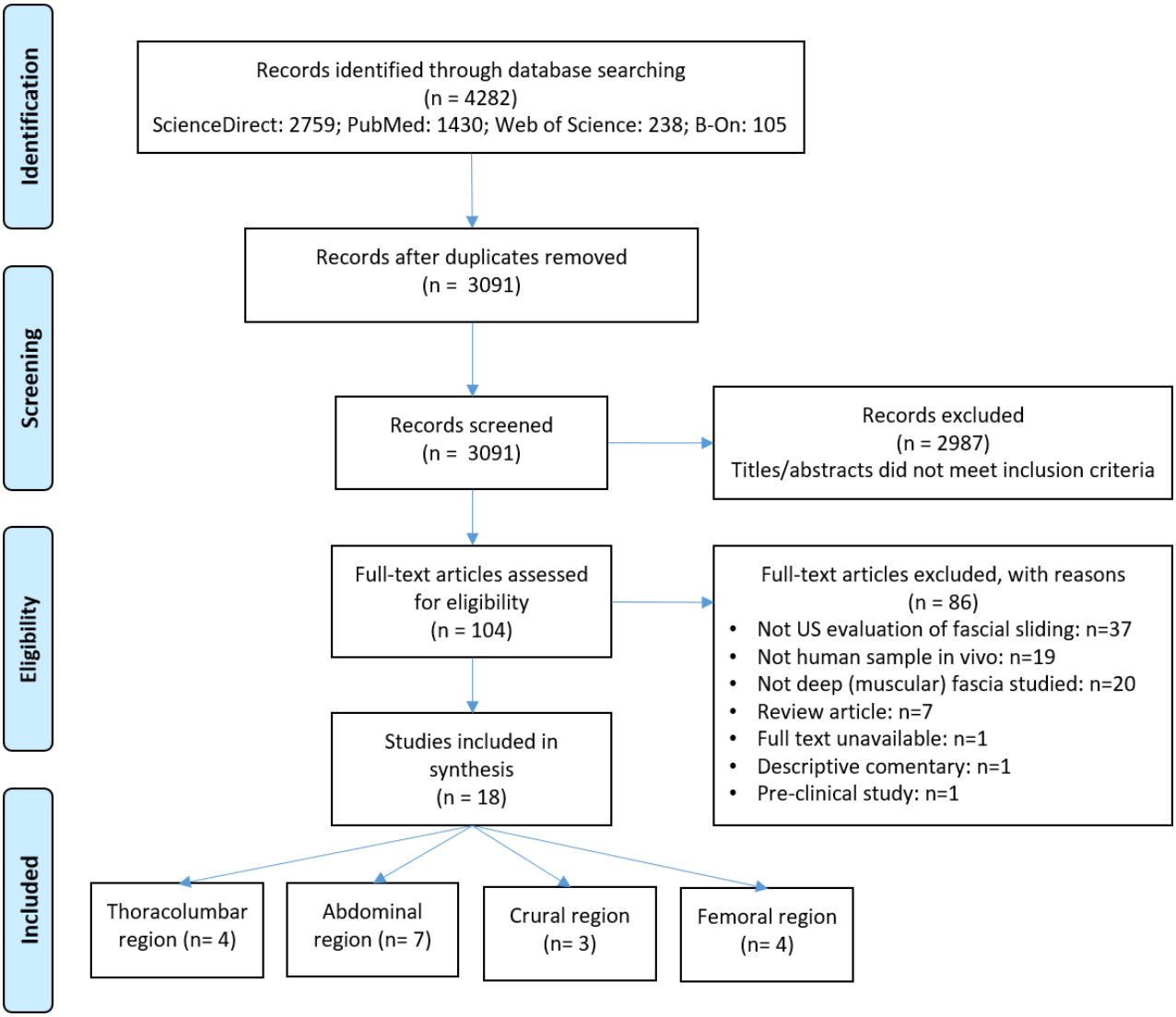

Figure 1: PRISMA flow diagram of studies identified, screened, selected and included in the review.

3.2. Synthesis of results

Table 3 collects the general characteristics of the articles included in the current review; tables 4-7 group the methodologic data from the studies of each studied region.

***Table 3**: General characteristics of included studies*

BODY REGION	STUDY IDENTIFICATION (Country of lead author)	STUDIED FASCIAE	SAMPLE CHARACTERISTICS						STUDY TYPE (Peinemann and Kleijnen 2015)	LEVEL OF EVIDENCE	
			Sample Size	n males	n females	n healthy	n clinical condition	Mean age (years)		Question	Level
Thoraco-lumbar (n=4)	(Langevin et al. 2011) (USA)	Thoracolumbar fascia (posterior layer)	121	62	59	50	71	43.2	Cross-sectional	Diagnosis	II
	(Tu, Woledge, and Morrissey 2016) (UK)	Thoracolumbar fascia (posterior layer)	12	8	4	12	0	22.9	Cross-sectional	Treatment	III
	(Griefahn et al. 2017) (Germany)	Thoracolumbar fascia (posterior layer)	38	13	25	38	0	23.3	Randomized controlled trial	Treatment	II
	(Engell et al. 2016) (Canada)	Thoracolumbar fascia (posterior layer) + Epimysial fascia of the thoracic paraspinal tissues	24	24	0	24	0	25.0	Within-group comparison	Treatment	III
		TOTAL	**195**	**107**	**88**	**124**	**71**	**28.6**			
Abdominal (n=7)	(Hides, Wong, et al. 2007) (Australia)	TrA anterior muscle-fascia junction	19	8	11	19	0	20.3	Cross-sectional	Diagnosis	II
	(Hides, Miokovic, et al. 2007) (Australia)	TrA anterior muscle-fascia junction	19	8	11	19	0	20.3	Within-group comparison	Diagnosis	III
	(Jhu et al. 2010) (Taiwan)	TrA anterior muscle-fascia junction	18	14	4	18	0	22.6	Cross-sectional	Diagnosis	II
	(Murakami, Sakuraba, and Nagai 2011) (Japan)	TrA anterior and posterior muscle-fascia junctions	51	51	0	14	37	22.9	Cross-sectional	Diagnosis	II
	(Chen et al. 2014) (Taiwan)	TrA anterior and posterior muscle-fascia junctions	40	25	15	20	20	25.4	Cross-sectional	Treatment	III
	(Chen et al. 2015a) (Taiwan)	TrA anterior and posterior muscle-fascia junctions	20	12	8	20	0	25.4	Cross-sectional	Diagnosis	II
	(Crommert, Unsgaard-Tøndel, and Vasseljen 2017) (Norway)	TrA anterior muscle-fascia junction	18	5	13	18	0	22.0	Cross-sectional	Diagnosis	II
		TOTAL	**185**	**123**	**62**	**128**	**57**	**22.7**			
Femoral (n=4)	(Langevin et al. 2007) (USA)	NS (fascia lata; quadriceps epimysial fascia)	12*	1	11	0	12	24-74	Cross-sectional	Diagnosis	II
	(Fox et al. 2014) (USA)	Fascia lata; Quadriceps epimysial fascia	11	6	5	11	0	21-57	Cross-sectional	Treatment	III
	(Ichikawa et al. 2015) (Japan)	Deep fascia of the vastus lateralis (fascia lata; vastus lateralis epimysial fascia)	12	12	0	12	0	27.0	Cohort	Treatment	III
	(Condino et al. 2015a) (Italy)	Iliotibial band (fascia lata)	2	2	0	2	0	31.5	Cross-sectional	Diagnosis	II
		TOTAL	**37**	**21**	**16**	**25**	**12**	**29.3**			
Crural (n=3)	(Luomala et al. 2014) (Finland)	Crural fascia (deep fascia in the calf area)	1	1	0	0	1	40.0	Case report	Treatment	IV
	(Cruz-Montecinos et al. 2015) (Chile)	Deep fascia of the medial gastrocnemius (epimysial fascia)	17	17	0	17	0	22.8	Cross-sectional	Diagnosis	II
	(Cruz-Montecinos et al. 2016) (Chile)	Deep fascia of the medial gastrocnemius (epimysial fascia)	15	15	0	15	0	23.0	Cross-sectional	Diagnosis	II
		TOTAL	**33**	**33**	**0**	**32**	**1**	**28.6**			
		TOTAL	**450**	**284**	**166**	**309**	**141**	**26.1**			
		TOTAL (%)	**%**	**63.1**	**36.9**	**68.7**	**31.3**				

