Universidade de Aveiro
2021

Cleide Sofia Lemos Martins

In vivo nerve excursion and strain in asymptomatic and symptomatic individuals: a systematic review

Deslize e tensão neural *in vivo* em indivíduos assintomáticos e sintomáticos: revisão sistemática

2021

Universidade de Aveiro
Ano 2021

Cleide Sofia Lemos Martins

In vivo nerve excursion and strain in asymptomatic and symptomatic individuals: a systematic review

Deslize e tensão neural in vivo em indivíduos assintomáticos e sintomáticos: revisão sistemática

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Fisioterapia Musculoesquelética, realizada sob a orientação científica da Doutora Anabela Gonçalves da Silva, Professora Adjunta da Escola Superior de Saúde da Universidade de Aveiro

Dedico este trabalho à minha família pelo apoio e, sobretudo, ao Pedro, o meu suporte, pela força e compreensão ao longo destes últimos meses.

o júri

presidente	Prof. Doutora Alda Sofia Pires de Dias Marques Professora Coordenadora S/ Agregação, Universidade de Aveiro
arguente	Prof. Doutor Raul Oliveira Professor Auxiliar, Faculdade de Motricidade Humana da Universidade de Lisboa
orientador	Prof. Doutora Anabela Gonçalves da Silva Professora Adjunta, Universidade de Aveiro

palavras-chave Deslize neural; Tensão; Sintomático; Assintomático

resumo

Introdução: O conhecimento da influência do movimento articular na biomecânica neural, particularmente tensão e excursão, é importante para a prática clínica. No entanto, a evidência é escassa. O objetivo desta revisão é sintetizar e caracterizar a evidência existente sobre a quantidade e direção da excursão dos nervos periféricos e a magnitude da tensão em resposta ao movimento articular em indivíduos assintomáticos e sintomáticos e determinar se há diferenças entre estes. Métodos: A pesquisa foi realizada na Pubmed, Physiotherapy Evidence Database (PEDro), Academic Search e os artigos completos foram avaliados, as informações foram extraídas e a sua qualidade metodológica foi avaliada. Resultados: Trinta e três estudos foram incluídos nesta revisão sistemática que avaliaram o nervo mediano (n = 17), o nervo cubital (n = 2), o nervo radial (n = 1), o nervo ciático (n = 8), o nervo tibial (n = 4) e o nervo femoral (n = 1). O movimento normal do nervo pode ir até 50,2 mm de excursão longitudinal. Participantes com Diabetes Mellitus apresentaram excursão do nervo tibial alterada em comparação com indivíduos assintomáticos. Participantes com dor não específica no membro superior e dor referida no membro inferior não apresentam diferenças na mobilidade neural comparativamente a indivíduos assintomáticos. Conclusão: A excursão do nervo depende do posicionamento dos membros, do movimento articular realizado, do local de medição e da presença de restrição do movimento do nervo ou não.

keywords Nerve Excursion; Strain; Symptomatic; Asymptomatic

abstract Introduction: Currently, the understand of the influence of joint movement on neural biomechanics, particularly strain and excursion is important for clinical practice. However, studies that evaluate this are in lack. The aim of this review is to synthesize and characterize existing evidence on the quantity and direction of peripheral nerves excursion and the magnitude of strain in response to joint movement in both asymptomatic and symptomatic individuals and to determine if there are differences between asymptomatic and symptomatic individuals. Methods: Studies were sought using Pubmed, Physiotherapy Evidence Database (PEDro), Academic Search Complete, Scopus, ScienceDirect, Web of Science and Scielo. Titles and abstracts were screened, full reports were assessed for potentially eligible studies, the information was extracted and its methodological quality was assessed. Findings: Thirty-three studies were included in this systematic review that assessed median nerve (n=17), cubital nerve (n=2), radial nerve (n=1), sciatic nerve (n=8), tibial nerve (n=4) and femoral nerve (n=1). Normal nerve movement can be up to 50.2mm of longitudinal excursion. Participants with Diabetes Mellitus presented altered tibial nerve excursion compared to asymptomatic individuals. Participants with non-specific arm pain and spinally referred leg pain had no restriction of nerve movement compared to asymptomatic participants. Conclusion: Nerve excursion depends on the positioning of limbs or trunk, on the joint movement performed, the site of measurement and the presence of pathology.

Index

List of Figures

List of Tables

List of abbreviations

ICC – Intraclass correlation coefficient

SEM – standard error of measurement

NSAP – Non-specific arm pain

CTS – Carpal tunnel syndrome

DM – Diabetes mellitus

SLR – Straight leg raise

NU – Normalized Units

1. Introduction

The nervous system can transmit the nervous impulses for a wide variety of functions and, simultaneously, adapt during body movements. The nervous system conducts the impulses to and from the other structures of the body, and this capacity requires normal biomechanics of the nervous tissue and the surrounding tissues [1]. Under physiological conditions, the peripheral nervous system has adaptative mechanisms that allow it to support compressive, stretching, or torsion forces present in practically all movements without interference to its function [1–3].

Tensile stress may be applied either parallel or perpendicular to the length of the nerve, causing longitudinal or transversal stress in the nerve. When joint motion causes elongation of the nerve bed, the nerve is inherently placed under tensile stress and accommodates the stress by both elongating and gliding [4]. The deformation or change in nerve length induced by longitudinal tensile stress is called strain and is expressed typically as percent elongation. Displacement or gliding of a nerve relative to the surrounding nerve bed is called excursion. The excursion may occur in a longitudinal or transversal plan, or both and is measured in millimeters [4]. With limb movement, nerve excursion occurs first in the nerve segment immediately adjacent to the moving joint but tends to occur at nerve segments that are progressively more distant as limb movement continues [4]. The structure of the peripheral nervous system appears suited to accommodate joint movement with minimal increases in strain. For example, the connective tissue that surrounds the nerve controls and facilitates nerve movement, while also protecting it, and the fascicules that contain the nerve fibers follow an undulatory course with several branches promoting dispersion of forces [5]. Normal strain tolerances for peripheral nerve tissue is between 6% and 8%, with damage occurring at 11% strain, due to demyelination or axonal tears [4].

A previous systematic review on the effect of limb movement on nerve strain and excursion concluded that during *in vivo* limb movement complex biomechanical changes occur in peripheral nerves, with the longitudinal and transversal movement of the nerves and only minor strain changes [6]. Another systematic review aiming to characterize nerve movement in response to joint movement, concluded that a variety of factors impact the quantity and direction of nerve longitudinal gliding in response to joint movement, including the range of motion, the number of joints moving, the position of adjacent joints, and whether the movement shortens or elongates the nerve [7]. For example, simultaneous elbow extension and cervical ipsilateral lateral flexion induced 10.2 mm of median nerve gliding while simultaneous elbow extension and cervical contralateral lateral flexion induced 1.8 mm of median nerve gliding [8].

Impairment of the neural biomechanical properties of the peripheral nerves compromises their ability to adjust to movement and posture while maintaining their function and, therefore, may be a contributing factor to the multifactorial etiology of many peripheral neuropathies [3]. Each internal or external disturbance that prevents the nerve from gliding can cause increased tension in the nerve, which can disrupt neural functioning due to inadequate neural transport and abnormal metabolism, resulting in poor neural conduction [1,2]. For instance, impaired median nerve movement through the carpal tunnel or forearm is one of the most reported features of carpal tunnel syndrome [3]. Diabetic neuropathy is a good example whereby the axons in a peripheral nerve may become swollen, endoneurial fluid pressure increases, scar tissue may develop and the nerve's mechanical function is compromised [9]. Besides the findings on diabetes and carpal tunnel syndrome, changes in the normal biomechanics of the nervous system have been also associated with painful disorders such as cubital tunnel syndrome and hamstring disorders [10–12].

In 1984, Ryvenik described nerve compression. Compression of a nerve at high pressure for a prolonged period may damage the endoneurial blood vessels resulting in impaired vascularization and endoneurial edema. Compression may also induce deformation of the nerve fibers, leading to demyelination and blocking the axonal transport [13]. Changes in intraneural blood flow, vascular permeability, and axonal transport occur when a peripheral nerve is compressed at 30-50mmHg, but if nerves are subjected to repeated or prolonged compression at these pressure levels, the consequences may be persistent [13]. In carpal tunnel syndrome, the symptoms could be related to this compression [13]. Synovial tissue from patients with CTS revealed increased fibroblast density, collagen fiber size, and vascular proliferation, and decreased elastin content around the synovial vessels [14]. Biomechanically, patients with

CTS have reductions in longitudinal and transversal nerve excursion of the median nerve compared to controls [15,16].

The assessment of the peripheral nervous system should include an assessment of conduction (sensation, strength, and reflexes) as well as a mechanosensitivity component. Increased mechanosensitivity can induce pain and protective responses to movement. The heightened sensitivity in response to mechanical stimuli has been attributed to local inflammatory processes within the nerve that are specifically related to its connective tissue [17,18]. To evaluate mechanosensitivity components, physical therapists use neurodynamic tests. These tests stimulate mechanically and move neural tissues to evaluate their mobility and sensitivity to mechanical stresses [19]. The basic neurodynamic tests are the Straight Leg Raise (SLR), the Slump Test, the Prone Knee Bend (PKB) test, the Passive Neck Flexion (PNF), and the Upper Limb Neurodynamic Tests (ULNT) 1, 2 and 3, for median, radial and ulnar nerves, respectively [1].

Besides, physical therapists also use neural mobilization techniques, which are a movement-based therapy, applied manually or actively, whose objective is to attempt to restore the dynamic balance between the relative movement of neural tissues and surrounding mechanical interfaces, allowing reduced intrinsic pressures on the neural tissue and promoting optimum physiologic function [20,21]. Being part of conservative treatment, sliding and tension techniques of neural mobilization are used to produce a sliding movement between neural structures and adjacent nonneural tissues – sliding techniques – and restore the physical capabilities of neural tissues to tolerate movements that lengthen the nerve bed – tensioning techniques [22].

With a tensioning technique, nerve mobilization is obtained by moving 1 or more joints in such a manner that the nerve bed is elongated, forcing the nervous system to slide relative to its surrounding structures. In a sliding technique, at least 2 joints are moved simultaneously in a manner that movement at one joint elongates the nerve, and movement in the other joint shortens the nerve (Silva et al., 2014). Sciatic nerve excursion during a sliding technique (17.0± 5.2mm) is approximately fivefold higher than during a tensioning technique (3.2± 2.1mm) [23]. In a systematic review, Neto et al conclude that neural mobilization has moderate positive effects on lower limb flexibility in healthy subjects and large effects on pain and disability in patients with low back pain [24]. Another systematic review, also concluded that neural mobilization is effective in reducing pain and disability in certain neuromusculoskeletal conditions, such as tarsal tunnel syndrome and nerve-related low back pain [21]. Nevertheless, none of these systematic reviews was able to conclude on the effectiveness of neural gliding compared to neural tensioning, despite an apparent distinct impact of these techniques on nerve movement. This is likely to be due to an insufficient number of studies making directed comparisons for these two neural mobilization techniques. Furthermore, sliding techniques have been advocated because they are believed to expose the nervous system to less strain and greater mobilization, which might be of preference when nerve mechanosensitivity is increased [21].

Choosing the best technique in a specific nerve dysfunction or the best combination of movements to assess for neural mechanosensitivity is based on clinical reasoning and knowledge of nerve biomechanics both in asymptomatic and symptomatic individuals. Therefore, it is important to understand the influence of joint movement on neural biomechanics, particularly strain and excursion, and how these change with a different combination of movements for different nerves in both symptomatic and asymptomatic individuals. Therefore, this systematic review aims to synthesize and characterize existing evidence on the quantity and direction of peripheral nerves excursion and the magnitude of strain in response to joint movement in both asymptomatic and symptomatic individuals and to determine whether there are significant differences for excursion and strain between asymptomatic ad symptomatic individuals.

2. Methods

The Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines were followed in this review [25].

2.1 Data sources and searches

Studies were sought using Pubmed, Physiotherapy Evidence Database (PEDro), Academic Search Complete, Scopus, ScienceDirect, Web of Science and Scielo. The search was conducted on 30 of May of 2020 and included references published since 2000, once the previous systematic review [7] did not find any article before this year. The key words combinations used in the different databases are shown below - see table 1.

Table 1 - Combinations of key words in different databases

Expression	Combination
"Neural elongation" OR "neural stretching" OR "neural lengthening" OR "neural excursion" OR "neural tension" OR "neural glid*" OR "neural biomechanic*" OR "neural strain"	Pubmed; Web of Science; Academic; ScienceDirect; Scopus; Scielo
"Neural elongation" AND "neural stretching"	PEDro
"Neural lengthening" AND "neural excursion"	PEDro
"Neural tension" AND "neural glid*"	PEDro
"Neural biomechanic*" AND "neural strain"	PEDro
"Nerve elongation" AND "nerve stretching"	PEDro
"Nerve lengthening" AND "nerve excursion"	PEDro
"Nerve tension" AND "nerve glid*"	PEDro
"Nerve biomechanic*" AND "nerve strain"	PEDro

To be included in this review studies must have:

- Been published as a full article or an abstract with sufficient detail to extract the main attributes of the study;
- Been written either in English or in Portuguese;

- Assessed either longitudinal or transversal excursion or tension (or both) of any component of the peripheral nervous system in response to any movement of one or several segments of the body with or without nerve injury or disease;
- Been conducted in human participants (in vivo) either healthy or with any pathology and from any age group.
- Reported the position of at least one joint adjacent to the one being mobilized.

Studies were excluded if participants had been submitted to surgery or any other invasive event likely to affect nerve biomechanics.

2.2. Data extraction, synthesis, and analysis

Articles were imported from databases into the Mendeley reference management software, version 1.19.4 (Mendeley Ltd, London, United Kingdom), and duplicates were removed. Then, titles and abstracts were screened by both authors (AGS and CM). Potentially eligible studies were identified and their respective full reports were obtained. Full reports were also assessed separately by both authors against eligibility criteria.

Once the studies that entered this review were identified, the following information was retrieved from each one of them: i) sample characteristics (number of participants, age and health condition); ii) measurement procedures used to quantify nerve excursion or tension; iii) involved joints and movement performed; iv) position of participant and position of joints adjacent to the moving joint; v) site where measurements of excursion and/or strain were taken, vi) mean values for excursion and/or strain in millimeters and percentage of change from baseline, respectively (or other indicators of strain presented in each study). Data were described using counts, minimum and maximum values, and presented using tables and graphs. Graphs were used only for data on the median nerve due to the limited number of data on the other nerves.

2.3. Assessment of methodological quality of studies

This systematic review used the same instruments as used in the previous review [7] to assess the methodological quality of the included studies. This instrument was a modified version of the quality assessment tool by Downs and Black [26]. Individual items were scored either 1 if appropriately addressed in the study, or 0, if not addressed in the study or if assessors were unable to determine it. The total quality scores were reported as the sum of the individual scores of each item resulting from the consensus between the two assessors. A score of 7 or less was considered low quality, 8–11 as fair quality, and greater than 11 as good quality [27].

3. Results

The search generated 5645 articles, of which 2111 were duplicates. A total of 3534 abstracts were read, of which 86 passed to the full-text screening phase. Of these, we were unable to find three references [28–30] , despite efforts to contact the authors via email. One of the authors, replied reporting that the full-text was never published. Following the application of the inclusion and exclusion criteria (see flow diagram), 33 articles entered this review (Figure 1).

