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REVIEW

# Displacement of the nervous system through articular movement by ultrasound. Bibliographic review

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**KEYWORDS**
Neurodynamics;
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**Abstract** The nervous system has the capacity to adapt to the mechanical forces of tension, compression and shearing to which it is exposed in daily movements. Reduction of nerve slide may alter its function by increasing neural tension, which may have an adverse effect, contributing to the onset of pain. The objective of the study was to review the current literature regarding the movement of the nervous system and how to measure it. To do this, a search was undertaken in Pubmed and PEDro of articles where neural displacement is measured by the ''frame-by-frame cross correlation system'' technique. Twenty studies were selected: 14 measured displacement in healthy subjects, and 6 compared some form of peripheral neuropathy. The results show that the peripheral nervous system is displaced during the different movements of body segments to adapt to the space through which it runs, although there is no significant difference in displacement between healthy people and patients with nerve involvement.


**PALABRAS CLAVE**
Neurodinámica;
Movimiento nervioso;
Plano a plano;
Sistema nervioso periférico

## Desplazamiento del sistema nervioso a partir del movimiento articular mediante ecografía. Revisión bibliográfica

**Resumen** El sistema nervioso tiene la capacidad de adaptarse a las fuerzas mecánicas de tensión, compresión y cizallamiento a las que se ve expuesto en los movimientos diarios. La reducción del deslizamiento del nervio puede alterar su función por el incremento de la tensión neural, pudiendo afectar negativamente y contribuir a la aparición de dolor. El objetivo del estudio es revisar la bibliografía actual respecto al desplazamiento del sistema nervioso y cómo medirlo. Para ello se realiza una búsqueda en Pubmed y PEDro de artículos donde se mida el desplazamiento neural mediante la técnica de «*frame-by-frame cross correlation system*».

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Se seleccionan 20 estudios: 14 de ellos miden el desplazamiento en personas sanas y 6 comparan con algún tipo de neuropatía periférica. Los resultados muestran la capacidad de movimiento del sistema nervioso periférico durante los diferentes movimientos de segmentos corporales para adaptarse al espacio por donde discurre, aunque no hay una diferencia significativa de desplazamiento entre personas sanas y pacientes con afectación nerviosa.


## Introduction

When body movements are performed, the joint or joints involved, the particular joints in question, the muscles that are performing the movement, and even the passive elements of stabilisation that might be acting, are clear. The nervous system is often the great forgotten area. The nervous system moves to adapt to body movement as well, and continues to perform its function of transmitting the nerve impulse.

Movements and positions adopted during activities of daily living generate forces of tension, compression and shearing on the nervous system. Under normal conditions, the nervous system has the biomechanical capacity to adapt to these forces in order to continue performing its functions.[1] The structural organisation of the peripheral nerves allow the axons to conduct the nerve impulses that will enable the individual to interact with their environment, while directing and tolerating thousands of trunk, head and limb positions.

It has been suggested that reducing the nerve's capacity of movement might alter its function due to increased neural tension, and might have a negative effect and contribute to the onset of pain.[2–4]

If nerve movement is impeded in any way during the movement of a joint, then the section of the nerve next to the moving joint will be subjected to greater tension in order to adjust to the change in the structure of the nerve bed through which it runs.[5–7] For the nervous system to move normally it must adapt correctly to three mechanical functions: tension, compression and displacement.[2] Adaptation to these mechanical functions takes place in both the central nervous system and the peripheral nervous system, and these functions interact with one another.