*Legend – USA: United States of America; UK: United Kingdom; TrA: transversus abdominis; NS: not stated; NA: not available; OCEBM: Oxford Centre for Evidence-Based Medicine; * two patients undergoing spinal fusion surgery and ten non-surgical subjects*

***Table 4**: Methodological data extracted from studies of the thoraco-lumbar region*

US MACHINE	IMAGING MODE	TRANSDUCER					SUBJECTS POSITION	OUTCOME MEASURE(S)	RELIABILITY	PROCEDURES USED TO INDUCE FASCIAL SLIDING	FASCIAL SLIDING ANALYSIS METHOD
		Array type	Freq. (MHz)	Depth (cm)	Location	Handling					
(Langevin et al. 2011)											
Terason 3000; Teratech Corporation, Burlington, MA	B-mode Elastography	Linear	10	4	2cm lateral to the midline at the level of the L2-L3 interspace	Fixing device	Prone-lying	Shear strain	Intra-rater: ICC=0.98	Passive trunk flexion (motorized articulated table)	Cross-correlation software techniques (automated tracking)
(Tu et al. 2016)											
Voluson i; GE Healthcare; WI, USA	B-mode (3D)	Linear	4-12	NS	3cm lateral to the middle of the L2-L3 spinous processes	Fixing device	Standing	Paracutaneous tissue translation	NA	Active velocity-guided lumbar flexion with and without KT	Cross-correlation software techniques (3D automated tracking)
(Griefahn et al. 2017)											
MyLab One; Esaote Biomedica Germany	B-mode	Linear	6-13	NS	2cm lateral to L2-L3 intervertebral space	Fixing device	Sitting	Fascial mobility	NA	Active thoracolumbar flexion of 30º	Cross-correlation software techniques (automated tracking)
(Engell et al. 2016)											
Sonix RP, Burnaby, BC, Canada	B-mode; Elastography	Linear	10	4	≈ 2 cm left of the spine's T7 segment midline	Fixing device	Prone-lying	Cumulative caudocephalic displacement; Relative shear	NA	Passive preload manoeuvre	Cross-correlation software techniques (automated tracking)

*Legend – US: ultrasound; ICC: Intraclass correlation coefficient; Freq.: frequencies; NS**:** not stated; NA: not available; KT: kinesio taping.*

***Table 5**: Methodological data extracted from studies of the abdominal region*

US MACHINE	IMAGING MODE	TRANSDUCER					SUBJECTS POSITION	OUTCOME MEASURE(S)	RELIABILITY	PROCEDURES USED TO INDUCE FASCIAL SLIDING	FASCIAL SLIDING ANALYSIS METHOD
		Array type	Freq. (MHz)	Depth (cm)	Location	Handling					
(Hides, Wong, et al. 2007)											
Synergy; GE Diasonics, San Jose, CA	B-mode	Curvilinear	5	NS	Perpendicular to the anterolateral abdominal muscles	Manual	Supine-lying	Slide of the anterior abdominal fascia	NA	Active static weight-bearing heel press (0% & 25% of body weight)	Start and end frames comparison
(Hides, Miokovic, et al. 2007)											
Synergy; GE Diasonics, San Jose, CA	B-mode	Curvilinear	5	NS	Perpendicular to the anterolateral abdominal muscles	Manual	Supine hook-lying	Slide of the anterior abdominal fascia	Intra-rater: - across measurements from the same image: ICC=0.98 - across images: ICC=0.44 - across 2 days: ICC=0.36	Abdominal drawing-in manoeuvre	Start and end frames comparison
(Jhu et al. 2010)											
HDI 5000; Philips/ATL, Bothell, WA, USA	B-mode	Linear	5-12	NS	At the level of the umbilicus, laterally transverse to the midline	Manual	Supine hook-lying	Changes in TrA length	Intra-rater: - ICC>0.75 - Within-subject CV <10%	Abdominal drawing-in manoeuvre	Start and end frames comparison
(Murakami et al. 2011)											
NEMIO SSA-550A, Toshiba	B-mode	Linear	7.5	NS	At the level of the umbilicus (anterior, anterolateral and posterior sides)	Manual	Supine-lying	Distance of fascia motion	Intra-rater: - anterior: 0.90<ICC<0.91 - anterolateral: 0.90<ICC<0.92 - posterior: 0.88<ICC<0.90	Abdominal drawing-in manoeuvre	Start and end frames comparison
(Chen et al. 2014)											
HDI 5000; Philips/ATL, Bothell, WA, USA	B-mode	Linear	5-12	NS	Inferior angle of the rib cage, at the level of the umbilicus (anterior or posterolateral sides)	Manual	Supine crook-lying	Sliding of the TrA muscle-fascia junction	NA	Abdominal drawing-in manoeuvre + myofascial release	Start and end frames comparison
(Chen et al. 2015a)											
Terason t3000; Teratech Corporation, Burlington, MA	B-mode	Linear	5-12	NS	Inferior angle of the rib cage, at the level of the umbilicus (posterolateral side)	Manual	Supine crook-lying	Sliding of the TrA muscle-fascia junction	Intra-rater: - ICC>0.70	Abdominal drawing-in manoeuvre	Start and end frames comparison
(Crommert et al. 2017)											
Vivid 7; GE-Vingmed US Horten, Norway	B-mode	Linear	10	NS	Halfway between the 11th costal cartilage and the iliac crest	Manual	Standing	Fascial slide	NA	Flexed and extended shoulder static positions, 3kg in each hand	Start and end frames comparison

Legend – US: ultrasound; ICC: Intraclass correlation coefficient; Freq.; frequencies; NS: not stated; NA: not available; CV: coefficient of variation; TrA: transversus abdominis (TrA).