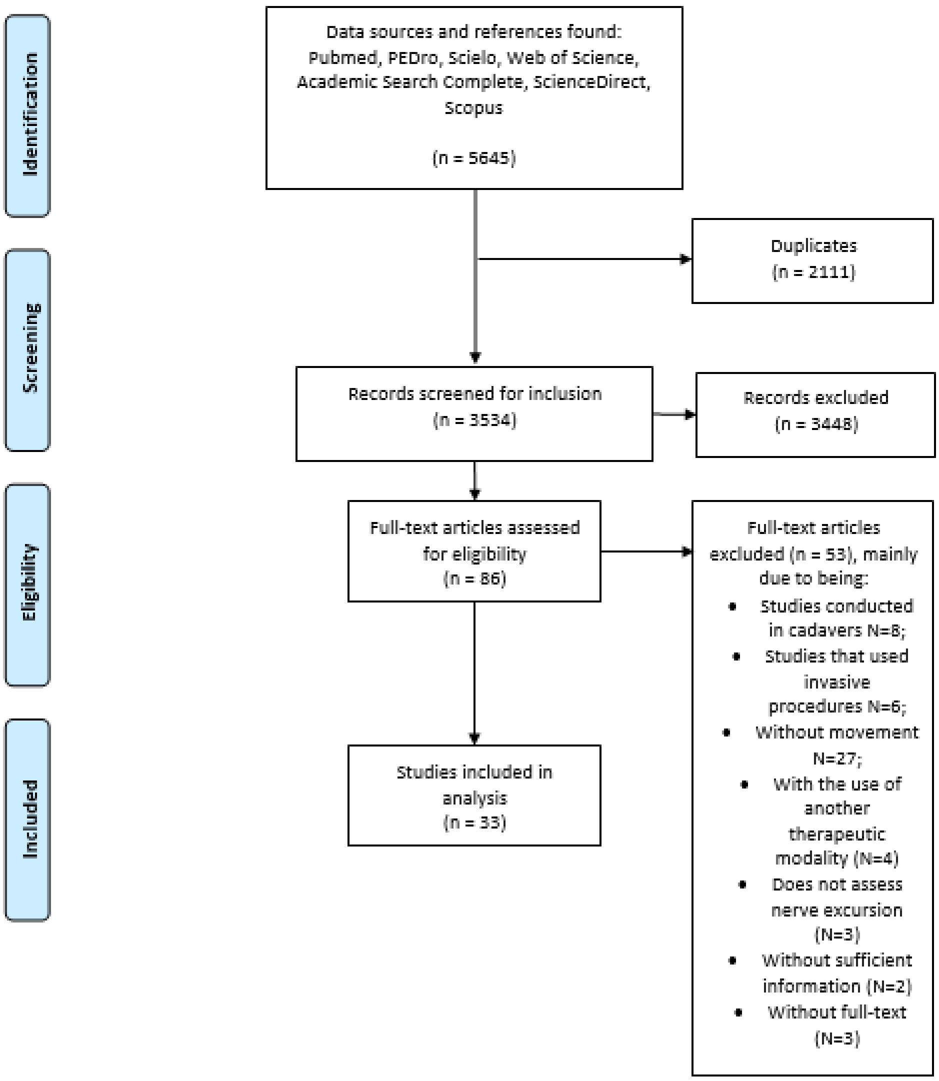

Figure 1 -Flow Diagram showing the process of article selection

3.1 Included studies

From the 33 studies included, 17 studied the median nerve [8,16,31–45], 8 examined the sciatic nerve [23,46–52], 4 studied the tibial nerve [10,53–55], 2 studies examined the cubital nerve [56,57], 1 study examined the radial nerve [58] and 1 studied the femoral nerve [59]. Please see Figure 2.

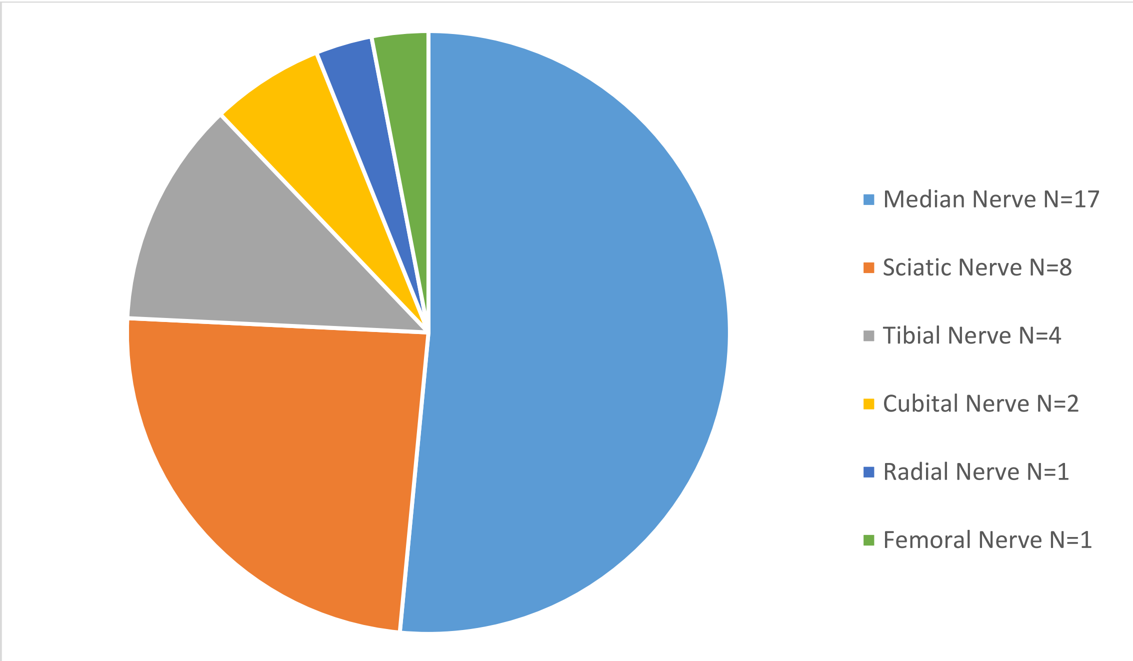

Figure 2 - Pie-chart of the nerves examined in the included studies

From the same 33 studies included, 22 used only asymptomatic participants and 11 compared asymptomatic participants with participants with different pathologies: carpal tunnel syndrome (n=6), diabetes (n=2), non-specific arm pain (n=1), spinally referred lower limb pain (n=1), non-specific arm pain and traumatic neck pain (whiplash) (n=1). All these studies that used participants with a clinical condition, compared measurements in these groups against measurements in asymptomatic participants.

All the 33 included studies used ultrasound to capture nerve images and reported the results in millimeters for excursion.[31,39,42,45]

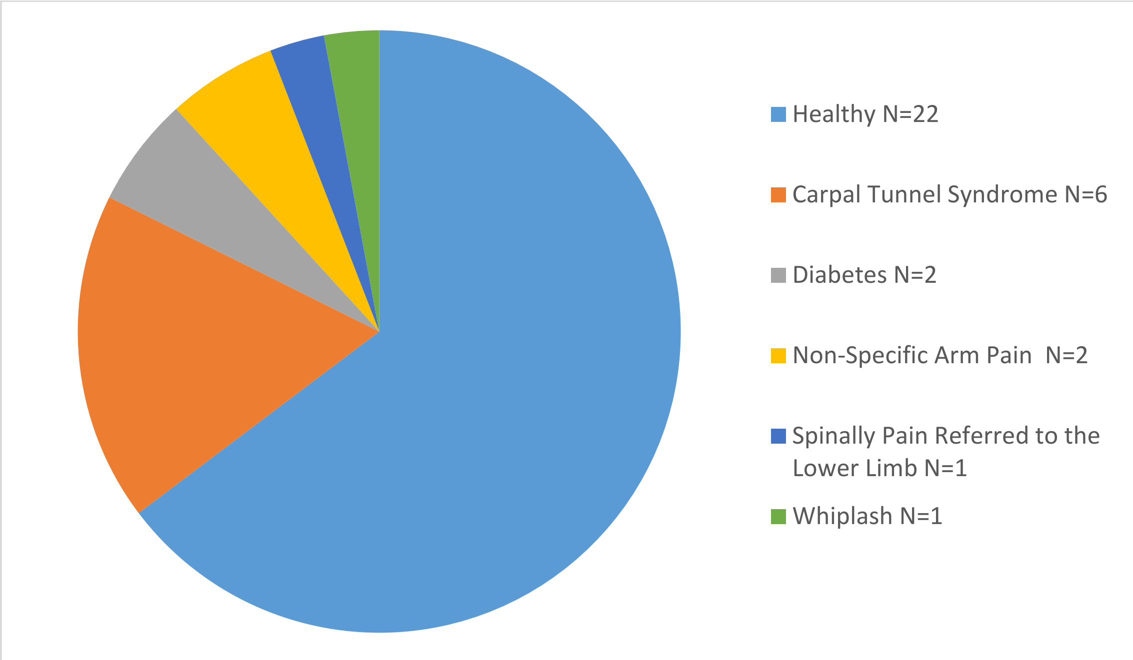

Figure 3 - Pie-chart of clinical conditions evaluated in the included studies

3.2 Methodological quality

The 33 studies included in this review scored between 8 and 16 points out of a maximum of 17 points on the modified Downs & Black's scale. Seventeen studies (51.5%) were rated with a score indicating fair quality (score between 8 and 11) and the other 16 (48.5%) were rated with a score indicating good quality (score greater than 11). Details of the methodological quality assessment are presented in Table 2.

Question	Hough et al. 2000	Dilley,et al.	Erel et al. 2003	Julius et al. 2004	Hough et al. 2007	Echigo et al. 2008	Coppieters, et al. 2009	Brochwicz 2013	Dilley,et al. 2007	Boyd et al. 2012	Ellis 2008	Ellis et al. 2012	Alexander et al 2012	Gonzalez-Suarez et al 2016	Greening et al 2005	Kasehagen et al 2016	Lopes et al 2011	Wang et al 2013	Carroll et al 2012	Shum et al 2013	Ridehalgh et al 2012	Ridehalgh et al 2014	Kang et al 2016	Korstanje et al 2012	Coppieters et al 2015	Ellis et al 2015	Sierra-Silvestre et al 2018	Ellis et al 2018	Pagnez et al 2019	Park et al 2017	Patel et al 2014	Ridehalgh et al 2015	Boyd et al 2014
Hypothesis/aim/objective	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Main outcomes	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Participants characteristics	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Confounders	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Findings	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Estimates of the random variability	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Actual probability values	0	0	0	0	1	1	1	0	0	1	0	1	1	1	0	0	1	1	1	1	1	1	1	0	0	1	1	1	0	1	1	1	1
Subjects representative population (asked)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
Subjects representative population (agreed)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0
Blinding of assessors	1	0	0	0	1	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1
“Data dredging”	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Appropriate statistical tests	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Outcome measures valid and reliable	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Internal validity (selection bias)	0	0	0	0	1	1	1	1	0	1	1	1	0	1	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1
Recruitment time period	0	0	0	0	1	1	1	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Adjustment for confounding	0	1	0	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1
Statistical power determined	0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	0	1
Total (mean score between assessors)	**9**	**9**	**8**	**9**	**15**	**13**	**14**	**10**	**10**	**13**	**13**	**15**	**8**	**14**	**11**	**11**	**9**	**11**	**11**	**12**	**11**	**11**	**12**	**12**	**11**	**16**	**12**	**14**	**10**	**13**	**10**	**13**	**13**

Table 2 - Methodological quality assessment

3.3 Reliability of nerve excursion and tension measurements

All included studies used ultrasound to obtain nerve images and 31 (93.9%) presented at least one of the indicators regarding either reliability or measurement error: 26 (78,8%) studies reported the standard error of measurement (SEM) [8,10,16,23,31,33,35,37–40,42,43,45–47,49–56,58,59], 24 (72,7%) included the intraclass correlation coefficient (ICC) [8,10,16,23,32,33,35,36,43–50,52–55,57–59] and 8 (24,2%) studies included the minimal detectable change (MDC) [8,10,39,42,45,48,54,58]. The ICC values were higher than 0.75 for 20 studies and varied between 0.61 and 0.75 for the remaining 4 studies that reported the ICC [48,49,57,58]. Several studies used more than 1 indicator of reliability/measurement error.

Table 4 provides details of the reliability of nerve excursion and tension measurements (see results section).

3.4 Characterisation of nerve movement and tension

3.4.1 Median nerve longitudinal excursion in healthy individuals

From the 17 studies that assessed median nerve excursion, only 15 studies assessed median nerve longitudinal excursion in response to several movements of the upper limb and cervical spine when measurements were taken at diverse anatomical locations (wrist [16,33–36,42–44], forearm [31,37,39–41,44], elbow [8,45] and arm [8,31,39,40,43]). Overall, the absolute mean nerve longitudinal excursion varied between -3.8 mm and 50.2 mm at the wrist, -4.2 mm and 5.9 mm at the forearm, -3.3 mm and 10.2 mm at the elbow, and -5.2 mm and 10.4 mm at the arm.

Nerve-gliding movements were used in 3 studies to evaluate median nerve excursion [8,39,41]. Gliding movements (for example, simultaneous active elbow extension and cervical ipsilateral lateral flexion) resulted in a larger amount of nerve longitudinal excursion (10.2 mm ± 2.8) than a tensioning movement (1.8 mm ± 4.0; P=0.0001) [8]. In the same study, contra-lateral flexion of the neck with the elbow pre-positioned in a flexed position (-3.3 mm ± 1.3) and also with the elbow in a more flexed position resulted in proximal excursion of the median nerve (-3.4 mm ±0.9) [8]. Also assessing nerve movement during upper limb movements, Dilley et al [39] when taking measurements at upper arm noted that median nerve gliding appears to be delayed when the limb was flexed (<45° shoulder abduction and/or 90° elbow flexion), and that with elbow extension the median nerve moved in a distal direction in the upper arm and a proximal direction in the forearm (upper arm: 10.4 mm ± 2.3; forearm: -3.0 mm ± 1.0). Also with gliding movements, Echigo and colleagues reported that passive extension of the wrist and fingers when the elbow was extended and the forearm pronated lead to a smaller amount of excursion when compared to a passive extension of the wrist and fingers when the elbow was flexed and the forearm supinated (elbow extended and forearm pronated: 1.9 mm ± 1.4; elbow flexed with the forearm supinated: 3.0 mm ± 1.3; P=0.001) [41].

3.4.1.1 The impact of wrist and fingers movement on median nerve longitudinal excursion

The three studies that evaluated median nerve longitudinal excursion at the hand level during fingers extension reported that excursion was in a distal direction [16,40,42]. Hough et al[16] assessed longitudinal nerve excursion during fingers and thumb extension. The mean longitudinal nerve excursion with the elbow extended was 11.2mm ± 2.8 and it was 12.5mm ± 2.5 with the elbow flexed at 90°. The other two studies evaluated the impact of metacarpophalangeal extension from 90° flexion to neutral position with the elbow extended and shoulder at 90° at forearm level and mean values were very similar (2.62 mm, range 1.62-4.54 mm vs 2.62 mm, range 1.63-4.54 mm) [40,42].

Median nerve longitudinal excursion during wrist extension was assessed in seven studies [34,36,39–41,43,45]. Passive wrist extension with the shoulder at 30°, elbow extension and with the forearm supinated induced a median nerve movement between 1.9 mm and 4.2 mm [39,41]. Wang et al[36] used active wrist extension and finger extension with the shoulder in a neutral position to evaluate median nerve longitudinal excursion at the proximal carpal tunnel, the median nerve longitudinal excursion was diminished compared to the studies mentioned above (0.4 Normalized Units (NU) equivalent to 0.72mm; 1 NU = 1.8mm) [39,41]. Increasing shoulder abduction to 45° and 90° of abduction seems to facilitate nerve gliding at the forearm during wrist extension (45° abduction: 4.7mm; 90° abduction: 4.2mm). Similarly, median nerve excursion with wrist extension varied with elbow flexion (90° elbow flexion: 2.2 mm ± 1.6 at forearm level; 120° elbow flexion: 22.1 mm ± 7.5 at wrist level). [34,39,41].

In the study of Gonzalez-Suarez et al [43], wrist extension up to 60° resulted in greater excursion of the median nerve with the neck prepositioned in 45° of ipsilateral lateral flexion (wrist: 15.5 mm, arm: 6.8 mm) than with the neck prepositioned in 45° contralateral lateral flexion (wrist: 13.4 mm, arm: 5.3 mm).

The only authors that assessed the impact of wrist flexion on median nerve gliding were Wang and colleagues [36]. They found that with fingers flexed in fist (approximately 3.24mm), median nerve excursion during wrist flexion was slightly greater than with fingers extended (approximately 2.7mm).