Neurodynamics can be defined as a manual therapy technique whose objective is to act on the nerve through the mobilisation and positioning of multiple joints,[8] integrating the biomechanical and physiological functions of the nervous system as the basis to explain potential alterations that might occur when it is not able to adapt to the mechanical forces to which it is exposed.[3]

The biomechanical data obtained show that joint movements performed in neurodynamic techniques increase the tension, displacement and compression of the nerve that is being assessed. When a joint movement is made at the end of neurodynamic mobilisation, the biomechanical effects move throughout the entire route of the nerve.[9,10]

Sequences of standardised movements are used to describe the different neurodynamic tests. Some clinicians are in favour of modifying the order of the sequences to adapt to each patient's symptoms. The different neurodynamic sequences are based on the belief that different orders of recruitment of the different joints will generate different levels of tension on one specific point of the nerve at the end of the neurodynamic sequence.[11] Even so, cadaveric studies show that when the joints move in similar movement ranges tension to the nerve does not change in different orders of movement, although clinically, when different movement sequences are applied, the joints move in different ranges of movement.[9,11]

Various studies[9,11–16] show that each individual component of the neurodynamic sequence induces an effect on the mechanical load of the nerve. This effect can generate longitudinal and/or transverse displacement of the nerve, increased tension on the nerve, increased compression... therefore, from a mechanical angle, we have data that support the plausibility of neurodynamic mobilisation.

The main objective of neurodynamic tests is to assess the mechanosensitivity of nerve tissue, in other words, the nerve tissue's capacity to adapt to mechanical stress, either by tension or compression.[17,18] It is not the objective to locate the point to which the assessed nerve is affected, but rather a more thorough exploration is required given the involvement of other structures, beyond the nervous system, in the responses caused by this alteration.[10,16,19,20] Various cadaveric studies[11,21,22] have shown that neurodynamic mobilisations cause displacement of the nerve through the tissues that surround it. The nerve will displace towards the joint, which elongates the nerve bed during mobilisation to dissipate the increased tension that will be exercised by the movement on the nerve.[21]

With regard to the therapeutic aspect of neurodynamic mobilisations, the type of mobilisations should be defined and the effects they will generate to re-establish normal functioning of the nerve.

There are two types of neurodynamic mobilisations: tensioner and slider techniques.[3,21,23] Tensioner mobilisations comprise performing the neurodynamic sequence of the nerve, elongating its nerve bed until reaching the point of first resistance to movement or reproduction of the patient's symptoms. At this point a single component, usually distal, of the sequence is moved. This type of mobilisation generates a dynamic variation of the intraneural pressure, improved venous return and enables evacuation of intraneural oedema.[24–26]

With regard to slider mobilisations, the neurodynamic sequence of the structure to be treated is also performed until first resistance or reproduction of the patient's symptoms. At this point, slider mobilisation is performed from two components of the sequence, more or less separated from one another, where one elongates the nerve bed while the other reduces it. Thus, increased movement of the nerve is observed with little modification of intraneural pressure.[21] The effects of slider mobilisations are that they work on a wide, painless range of motion, reduce the proliferation of fibroblasts and, therefore, reduce scar tissue at the level of the nerve that has been worked on, as well as improving vascularisation of the nervous system and venous return.[11,24,27]

## Ultrasound of the nervous system

The development of high frequency linear transducers has improved ultrasound image resolution. In the case of peripheral compressive neuropathies, ultrasound imaging can be complemented with magnetic resonance and nerve conduction study. Compared to magnetic resonance, ultrasound is more economical, is less time-consuming, presents fewer artefacts, is dynamic and improves longitudinal exploration of the nerve. By contrast, the field of vision is small, depth is limited and there can be an anisotropic effect when nerves are explored. The frequency used to observe the peripheral nerves ranges from 7 to 12 MHz.[28,29]

Fornage[30] made the first anatomical description by ultrasound of the peripheral nervous system, and observed the median, ulnar, sciatic and tibial nerves. According to the literature, a normal peripheral nerve displays a tubular structure that alternates hypoechogenic areas and hyperechogenic areas, which correspond to the nerve fibres and the perineurium, giving a honeycomb image when we take a transverse image. There are various factors that can affect nerve calibre, such as body mass index, age and gender.[31]

Ultrasound differentiation between the tendon and the peripheral nerve is based on the fact that the tendons, unlike the nerves, display numerous parallel hyperechoic lines, separated by hypoechoic lines. Furthermore, reduction of nerve displacement during an active or passive movement of a limb will be a good benchmark in differentiating it from a tendon.[32]

Ultrasound is recommended to assess the morphology and mobility of the peripheral nerve, and it has been demonstrated to help in the diagnosis of compressive neuropathies.[33,34] It has potential advantages over other static imaging techniques in that it enables dynamic and functional evaluation of compressive neuropathies.[35,36] The difficulty lies in quantifying the longitudinal neural displacement *in vivo*, since it is a continuous structure where markers cannot be placed and will present some transverse displacement, which can make it difficult to follow the nerve in certain areas.