***Table 6**: Methodological data extracted from studies of the femoral region*

US MACHINE	IMAGING MODE	TRANSDUCER					SUBJECTS POSITION	OUTCOME MEASURE(S)	RELIABILITY	PROCEDURES USED TO INDUCE FASCIAL SLIDING	FASCIAL SLIDING ANALYSIS METHOD
		Array type	Freq. (MHz)	Depth (cm)	Location	Handling					
(Langevin et al. 2007)											
GE System Five, Vingmed	B-mode Elastography	Linear	10	4	18cm superior to the middle of the superior edge of the patella	Manual	NS	Tissue displacement (during needle rotation)	NA	Passive robotic acupuncture needling	Cross-correlation software techniques (automated tracking)
(Fox et al. 2014)											
Terason 3000; Teratech Corporation, Burlington, MA	B-mode Elastography	Linear	10–12	NS	(1) between RF and VL muscles, 15cm rostral to the patella (2) over the RF belly, 2 cm medial to place (1)	Fixing device	NS	Tissue displacement (axial/lateral); Shear strain (axial/lateral)	NA	Passive robotic acupuncture needling	Cross-correlation software techniques (automated tracking)
(Ichikawa et al. 2015)											
EUB-7500; Hitachi Medical Corporation, Tokyo, Japan	B-mode	Linear	NS	NS	Midway between the greater trochanter and lateral epicondyle of the femur	Manual	Lateral decubitus	Fascial gliding motion	Intra-rater: - Minimal detectable change >95%	Myofascial release; Hot pack therapy + passive knee extension (0º-45º)	Start and end frames comparison
(Condino et al. 2015a)											
Philips iU22; Philips/ATL, Bothell, WA, USA	B-mode (3D)	Linear	5-13	**NS**	Midway between the greater trochanter and lateral epicondyle of the femur	Fixing device	Supine-lying	Fascial mobility	Automatic validation process to evaluate the reliability of feature matches	Isometric knee extension	Cross-correlation software techniques (3D automated tracking – block matching algorithm)

Legend – US: ultrasound; ICC: Intraclass correlation coefficient; Freq.: frequencies; NS: not stated; NA: not available; RF: rectus femoris; VL: vastus lateralis.

***Table 7**: Methodological data extracted from studies of the crural region*

US MACHINE	IMAGING MODE	TRANSDUCER					SUBJECTS POSITION	OUTCOME MEASURE(S)	RELIABILITY	PROCEDURES USED TO INDUCE FASCIAL SLIDING	FASCIAL SLIDING ANALYSIS METHOD
		Array type	Freq. (MHz)	Depth (cm)	Location	Handling					
(Luomala et al. 2014)											
GE Healthcare's LOGIQ P6	B-mode	Linear	9-15	NS	(1) gastrocnemius lateral part, halfway up the calf, towards the peroneus muscle (2) medial to the biceps femoris, midway on thigh	Manual	Prone-lying	Fascial gliding	NA	Fascial Manipulation® + active, maximal dorsi & plantar flexion	Start and end frames comparison
(Cruz-Montecinos et al. 2015)											
SonoSite TITAN®; Sonosite, Bothell, WA, USA	B-mode	Linear	5-10	3.9	On the muscle belly of the medial gastrocnemius on the dominant limb	Fixing device	Siting	Fascial displacement	Intra-rater: ICC = 0.903 Manual tracking VS LKP tracking: - ICC = 0.973 - average difference between methods < 0.95%	Active pelvic anteversion (start at maximum retroversion)	Cross-correlation software techniques (automatic tracking)
(Cruz-Montecinos et al. 2016)											
SonoSite TITAN®; Sonosite, Bothell, WA, USA	B-mode	Linear	5-10	3.9	On the muscle belly of the medial gastrocnemius on the dominant limb	Fixing device	Siting	Fascial displacement	NA	Maximal active cervical spine flexion (start at neutral position)	Cross-correlation software techniques (automatic tracking)

Legend – US: ultrasound; ICC: Intraclass correlation coefficient; Freq.; frequencies; NS: not stated; NA: not available.

3.2.1. Study designs and levels of evidence

According to their methodologic design, most of the papers included in the review were observational cross-sectional studies (72.1%; n=13) (Chen et al. 2015a, 2014; Condino et al. 2015b; Crommert et al. 2017; Cruz-Montecinos et al. 2016, 2015; Fox et al. 2014; Hides, Wong, et al. 2007; Jhu et al. 2010; Langevin et al. 2011, 2007; Murakami et al. 2011; Tu et al. 2016). The remaining were within-group comparison studies (also known as before-and-after studies) (n=2) (Engell et al. 2016; Hides, Wong, et al. 2007), a prospective cohort study (Ichikawa et al. 2015), a case study (Luomala et al. 2014) and a RCT that assessed the thoraco-lumbar region (Griefahn et al. 2017).

This systematic research reported papers with levels of evidence ranging from II to IV: LoE II (61.1%; n=11), LoE III (33.3%; n=6), LoE IV (5.6%; n=1). The majority of articles (61.1%; n=11) focused on diagnosis questions, while the remaining (38.9%; n=7) analysed treatment benefits. There was a tendency for articles analysing diagnostic questions to present levels of evidence slightly higher [LoE II (n=10) and III (n=1)] than those that addressed treatment benefits [LoE II (n=1), III (n=6) and IV (n=1)]. All body regions presented articles rated as LoE II and III, with the exception of the crural region that presented two studies with LoE II and another with LoE IV.

3.2.2. Sample characteristics

Overall, the 18 articles included in the current review involved 450 participants. The sample sizes in individual studies ranged from 1 (Luomala et al. 2014) to 121 participants (Langevin et al. 2011). The studies of the thoracolumbar and abdominal region presented bigger sample sizes (195 and 185 participants, respectively) than those addressing the femoral and crural regions (37 and 33, respectively). Globally, 63.1% of the participants were men (n=284) and 36.9% were women (n=166), although the studies assessing the crural region fasciae included only men. Most of the participants (68.7%; n=309) were asymptomatic, and the remaining 31.3% (n=141) presented some clinical condition. In the three crural region studies, only the case-study presented a subject with a clinical condition. The subjects were mainly young with a mean age of 26.1 years; 2 studies (Fox et al. 2014; Langevin et al. 2007) of the femoral region only presented the minimum and maximum ages.