3.4.1.2 The impact of elbow movement on median nerve longitudinal excursion

The impact of elbow extension on median nerve gliding was evaluated in three studies [8,39,40]. The nerve moved in a distal direction in the upper arm (10.4 mm ± 2.3) and in a proximal direction in the forearm (-3.0 mm ± 1.0) with elbow extension from 90° flexion to neutral at 90° shoulder abduction [39]. The same authors, in a study of 2008 [40] obtained a mean of -4.07 mm of proximal median nerve movement during elbow extension at the forearm level. Elbow extension with the wrist at 45º extension induced a mean of 4.2 mm of proximal gliding in the forearm [39]. So these results suggest that during elbow extension, the median nerve moves in different directions: proximally at the forearm and distally at the upper arm [8,39,40].

Coppieters and colleagues[8] evaluated median nerve excursion during elbow extension with the neck in ipsilateral lateral flexion (mean of 5.5 mm ± 2.9) and with the neck in contralateral lateral flexion (mean of 5.6 mm ± 2.1). In both cases, the nerve moved in a distal direction at the upper arm and no significant differences between the two positions were found ($P>0.05$).

3.4.1.3 The impact of shoulder movement on median nerve longitudinal excursion

Two studies already included in the previous systematic review[7] measured the effect of shoulder movements on median nerve gliding [31,39]. The median nerve moved in a proximal direction during shoulder abduction (5.2 mm in the arm and 3.4 mm in the forearm) and shoulder protraction (5.9mm in the arm and 3.5 mm in the forearm) [31,39].

3.4.1.4 The impact of neck movement on median nerve longitudinal excursion

The impact of neck movements on median nerve excursion was evaluated in five studies [8,31,37,39,43].

Contra-lateral lateral neck flexion was evaluated in four studies and mean values ranged from -0.6 mm to -3.8 mm at wrist/ distal forearm level and from -0.9 mm to -4.9 mm at arm level. The direction of the movement was proximal in all of them [8,31,37,43]. Contralateral lateral flexion with a prepositioned wrist in extension produced lesser excursion of the median nerve in the arm and wrist (Wrist Level: -3.80 mm ± 0.31; Arm Level: -4.87 mm ± 2.49) than wrist extension with a pre-positioned ipsilateral lateral flexion (technique 1), wrist extension with a pre-positioned contra-lateral lateral flexion (technique 2) and ipsilateral lateral flexion with the wrist extended (technique 3) – (Wrist level - technique 1: 15.53 mm ± 7.04, technique 2: 13.43 mm ± 5.64, technique 3: 5.98 mm ± 2.73; arm level – technique 1: 6.82 mm ± 2.97, technique 2: 5.33 mm ± 2.37, technique 3: 3.52 mm ± 1.45)($P<0.0001$) [43].

Median nerve gliding seems to be diminished during cervical contralateral lateral flexion with shoulder protraction (a 60% reduction) compared to the same movement with the shoulder in neutral or in an abducted position (protraction – arm: 0.9 mm, forearm: 0.6 mm; neutral – arm: 2.3 mm, forearm: 1.5 mm; 30° of abduction – forearm: 1.9 mm to 2.3 mm) [31,37]. Lateral flexion of the neck produced similar nerve excursion when the elbow was in flexion or when it was in extension (elbow flexion: 3.4 mm; elbow extension: 3.3 mm) [8].

Cervical lateral glide (away from the side to be tested) at C5/C6 resulted in a significantly larger amount of longitudinal nerve movement (mid-forearm: 3.3 mm; distal forearm: 2.5 mm) compared with cervical contralateral lateral gliding (mid-forearm: 2.3 mm; distal forearm: 1.9 mm) ($P\leq0.05$) [37].

The impact of neck flexion on median nerve gliding was assessed in one study, and resulted in proximally median nerve excursion in both measurement sites (arm: -1.3 mm ± 0.7; forearm: -0.8 mm ± 0.3) [39].

Bringing the head forward (forward head posture) produced no detectable median nerve excursion in the forearm, resulting in a mean of 0.1 mm excursion in a proximal direction [31].

3.4.2 Median Nerve Transversal Excursion in Healthy Individuals

Five studies assessed the median nerve transversal movement [16,32,38,42,44].

Alexander and colleagues [38] evaluated transversal excursion in eight different posture combinations when moving the wrist from full flexion to 30° of extension. Nerve excursion was mainly in a radial and dorsal direction, from a minimum of 1.8 mm up to 3.57 mm of transversal movement at the wrist level.

Kang et al [32] assessed median nerve transversal excursion during finger and grip motion at wrist level. During finger flexion, nerve movement ranged from mean values of 0.32 mm up to 0.95 mm in a dorsopalmar direction, and from 0.81 mm up to 1.05 mm in a radioulnar direction. Grip motion resulted in a mean of 0.64 mm of nerve excursion in a dorsopalmar direction and 0.84 mm in a radioulnar direction.

The median nerve moved in a radial direction with metacarpophalangeal extension from 90° or full finger flexion and the mean nerve excursion ranged from 1.55 mm to 1.75 mm at wrist level [16,42]. Furthermore, the median nerve moved in the axial plane in a deeper direction (0.35 mm ± 0.3) during fingers and thumb extension [16]. The median nerve moved in a cubital direction when the wrist was positioned in both 30° of flexion and 30° of extension and the mean excursion was -0.39± 0.52mm at wrist level [44].

3.4.3 Median Nerve Strain in Healthy Individuals

Dilley et al[39], calculated strain values for wrist, shoulder, elbow, and neck movements. With the wrist extended to 40°, shoulder abducted to 90°, and elbow straight, the total strain in the proximal forearm was 2.1% (sum of additional strain in the forearm for shoulder abduction – 1.0% - and 40° wrist extension – 1.1%). Furthermore, contralateral lateral flexion increased median nerve strain by 0.2% in the forearm.

3.4.4 Cubital Nerve Longitudinal Excursion in Healthy Individuals

One study reported on ulnar nerve gliding [56]. The cubital nerve glided distally at the forearm with wrist extension (1.1 mm to 3.0 mm). Elbow flexion induced proximal gliding at the forearm (0.8 mm) and virtually no movement at the upper arm. Shoulder abduction (40º to 90º) induced virtually no longitudinal excursion of the cubital nerve [56].

3.4.5 Cubital nerve strain in healthy individuals

The cross-sectional area (CSA) of the cubital nerve was measured at the elbow at two different elbow angles (30° and 90° flexion) in both upper limbs and no statistically significant difference was found between positions (30°: 9.77 mm^2 VS 90°: 9.93 mm^2; P=0.341) [57].

3.4.6 Radial nerve longitudinal excursion in healthy individuals

Kasehagen and colleagues [58], reported that radial nerve excursion ranged from 0.41 mm to 4.03 mm with wrist flexion when measurements were taken at elbow level: wrist movements with the forearm supinated produced larger radial nerve excursion (mean of 1.41 ± 0.32 mm) than the same movements with the forearm pronated (mean of 1.06 ± 0.31 mm) (P<0.01) and passive movements produced significantly greater nerve excursion than active movements (passive: 1.42 ± 0.42 mm; active: 1.04 ± 0.28 mm; P<0.001).

3.4.7 Sciatic nerve longitudinal excursion in healthy individuals

From the eight studies on the sciatic nerve, seven studies assessed the sciatic nerve movement in response to joint movement and reported longitudinal nerve excursion in response to neck [46,47], hip [23], and knee joint movement [23,46–48,50–52]. Nerve excursion was measured at posterior thigh [23,49–51,60] or mid-thigh level [46–48]. Ellis et al used different combinations of movements and showed that sliders (3.2mm±2.0) were associated with a significantly higher amount of excursion when compared to tensioners (2.6mm±1.5 P=0.002) [46]. In another study a few years later, Ellis et al evaluated the influence of neck flexion (tensioner technique) and neck extension (slider technique) during the movement of passive knee extension in two different positions: slumped posture (slider: 6.4 ± 2.7 mm; tensioner: 6.0 ± 2.9 mm) and upright sitting posture and reported no significant difference between upright-sitting and slump-sitting (slider: 6.9 ± 2.6 mm; tensioner: 6.4 ± 2.7 mm; P=0.26) [47]. Furthermore, in a recent study, Ellis et al evaluated sciatic nerve excursion during active and passive knee flexion and extension and found no statistically significant differences between them (knee flexion: active: 5.38 ± 2.20 mm; passive: 4.68 ± 3.14 mm; P=0.07; knee extension: active: 4.52 ± 2.63 mm; passive: 4.34 ± 2.81 mm; P=0.69) [48].

Coppieters et al [23] evaluated sciatic nerve excursion for tensioning techniques (simultaneous knee extension and hip flexion) and gliding techniques (simultaneous knee and hip extension) and found a mean excursion for the gliding technique of 17.0 ± 5.2 mm at the posterior lateral thigh, resulting in the largest excursion of the sciatic nerve.

The Straight Leg Raise Test (SLR) and a modified version were the movement patterns used by Ridehalgh and colleagues in their three studies [50–52]. They evaluated full knee extension from 90° flexion with the hip in two different flexion positions (60° and 30°), and concluded that sciatic longitudinal excursion was greater with 60° (mean of 12.5mm) than with 30° of hip flexion (mean of 10.0mm) and the nerve glided in a distal direction when measurements were taken at the posterior upper thigh.

3.4.8 Sciatic nerve strain in healthy individuals

In the Pagnez et al study [49], the CSA of the sciatic nerve was in 3 different positions (A: knee extended; B: knee flexed; C: knee extended and ankle dorsiflexed) with the lumbar spine in a neutral position and also with the lumbar spine flexed (D: knee extended; E: knee flexed; F: knee extended and ankle dorsiflexed). The CSA varied among the different positions, for example, position B showed a higher mean CSA (59.71 ± 17.41 mm²) compared with position C – (48.37 ± 16.35 mm²; P=0.009), D – (51.18 ± 13.81 mm²; P=0.005) and position F – (48.71 ± 15.16 mm²; P=0.004). However, lumbar position (neutral or flexed) did not impact the sciatic nerve CSA (P>0.05) [49].

3.4.9 Tibial nerve longitudinal excursion in healthy individuals

Three of the four studies that assessed the tibial nerve, evaluated tibial nerve longitudinal excursion during ankle dorsiflexion, which ranged from 2.18 mm at the popliteal level up to 3.03 mm at the medial malleolus [10,53,54]. Boyd et al, assessed tibial nerve movement at the popliteal level during ankle dorsiflexion in neutral hip position and in a flexed hip position (≈62°) and reported a statistically significant lower excursion when the hip was flexed (neutral: 2.18 mm ± 0.48; flexion: 0.66 mm ± 0.25; P=0.043) [53]. At the knee level, the nerve moved in a distal, medial and superficial direction [10,53] and at the ankle the nerve moved in a distal, posterior and superficial direction [10].

The remaining study evaluated the influence of trunk forward bending on tibial nerve movement [55] and reported that trunk forward bending induced proximal excursion of the tibial nerve at the popliteal fossa (mean of 12.2 mm ± 2.2) [55].

3.4.10 Tibial nerve transverse excursion in healthy individuals

Boyd et al[53] also evaluated tibial nerve transversal excursion in both positions: neutral hip and flexed hip (≈62°) during ankle dorsiflexion. In both hip positions the nerve showed medial (neutral: 1.36 ± 0.99 mm; flexed: 1.44 ± 0.93 mm) and superficial (neutral: 3.98 ± 1.70 mm; flexed: 3.67 ± 1.47 mm) nerve excursion.

3.4.11 Femoral nerve longitudinal and transversal excursion in healthy individuals

One study assessed the excursion of the femoral nerve during knee and neck flexion [59]. Below the inguinal ligament, the femoral nerve moved predominantly in a distal, medial, and superficial direction during knee flexion and neck flexion did not result in any longitudinal excursion. The distal excursion was greater in a supine than in a semi-seated position (mean difference: 2.5 mm ±2.5; $P<0.001$)[59].

3.5 Comparison between asymptomatic and non-asymptomatic participants for the median nerve

3.5.1 Median nerve excursion in carpal tunnel syndrome

Three studies compared the median nerve longitudinal excursion between asymptomatic participants and participants with carpal tunnel syndrome and another three transversal excursion [16,32–35,42]. In the study of Hough et al [16], longitudinal nerve excursion in asymptomatic individuals was greater than in participants with carpal tunnel syndrome. At the wrist, with finger flexion with the elbow in both a flexed position and an extended position. Statistically significant difference was found between the asymptomatic group and the carpal tunnel syndrome group with the elbow extended (asymptomatic: 11.2 mm ± 2.8; carpal tunnel syndrome: 8.3 mm ± 2.6; P=0.013) but not with the elbow flexed (asymptomatic: 12.5 mm ± 2.5; carpal tunnel syndrome: 10.2 mm ± 3.1; P=0.089). One study found no differences between groups during metacarpophalangeal extension from 90º to neutral (asymptomatic mean: 2.62mm; carpal tunnel syndrome: 2.20mm; P>0.1) [42]. Korstanje et al, compared median nerve longitudinal excursion in the most affected hand and in the least affected hand, and median nerve excursion was smaller in the most affected hand (P=0.004) [33].

Three studies compared the transversal excursion of the median nerve. It was found to be significantly diminished on the most affected side (40% reduction) compared to the least affected one (P<0.05) [42] and asymptomatic participants were found to have significantly greater transversal excursion than participants with carpal tunnel syndrome (by 4.2 mm) in all motions (P=0.008) [34] and the remaining study reported that nerve movements during third finger flexion in the dorso-palmar axis, grip motion in dorso-palmar and radio-cubital axis and during second finger flexion in the radio-cubital axis was found a significantly difference between asymptomatic and symptomatic groups, being diminished in symptomatic group [32].

Park and colleagues [35] compared asymptomatic participants and participants with carpal tunnel syndrome at different stages of severity (stages 1, 2 and 3, with higher stages indicating higher severity). Median nerve displacement was significantly lower in participants with stage 3 of carpal tunnel syndrome compared with asymptomatic individuals and with participants with least severe stages of carpal tunnel syndrome (asymptomatic: 0.5 mm ±0.10; carpal tunnel syndrome stage 1: 0.51 mm ±0.17; carpal tunnel syndrome stage 2: 0.45 mm ±0.09; carpal tunnel syndrome stage 3: 0.25 mm ±0.08 P<0.001). No significant differences were found between asymptomatic participants and participants with carpal tunnel syndrome stages 1 and 2 (P≥0.05).

3.5.2 Median Nerve excursion in Non-Specific Arm Pain

Two studies compared median nerve longitudinal excursion between asymptomatic participants and participants with non-specific arm pain [40,44]. Greening et al evaluated longitudinal median nerve movement during maximal inspiration and verified a 68% reduction in nerve movement in the group of participants with arm pain (mean of 0.49 ± 0.19 mm) compared to controls (mean of 1.55 ± 0.19 mm) (P<0.05) [44]. Dilley and colleagues evaluated the impact of the metacarpophalangeal, wrist and elbow joint movement and reported no differences between groups (P>0.05) [40].

3.5.3 Median nerve excursion in whiplash

Only one study assessed longitudinal and transversal median nerve movement in participants with whiplash and found a significant reduction of longitudinal nerve excursion when compared to the asymptomatic group (whiplash: 0.38 ± 0.08 mm; asymptomatic: 1.32 ± 0.17 mm; P<0.05). In contrast, the transversal movement was significantly higher in participants with whiplash when compared to asymptomatic participants (asymptomatic: -0.39 ± 0.52 mm cubital direction; whiplash: 2.57 ± 0.80 mm radial direction; P<0.05) [44].

3.6. Comparison between asymptomatic and non-asymptomatic participants for the Sciatic Nerve

3.6.1 Sciatic nerve movement in spinally referred leg pain

One study evaluated the sciatic nerve longitudinal movement in participants with lower limb pain (somatic pain, radicular pain, and radiculopathy-related pain) [52]. Participants performed a side-lying modified SLR in two different hip angles (30° and 60° of flexion) and no significant difference was found between the groups with and without pain for longitudinal excursion (mean values at 30° hip flexion – asymptomatic: 10.0 mm; somatic group: 10.3 mm; radicular: 8.8 mm; radiculopathy: 9.4 mm; at 60° hip flexion – asymptomatic: 12.5 mm; somatic: 8.2 mm; radicular: 10.2 mm; radiculopathy: 9.7 mm; P=0.14) when measurements were taken at the posterior thigh level.