Dilley et al.[37] with the help of Matlab, developed an algorithm to measure nerve movement. The ''frame-by-frame cross correlation system'' is considered a reliable tool to calculate longitudinal nerve movement. This algorithm can successfully calculate movements between 1 mm and 3 mm in the transducer, with less than 10% error. To take the measurements, a video is made of the nerve movement by ultrasound to observe the movement from the start position to the end of the movement requested. These video sequences are turned into pixels, generating between 50 and 100 frames of images per second of video. Regions of interest are chosen, from which the programme calculates the relative movement of the nerve comparing the greyscales of each adjacent region, turning the value into millimetres. It takes the value of each pixel of a greyscale and compares it with the greyscale of the following frame. A correlation coefficient is calculated for each change of individual pixels. The peak of a quadratic equation adjusted to the three maximum correlation coefficients is equivalent to the displacement or movement of pixels between adjacent frames.

In order to avoid any alteration at the level of the transducer, a static structure will be measured in the same way as we did with the nerve, such as the subcutaneous layers. This movement will be deducted from the result obtained by the nerve to obtain the most exact value possible for the nerve movement.[37-39]

The aim of the study was to perform a literature review to determine the reliability of ultrasound in evaluating nerve displacement and to observe the displacement of different nerves in different neurodynamic sequences.

## Methodology

A search was performed of Pubmed, Medline and PEDro using the following keyword combinations (Fig. 1): [Excursion nerve AND Ultrasound], [Neurodynamics AND Ultrasound] and [Nerve movement AND Ultrasound AND (frame-by-frame)].

The inclusion criteria were clinical trials published in English or Spanish that use the technique described by Dilley to measure nerve system movement.

Articles of studies performed on cadavers or animals were excluded.

The search included articles published from January 2001 until December 2016.

Given that most of the studies were observational, we checked that they met the directives for reporting observational studies stated in the initiative *Strengthening the Reporting of Observational Studies in Epidemiology* (STROBE).

A total of 107 results were obtained. Once duplications were removed, a total of 80 articles remained to review. Of these 44 were rejected after reading the title and abstract, leaving 36 for full-text reading. Three articles were rejected as they had been performed on cadavers and not *in vivo* and another 13 because they had not used the frame-by-frame cross correlation system described by Dilley et al. We were left with a total of 20 articles to undertake the review.

## Results

Of the 20 articles chosen for the review, 6 compared nerve movement in people with a peripheral neuropathy of some type or non-specific pain with a control group of asymptomatic people[40-45] (Table 1). The remaining 14 measured nerve movement in healthy people based on the median nerve,[37,46-50] the radial nerve[51] and of the sciatic nerve and its endings[52-58] (Table 2).

It seems that the reliability of ultrasound, and specifically Dilley's system for measuring longitudinal peripheral nerve movement, shows excellent results. In the study by Ellis et al.[58] an ICC = .75 for longitudinal sciatic nerve excursion was obtained. Carroll et al.[53] obtained an ICC = .93 for tibial