3.2.3. Studied fasciae

The studies included in this review approached the mobility of several deep fascial layers. The articles related to the thoraco-lumbar region addressed the posterior layer of the TLF (Engell et al. 2016; Griefahn et al. 2017; Langevin et al. 2011; Tu et al. 2016) [the "superficial layer of the deep fascia of the back" (Stecco 2015)] and one of them (Engell et al. 2016) also approached the superficial, intermediate and deep layers of the thoracic paraspinal tissues, which included the posterior layer of the TLF and the epimysial fascia of the of the erector spinae [which belongs to the "deep layer of the deep fascia of the back" (Stecco 2015)]. The articles that assessed the fascial mobility of the abdominal region fasciae focused on the movement of the anterior and/or posterior muscle-fascia junctions of the TrA muscle (Chen et al. 2015a, 2014; Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Jhu et al. 2010; Murakami et al. 2011). Four studies analysed the sliding of the anterolateral fasciae of the thigh (Condino et al. 2015a; Fox et al. 2014; Ichikawa et al. 2015; Langevin et al. 2007) – the fascia lata and the epimysial fascia of the quadriceps muscle, particularly the VL fascia (Ichikawa et al. 2015). For the crural region, the research included three studies that approached the mobility of the crural fascia and the gastrocnemius epimysial fascia (Cruz-Montecinos et al. 2015, 2016; Luomala et al. 2014).

3.2.4. US equipment characteristics

Several US devices equipped with linear or curvilinear array transducers, with distinct central frequencies and operating in B-mode, 3D B-mode or B-mode with elastography were used across the included studies.

The thoraco-lumbar (Engell et al. 2016; Griefahn et al. 2017; Langevin et al. 2011; Tu et al. 2016), femoral (Condino et al. 2015a; Fox et al. 2014; Ichikawa et al. 2015; Langevin et al. 2007) and crural (Cruz-Montecinos et al. 2015, 2016; Luomala et al. 2014) regions were always assessed with linear array transducers, while both curvilinear (Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007) and linear (Chen et al. 2015a, 2014; Crommert et al. 2017; Jhu et al. 2010; Murakami et al. 2011) array transducers were used to evaluate the abdominal region fasciae.

Most articles presented the US transducer frequency ranges, which overall varied from 4MHz to 15MHz. However, specific acquisition frequencies were rarely reported. One paper (Engell et al. 2016) revealed the acquisition frequency (10MHz) used in the thoracolumbar region to assess the TLF, and another (Murakami et al. 2011) mentioned

an acquisition frequency of 7.5MHz to visualise the sliding of the TrA anterior muscle-fascia junction.

The US acquisition depth data were also scarce. A specific acquisition depth of 4cm was reported in two studies of the thoracolumbar region fasciae (Engell et al. 2016; Langevin et al. 2011) and in one study evaluating the anterior thigh perimuscular fascia (Langevin et al. 2007). For the crural region fasciae, Cruz-Montecinos et al. (2015, 2016) described acquisition depths of 39mm in both their studies (Cruz-Montecinos et al. 2016, 2015). Jhu et al. underline that the acquisition depth to assess the TrA anterior muscle-fascia junction was "automatically adjusted by the scanning depth" (Jhu et al. 2010).

The available data revealed that B-mode was the imaging mode employed in most of the studies (Chen et al. 2015a, 2014; Crommert et al. 2017; Cruz-Montecinos et al. 2016, 2015; Griefahn et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Ichikawa et al. 2015; Jhu et al. 2010; Luomala et al. 2014; Murakami et al. 2011). 3D B-mode (Condino et al. 2015a; Tu et al. 2016) and B-mode with elastography (Engell et al. 2016; Fox et al. 2014; Langevin et al. 2011, 2007) were also used to explore fascial sliding of the thoracolumbar and femoral region fasciae, while the abdominal and crural region fasciae were explored with standard B-mode only. Luomala et al. (2014) also used B-mode with elastography to assess fascial stiffness (Luomala et al. 2014).

3.2.5. Subjects positioning and procedures to induce fascial sliding mobility

The subjects positioning depended on the procedure used to induce the fascial layers' mobility. Globally, the participants were supine, supine-crook/hook lying, prone-lying, sitting, standing and in lateral decubitus. There were used several procedures to induce fascial layers' mobility, which involved active and passive movements, passive manoeuvres, passive therapeutic techniques and passive treatment techniques combined with passive and active movements.

In the thoracolumbar region there was no pattern, and there were studies evaluating the subjects in prone-lying (Engell et al. 2016; Langevin et al. 2011), standing (Tu et al. 2016) and sitting (Griefahn et al. 2017) positions. Thoracolumbar flexion movements were used to induce fascial sliding either actively (Griefahn et al. 2017), passively using a motorized articulated table (Langevin et al. 2011) or by combining active lumbar flexion with Kinesiotape® (Tu et al. 2016). On the other hand, Engell et al. (2016) applied a passive manoeuvre to induce tension in the thoracic paraspinal tissue layers (Engell et al. 2016).

In most studies of the abdominal region the subjects were assessed supine (Hides, Wong, et al. 2007; Murakami et al. 2011) or supine-crook/hook lying (Chen et al. 2015a, 2014; Hides, Miokovic, et al. 2007; Jhu et al. 2010), but one study evaluated them standing (Crommert et al. 2017). The TrA activation, performed through an abdominal drawing-in manoeuvre (ADIM), was the main procedure used to induce fascial sliding (Chen et al. 2015a, 2014; Hides, Miokovic, et al. 2007; Jhu et al. 2010; Murakami et al. 2011). Chen et al. (2014) have also applied a passive myofascial release technique (Chen et al. 2014), and in the study by Crommert et al. (2017), the fascial slide was induced by "holding both arms symmetrically while standing, in flexed and extended shoulder static positions, with a dumbbell in each hand" (Crommert et al. 2017).

To assess the femoral region fasciae, the participants were positioned in lateral decubitus (Ichikawa et al. 2015) or supine (Condino et al. 2015a); 2 studies (Fox et al. 2014; Langevin et al. 2007) did not specify the positioning, though it is possible to presume that the subjects were supine-lying. The procedures used to induce the fascial layers' mobility included passive treatment techniques (myofascial release and hot pack therapy) combined with passive knee flexion movement for VL deep fascia (Ichikawa et al. 2015), robotic needling to evaluate the anterior thigh perimuscular fascia (Fox et al. 2014; Langevin et al. 2007), and active isometric knee extension to study the fascia lata mobility (Condino et al. 2015a).

In the studies of the crural region fasciae, the subjects were analysed in a sitting (Cruz-Montecinos et al. 2015, 2016) or prone-lying position (Luomala et al. 2014). The procedures used to induce fascial sliding included "local" active dorsi- and plantar-flexion movements combined with treatment procedures (Fascial Manipulation^{TM}) (Luomala et al. 2014), maximal active cervical spine flexion (Cruz-Montecinos et al. 2016) and active pelvic anteversion "over a distance" (Cruz-Montecinos et al. 2015).

3.2.6. Measurement sites and procedures used to standardize the US probe location

The studied fasciae were assessed at different sites and the US transducer location was retained either manually (55.6%; n=10) or by means of a fixing device (44.4%; n=8).

The TLF was assessed 2 or 3cm laterally to the midline at the level of the L2-L3 intervertebral space (Griefahn et al. 2017; Langevin et al. 2011; Tu et al. 2016) and Engell et al. (2016) placed the transducer 2cm laterally to the T7 segment midline to investigate the thoracic paraspinal tissues (Engell et al. 2016). Every study used a different procedure to standardize the US probe location by fixing one of its ends to the participants' skin

with surgical tape (Langevin et al. 2011), with some type of template structure (Griefahn et al. 2017; Tu et al. 2016) or with a clamping system (Engell et al. 2016).