3.7. Comparison between asymptomatic and non-asymptomatic participants for the tibial nerve

3.7.1 Tibial nerve excursion in diabetes mellitus

Two studies compared the tibial nerve excursion between asymptomatic participants and participants with diabetes mellitus (DM) [10,53]. In one study, patients with diabetes mellitus showed significantly less distal movement of the tibial nerve with active dorsiflexion (asymptomatic: 2.18 ± 0.48 mm; DM: 0.83 ± 0.45 mm; P=0.009) and less superficial movement of the nerve compared with the asymptomatic group at the popliteal fossa (asymptomatic: 3.67 ± 1.47 mm; DM: 1.00 ± 0.60 mm, P=0.016) [53].

Similarly, in the other study, the movement of ankle dorsiflexion was associated with less longitudinal excursion of the tibial nerve in participants with diabetes than in asymptomatic participants at the knee (DM: 1.30 ± 0.67 mm; asymptomatic: 2.17 ± 0.67 mm, P=0.001) and the ankle (DM: 2.06 ± 0.92 mm; asymptomatic: 3.14 ± 1.26 mm; P=0.006) [10]. In contrast, in this study, the transversal movement in a posterior direction was found to be higher in participants with DM compared with asymptomatic participants at the ankle level (DM: 1.98 ± 1.90 mm; asymptomatic: 0.32 ± 1.79 mm; P=0.015) [10].

Table 3 - Reliability data of the included studies

Study	Nerve	Ultrasound characteristics	Movement	ICC 2,1 (95% CI)	SEM (mm)	MDD (mm)
Alexander et al 2012 [38]	Median	Ultrasound images captured at 50 frames using a 26mm transducer	Wrist Extension (from full comfortable flexion to 30° of wrist extension)		P1: Radial: 0.367; Volar: 0.19;	
					P2: Radial: 0.509; Volar 0.1801;	
					P3: Radial 0.465; Volar 0.135;	
					P4: Radial 0.392 Volar 0.168	
					P5: Radial 0.281 Volar 0.1477	
					P6: Radial 0.275 Volar 0.189	
					P7: Radial 0.313 Volar 0.1145	
					P8: Radial 0.303 Volar 0.161	
Brochwicz et al 2013 [37]	Median	Ultrasound video sequences analysed with frame-by-frame cross-correlation algorithm	T1-Cervical Lateral Glide at C5-C6 (Translational movement away from the side to be tested)		T1 – Middle Forearm: 0.3 Distal Forearm: 0.2	
			T2-Cervical Contralateral Lateral Flexion		T2 – Middle Forearm: 0.1 Distal forearm: 0.2	
Coppieters et al 2009 [8]	Median	Ultrasound images analysed using a	A – sliding technique (elbow extension and ipsilateral cervical lateral flexion);	Inter-tester: 0.96 (0.88; 0.98)	0.66	1.84

		cross-correlation algorithm	B – tensioning technique (elbow extension and contralateral cervical lateral flexion); C – elbow extension with the neck in contralateral lateral flexion; D – elbow extension with the neck in ipsilateral lateral flexion; E – cervical contralateral lateral flexion with the elbow in more extended position; F – Cervical contralateral lateral flexion with the elbow in flexed position.			
Dilley et al 2003 [39]	Median	Ultrasound images analysed using a cross-correlation algorithm	Supine; Shoulder at 45° Abduction; Elbow in full extension; Forearm supinated; Digits and metacarpophalangeal joints neutral (N=10)		Proximal forearm = 0.2 Distal forearm = 0.4	Proximal forearm=1.1 Distal forearm=1.5
			Supine; Shoulder at 90° abduction; Elbow in full extension; forearm supinated; digits and metacarpophalangeal joints in neutral (N=10)		Proximal forearm = 0.2 Distal forearm = 0.5	Proximal forearm=1.1; Distal forearm=2.0;

			Supine; Shoulder at 30° abduction; elbow at 90° flexion; forearm supinated; digits and metacarpophalangeal joints neutral (N=4)			
			Supine; Elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=4)		0.2	1.0
			Supine; Shoulder at 90° abduction; wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=7)		0.6	0.6
			Supine; Shoulder at 90° Abduction; Forearm supinated, wrist at 45° extension; digits and metacarpophalangeal joints neutral (N=4)			
			Supine; Shoulder at 30° Abduction, elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=8)		0.1	0.1

			Supine; Shoulder at 90° Abduction, elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints in neutral (N=9)		0.1	0.2
Dilley et al 2007 [56]	Cubital	Ultrasound imaging using a cross-correlation algorithm	T1- Wrist Extension (0°-40°)		a) proximal forearm: 0.5; distal forearm: 0.5 P<0.05 b) distal forearm: 0.3; proximal forearm: 0.5 c) distal forearm 0.5; proximal forearm 0.3 P<0.01	
			T2- Elbow Flexion (0°-90°)		Distal third forearm (N=4): 0.2; Proximal upper arm (N=2): 0.3	
			T3- Elbow Flexion (90°-140°)		Not possible to measure	
			T4- Shoulder Abduction (40°-90°)		a) 0.2 b) 0.2	
Dilley et al 2008 [40]	Median	Ultrasound imaging using a cross-correlation algorithm	A) In 45° shoulder abduction, elbow extension, MCP joints and finger extension and the wrist is moved to 40° extension.		A) a) Non-specific arm pain: (SEM 0.33 Range 3.06-4.73) Healthy: (SEM 0.20 Range 3.43-5.57) b) Non-specific arm pain: (SEM 0.25 range 1.43-2.74) Healthy: (SEM 0.31 range 1.43-3.30) Timing: Non-specific arm pain: 53.4° (SEM 2.2)	

					Healthy: 52.0° (SEM 4.8)	
			B) In 90° shoulder abduction, elbow extension, wrist in neutral position, the fingers start in 90° flexion and are brought to neutral position;		B) a) Non-specific arm pain: 0.44 range 1.46-4.01 Healthy: 0.15 range 1.63-4.54	
			C) In 90° shoulder abduction, wrist and fingers neutral, the elbow is extended from 90° flexion to neutral		C) c) Non-specific arm pain: 0.35 range 1.26-4.38 Healthy: 0.20 range 2.93-4.88	
Echigo et al 2008 [41]	Median	Ultrasound images and with the use of cross-correlation analysis				

Erel et al 2003 [42]	Median	Ultrasound images with frame-by-frame cross-correlation algorithm	MCP 90° flexion to neutral position of fingers 2 to 5		Longitudinal Excursion: CTS: 0.2 range 1.1-4.8; Healthy: 0.1 range 1.6-4.5 Transversal Excursion: Control: 0.24 radial direction; CTS most affected side: 0.28 CTS least affected side: 0.35 Control vs CTS most affected side (P>0.08) CTS most affected side vs least affected (P<0.05)	Single Session sw= 0.3mm; Separate Sessions sw=0.4mm
Gonzalez-Suarez et al 2016 [43]	Median	Dynamic Ultrasound imaging with motion tracking analysis program employing a fast template tracking method	Technique 1 and 2: Wrist Extension Technique 3 and 4: ipsilateral and contralateral neck lateral flexion		Wrist Level Technique 1: (SEM 1.57) Technique 2: (SEM 1.26) Technique 3: (SEM 0.61) Technique 4: (SEM 0.31) Arm Level Technique 1: (SEM 0.66) Technique 2: (SEM 0.53) Technique 3: (SEM 0.32) Technique 4: (SEM 0.56)	
Greening et al 2005 [44]	Median	Ultrasound imaging using a frame-by-frame cross-correlation algorithm	Longitudinal images: Maximal inspiration followed by forced expiration Transversal images: Wrist at 30° flexion and at 30° of extension			
Hough et al 2000 [45]	Median	Colour Doppler Ultrasound imaging	Wrist extension (0-60°)	0.92 (0.87; 0.96)	0.6	1.6

		using Scion Image Programme				
Hough et al 2007 [16]	Median	Doppler Ultrasound Technique and Image J image program	Fingers and thumb extension T1: Elbow Flexed at 90°; T2: Elbow fully Extended.	Intra-rater: T1: 0.95 (0.77; 0.99) T2: 0.89 (0.58; 0.99)	T1: 0.32 T2: 0.49	
Julius et al 2004 [31]	Median	Ultrasound imaging with a cross-correlation algorithm	T1: N=8 Forward head position: lower cervical spine flexion and upper cervical spine extension;		T1: 0.02	
			T2: N=8 Active trunk flexion with pelvis posterior tilt;		T2: 0.1	
			T3: N=13 passive shoulder girdle protraction;		T3: a) 0.3; b) 0.6;	
			T4: N=11 passive contralateral neck side flexion.		T4-A a) 0.2 b) 0.2; T4-B a) 0.1; b) 0.2	
Kang et al 2016 [32]	Median	Ultrasound imaging of median nerve, analysed using a ultrasound tracing program	Flexion of first, second and third fingers	Intra-rater: 0.84 (0.43; 0.97)		

Korstanje et al 2012 [33]	Median	Ultrasound video sequences analysed with “in-house-developed” tracking software	Active Extension to fist movement of most affected and least affected hands		2.548	
Lopes et al 2011 [34]	Median	Doppler Ultrasound images and using Image J programe	T1 – MCP flexion to 90°; T2 – Full fist T3 – Wrist extension to 60° T4 – Wrist extension and full fist; T5 – Wrist extension with static 3 finger pinch			
Park et al 2017 [35]	Median	Cross-sectional Ultrasound images and using Preview program	Thumb flexion; 2nd finger flexion; 3rd finger flexion; grasp; wrist ulnar deviation with finger extension; Wrist radial deviation with finger extension	Intra-rater: 0.98 (0.97; 0.98)	Maximal change value of displacement: 2.986; Maximal change area: 1.281	
Wang et al 2014 [36]	Median	Dynamic ultrasound images evaluated using Analyze 11.0 software	T1-Finger flexion; T2-Wrist flexion with finger extension; T3-Wrist flexion with finger flexion; T4: Wrist extension with finger extension; T5: Wrist Extension with finger flexion; T6: Wrist ulnar deviation with finger flexion	Intra-observer 0.91 (0.67; 0.98) Inter-observer 0.90 (0.60; 0.98)		

Coppieters et al 2015 [23]	Sciatic	Ultrasound imaging and using a software with cross-correlation analysis	T1- Simultaneous knee extension and hip flexion; T2- Simultaneous knee and hip extension; T3- Knee extension with hip in neutral; T4- Knee extension with hip in neutral; T5- Hip flexion with the knee flexed; T6- Hip flexion with the knee in extension	0.97 (0.90; 0.99)	0.94	
Ellis et al 2012 [46]	Sciatic	Ultrasound sequence video, using a method frame-by-frame cross-correlation analysis	T1- Simultaneous passive Knee Extension (From 80° to 20° flexion) and active neck extension (from full flexion to full extension); T2- Passive Knee Extension (from 80° to 20° flexion), neck in neutral; T3- Active cervical flexion (full extension to full flexion), knee at 80° flexion; T4- Passive Knee Extension (from 80° to 20° flexion) simultaneously active cervical flexion (from full extension to full flexion)	0.95 (0.92; 0.96)	0.2	
Ellis et al 2015 [47]	Sciatic	Ultrasound imaging with Image J to analyse images and	T1 - Passive Knee extension from 90°flexion to 4/10 point of stretch discomfort;	Intra-rater: Slump position – 0.86 (0.84; 0.92)	Slump position: 0.25 Upright position: 0.21	

		cross-correlation algorithm	T2 – Passive knee extension from 90° flexion to 4/10 point of stretch discomfort and active cervical spine extension from full comfortable flexion to full comfortable extension; T3- Passive knee extension from 90° flexion to 4/10 point of stretch discomfort and active cervical flexion from full comfortable extension to full comfortable flexion.	Upright position – 0.89 (0.85; 0.92)		
Ellis et al 2018 [48]	Sciatic	Ultrasound imaging	Knee extension from 80° to 20° of flexion and flexion from 20° to 80°: T1- Active; T2- Passive	Intra-rater within session: Extension T1 – 0.89 (0.66; 0.98) T2 – 0.64 (-0.14; 0.9) Flexion T1 – 0.79 (0.25; 0.96) T2 – 0.83 (0.5; 0.96)		Shear strain: Flexion: T1 73.06-41.25 T2 80.92-43.37 Extension: T1 59.84-32.24 T2 63.26-40.29
Pagnez et al 2019 [49]	Sciatic	Ultrasound imaging and image analysis	Initial positions: A-Neutral lumbar position: lying in prone, neutral lumbar, knee extended and ankle in neutral;	Interexaminer: A-0.85 (0.68;0.93) B-0.76 (0.49;0.89) C-0.76 (0.49;0.89) D-0.73 (0.43;0.87)	Interexaminer: A-5.71 B-10.42	

		with ImageJ software	B-Knee flexion position: lying in prone, neutral lumbar, knee flexed, neutral ankle; C-Ankle dorsiflexion position: lying in prone, neutral lumbar, knee extended, ankle in maximal active dorsiflexion; Final positions: D-Flexed Lumbar position: lying in prone, flexed lumbar, knee extended, ankle in neutral; E- Knee flexion position: lying in prone, flexed lumbar, knee flexed and neutral ankle; F- Ankle dorsiflexion position: lying in prone, flexed lumbar, knee extended and ankle in maximal active dorsiflexion	E-0.72 (0.41;0.87) F-0.75 (0.47;0.88) Intraexaminer: A-0.80 (0.59;0.91) B-0.79 (0.55;0.90) C-0.65 (0.26;0.83) D-0.86 (0.70;0.93) E-0.84 (0.67;0.92) F-0.86 (0.70;0.93)	C-8.06 D-7.86 E-7.99 F-8.50 Intraexaminer: A-5.67 B-7.51 C-8.89 D-5.15 E-4.90 F-5.22	
Ridehalgh et al 2012 [50]; Ridehalgh et al 2014 [51]; Ridehalgh et al 2015 [52]	Sciatic	Ultrasound imaging analysed with frame-by-frame cross-correlation and Image J program	Full knee extension from 90°: A- Hip 30° flexion;	A- 0.92 (0.79;0.97)	0.69	
			B – Hip 60°flexion	B- 0.96 (0.89;0.99)	0.87	

Boyd et al 2012 [53]	Tibial	Ultrasound imaging and with cross-correlation analysis	From > 30° Plantar Flexion to > 0° Dorsal Flexion A – Neutral: 20° of hip flexion, knee extension, ankle neutral; B – Flexion: up to sensory response	Longitudinal motion: 0.97 (0.94; 0.99) Medial-lateral motion: 0.98 (0.94; 0.99) Superficial-deep motion 0.98 (0.97; 0.99)	Longitudinal motion: 0.23; Medial-lateral Motion: 0.42; Superficial-deep motion: 0.34	
Boyd et al 2014 [10]	Tibial	Ultrasound imaging with Image J software and with cross-correlation analysis	From active maximal plantar flexion to active maximal dorsiflexion. A – Knee (popliteal crease);	A – Longitudinal: 0.87 (0.73;0.95); Medial-lateral 0.95 (0.89;0.98); Superficial-deep: 0.95 (0.89;0.98);	A – Longitudinal: 0.21; Medial-lateral: 0.21; Superficial-deep: 0.15;	Healthy: 0.4% (SD 0.3) DM Group: 0.2% (SD 0.3) (P=0.102)

			B – Ankle (at the medial malleolus level);	B – Longitudinal: 0.87 (0.73;0.94); Anterior-Posterior: 0.96 (0.92;0.98); Superficial-deep 0.92 (0.83;0.96)	B – Longitudinal: 0.33; Anterior-Posterior: 0.16; Superficial-deep: 0.21.	
Carroll et al 2012 [54]	Tibial	Ultrasound imaging using frame-by-frame cross-correlation analysis	Movement from a position of 20° plantar flexion to a position of 10° dorsiflexion	Intrarater: 0.93 (0.70; 0.96)	Session 1: 0.28 Session 2: 0.22	SRM (smallest real difference) session 1 0.84mm; session 2 0.68mm
Shum et al 2013 [55]	Tibial	Ultrasound imaging using frame-by-frame cross-correlation analysis	Trunk forward bending as far as comfortably possible	Longitudinal: 0.96 (0.93;0.98);	Longitudinal: 0.70;	
				Axial: 0.82 (0.68;0.92);	Axial: 1.31;	
Patel et al 2014 [57]	Cubital	Ultrasound measurement with ellipse method	T1- Elbow at 30°;	Interrater: 0.66 Intrarater: 0.87		
			T2- Elbow at 90°	Interrater: 0.61 Intrarater: 0.82		

Sierra - Silvestre et al 2018 [59]	Femoral	Ultrasound imaging and using cross-correlation analysis	T1: Knee flexion T2: Neck flexion	Longitudinal 0.87 (0.69;0.96)	Longitudinal: 0.84	
				Transversal X-axis (medio-lateral): 0.87 (0.47;0.97)	Transversal x-axis: 0.09	
				Transversal Y-axis (antero-posterior): 0.97 (0.87;0.99)	Transversal y-axis: 0.03	
Kasehagen et al 2016 [58]	Radial	Ultrasound imaging and using cross-correlation analysis	Forearm pronated: T1: a) Active wrist flexion;	T1 a)0.72 (0.49;0.86)	T1 a) 0.19	T1 a) 0.53
			T1: b) Passive wrist flexion;	T1 b)0.77 (0.57;0.88)	T1 b) 0.48	T1 b) 0.80
			T2: a) Active wrist ulnar deviation;	T2 a)0.85 (0.71;0.93)	T2 a) 0.20	T2 a) 0.56
			T2: b) Passive wrist ulnar deviation	T2 b)0.86 (0.73;0.93)	T2 b) 0.22	T2 b) 0.62
			Forearm supinated: T3: a) Active wrist flexion;	T3 a)0.79 (0.60;0.88)	T3 a) 0.16	T3 a) 0.44
			T3: b) Passive wrist flexion;	T3 b)0.76 (0.56;0.88)	T3 b) 0.34	T3 b) 0.49

			T4: a) Active wrist ulnar deviation;	T4 a)0.70 (0.46;0.84)	T4 a) 0.30	T4 a) 0.84
			T4: b) Passive wrist ulnar deviation.	T4 b) 0.63 (0.36;0.81)	T4 b) 0.40	T4 b) 1.11

Table 4- Excursion of Median Nerve – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm) (SD)
Alexander A., et al 2012 [38]	N = 16 No age data (11 Female)	**P1** - Supine; Shoulder neutral, elbow extended, forearm supinated;	Wrist crease	Wrist Extension (from full comfortable flexion to 30° of wrist extension)	**P1**: Radial: 3.52 (1.46) Dorsal: 0.96 (0.75)
		P2 – Supine: Shoulder neutral, elbow extended, forearm pronated;			**P2**: Radial: 1.30 (2.03) Dorsal: 0.55 (0.72)
		P3 – Supine: shoulder abducted 90°, elbow extended, forearm supinated;			**P3**: Radial: 3.57 (1.86) Dorsal: 0.84 (0.54)
		P4 – Supine: Shoulder abducted 90°, elbow extended, forearm pronated;			**P4**: Radial: 2.44 (1.56) Dorsal: 0.24 (0.67)
		P5- Supine: Shoulder neutral, elbow flexed to 90°, forearm supinated;			**P5**: Radial: 3.38 (1.12) Dorsal: -0.22 (0.59)
		P6- Supine: Shoulder neutral, elbow flexed to 90°, forearm pronated;			**P6**: Radial: 2.29 (1.10) Dorsal: 0.36 (0.75);
		P7- Supine: Shoulder abducted 90°, elbow flexed to 90°, forearm supinated;			**P7**: Radial: 2.65 (1.25) Dorsal: 0.02 (0.45)

		P8- Supine: Shoulder abducted 90°, elbow flexed 90°, forearm pronated			**P8**: Radial: 2.33 (1.21) Dorsal: 0.26 (0.64)
Brochwicz et al 2013 [37]	N=11 25.6y ±2.3 (6 Female)	Shoulder at 30° Abduction, Depression and external rotation, elbow in full extension, forearm in full supination	a) Middle forearm; b) Distal forearm;	T1-Cervical Lateral Glide at C5-C6 (Translational movement away from the side to be tested)	T1 – a) 3.3 b) 2.5
				T2-Cervical Contralateral Lateral Flexion	T2 – a)2.3 b) 1.9
Coppieters et al 2009 [8]	N = 15 30 y ±8 (8 Females)	Shoulder girdle fixated, 90 shoulder abduction and external rotation, 90 elbow flexion, forearm supinated, wrist neutral and fingers extended	Elbow (transversal scan); Medial Bicipital Furrow 7 to 10 cm proximal to medial epicondyle (longitudinal)	**A** – sliding technique (elbow extension and ipsilateral cervical lateral flexion);	**A** – 10.2 (2.8)
				B – tensioning technique (elbow extension and contralateral cervical lateral flexion);	**B** – 1.8 (4.0)
				C – elbow extension with the neck in contralateral lateral flexion;	**C** – 5.6 (2.1)
				D – elbow extension with the neck in ipsilateral lateral flexion;	**D** – 5.5 (2.9)
				E – cervical contralateral lateral flexion with the elbow in more extended position;	**E** - -3.3 (1.3)
				F – Cervical contralateral lateral flexion with the elbow in flexed position.	**F - -**3.4 (1.9)
Dilley et al. 2003 [39]	N= 34 Age range 20-59 y (23 Female)	**A1**- Supine; Shoulder at 45° Abduction; Elbow in full extension; Forearm supinated; Digits and metacarpophalangeal joints neutral (N=10)	Measurement: a) Distal Upper Arm; b) Mid-Forearm	**A** – Wrist Extension (0°-40°)	**A1**: Distal Upper arm: 2.4 (1.8); Mid-forearm: 4.7 (0.5);

		A2- Supine; Shoulder at 90° abduction; Elbow in full extension; forearm supinated; digits and metacarpophalangeal joints in neutral (N=10)			**A2**: Distal upper arm: 1.8 (0.4); Mid-forearm: 4.2 (0.6);
		A3 – Supine; Shoulder at 30° abduction; elbow at 90° flexion; forearm supinated; digits and metacarpophalangeal joints neutral (N=4)		**B** – Wrist Extension (40°-0°)	**A3**: Distal upper arm: 0.2 (0.2); Mid-forearm: 5.6 (0.9);
		B1 – Supine; Shoulder at 45° abduction; elbow in full extension; forearm supinated; digits and metacarpophalangeal joints neutral (N=6)			**B1**: Distal Upper arm: 0.5 (0.4); Mid-forearm: 3.1 (0.3);
		B2 – Supine; Shoulder at 90° abduction; elbow in full extension; forearm supinated; digits and metacarpophalangeal joints neutral (N=3)		**C** – Shoulder Abduction (10°-90°)	**B2**: Distal Upper arm: 0.6 (0.4); Mid-forearn: 3.1 (0.2);
		C – Supine; Elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=4)			**C:** a) -5.2 (0.7); b) -3.4 (0.8);
		D1 – Supine; Shoulder at 90° abduction; wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=7)		**D** – Elbow Extension (90°-0°)	**D1**: Distal Upper Arm: 10.4 (2.3); Mid-forearn: -3.0 (1.0);

		D2 – Supine; Shoulder at 90° Abduction; Forearm supinated, wrist at 45° extension; digits and metacarpophalangeal joints neutral (N=4)			**D2**: Mid-forearn: -4.2;
		E1 – Supine; Shoulder at 30° Abduction, elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints neutral (N=8)		**E** – Neck Flexion (0°-35°)	**E1**: Distal Upper Arm: -0.5 (0.8) Mid-forearn: -0.3 (0.6);
		E2 – Supine; Shoulder at 90° Abduction, elbow in full extension, wrist neutral (0°), forearm supinated, digits and metacarpophalangeal joints in neutral (N=9)			**E2**: Distal Upper Arm: -1.3 (0.7); Mid-forearn: -0.8 (0.3)
Dilley et al 2008 [40]	N=39 Mean Age= 34.1±11.7 (23 Female)	**A)** In 45° shoulder abduction, elbow extension, MCP joints and finger extension and the wrist is moved to 40° extension.	Measurement: a) Distal third of the forearm; b) The upper arm near the elbow; c) Mid forearm.	**A)** Wrist Extension;	**A)** a) 4.40mm (range 3.43-5.57) b) 2.31mm (range 1.43-3.30)
		B) In 90° shoulder abduction, elbow extension, wrist in neutral position, the fingers start in 90° flexion and are brought to neutral position;		**B)** MCP Extension;	**B)** a) 2.62mm (range 1.63-4.54)
		C) In 90° shoulder abduction, wrist and fingers neutral, the elbow is extended from 90° flexion to neutral		**C)** Elbow Extension.	**C)** c) 4.07mm (range 2.93-4.88)

Echigo et al 2008 [41]	N= 34 (No age data) (100% Female)	Supine Position with the right shoulder in 30° of abduction: **A1)** Elbow Extension, forearm in 80° supination; **A2)** Elbow Extension, forearm in 70° supination; **A3)** 90° elbow flexion, forearm in 80° supination; **A4)** 90° elbow flexion, forearm in 70° supination.	Volar aspect of the Proximal third part of Forearm	**A)** Passive extension of the wrist and fingers;	**A1)** 3.0 (1.81) **A2)** 1.9 (1.43) **A3)** 3.0 (1.34) **A4)** 2.2 (1.66)
		Supine position, with the right shoulder in 30° of abduction, elbow extension, supination 80°, wrist 0° extension and fingers slightly flexed position: **B1)** Proximal Interphalangeal and Distal Interphalangeal bent gently until the tips touched the palm; **B2)** Proximal Interphalangeal, Distal Interphalangeal and metacarpophalangeal gently flexed until the tips touched the palm.		**B)** Active flexion of the fingers;	**B1)** 0.8 (0.76) **B2)** 1.3 (0.96)
Erel et al 2003 [42]	N= 19 41.3y ±9.9 (68% Female)	Supine Position, elbow full extended, forearm supinated, finger extension: a) 90° shoulder abduction; b) 45° shoulder abduction.	5-15 cm proximal from the distal wrist crease	MCP 90° flexion to neutral position of fingers 2 to 5	Longitudinal Excursion: 2.6 Transverse Excursion: 1.55 (radial direction;
Gonzalez-Suarez et al 2016 [43]	N= 20 Age range (18-50) Male N=10 (25.5±1.7)	**Technique 1 and 2**: Wrist Extension **Technique 3 and 4:** ipsilateral and contralateral neck lateral flexion	Wrist Level and Arm Level	Supine Position, Head in neutral position, Shoulder abducted at 90° and external rotated. Elbow, MTP and IP joints of fingers and thumb in full extension	

	Female N=10 (25.4±2.7)			**T1**: Passive extension of wrist up to 60° with cervical spine prepositioned at 45° of ipsilateral lateral flexion;	**Wrist Level:** 15.5 (7.0) **Arm Level:** 6.82 (2.97)
				T2: Passive extension of wrist up to 60° with cervical spine prepositioned at 45° of contralateral lateral flexion;	**Wrist Level**: 13.4 (5.6) **Arm Level:** 5.33 (2.37)
				T3: Passive ipsilateral lateral flexion of cervical spine to 45° with the wrist prepositioned at 60° extension;	**Wrist Level:** 5.98 (2.73) **Arm Level:** 3.52 (1.45)
				T4: Passive contralateral lateral flexion of cervical spine to 45° with the wrist prepositioned at 60° extension;	**Wrist Level**: -3.8 (0.31) **Arm Level:** -4.87 (2.49)
Greening et al 2005 [44]	Control 1 (Group of Whiplash) N=8 (mean age 40) (4 Female) Control 2 (group of non-specific arm pain) N=7 (mean age 32) (7 Female)	**Longitudinal Imaging**: Supine with shoulder abducted to 30°, elbow fully extended and forearm supinated, wrist and digits in neutral.	**Longitudinal imaging**: Mid forearm, both sides.	**Longitudinal images:** Maximal inspiration followed by forced expiration	**Longitudinal results:** Control 1: 1.32 (0.17) Control 2: 1.55 (0.19)
		Transversal Imaging: Supine, shoulder abducted at 30°, elbow fully extended and forearm supinated, digits and MCP joints neutral. T1: Wrist in 30° of flexion; T2: Wrist in 30° of extension.	**Transversal Imaging**: Palmer surface of the wrist at the distal wrist crease	**Transversal images**: Wrist at 30° flexion and at 30° of extension	**Transversal Results** Control: -0.39 (0.52) ulnar direction;
Hough et al 2000 [45]	N=16 (mean age 38; range 26-61) (9 Females)	Supine; Shoulder at 45° Abduction; Elbow in full extension; forearm supinated; Thumb aducted and fingers extended	Anterior Aspect of Elbow Joint	Wrist extension (0-60°)	**All data** (N=32): 9.0 (2.1) **Dominant arm** (N=16): 8.5 (1.8) **Non-Dominant Arm** (N=16): 9.4 (2.3)

Hough et al 2007 [16]	N=37 (48±10y) (29 Female)	Supine position, shoulder abducted at 45° and forearm supinated. Head at a neutral position. Wrist 30° of extension. Fingers fully flexed (MCP and IP). **T1:** Elbow Flexed at 90°; **T2:** Elbow fully Extended.	Wrist, level of the lunate-capitate intercarpal joint	Fingers and thumb extension	**T1:** Control: 12.5±2.5 **T2:** Control: 11.2±2.8 **Transversal displacement:** 0.35±0.3 Axial direction; 1.75±1.3 lateral direction
Julius et al 2004 [31]	N= 14 (mean age 32) (9 Female)	**T1, T2, T3**: Upright on a chair: hips and knees at 90° flexion, right upper limb with glenohumeral joint in 90° flexion and 20° abduction, elbow at full extension, 45° forearm supination, wrist, hand and fingers neutral. T4-A Supine position, 90° shoulder abduction. Scapulothoracic joint in neutral. Elbow extended, forearm supinated, wrist, hand and fingers neutral. T4-B Supine position, 90° shoulder abduction. Scapulothoracic joint in full protraction. Elbow extended, forearm supinated, wrist, hand and fingers neutral.	T1 e T2: proximal forearm; T3: a) forearm b)forearm; T4: a) distal forearm; b) upper arm	**T1**: N=8 Forward head position: lower cervical spine flexion and upper cervical spine extension;	**T1:** 0.1;
				T2: N=8 Active trunk flexion with pelvis posterior tilt;	**T2:** 0.1
				T3: N=13 passive shoulder girdle protraction;	**T3:** a)3.5; b)5.9;
				T4: N=11 passive contralateral neck side flexion.	**T4-A** a)1.5 b)2.3; **T4-B** a)0.6; b)0.9
Kang et al 2016 [32]	N=23 (54.87y± 1.85) (23 Female)	Supine, shoulder at 45° abduction, elbow fully extended, supinated forearm, neutral wrist, fingers fully extended.	Distal Wrist Crease	Flexion of first, second and third fingers	**Dorsopalmar - First** 0.32 (0.06)
					Dorsopalmar - Second 0.50 (0.10)
					Dorsopalmar - Third 0.95 (0.14)
					Dorsopalmar - Grip 0.64 (0.11)