For the abdominal region imaging procedures, all the authors manually handled the transducers and the level of the umbilicus was the main anatomical reference (Chen et al. 2015a, 2014; Jhu et al. 2010; Murakami et al. 2011), with the exception of Crommert et al. (2017) that used the 11th costal cartilage and the iliac crest (Crommert et al. 2017). However, to standardise the transducer position and to accomplish the fascial mobility measurements, different tactics were used. These included: 1) matching anatomic references (like the anterior and the posterior myofascial insertions of the TrA muscle) with the outer edges of the US image (Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Jhu et al. 2010; Murakami et al. 2011); 2) using external markers on the participants skin (Murakami et al. 2011) such as "nylon threads, made of US echo-absorptive material, attached to the participant's abdomen with cellotape to generate a reference line on the US image" (Chen et al. 2015a, 2014; Jhu et al. 2010); or 3) via a belt with a hole cut out that exactly fitted the transducer, wore by the participants to help minimize the transducer movement (Crommert et al. 2017).

In the femoral region, the US transducers were positioned half way between the greater trochanter and the lateral epicondyle of the femur for VL deep fascia (Ichikawa et al. 2015) and ileo-tibial band (fascia lata) assessment (Condino et al. 2015a); and "18cm superior to the middle of the superior edge of the patella" (Langevin et al. 2007) or "between rectus femoris and VL muscles, 15cm rostral to the patella and over the belly of the rectus femoris" (Fox et al. 2014) for evaluation of the anterior thigh perimuscular fascia. The probe positions were standardised by a fixing device (Condino et al. 2015a; Fox et al. 2014) or by placing aluminium tape on the patient's skin, which "appears as a reference black vertical shadowed band on the US image to stabilize the position and orientation of the probe" (Ichikawa et al. 2015).

In order to analyse the deep fascia in the calf area, the transducers were positioned over the lateral (Luomala et al. 2014) and medial (Cruz-Montecinos et al. 2015, 2016) bellies of the gastrocnemius muscle and the positions were standardized by a black marked spot on the skin (Luomala et al. 2014) or by means of a fixing device (Cruz-Montecinos et al. 2015, 2016).

3.2.7. Outcome measures and fascial sliding analysis methods

A multiplicity of terms was used to describe the outcome measures which traduced the sliding between fascial layers, namely: "shear strain" (Langevin et al. 2011), "paracutaneous tissue translation" (Tu et al. 2016), (fascial) "mobility" (Griefahn et al. 2017) and "relative shear deformation" (Engell et al. 2016) for the thoracolumbar fasciae; (fascial) "slide" or "sliding" (Chen et al. 2015a, 2014; Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Jhu et al. 2010) and "distance of fascia motion" (Murakami et al. 2011) for the abdominal fasciae; "displacement" (Langevin et al. 2007), "axial and lateral tissue displacement" and "shear strain between layers" (Fox et al. 2014), "fascial gliding motion" (Ichikawa et al. 2015) and "fascial layers mobility" (Condino et al. 2015a) for the femoral region fasciae; and "fascial gliding" of the superficial, middle and deepest sublayers of the deep fascia (Luomala et al. 2014) and "deep fascia displacement" (Cruz-Montecinos et al. 2015, 2016) for the crural region fasciae.

To analyse and quantify the fascial mobility, US videos were recorded in all the studies and posteriorly analysed through distinct strategies. Cross-correlation software techniques using automatic tracking algorithms were employed to measure thoracolumbar (Engell et al. 2016; Griefahn et al. 2017; Langevin et al. 2011; Tu et al. 2016), femoral (Condino et al. 2015a; Fox et al. 2014; Langevin et al. 2007) and crural (Cruz-Montecinos et al. 2015, 2016) regions fasciae sliding motion. On the other hand, start (usually in a relaxed muscular state) and end (usually in a target muscular contraction state) US frames comparison were used to measure the sliding motion of abdominal (Chen et al. 2015a, 2014; Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Jhu et al. 2010; Murakami et al. 2011), femoral (Ichikawa et al. 2015) and crural (Luomala et al. 2014) region fasciae. A note for the fact that the studies targeting the thoracolumbar region only used cross-correlation software techniques and the abdominal region studies only used start and end frames comparison, while both methods were used in the studies of the femoral and crural regions fasciae.

3.2.8. Reliability of fascial sliding measurements

Eight of the eighteen studies in this review analysed the reliability of the fascial sliding outcome measures. In one of the four thoracolumbar region papers, Langevin et al. (2011) concluded that the intra-rater reliability of US measurements of TLF shear strain calculations was high (ICC=0.98) (Langevin et al. 2011). Four out of seven studies (Chen

et al. 2015a; Hides, Miokovic, et al. 2007; Jhu et al. 2010; Murakami et al. 2011) assessed the reliability of the US fascial sliding measures used in the abdominal region and revealed overall good to excellent reliability. In particular, it was studied the reliability of measuring the slide of the anterior abdominal fascia by a novice physical therapist rater and the results yielded "very high reliability across measurements from the same image, but very low reliability across images and across different days" (Hides, Miokovic, et al. 2007).

The reliability of the US measurements for the femoral fasciae mobility was accessed by Ichikawa et al. (2015), who aimed to compare the effects of myofascial release and hot pack therapy on fascial gliding of the deep fascia of the VL muscle by measuring tissue changes through US. The authors found high reliability of the US measurement which used an external marker as a reference point (Ichikawa et al. 2015). The work developed by Condino et al. (2015) proposed the application of "3D US screening for the *in vivo* 3D fascial motion assessment" and presented an innovative semiautomatic method allowing, for each fascial layer, "the estimation and the validation of a 3D motion vector field describing the displacement of salient fascial features during a muscular contraction"; the validation process to evaluate the reliability of salient fascial feature matches consisted of inter-rater agreement among three experienced radiologists, and the authors concluded that the results "preliminarily demonstrate the viability of the proposed method for estimating the 3D fascial motion from 3D US datasets" (Condino et al. 2015a).

Only one article assessed the reliability of the US measurements in the crural region. Cruz-Montecinos et al. (2015) found very high reliability between manual tracking and tracking with the Lucas–Kanade pyramidal algorithm (ICC = 0.973) and good intra-rater reliability for the model of myofascial connectivity over a distance between the pelvis and leg (ICC = 0.903) (Cruz-Montecinos et al. 2015).

4. DISCUSSION

4.1. Study designs and levels of evidence

The present review highlights the cross-sectional as the study design elected to explore deep fascia sliding *in vivo*, especially for diagnosis purposes. In fact, most of the included articles explored diagnosis questions, which is plausible given the novelty of the subject and the need to develop valid and reliable diagnostic tools for later application in experimental clinical settings. A lack in RCTs on the theme is also revealed. The single

RCT included analysed the TLF sliding in a LoE II treatment benefits study. All other papers that focused on treatment benefits scored lower levels of evidence.

4.2. Sample characteristics

In general, the study samples included in this review were small, particularly those assessing the femoral and crural regions fasciae ($n \leq 17$). Most studies included more men than women, and the crural region papers just studied men. Langevin et al. (2011) concluded that "appears to be some sex-related differences in TLF shear strain that may also play a role in altered connective tissue function" (Langevin et al. 2011). Thus, special attention should be given to possible sex-related influences, such as hormonal differences, in fascial layers sliding.

Studied samples also included mostly healthy young subjects. On this subject, Cruz-Montecinos et al. (2015) questioned the replicability of their results, as the studies focused only on young men with a healthy weight, since under other conditions the US soft tissue artefacts could generate a greater range of error (Cruz-Montecinos et al. 2015). In fact, a body mass index within the recommended parameters was one of the inclusion criteria in several studies (Chen et al. 2015b, 2014; Cruz-Montecinos et al. 2015; Griefahn et al. 2017; Tu et al. 2016). So, it is relevant to understand if different body compositions, clinical conditions or ages influence fascial mobility and if the US methods present the same levels of reliability and diagnostic accuracy.

4.3. Studied fasciae

The abdominal (TrA fascia) and thoracolumbar fasciae (TLF and epimysial fasciae of the erector spinae) were the most studied. Three papers addressed the TLF posterior layer through trunk flexion movements and one analysed the fascial layers of the thoracic paraspinal muscles (the posterior layer of the TLF and the epimysial fasciae of the erector spinae) by applying a passive manoeuvre. On the other hand, seven articles studied the TrA anterior and/or posterior muscle-fascia junctions sliding mostly through abdominal drawing-in manoeuvres. The major interest in the study of the properties of this region may be justified by their role in lumbar segmental control and low back pain. In fact, Stecco (2015) explains that the TLF is a significant aponeurotic fascia that plays an essential role in the transfer of loads between the trunk and the extremities and helps to maintain stability of the lumbosacral area (Stecco 2015). It is formed by a posterior layer (located in the lumbar region just under the subcutaneous tissue) and an anterior layer

which fuse to form the lateral raphe (Stecco 2015). In turn, the large muscles of the abdomen [external oblique (EO), internal oblique (IO), TrA and rectus abdominis) have thin epimysial fasciae with proprioceptive functions and aponeurotic fasciae with force transmission functions which fuse with each other anteriorly to form the rectus sheath (Stecco 2015). Posteriorly, the fasciae of the IO and TrA muscles are inserted to the anterior layer of the TLF (Stecco 2015). This anatomical continuity between the abdominal muscles and the TLF assures the synchronization between the anterior and posterior muscular–fascial elements, playing an important role in lumbar segmental control (Stecco 2015).

The remaining studies explored the lower limb fascia. The deep fascia of the lower limbs can be considered as a support stocking that envelops the entire foot (plantar fascia and dorsal fascia), leg (crural fascia) and thigh (fascia lata) as a unique fibrous layer, proximally connected to the pelvis and abdomen by the myofascial insertions of the gluteus maximus, tensor fasciae latae, EO, IO and TrA muscles (Stecco 2015). Four studies analysed the sliding of the anterolateral fasciae of the thigh, the fascia lata and the epimysial fascia of the quadriceps muscle (in particular the VL), essentially through knee extension movements or robotic needling. Three studies addressed the mobility of the crural fascia and the gastrocnemius epimysial fascia, resorting to plantar/dorsal flexion movements.

Emphasis should be given to the fact that there have been found no studies addressing the thorax, upper back and the upper limb fasciae. It is not clear that the conclusions about the measurement of fascial sliding *in vivo* drawn from the studies composing this review can be extrapolated to other regions. This is in line with Condino et al. (2015), which considered that "other anatomical regions must be analysed and specific protocols for the acquisition of 3D US musculoskeletal datasets in each anatomical region should be defined" (Condino et al. 2015a). These authors also signed that further refinements in their 3D model are needed "to improve the effectiveness of the algorithm in specific anatomical regions" and moreover that "the muscular contraction tasks must be standardized".

In this regard, it should be noted that the option to include only studies related to deep muscular fascia conditioned the US assessment of other fascial elements, which was a matter for debate during this review. For example, the eligibility of studies on the mobility of aponeurosis was strongly discussed, namely the aponeurosis of the VL (Bojsen-Moller et al. 2003), semitendinosus and semimembranosus (Kellis 2016; Kellis,

Patsika, and Karagiannidis 2013) or tibialis anterior muscles (Raiteri, Cresswell, and Lichtwark 2016). However, those studies were not included in the review as they did not address the mobility of deep (muscular) fascia. Instead, they were directed to tendons or aponeuroses mobility which, according to Stecco (2015), are anatomically distinct structures from deep fasciae. According to the author, the difference between aponeurosis and aponeurotic fascia is based on the anatomical distinction concerning the multi-layered structure with collagen fibres in different directions of aponeurotic fasciae – deep muscle fascia, which differentiates it from aponeurosis – a type of flattened tendon that contains unidirectional parallel-arranged collagen fibres (Stecco 2015). Nevertheless, since they are all functionally interconnected, the inclusion or exclusion of these studies might be controversial given that they might add important facts on this issue. In fact, though not included in this analysis, it becomes important to reference a few studies that used US Doppler imaging to evaluate the excursion of the flexor digitorum tendons in the carpal region relative to the subsynovial connective tissue, and the relationship between changes in the resultant shear forces and carpal tunnel pathology (Van Doesburg et al. 2012; Kociolek and Keir 2015; J. H. Korstanje et al. 2012; J. W. H. Korstanje et al. 2012; Tat, Kociolek, and Keir 2013; Tat, Wilson, and Keir 2015; Yoshii et al. 2009), given that this US imaging method could add valuable information for the fascial sliding analysis. In addition, several articles that evaluated the mobility of visceral fasciae were found, such as the pre-tracheal and the retropharyngeal (Tozzi et al. 2011), the renal (Tozzi, Bongiorno, and Vitturini 2012; Tozzi et al. 2011) and the pelvic fasciae (Baron et al. 2018; Dietz et al. 2004; Piccolboni, Ciccone, and Settembre 2009; Spens, Bird, and Bright 2018; Tozzi et al. 2011), particularly in post-caesarean women in whom the visceral slide (i.e. the “back and forth” movement of the peritoneal layer in rhythm with respiration in relation to the steady inner fascial layer) was evaluated as a predictor of the presence of post-surgical adhesions or the development of complications in future surgeries (Baron et al. 2018; Piccolboni et al. 2009; Spens et al. 2018).

4.4. US equipment characteristics

The authors of the included studies used a multiplicity of US devices and different types of transducers. In this review, thoracolumbar (Engell et al. 2016; Griefahn et al. 2017; Langevin et al. 2011; Tu et al. 2016), femoral (Fox et al. 2014; Ichikawa et al. 2015; Langevin et al. 2007) and crural region fasciae (Cruz-Montecinos et al. 2015, 2016; Luomala et al. 2014) were visualized through linear array transducers, while both linear

(Chen et al. 2015a, 2014; Crommert et al. 2017; Jhu et al. 2010; Murakami et al. 2011) and curvilinear transducers (Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007) were used in the abdominal region assessments. It is known that the linear array probe is the workhorse transducer for musculoskeletal imaging, while the curvilinear arrays are the tools of choice for most general imaging applications involving the abdomen (Adams, 2013).