					Radioulnar - First 0.81 (0.18)
					Radioulnar - Second 0.98 (0.21)
					Radioulnar - Third 1.05 (0.27)
					Radioulnar - Grip 0.84 (0.18**)**
Korstanje et al 2012 [33]	N=51 (50.6y ±13.0) (37 Female)	Sitting position, arm positioned on a table, supinated and the elbow 90°of flexion, wrist and fingers in neutral.	Carpal Tunnel at the wrist crease level	Active Extension to fist movement of most affected and least affected hands	Controls N=49 hands 8.1 (range 0.0-23.8)
Lopes et al 2011 [34]	N=16 (33.1y±11.5) (9 Females)	Sitting position, forearm supinated, on a table and elbow flexed at 120° **T1:** fingers extended	Volar aspect of the wrist	**T1 –** MCP flexion to 90°;	**T1- Left hand** 13.4 (3.8) **Right hand** 11.8 (3.7)
		T2: fingers extended		**T2 –** Full fist	**T2- Left hand** 29.4 (10.7) **Right hand** 24.8 (8.0)
		T3: wrist neutral, fingers extended		**T3 –** Wrist extension to 60°	**T3- Left hand** 20.0 (7.1) **Right hand** 22.1 (7.5)
		T4: wrist at 60° extension, fingers extended		**T4 –** Wrist extension and full fist;	**T4- Left hand** 45.8 (15.9) **Right hand** 50.2 (10.8)
		T5: wrist at 60° extension with 2nd and 3rd digits opposed to thumb (in a pinch grip)		**T5 –** Wrist extension with static 3 finger pinch	**T5- Left hand** 26.6 (8.6) **Right hand** 23.7 (8.4)
Park et al 2017 [35]	N=10 (59.85y ±13.41) (5 Females)	Supine position with elbow extended, forearm supinated, shoulder in neutral.	Proximal carpal tunnel	Thumb flexion; 2nd finger flexion; 3rd finger flexion; grasp; wrist ulnar deviation with finger extension; Wrist radial deviation with finger extension	**MVC of displacement** 0.5 (0.10) **MVC of area** 5.00 (0.84**)**
Wang et al 2014 [36]	N=10 (39.1y ±9.8) (6 Females)	Sitting position with shoulder in neutral, forearm supinated, wrist in neutral.	Proximal carpal tunnel 1 NU = 1.8mm	**T1-**Finger flexion;	**T1**: 0.2NU
				T2-Wrist flexion with finger extension;	**T2**: 1.5NU;
				T3-Wrist flexion with finger flexion;	**T3**: 1.8NU;
				T4: Wrist extension with finger extension;	**T4:** 0.4NU;

				T5: Wrist Extension with finger flexion;	**T5**: 0.5NU;
				T6: Wrist ulnar deviation with finger flexion	**T6**: 2.8NU

Table 5 - Excursion of Cubital Nerve – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm)(SD)
Dilley et al 2007 [56]	N=15 30y±6 (10 Female)	T1- a) Supine, shoulder at 90° abduction, elbow in full extension, forearm supinated, digits and MCP joints in neutral; (N=6) b) Supine, shoulder at 90° abduction, elbow at 90° flexion, forearm supinated, digits and MCP joints neutral; (N=4) c) Supine, shoulder at 40° abduction, elbow in full extension, forearm supinated, digits and MCP joints in neutral; (N=4)	Proximal forearm; Distal Forearm; Mid forearm; Upper arm proximal to elbow;	T1- Wrist Extension (0°-40°)	T1- a) proximal forearm: 1.1; distal forearm: 2.1 Proximal vs distal (P<0.05) T1 b) distal forearm 4.0; proximal forearm 2.3 T1- c) distal forearm 3.0; Proximal forearm 1.6 T1 b > T1 c (P<0.01)

		T2- Supine, shoulder at 90° abduction, elbow at 0°, forearm supinated, digits and MCP joints neutral;		T2- Elbow Flexion (0°-90°)	T2- distal third forearm (N=4) 0.8; proximal upper arm (N=2): 0.1
		T3- Supine, shoulder at 90° abduction, elbow at 90°, forearm supinated, digits and MCP joints neutral; (N=1)		T3- Elbow Flexion (90°-140°)	T3- 2.7
		T4- Supine, shoulder at 40°, wrist, digits and MCP neutral, elbow: a) straight (N=5); b) at 90° flexion (N=2).		T4- Shoulder Abduction (40°-90°)	T4- a) 0.1 b) 0.1
Patel et al 2014 [57]	N=25 (no age data) (18 Female)	Supine position, with a pillow under the extremity being scanned; wrist supinated position.	Retroepicondylar groove	T1- Elbow at 30°;	Flattening ratio T1- 0.52±0.09
				T2- Elbow at 90°	Flattening ratio T2- 0.57±0.10

Table 6 - Excursion of Radial Nerve – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm) (SD)
Kasehagen et al 2016 [58]	N=30 29.8y ±8.4 (18 Female)	Supine position, arm on a table, shoulder at 45 °abduction, elbow full extension; wrist unsupported to allow full movement at participant´s maximum tolerable range of motion. Thermoplastic splint maintaining MCP joints at 30° flexion, allowing wrist free motion	1-5cm proximal to the humeroulnar joint	<u>Forearm pronated:</u> T1: a) Active wrist flexion;	T1 a)0.93 ±0.36
				b) Passive wrist flexion;	T1 b)1.42 ±0.60
				T2: a) Active wrist ulnar deviation;	T2 a)1.07 ±0.52
				b) Passive wrist ulnar deviation	T2 b)0.82 ±0.60
				<u>Forearm supinated:</u> T3: a) Active wrist flexion;	T3 a)1.01 ±0.35
				b) Passive wrist flexion;	T3 b)1.78 ±0.69
				T4: a) Active wrist ulnar deviation;	T4 a)1.16 ±0.55
				B) Passive wrist ulnar deviation.	T4 b)1.69 ±0.66

Table 7 - Excursion of Sciatic Nerve – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm)(SD)
Coppieters et al 2015 [23]	N=15 (27.5y ±2.7) (9 Females)	Left side-lying, The upper body rested, ankle and foot in neutral	Posterior lateral thigh at a distance varying from 12 to 24 cm from the greater trochanter and 21 to 30 cm from the lateral epicondyle of the knee	T1- Simultaneous knee extension and hip flexion;	T1: 1.0 ±3.8;
				T2- Simultaneous knee and hip extension;	T2: 17.0 ±5.2; (T2 > T1, T3, T4, T5, T6 P<0.001)
				T3- Knee extension with hip in neutral;	T3: 6.9 ±2.5;
				T4- Knee extension with hip in neutral;	T4: 8.8 ±3.5;
				T5- Hip flexion with the knee flexed;	T5: -11.7 ±4.8;
				T6- Hip flexion with the knee in extension	T6: .7.0 ±3.8
Ellis et al 2012 [46]	N=31 (29y±9) (22 Females)	Sitting position at Isokinetic Dynamometer, with slumped spinal posture (thoracic and lumbar in a flexed position), hips at 90° of flexion; chest against a 45cm diameter ball.	Posterior midthigh (halfway between the gluteal crease and popliteal crease)	T1- Simultaneous passive Knee Extension (From 80° to 20° flexion) and active neck extension (from full flexion to full extension);	T1: 3.3 (2.0);
				T2- Passive Knee Extension (from 80° to 20° flexion), neck in neutral;	T2: 2.6 (1.4);
				T3- Active cervical flexion (full extension to full flexion), knee at 80° flexion;	T3: -0.1 (0.1)
				T4- Passive Knee Extension (from 80° to 20° flexion) simultaneously active cervical flexion (from full extension to full flexion)	T4: 2.6 (1.5)
Ellis et al 2015 [47]	N=38 (males N=18	A – Slump-sitting: slumped spine posture with sternum against 45cm ball;	Posterior mid-thigh (half-way between the gluteal and popliteal creases)	T1 - Passive Knee extension from 90°flexion to 4/10 point of stretch discomfort;	T1 – A 6.2 ±2.9; T1 – B 6.1 ±2.5;

	27.4y ±4.4; females N=16 32.5y ±13.09)	B- Upright-sitting: trunk relaxed into the back-rest.		T2 – Passive knee extension from 90° flexion to 4/10 point of stretch discomfort and active cervical spine extension from full comfortable flexion to full comfortable extension;	T2 – A 6.4 ±2.7; T2 – B 6.9 ±2.6;
				T3- Passive knee extension from 90° flexion to 4/10 point of stretch discomfort and active cervical flexion from full comfortable extension to full comfortable flexion	T3- A 6.0 ±2.9; T3 – B 6.4 ±2.7 A vs B (P=0.17)
Ellis et al 2018 [48]	N=12 (23.9y ±4.74) (10 Female)	Seated upright, spine resting against rigid back, knee in 80° flexion, ankle in neutral	Posterior mid-thigh at or immediately distal to halfway between the gluteal and popliteal creases	T1 - Knee extension from 80° to 20° of flexion – active	T1: 4.52 ±2.63; Flexion:
				T1- Knee flexion from 20° to 80° - active	T1: 5.38 ±2.20;
				T2 - Knee extension from 80° to 20° of flexion – passive	T2: 4.34 ± 2.81;
				T2- Knee flexion from 20° to 80° - passive	T2: 4.68 ±3.14
Pagnez et al 2019 [49]	N=30 (35.5y ±6.2) (16 Female)	Lying in prone position, with head in neutral and supported position, upper limbs stretched forward and supported, thoracic and lumbar spine supported on the fixed seats and pelvis and lower limbs on the movable seat.	Posterior left thigh: mean distance between the trochanter and the knee joint, 15 cm above the popliteal fossa	A-Neutral lumbar, knee extended and ankle in neutral;	A-(54.34; 49.21-59.47)
				B-Neutral lumbar, knee flexed, neutral ankle;	B-(59.71; 53.21-66.21)
				C-Neutral lumbar, knee extended, ankle in maximal active dorsiflexion;	C-(48.37; 42.26-54.47)
				D-Flexed lumbar, knee extended, ankle in neutral;	D-(51.18; 46.03-56.34)
				E- Flexed lumbar, knee flexed and neutral ankle;	E-(53.57; 48.57-58.56)
				F- Flexed lumbar, knee extended and ankle in maximal active dorsiflexion	F-(48.71; 43.05-54.37)
Ridehalgh et al 2012 [50]	N= 18 (28.9y ±14.3) (9 male)	Full knee extension from 90° 1-Baseline; 2-48h later	Posterior upper thigh on a line between the ischial tuberosity and the great trochanter and 7-10 cm distal to the gluteal fold	A - Side lying, chosen leg upper most, hip joint with 30° flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	1-A 9.9 ±2.2;
					1-B 12.4 ±4.4;
				B - Side lying, chosen leg upper most, hip joint with 60°flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	2-A 10.1 ± 2.5
					2-B 12.5 ±4

Ridehalgh et al 2014 [51]	N= 18 (28.9y ±14.3) (9 male)	Full knee extension from 90°	Posterior upper thigh on a line between the ischial tuberosity and the great trochanter and 7-10 cm distal to the gluteal fold	A - Side lying, chosen leg upper most, hip joint with 30° flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	Transversal excursion: N=16 A: 4.4 ±2.2; B: 3.6 ±2.3
				B – Side lying, chosen leg upper most, hip joint with 60°flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	Longitudinal Excursion: A: 9.9 ± 2.2; B: 12.4 ±4.42
Ridehalgh et al 2015 [52]	N=16 (28.9y ±14.3) (44% Female)	Full knee extension from 90° (symptomatic leg selected)	Mid-posterior thigh, 10 cm distal to gluteal fold	A- Side lying, chosen leg upper most, hip joint with 30° flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	A: 10.0;
				B – Side lying, chosen leg upper most, hip joint with 60°flexion positioned over the joint of the jig, lumbar spine in neutral, cervical spine neutral;	B: 12.5;

Table 8 - Tibial Nerve Excursion – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm) (SD)
Boyd et al 2012 [53]	N= 5 (40 ±11.8) (4 Female)	Side Lying; Spine in Neutral; Hip Flexion (20°), Knee Extended (0°);	Poplitea Fossa	From > 30° Plantar Flexion to > 0° Dorsal Flexion	Longitudinal (distal direction) A – 2.18 (0.48) P=0.001; B – 0.66 (0.25) P=0.004;

		Side Lying; Spine in Neutral; Hip Flexion (≈62°), Knee Extended (0°).		A – Neutral: 20° of hip flexion, knee extension, ankle neutral; B – Flexion: up to sensory response	Transversal medial movement: A-1.36 (0.99 P=0.038) B-1.44 (0.93 P=0.026)
					Transversal superficial movement: A- 3.98 (1.70 P=0.006); B- 3.67 (1.47, P=0.005)
Boyd et al 2014 [10]	N=20 (46.4y ±13.8) (10 Female)	Right side lying position, spine in neutral. Right limb at 20° hip flexion and full knee extension, relaxed ankle position. Left limb in hip and knee flexion supported by a pillow to avoid adduction and hip rotation.	A – Knee (popliteal crease);	From active maximal plantar flexion to active maximal dorsiflexion	A – Longitudinal: 2.17 ±0.67 (P=0.001)
			B – Ankle (at the medial malleolus level)		B – Longitudinal: 3.14 ±1.26 (P=0.006) Transversal: (Posterior direction) 0.32 ±1.79 (P=0.015)
Carroll et al 2012 [54]	N=16 34.7y ±9.3 (10 Female)	Left foot on a weight-bearing plataform and right foot parallel position	1cm superior to the medial malleolus with transducer aligne longitudinally in the plane of tibial nerve	Movement from a position of 20° plantar flexion to a position of 10° dorsiflexion	Session 1: 3.03±1.07 Session 2: 2.99±0.86
Shum et al 2013 [55]	N= 25	Standing position, looking straight ahead,	Popliteal crease		Longitudinal: 11.3±2.0

	28.54y ±9.48 (14 Female)	arms folded across chest, feet positioned shoulder width apart		Trunk forward bending as far as comfortably possible	
					Axial: 4.3±1.7
					Hypotenuse: 12.2±2.2

Table 9 – Femoral Nerve Excursion – Asymptomatic

Authors	Sample Size and Age (mean SD)	Participant position and position of adjacent joints	Site of Measurement	Movement and Involved Joints	Excursion mean (mm) (SD)
Sierra-Silvestre et al 2018 [59]	N=30 25.7y ±2.9 (15 Female)	T1: Left Leg a) Supine position, hip 0°, posterior thigh rested on a plinth, lower leg outside de plinth. Right leg in hip and knee flexion, foot relaxed at the level of the plinth	Below Inguinal Ligament	T1: Knee flexion T2: Neck flexion	Longitudinal direction: T1: a) 3.6mm (2.0) p≤0.01 b) 1.1mm (1.6) p≤0.01 T2: 0.0mm (0.3)

		T1: Left Leg b) Semi-seated position, hip ≈40°.			Transversal X-axis: T1: a)1.4mm (0.3) p≤0.01 b) 0.7mm (0.1) p≤0.01 T2: 1.1mm (0.5)
		T2: Side-lying slump with left hip in extension and the left knee in flexion.			Transversal Y-axis: T1 a)0.2mm (0.2) p≤0.01 b) 0.1mm (0.2) T2: 0.0mm (0.1)

Table 10 - Excursion and Strain in Nerves of Symptomatic Individuals

Authors	Sample Size and Age (mean SD)	Health condition	Movement and Involved Joints	Participant position and position of adjacent joints	Site of Measurement	Excursion mean (SD)(mm)	Strain (%)
Median Nerve							
Dilley et al 2008 [40]	N= 18 Mean Age= 36.9±9.5	Non-specific arm pain (NSAP)	**A)** Wrist Extension; **B)** MCP Extension; **C)** Elbow Extension.	**A)** In 45° shoulder abduction, elbow extension, MCP joints and finger extension and the wrist is moved to 40° extension.	Measurement: a) Distal third of the forearm; b) The upper arm near the elbow; c) Mid forearm.	**A)** a) NSAP: 3.97mm (SEM 0.33 Range 3.06-4.73) b) NSAP: 2.00mm (SEM 0.25 range 1.43-2.74) **B)** a) NSAP: 2.68mm (SEM 0.44 range 1.46-4.01)	

				B) In 90° shoulder abduction, elbow extension, wrist in neutral position, the fingers start in 90° flexion and are brought to neutral position; **C)** In 90° shoulder abduction, wrist and fingers neutral, the elbow is extended from 90° flexion to neutral		**C)** c) NSAP: 3.34 mm (SEM 0.35 range 1.26-4.38) No significant difference in nerve sliding (p>0.05) Timing: NSAP: 53.4° (SEM 2.2) (p>0.05)	
Erel et al 2003 [42]	N= 17 44.8±8.8	Carpal Tunnel Syndrome	MCP 90° flexion to neutral position of fingers 2 to 5	Supine Position, elbow full extended, forearm supinated, finger extension: a) 90° shoulder abduction; 45° shoulder abduction.	Measurement: 5-15 cm proximal from the distal wrist crease	Longitudinal Excursion: CTS: 2.2mm (SEM 0.2 range 1.1-4.8); Transverse Excursion: CTS most affected side: 0.89mm (SEM 0.28) CTS least affected side: 1.49mm (SEM 0.35) asymptomatic vs CTS most affected side (P>0.08) CTS most affected side vs least affected (P<0.05)	
Greening et al 2005 [44]	Whiplash N=9 (mean age 37) NSAP N=8 (mean age 32)	Whiplash NSAP	**Longitudinal images:** Maximal inspiration followed by forced expiration **Transverse images**: Wrist at 30° flexion and at 30° of extension	**Longitudinal Imaging**: Supine with shoulder abducted to 30°, elbow fully extended and forearm supinated, wrist and digits in neutral. **Transverse Imaging**: Supine, shoulder abducted at 30°, elbow fully extended and forearm	Measurement: **Longitudinal imaging**: Mid forearm, both sides. **Transversal Imaging**: Palmer surface of the wrist at the distal wrist crease	**Longitudinal results:** Whiplash symptomatic side: (0.38± 0.08mm) Whiplash less/non symptomatic side: (0.66± 0.12mm) Asymptomatic vs Less/non symptomatic P<0.05 Asymptomatic vs Symptomatic P<0.05 NSAP: 0.49± 0.19mm P<0.05	

				supinated, digits and MCP joints neutral. T1: Wrist in 30° of flexion; T2: Wrist in 30° of extension.		No difference between whiplash control and NSAP control (P=0.40) **Transversal Results** Whiplash: Symptomatic side: 2.57± 0.80mm radial direction Vs asymptomatic group (P<0.05); Symptomatic (N=6): 2.93± 0.85mm vs Non-symptomatic side (N=6): 2.29± 1.02mm P=0.36	
Hough et al 2007 [16]	N=19 (57±15y)	CTS	Fingers and thumb extension	Supine position, shoulder abducted at 45° and forearm supinated. Head at a neutral position. Wrist 30° of extension. Fingers fully flexed (MCP and IP). **T1:** Elbow Flexed at 90°; **T2:** Elbow fully Extended.	Wrist	**T1:** CTS: 10.2±3.1 (p=0.089) **T2:** CTS: 8.3±2.6 (p=0.013)	
Kang et al 2016 [32]	N=22 (56.82y± 2.30)	CTS	Flexion of first, second and third fingers	Supine, shoulder at 45° abduction, elbow fully extended, supinated forearm, neutral wrist, fingers fully extended.	Distal Wrist Crease	CTS (N=31) **Dorsopalmar** **First** CTS 0.22mm ±0.07 (P=0.195); **Second** CTS 0.30mm ±0.10 (P=0.099); **Third** CTS 0.36mm ±0.11 (P<0.05); **Grip** CTS 0.29mm ±0.08 (P<0.05) **Radioulnar**	

						First CTS 0.29mm ±0.08 (P<0.05) **Second** CTS 0.40mm ±0.12 (P<0.05) **Third** CTS 0.55mm ±0.16 (P=0.195) **Grip** CTS 0.40mm ±0.13 (P<0.05)	
Korstanje et al 2012 [33]	N=51 (50.6y ±13.0)	CTS	Active Extension to fist movement of most affected and least affected hands	Sitting position, arm positioned on a table, supinated and the elbow 90°of flexion, wrist and fingers in neutral.	Carpal Tunnel	Cases N=49 hands 5.3 (0.0-12.2)	
Lopes et al 2011 [34]	N=25 (37.2y ±13.4) N=6 N=3	All subjects Self-reported symptomatic group Wheelchair group	**T1 –** MCP flexion to 90°; **T2 –** Full fist **T3 –** Wrist extension to 60° **T4 –** Wrist extension and full fist; **T5 –** Wrist extension with static 3 finger pinch	Sitting position, forearm supinated, on a table and elbow flexed at 120° **T1:** fingers extended **T2:** fingers extended **T3**: wrist neutral, fingers extended **T4:** wrist at 60° extension, fingers extended **T5:** wrist at 60° extension with 2nd and 3rd digits opposed to thumb (in a pinch grip)	Volar aspect of the wrist	**T1- Left hand** Symptomatic 9.9mm (4.4) **Right hand** Symptomatic 6.9mm (1.8) **T2- Left hand** Symptomatic 21.2mm (11.1) **Right hand** Symptomatic 25.5mm (14.4) **T3- Left hand** Symptomatic 30.2mm (14.4) **Right hand** Symptomatic 27.1mm (8.7) **T4- Left hand** Symptomatic 36.4mm (20.6) **Right hand** Symptomatic 35.7mm (8.6) **T5- Left hand** Symptomatic 28.7mm (12.4) **Right hand** Symptomatic 31.1mm (4.9) Asymptomatic > Symptomatic group (p=0.008), excepted T3 (p=0.04)	

Park et al 2017 [35]	N=27 (60.74y ±10.80)	CTS (subdivided in 3 severity stages)	Thumb flexion; 2nd finger flexion; 3rd finger flexion; grasp; wrist ulnar deviation with finger extension; Wrist radial deviation with finger extension	Supine position with elbow extended, forearm supinated, shoulder in neutral.	Proximal carpal tunnel	**MVC of displacement** **CTS Stage 1:** 0.51±0.17 **CTS Stage 2:** 0.45±0.09 **CTS Stage 3:** 0.25±0.08 P<0.001 **MVC of area** **CTS Stage 1:** 5.02±1.80 **CTS Stage 2:** 2.75±1.42 **CTS Stage 3:** 1.93±0.69 P<0.001	
Sciatic Nerve							
Ridehalgh et al 2015 [52]	N=11 (57.5y ±10.6) N=29 (47.8y ±12.2) N=20 (55.9y± 13.6)	Symptomatic (Somatic) (Radicular) (Radiculopathy)	Full knee extension from 90° (symptomatic leg selected)	Side lying, chosen leg upper most, cervical spine neutral, A-Hip 30° flexion; B-Hip 60° flexion;	Posterior thigh	Somatic: A: 10.3mm; B: 8.2mm; Radicular: A: 8.8mm; B: 10.2mm; Radiculopathy: A: 9.4mm; B: 9.7mm No difference hip position (p=0.32) or sub-group (p=0.14)	
Tibial Nerve							
Boyd et al 2012 [53]	N=5 (57 ±10.1)	Diabetes Mellitus (DM) type 2	From > 30° Plantar Flexion to > 0° Dorsal Flexion A – Neutral: 20° of hip flexion, knee extension, ankle neutral;	Side Lying; Spine in Neutral; Hip Flexion (20°), Knee Extended (0°); Side Lying; Spine in Neutral; Hip Flexion (≈62°), Knee Extended (0°).	Poplitea Fossa	**DM type 2**: **Longitudinal** A – 0.83mm (0.45 P=0.015) B – 0.42mm (0.16 P=0.004) **Transverse medial movement**: A – 2.92mm (1.69 P=0.018) B – 3.11mm (1.06 P=0.003) **Transverse superficial movement**: B – 1.00mm (0.60 P=0.020)	DM Group: 0.2% (SD 0.3) (P=0.102)

			B – Flexion: up to sensory response				
Boyd et al 2014 [10]	N=20 (51.1y ±10.8)	DM type 1 and 2	From active maximal plantar flexion to active maximal dorsiflexion	Right side lying position, spine in neutral. Right limb at 20° hip flexion and full knee extension, relaxed ankle position. Left limb in hip and knee flexion supported by a pillow to avoid adduction and hip rotation.	Measurement: A – Knee (popliteal crease); B – Ankle (at the medial malleolus level)	A – **Longitudinal**: DM Group 1.30mm ±0.67 (P=0.001) **Transverse** (medial or superficial): No difference (P= 0.853-0.904) B – **Longitudinal**: DM Group: 2.06mm ±0.92 (P=0.006) **Transversal**: (Posterior direction) DM Group: 1.98mm ±1.90 (P=0.015) No difference deep movement at the ankle (P=0.675)	

4. Discussion

This systematic review synthetized existing evidence on peripheral nerve movement and strain in response to joint movement both in asymptomatic participants and participants with diverse diseases. Despite the growing number of studies aiming to characterize nerve excursion in response to joint movement over the past few years, most of them focus on the median and sciatic nerves. Few studies assessed other peripheral nerves.

Nerve excursion in asymptomatic participants

Given the results, the maximal variation of longitudinal nerve excursion for the median nerve was reported at the wrist (between -3.8 mm and 50.2 mm). Median nerve excursion was larger compared to other nerves tested both in the upper and lower limbs. Sliding techniques resulted in the largest amount of median nerve excursion independently of the nerve investigated. Physiologically, this can be explained by the fact that in a sliding technique the nerve bed is elongated on one side and shortened at the other side, yet in a tensioning technique the nerve bed is elongated at both sides [8].

The positioning of the limbs has an impact on the amount of excursion of the nerves in response to a specific movement. The median nerve transversal excursion seems to be facilitated when the forearm is supinated [38] and shoulder abduction induces more median nerve excursion than a neutral position during wrist extension [36,39,41]. At the lower limb, a flexed hip facilitates sciatic longitudinal excursion [50–52].

Nerve excursion decreases as the distance from the moving joints increases. For wrist extension, measures at wrist level resulted in a larger longitudinal excursion (15.5 mm) than measures at arm level (6.82 mm) [43]. In its turn, for ankle dorsiflexion, measurement at knee level (2.17 mm) showed less longitudinal excursion of the tibial nerve than at the medial malleolus (3.14 mm) [10]. This fact is important to future studies at the time of outlining the measurement sites. Furthermore, biomechanically nerve behaves differently at different measurement sites: at the knee nerve moved in a distal, medial and superficial direction [10,53], yet at ankle level nerve moved in distal, posterior and superficial direction [10].

Depending on the joint movement performed, the nerve movement can be in different directions (proximal or distal direction). This fact was observed during elbow extension, where median nerve moved proximally at the forearm, and distally at the arm [8,39,40]. This movement is named convergence, when nerve glides toward the moving joint during the elongation of the nerve bed. On the other hand, when the tension in the nerve bed is relieved during the joint movement, the nerve behaves differently, moving away from the moving joint and this phenomenon is named divergence [4].

Nerve strain in asymptomatic participants

A decrease in the CSA of a nerve is used as an indicator of the strain in that structure [4]. The combination of knee extension and ankle dorsiflexion reduced the CSA of sciatic nerve, and flexing the knee and keeping the ankle in the neutral position increased it (knee extension + ankle dorsiflexion: 48.37 mm^2 ±16.35; flexing the knee + ankle in neutral: 59.71 mm^2 ± 17.41). This is important for clinical practice, since this position increasing the CSA and, consequently, reducing nerve strain, could be used in patients with symptoms related to the sciatic nerve [49].

Dilley et al study [39] calculated strain values for wrist, shoulder, elbow and neck movements. The total strain in the proximal forearm is 2.1% and contra-lateral lateral flexion only increases median nerve strain by 0.2% in the forearm.

According to Dilley et al [39], median nerve strain values during upper limb movements do not limit the intraneural blood supply or the nerve conduction. Normal strain tolerances for peripheral nerve tissue is between 6% and 8%, with damage occurring at 11% strain, due to demyelination or axonal tears [4], and Dilley et al [39] results are below that. However, more investigation of the impact of joint movement on nerve strain is needed to understand which techniques can cause less strain and be more beneficial to individuals whether they are symptomatic or asymptomatic.

Nerve excursion in asymptomatic and symptomatic participants

This systematic review analysed the excursion and strain in response to joint movement in both asymptomatic and symptomatic individuals and the possible significant differences between them.

There was a small number of studies exploring the differences in nerve excursion and strain between asymptomatic and symptomatic individuals and for diverse pathologies. From the eleven studies that evaluated symptomatic participants, more than half studied the median nerve and the carpal tunnel syndrome. Study results are conflicting: three studies reported that median nerve showed greater longitudinal excursion in asymptomatic than in symptomatic individuals, one reported no between-group differences, one suggested that the severity of the carpal tunnel syndrome might impact nerve movement with differences between symptomatic and asymptomatic participants reported only for the group of participants with more severe carpal tunnel syndrome [35], and the other one only reported statistically significant differences between the two groups in three movements in one or both axis (third finger flexion, grip motion and second finger flexion) of all four movements evaluated [32]. The heterogeneity of the results seems not to be due to the measurement site which is very close among the studies. A sample with a reduced number of participants, the various participants' limb positions and the fact that some studies do not specify neither subdivided the symptomatic participants in more or less severe stages of carpal tunnel syndrome make the comparison of results difficult and constitute limitations of existing studies.

Only two studies compared median nerve excursion in participants with non-specific arm pain and asymptomatic individuals. Maximal inspiration in participants with non-specific arm pain is significantly reduced compared with asymptomatic participants [44]. This could be explained by the fact that in non-specific arm pain condition patients have muscle weakness, pain, limited movement and discomfort and the decrease of proximal nerve gliding during maximal inspiration could be related to the absence or reduction of movement in first rib which has a close relation to the brachial plexus and, consequently, median nerve or shortened scalene muscles [44,61]. Elbow extension, wrist extension and metacarpophalangeal extension showed no statistically significant differences on median nerve gliding between asymptomatic and symptomatic participants with non-specific arm pain [40]. According to these results, abnormal nerve gliding does not seem to be at the basis of non-specific arm pain, but more studies are needed to consolidate these conclusions.

Ridehalgh and colleagues[52] compared the impact of two different angles (30° and 60° of flexion) during a modified Straight Leg Raise between individuals with spinally referred leg pain (somatic pain, radicular pain and radiculopathy pain) and asymptomatic individuals. In individuals with spinally referred leg pain the sciatic nerve excursion does not seem restricted. Yet, the small sample size and the fact that only one study assessed participants with spinally referred leg pain shows the need for further studies.

One study compared the longitudinal and transversal median nerve movement in participants with whiplash and asymptomatic individuals [44]. The longitudinal median nerve excursion presented a 71% reduction in participants with whiplash compared to asymptomatic. Furthermore, transversal excursion of median nerve was in a different direction in the two groups (symptomatic: 2.57 mm ± 0.80 radial direction; asymptomatic: -0.39 mm ± 0.52 cubital direction). So, an abnormal median nerve gliding may play a role in symptoms in individuals with whiplash.

Tibial nerve biomechanics is altered in participants with DM. During active ankle dorsiflexion, participants with DM presented reduced tibial nerve longitudinal excursion [53] and an increase in the amount of posterior tibial nerve excursion [10]. It should be noted that tibial nerve glide in three different directions: longitudinally towards the axis of movement, medial and superficially at the knee and during ankle dorsiflexion it travels in a superficial direction. The nerve biomechanics could be diminished in patients with DM. Other explanations for the reduced tibial nerve longitudinal excursion could be an increased quantity or stiffening of the connective tissue within the nerve and between the nerve and surrounding tissues [53].

The included studies have some methodological limitations, failing to use a representative sample (only 4 in 33 studies used a representative sample) and failed to blind the assessors (only 9 in 33 use a blinded assessor). Sample sizes varied between 1 and 76 participants in total (resulting in the sum of participants of various groups). Only 10 of all included studies calculated sample sizes. Future studies should consider these factors.

Taken all the results together, nerve excursion depends on different joint movements and different joint positioning which have different effects on longitudinal and transversal nerve excursion on asymptomatic and symptomatic individuals.

These results contribute to a better understanding of nerve direction and magnitude of excursion and strain and can assist in more individualized technique selection and effectiveness depending on the presence of some pathological condition, selecting the best combination of joint movements and range of motion during neural mobilization. Future studies should analyse which mechanical effects are associated with therapeutic effects in symptomatic conditions and which may be harmful.

5. Limitations

The major limitation of this systematic review is the difficulty to match the results because the studies are disparate and heterogeneous. Different nerves, joint movements, and starting positions measured at different sites make it difficult to compare the results across the different studies.

6. Clinical Implications

This systematic review may help physical therapists to better adequate neural mobilization techniques to asymptomatic individuals. Individuals with carpal tunnel syndrome may benefit from neural mobilization to restore normal longitudinal and transversal nerve movement which is limited in the most severe stages. Having a better knowledge of which joint movements induce a greater nerve excursion, and whether joint movement elongates or shortens nerve bed, the selection of neural mobilization exercises may be better targeted.