Regarding the frequency and depth of acquisition, emphasis should be given for the fact that specific data were rarely available. Only three studies reported the depth of 4cm to assess the TLF (Engell et al. 2016; Langevin et al. 2011) and the thigh fascia (Langevin et al. 2007), while two studies revealed 3.9cm of depth for the crural fascia imaging (Cruz-Montecinos et al. 2016, 2015). Specific information would be very useful to allow comparisons and to standardize the US evaluation methods for different anatomical structures, namely deep fasciae.

The frequency ranges of the US probes used in the included articles varied from 4MHz to 15MHz. High-frequency probes seem to provide high-quality images at a low depth, whereas low-frequency probes are best at giving deeper structure images, though there may be a compromise in image clarity (Adams 2013). Adams (2013) explains that "the vast majority of musculoskeletal US work is done at 10MHz, with a smattering at 12MHz for the more superficial structures (within 2cm depth) and some at 8MHz for slightly deeper structures (4–5cm depth)" (Adams 2013). Bogaerts et al. (2017) used a high-frequency (21MHz) US acquisition system to explore the intratendinous deformation patterns of normal Achilles tendons *in vivo* by means of US based speckle tracking (Bogaerts et al. 2017). Similarly, fascial mobility research may consider the use of high-frequency transducers, allowing the tracking of speckle patterns of smaller structures and henceforth a better description of tissue deformation.

Overall, conventional B-mode was the main US imaging mode used to assess fascial sliding mobility (Chen et al. 2014, 2015a; Crommert et al. 2017; Cruz-Montecinos et al. 2016, 2015; Griefahn et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Ichikawa et al. 2015; Jhu et al. 2010; Murakami et al. 2011). In fact, B-mode is the standard mode of US devices and produces a bi-dimensional grayscale cross-sectional image representing tissue and organ boundaries within the body (Peter Hoskins; Kevin Martin; Abigail Thrush 2010). However, this US mode does not reproduce the 3D characteristic of fascial structures. It is worth mentioning the development of a 3D US

evaluation model by Condino et al. (2015), specifically for the assessment of fascial mobility (Condino et al. 2015a; Turini et al. 2015).

Elastography is a computational technique utilizing cross-correlation methods to quantify tissue motion based on a series of US images acquired in rapid succession (Langevin et al. 2011). It measures mechanical strain changes in tissues, based on the principle that US signals coming from a structure in response to an external compression (mechanical or acoustic wave) is an indirect measure of its biomechanical properties (Fusini et al. 2017; Langevin et al. 2011; Luomala et al. 2014). This method was used by Loumala et al. (2014) to assess fascial stiffness ("the axial elasticity or compressibility") (Luomala et al. 2014), while in other studies it was also used to measure fascia lateral motion, allowing an estimation of fascial sliding (Engell et al. 2016; Fox et al. 2014; Langevin et al. 2011, 2007).

4.5. Subjects positioning and procedures to induce fascial sliding mobility

In the studies' protocols composing this review, the subjects positioning depended on the procedure used to induce the fascial layers' mobility. These procedures involved active and passive isolated movements, passive manoeuvres, passive therapeutic techniques, and passive treatment techniques combined with passive and active movements. However, only two studies assessed fascial force transmission over a distance through active movements (Cruz-Montecinos et al. 2015, 2016). On this subject, two systematic reviews focused on identifying scientific evidence on the transmission of tensile force along myofascial chains based on dissection and *in vivo* studies (Krause et al. 2016; Wilke et al. 2016). Their authors suggested that future research should focus on the *in vivo* function of myofascial continuity during the application of actively or passively isolated tissue tension, including in exercise, prevention and rehabilitation scenarios (Krause et al. 2016; Wilke et al. 2016).

4.6. Measurement sites and procedures used to standardize the US probe location

In all the included studies, the US measurements of fascial sliding mobility were performed in a single place. This is a limitation underlined by some authors (Condino et al. 2015a; Cruz-Montecinos et al. 2015; Ichikawa et al. 2015; Langevin et al. 2011; Murakami et al. 2011; Tu et al. 2016), along with the limited size of the US probe (Chen et al. 2014; Ichikawa et al. 2015; Langevin et al. 2011; Murakami et al. 2011; Tu et al. 2016). For instance, Chen et al. (2014) explained that the changes that occurred at anterior

and posterior sites of muscle-fascial junction of the TrA could not be measured simultaneously by US due to the limitation of the transducer (Chen et al. 2014). Different possibilities exist that could be used in fascial sliding research to evaluate the fascial behaviour in more than one place, including over a distance. Cruz-Montecinos et al. (2015) suggest the possibility of incorporating more than one transducer, allowing for simultaneously determining the fascia displacement over a distance (Cruz-Montecinos et al. 2015). On this subject, it is also worth to mention Kellis et al. (2013) and Kellis (2016) who used two synchronized US probes to image the movement of hamstrings tendons (Kellis 2016; Kellis et al. 2013). In turn, Raitieri et al. (2016) studied the tibialis anterior central aponeurosis width and length through a 3D-US method in which transverse sweeping scans were performed while video capture of the probe position was monitored and synchronized with the US images (Raiteri et al. 2016). However, such strategies may be methodologically more demanding and less viable in clinical practice.

Probe handling is essential to the proper performance of an accurate and repeatable US exam (Adams 2013). Diagnostic accuracy of US measurements depends on the operator's technical capabilities (Erkonen, W. E., & Smith 2009; Soni, N., Arntfield, R., & Kory 2015), since it manually controls the transducer, so that variations in the compression pressure, orientation or direction of the probe can modify the resulting images (operator bias) (Drakonaki et al. 2009). The undesirable movement of the transducer and its impact on the slide measurements is a key concern reported by some authors (Crommert et al. 2017; Engell et al. 2016; Hides, Miokovic, et al. 2007), given that the measurements aim to identify changes in the anatomic location over time, based on a sonogram that was kept in the same position (Crommert et al. 2017). Engell et al. (2016) stressed that the problems with out-of-plane motion may interfere with the fascial movement software analysis method (speckle tracking) (Engell et al. 2016). About this subject, Crommert et al. (2017) stated that “standardized placement of the US transducer and keeping it still during recordings are critical in sonography” (Crommert et al. 2017). To overcome this potential source of bias there have always been efforts to standardize the US probe position at the site chosen for measurement. Several fixation procedures were used, such as fixing one of the probe’s ends to the participants’ skin with surgical tape (Langevin et al. 2011), building a template structure (Griefahn et al. 2017; Tu et al. 2016) or using a custom probe fixing device (Condino et al. 2015a; Cruz-Montecinos et al. 2015, 2016; Engell et al. 2016; Fox et al. 2014). When the US probe was manipulated, other strategies were used to standardize the measurement position, such as matching

anatomic references with the outer edges of the US image (Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Jhu et al. 2010; Murakami et al. 2011) or using external markers as reference points for the measurements made on the recorded US images (Chen et al. 2015a, 2014; Ichikawa et al. 2015; Jhu et al. 2010; Luomala et al. 2014; Murakami et al. 2011).

4.7. Outcome measures and fascial sliding analysis methods

Several terminologies were used to describe the fascial sliding outcome measures. However, in order to facilitate the comparison between studies, uniformity of terminology related to fascia is necessary. In this review, the term "sliding" was used to summarize all the terminology that refers to the mobility between fascial collagen layers among themselves and in relation to the underlying muscles and organs (Chaitow 2017; Cowman et al. 2015; Roman et al. 2013; Stecco 2015).

The technological evolution of the US equipment and the software with which the analysis and measurements are made, has allowed greater diagnostic and methodological rigor over the years. Through the analysis of the works included in this review, it can be observed that the effective measurement of fascial sliding mobility through US has used two main techniques. The first consists of superimposing and comparison between the initial and final position of anatomical structures and/or its relation with external references ("start and end frames comparison") – used in 9 papers (Chen et al. 2015a, 2014; Crommert et al. 2017; Hides, Miokovic, et al. 2007; Hides, Wong, et al. 2007; Ichikawa et al. 2015; Jhu et al. 2010; Luomala et al. 2014; Murakami et al. 2011). The second refers to cross-correlation analysis techniques through automatic tracking software algorithms that compare the movement of greyscale, speckle features between individual US frames within specified regions of interest (also known as speckle tracking) ("cross-correlation software techniques") – used in 9 papers (Condino et al. 2015a; Cruz-Montecinos et al. 2015, 2016; Engell et al. 2016; Fox et al. 2014; Griefahn et al. 2017; Langevin et al. 2011, 2007; Tu et al. 2016). Among the cross-correlation techniques, emphasis should be given to a semiautomatic method, based on the generation of a motion vector field describing, for each fascial layer, the displacement of salient fascial features during a muscular contraction, enabling a 3D US evaluation of fascia mobility *in vivo* (Condino et al. 2015a).

US techniques measuring mobility have been used in various body tissues. A systematic review carried out by Kasehagen et al. (2018) about peripheral nerve excursion

found that speckle tracking (cross-correlation software technique) was the most commonly reported protocol for US imaging measurements of nerve excursion *in vivo*, having been used in 13 of the 18 included studies, followed by digital measurement of the change in nerve position between the first and final frames of US video recordings and, finally, the use real-time spectral Doppler US imaging to quantify nerve excursion (Kasehagen et al. 2018). Likewise, tendon excursion/displacement has also been extensively measured by speckle tracking cross-correlation techniques (An, Ph, and Amadio 2010; Bogaerts et al. 2017; Chen et al. 2004; Van Doesburg et al. 2012; J. H. Korstanje et al. 2012; J. W. H. Korstanje et al. 2012; Yoshii et al. 2009) and Doppler US imaging (Kociolek and Keir 2015; Oh et al. 2007; Sumi and Sato 2008; Tat et al. 2013; Tat, Kociolek, and Keir 2015).

4.8. Reliability of fascial sliding measurements

The studies in this review revealed that both US methods ("start and end frames comparison" and "cross-correlation software techniques") are reliable tools to measure fascial sliding *in vivo* at specific anatomic locations, which is consistent with the reliability found for the use of US to evaluate the peripheral nerve excursion (Kasehagen et al. 2018).

Cross-correlation software techniques showed highly reliable to measure the sliding of the TLF at the level of the L2-L3 interspace (Langevin et al. 2011), and the sliding between the crural fascia and the gastrocnemius epimysial fascia over the medial gastrocnemius muscle belly (Cruz-Montecinos et al. 2015). Cruz-Montecinos et al. (2015) found very high reliability between manual tracking and automatic tracking (Lucas–Kanade pyramidal algorithm) (Cruz-Montecinos et al. 2015). Furthermore, superimposing and comparison of start and end US frames was considered reliable to assess the sliding of the TrA at the anterior (Chen et al. 2015a; Hides, Miokovic, et al. 2007; Jhu et al. 2010; Murakami et al. 2011) and posterior (Chen et al. 2015a; Murakami et al. 2011) muscle-fascia junctions at the level of the umbilicus. Both methods were considered reliable to assess the fascia lata sliding midway between the greater trochanter and lateral epicondyle of the femur (Condino et al. 2015a; Ichikawa et al. 2015). Ichikawa et al. (2015) found high reliability of the comparison method which used an external marker as a reference point for the measurement (Ichikawa et al. 2015). On the other hand, the validation process to evaluate the reliability of salient fascial feature matches in the 3D US screening for the *in vivo* 3D fascial motion assessment model developed by

Condino et al. (2015) consisted of inter-rater agreement among three experienced radiologists, and the authors concluded that the results "preliminarily demonstrate the viability of the proposed method for estimating the 3D fascial motion from 3D US datasets" (Condino et al. 2015a).

Despite these favourable results, care should be given when extrapolating the reliability of the US methods to other fasciae.

4.8. Limitations

Despite the efforts to objectively define the boundaries of this review to deep fasciae, their sliding mobility and respective *in vivo* US evaluation methods, the heterogeneity of the terminology used by the different authors to describe the fascial structures and its sliding mobility may have influenced the articles selection and analysis. In fact, the subject of fascia has generated a passionate debate between clinical specialists and researchers, which has justified the creation of "The Fascia Nomenclature Committee" to reach consensus on terminology related to fascia (Adstrum et al. 2017; Stecco et al. 2018).

Although it was decided to limit the scope of this review to deep fascial sliding, it should be stressed the importance of other structures of the fascial system (such as aponeuroses, tendons or visceral fasciae) and fascial properties (such as its thickness, stiffness or state of hydration) which, together with the sliding capacity, are involved in the normal functioning of the fascial system and, therefore, in efficient movement (Stecco 2015; Zügel et al. 2018).

5. CONCLUSIONS

US sliding measurements have used methods of superimposing and comparison between start and end frames of an US video recording and cross-correlation analysis through automated tracking algorithms, including a specific 3D B-mode model developed to assess fascial mobility. These methods had proven to be reliable tools to measure sliding between TLF, TrA muscle-fascia junctions, fascia lata and crural fascia and the adjacent epimysial fasciae. However, the papers included in this review presented heterogeneous terminologies, research questions, participant populations and methodologies. Thus, attention must be paid when extrapolating the reliability of those methods to other anatomical regions or populations. Moreover, high quality research is necessary to determine the reliability of the current methods to assess other fasciae and evaluate the

influence of aging, sex-related characteristics, body composition or specific clinical conditions on fascial sliding measurements. Terminological and methodological standardization is mandatory and specific protocols are needed to assess each anatomical region so that the US assessment of fascial sliding *in vivo* can be used properly in research and clinical practice, namely in exercise, prevention or rehabilitation scenarios.

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