6. Conclusions

This systematic review showed that normal nerve longitudinal excursion can be up to 50.2mm and normal transversal excursion can be up to 4.4mm. Sliding techniques lead to the largest amount of excursion both in upper and lower limbs. The total strain values obtained were of 2.1%.

Plus, individuals with diabetes mellitus have altered tibial nerve biomechanics and individuals with a severe condition of carpal tunnel syndrome condition have less median nerve excursion. Existing evidence on non-specific arm pain and spinally referred leg pain suggested no restriction of nerve movement.

7. Bibliography

1. Butler D. *Mobilization of the Nervous System*. Churchill Livingstone; 1991.

2. Wolny T. The Use of Neurodynamic Techniques in the Conservative Treatment of Carpal Tunnel Syndrome - a Critical Appraisal of the Literature. *Ortop Traumatol Rehabil*. 2017;19(5):427-440. doi:10.5604/01.3001.0010.5822

3. Kasehagen B, Ellis R, Pope R, Russell N, Hing W. Assessing the Reliability of Ultrasound Imaging to Examine Peripheral Nerve Excursion: A Systematic Literature Review. *Ultrasound Med Biol*. 2018;44(1):1-13. doi:10.1016/j.ultrasmedbio.2017.08.1886

4. Topp KS, Boyd BS. Structure and biomechanics of peripheral nerves: Nerve responses to physical stresses and implications for physical therapist practice. *Phys Ther*. 2006;86(1):92-109. doi:10.1093/ptj/86.1.92

5. Gifford L. Neurodynamics. In: *Pitt-Broke: Rehabilitation of Movement: Theoretical Bases of Clinical Practice.* ; 1997:159-195.

6. Szikszay T, Hall T, Von Piekartz H. In vivo effects of limb movement on nerve stretch, strain, and tension: A systematic review. *J Back Musculoskelet Rehabil*. 2017;30(6):1171-1186. doi:10.3233/BMR-169720

7. Silva A, Manso A, Andrade R, Domingues V, Brandão M, Silva A. Quantitative in vivo longitudinal nerve excursion and strain in response to joint movement: A systematic literature review. *Clin Biomech*. 2014;29(8):839-847. doi:10.1016/j.clinbiomech.2014.07.006

8. Coppieters MW, Hough AD, Dilley A. Different nerve-gliding exercises induce different magnitudes of median nerve longitudinal excursion: An in vivo study using dynamic ultrasound imaging. *J Orthop Sports Phys Ther*. 2009;39(3):164-171. doi:10.2519/jospt.2009.2913

9. Shacklock M. Clinical Neurodynamics in Sports Injuries. *Sport Rehabil*. 2014;(January 2014):50-56.

10. Boyd BS, Dilley A. Altered tibial nerve biomechanics in patients with diabetes mellitus. *Muscle and Nerve*. 2014;50(2):216-223. doi:10.1002/mus.24155

11. Bueno-Gracia E, Pérez-Bellmunt A, Estébanez-de-Miguel E, et al. Differential movement of the sciatic nerve and hamstrings during the straight leg raise with ankle dorsiflexion: Implications for diagnosis of neural aspect to hamstring disorders. *Musculoskelet Sci Pract*. 2019;43:91-95. doi:10.1016/j.msksp.2019.07.011

12. Yoshii Y, Tanaka T, Ishii T. Correlations of Median Nerve Area, Strain, and Nerve Conduction in Carpal Tunnel Syndrome Patients. *Hand*. 2016;11(2):161-167. doi:10.1177/1558944715616954

13. Rydevik B, Brown M, Lundborg G. Pathoanatomy of Nerve Compression. *Spine (Phila Pa 1976)*. 1984;9:7-15.

14. Uchiyama S, Itsubo T, Nakamura K, Kato H, Yasutomi T, Momose T. Current concepts of carpal tunnel syndrome: Pathophysiology, treatment, and evaluation. *J Orthop Sci*. 2010;15(1):1-13. doi:10.1007/s00776-009-1416-x

15. Ellis R, Blyth R, Arnold N, Miner-Williams W. Is there a relationship between impaired median nerve excursion and carpal tunnel syndrome? A systematic

review. *J Hand Ther*. 2017;30(1):3-12. doi:10.1016/j.jht.2016.09.002

16. Hough AD, Moore AP, Jones MP. Reduced Longitudinal Excursion of the Median Nerve in Carpal Tunnel Syndrome. *Arch Phys Med Rehabil*. 2007;88(5):569-576. doi:10.1016/j.apmr.2007.02.015

17. Gugliotti M, Cohen D, Hernandez A, Hinrichs K, Osmundsen N. Impact of shoulder internal rotation on normal sensory response during ulnar nerve-based neurodynamic testing of asymptomatic individuals. *J Man Manip Ther*. 2017;25(1):39-46. doi:10.1080/10669817.2016.1173317

18. Bove GM, Ransil BJ, Lin HC, Leem JG. Inflammation induces ectopic mechanical sensitivity in axons of nociceptors innervating deep tissues. *J Neurophysiol*. 2003;90(3):1949-1955. doi:10.1152/jn.00175.2003

19. Shacklock M. Neurodynamics. Published online 1995.

20. Shacklock M. *Clinical Neurodynamics: A New System of Neuromusculoskeletal Treatment*.; 2005.

21. Basson A, Olivier B, Ellis R, Coppieters M, Stewart A, Mudzi W. The effectiveness of neural mobilization for neuromusculoskeletal conditions: A systematic review and meta-Analysis. *J Orthop Sports Phys Ther*. 2017;47(9):593-615. doi:10.2519/jospt.2017.7117

22. Nee RJ, Butler D. Management of peripheral neuropathic pain: Integrating neurobiology, neurodynamics, and clinical evidence. *Phys Ther Sport*. 2006;7(1):36-49. doi:10.1016/j.ptsp.2005.10.002

23. Coppieters MW, Andersen LS, Johansen R, et al. Excursion of the sciatic nerve during nerve mobilization exercises: An in vivo cross-sectional study using dynamic ultrasound imaging. *J Orthop Sports Phys Ther*. 2015;45(10):731-737. doi:10.2519/jospt.2015.5743

24. Neto T, Freitas SR, Marques M, Gomes L, Andrade R, Oliveira R. Effects of lower body quadrant neural mobilization in healthy and low back pain populations: A systematic review and meta-analysis. *Musculoskelet Sci Pract*. 2017;27:14-22. doi:10.1016/j.msksp.2016.11.014

25. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ*. 2009;339(7716):332-336. doi:10.1136/bmj.b2535

26. Downs SH, Black N. The feasibility of creating a checklist for the assessment of the methodological quality both of randomised and non-randomised studies of health care interventions. *J Epidemiol Community Health*. 1998;52(6):377-384. doi:10.1136/jech.52.6.377

27. Fernando M, Crowther R, Lazzarini P, et al. Biomechanical characteristics of peripheral diabetic neuropathy: A systematic review and meta-analysis of findings from the gait cycle, muscle activity and dynamic barefoot plantar pressure. *Clin Biomech*. 2013;28(8):831-845. doi:10.1016/j.clinbiomech.2013.08.004

28. Johnson JE, Fischer KJ, McIff TE. Peripheral nerve strain: A comparison of strain measuring techniques. In: *Proceedings of the ASME Summer Bioengineering Conference, SBC2008*. ; 2009:627-628.

29. Langley A, McNally D, Haslegrave CM. Exploring median nerve biomechanics within the wrist using ultrasonography. In: *Contemporary Ergonomics 2007*. ;

2007:487-492.

30. Takahashi T, Kato A, Ikegaya N, et al. Ultrasound changes of the carpal tunnel in patients receiving long-term hemodialysis: a cross-sectional and longitudinal study. *Clin Nephrol*. 2002;57(3):230-236. doi:10.5414/cnp57230

31. Julius A, Lees R, Dilley A, Lynn B. Shoulder posture and median nerve sliding. *BMC Musculoskelet Disord*. 2004;5:23. doi:10.1186/1471-2474-5-23

32. Kang HJ, Yoon JS. Effect of finger motion on transverse median nerve movement in the carpal tunnel. *Muscle Nerve*. 2016;54(4):738-742. doi:10.1002/mus.25101

33. Korstanje J-WH, Scheltens-De Boer M, Blok JH, et al. Ultrasonographic assessment of longitudinal median nerve and hand flexor tendon dynamics in carpal tunnel syndrome. *Muscle Nerve*. 2012;45(5):721-729. doi:10.1002/mus.23246

34. Lopes MM, Lawson W, Scott T, Keir PJ. Tendon and nerve excursion in the carpal tunnel in healthy and CTD wrists. *Clin Biomech*. 2011;26(9):930-936. doi:10.1016/j.clinbiomech.2011.03.014

35. Park D. Ultrasonography of the Transverse Movement and Deformation of the Median Nerve and Its Relationships With Electrophysiological Severity in the Early Stages of Carpal Tunnel Syndrome. *PM R*. 2017;9(11):1085-1094. doi:10.1016/j.pmrj.2017.03.015

36. Wang Y, Zhao C, Passe SM, et al. Transverse Ultrasound Assessment of Median Nerve Deformation and Displacement in the Human Carpal Tunnel during Wrist Movements. *Ultrasound Med Biol*. 2014;40(1):53-61. doi:https://doi.org/10.1016/j.ultrasmedbio.2013.09.009

37. Brochwicz P, von Piekartz H, Zalpour C. Sonography assessment of the median nerve during cervical lateral glide and lateral flexion. Is there a difference in neurodynamics of asymptomatic people? *Man Ther*. 2013;18(3):216-219. doi:10.1016/j.math.2012.10.001

38. Alexander A. Scientific study of the extent of transverse movement of the median nerve at the wrist during active wrist extension in static positions of the upper limb tension test one. *Hand Ther*. 2012;17(1):2-10. doi:10.1258/ht.2011.011017

39. Dilley A, Lynn B, Greening J, DeLeon N. Quantitative in vivo studies of median nerve sliding in response to wrist, elbow, shoulder and neck movements. *Clin Biomech*. 2003;18(10):899-907. doi:10.1016/S0268-0033(03)00176-1

40. Dilley A, Odeyinde S, Greening J, Lynn B. Longitudinal sliding of the median nerve in patients with non-specific arm pain. *Man Ther*. 2008;13(6):536-543. doi:10.1016/j.math.2007.07.004

41. Echigo A, Aoki M, Ishiai S, Yamaguchi M, Nakamura M, Sawada Y. The Excursion of the Median Nerve during Nerve Gliding Exercise: An Observation with High-resolution Ultrasonography. *J Hand Ther*. 2008;21(3):221-228. doi:10.1197/j.jht.2007.11.001

42. Erel E, Dilley A, Greening J, Morris V, Cohen B, Lynn B. Longitudinal sliding of the median nerve in patients with carpal tunnel syndrome. *J Hand Surg Am*. 2003;28 B(5):439-443. doi:10.1016/S0266-7681(03)00107-4

43. Gonzalezsuarez C, Nathleendizon J, Cua R, et al. Determination of the

longitudinal median nerve mobility in different neurodynamic techniques. *Hand Ther*. 2016;21(1):16-24. doi:10.1177/1758998315617784

44. Greening J, Dilley A, Lynn B. In vivo study of nerve movement and mechanosensitivity of the median nerve in whiplash and non-specific arm pain patients. *Pain*. 2005;115(3):248-253. doi:10.1016/j.pain.2005.02.023

45. Hough AD, Moore AP, Jones MP. Peripheral nerve motion measurement with spectral Doppler sonography: A reliability study. *J Hand Surg Am*. 2000;25 B(6):585-589. doi:10.1054/jhsb.2000.0453

46. Ellis RF, Hing WA, McNair PJ. Comparison of longitudinal sciatic nerve movement with different mobilization exercises: An in vivo study utilizing ultrasound imaging. *J Orthop Sports Phys Ther*. 2012;42(8):667-675. doi:10.2519/jospt.2012.3854

47. Ellis R, Osborne S, Whitfield J, Parmar P, Hing W. Examining the influence of seated spinal postures (slump versus upright) upon longitudinal sciatic nerve excursion during neural mobilisation exercises. *Physiotherapy*. 2015;101(Supplement 1):e358-e358. http://10.0.3.248/j.physio.2015.03.571

48. Ellis R, Rohan M, Fox J, Hitt J, Langevin H, Henry S. Ultrasound elastographic measurement of sciatic nerve displacement and shear strain during active and passive knee extension. *J Ultrasound Med*. 2018;37(8):2091-2103. doi:10.1002/jum.14560

49. Pagnez MAM, Corrêa LA, Almeida RS, et al. The Variation of Cross-Sectional Area of the Sciatic Nerve in Flexion-Distraction Technique: A Cross-Sectional Study. *J Manipulative Physiol Ther*. 2019;42(2):108-116. doi:https://doi.org/10.1016/j.jmpt.2019.03.003

50. Ridehalgh C, Moore A, Hough A. Repeatability of measuring sciatic nerve excursion during a modified passive straight leg raise test with ultrasound imaging. *Man Ther*. 2012;17(6):572-576. doi:10.1016/j.math.2012.06.002

51. Ridehalgh C, Moore A, Hough A. Normative sciatic nerve excursion during a modified straight leg raise test. *Man Ther*. 2014;19(1):59-64. doi:10.1016/j.math.2013.07.012

52. Ridehalgh C, Moore A, Hough A. Sciatic nerve excursion during a modified passive straight leg raise test in asymptomatic participants and participants with spinally referred leg pain. *Man Ther*. 2015;20(4):564-569. doi:10.1016/j.math.2015.01.003

53. Boyd BS, Gray AT, Dilley A, Wanek L, Topp KS. The pattern of tibial nerve excursion with active ankle dorsiflexion is different in older people with diabetes mellitus. *Clin Biomech*. 2012;27(9):967-971. doi:10.1016/j.clinbiomech.2012.06.013

54. Carroll M, Yau J, Rome K, Hing W. Measurement of tibial nerve excursion during ankle joint dorsiflexion in a weight-bearing position with ultrasound imaging. *J Foot Ankle Res*. 2012;5(1). doi:10.1186/1757-1146-5-5

55. Shum GL, Attenborough AS, Marsden JF, Hough AD. Tibial Nerve Excursion During Lumbar Spine and Hip Flexion Measured with Diagnostic Ultrasound. *Ultrasound Med Biol*. 2013;39(5):784-790. doi:10.1016/j.ultrasmedbio.2012.11.023

56. Dilley A, Summerhayes C, Lynn B. An in vivo investigation of ulnar nerve sliding during upper limb movements. *Clin Biomech*. 2007;22(7):774-779.

doi:https://doi.org/10.1016/j.clinbiomech.2007.04.004

57. Patel P, Norbury JW, Fang X. Sonographic Measurements of the Ulnar Nerve at the Elbow With Different Degrees of Elbow Flexion. *PM&R*. 2014;6(5):395-399. doi:https://doi.org/10.1016/j.pmrj.2013.12.011

58. Kasehagen B, Ellis R, Mawston G, Allen S, Hing W. Assessing the reliability of ultrasound imaging to examine radial nerve excursion. *Ultrasound Med Biol*. 2016;42(7):1651-1659. doi:10.1016/j.ultrasmedbio.2016.02.013

59. Sierra-Silvestre E, Bosello F, Fernández-Carnero J, Hoozemans MJM, Coppieters MW. Femoral nerve excursion with knee and neck movements in supine, sitting and side-lying slump: An in vivo study using ultrasound imaging. *Musculoskelet Sci Pract*. 2018;37:58-63. doi:10.1016/j.msksp.2018.06.007

60. Ridehalgh C, Moore A, Hough A. Straight leg raise treatment for individuals with spinally referred leg pain: effects on sciatic nerve excursion. *Physiotherapy*. 2015;101(Supplement 1):e1283-e1284. http://10.0.3.248/j.physio.2015.03.1197

61. Boocock MG, Collier JMK, McNair PJ, Simmonds M, Larmer PJ, Armstrong B. A Framework for the Classification and Diagnosis of Work-Related Upper Extremity Conditions: Systematic Review. *Semin Arthritis Rheum*. 2009;38(4):296-311. doi:10.1016/j.semarthrit.2007.10.006