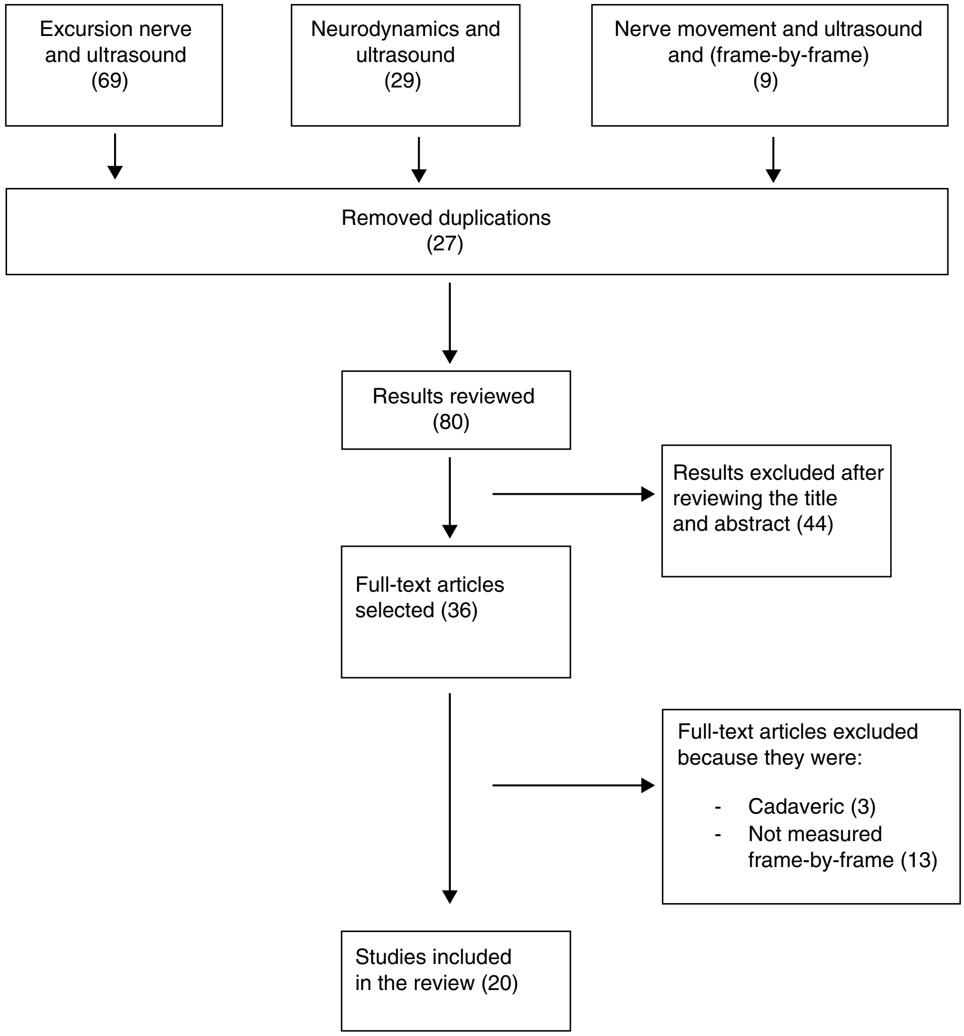


**Figure 1** Flowchart.

nerve excursion, similar to the study by Ridehalgh et al.,[38] whose result for sciatic nerve excursion on Straight Leg Raising (SLR) was ICC = .93−.96. At the level of the upper limb, a moderate to high correlation was observed in the study of radial nerve excursion undertaken by Kasehagen et al.[51] (ICC = .63−.86).

At the level of the upper limb, the median nerve is most assessed, possibly because it is easier to locate and measure its movement. We observed a disparity of criteria in the position adopted by the patient for data collection, making it difficult to compare the results. The position of the shoulder girdle varies from the 20° abduction of Julius et al.[51] to the 90° of Dilley et al. and Coppieters et al.,[49] through 30° and 45°. There were also many variants at the level of the elbow, wrist and fingers, depending on the movement requested of the person. In this regard, different active as well as passive movements were requested. In all cases it was observed that the nerve moved towards the joint, which elongated the nerve bed. More nerve displacement was observed in the area near the joint being mobilised. Nerve displacement reduced, the greater the distance from the joint requested. In the slider mobilisations, the nerve movement in the measurement area was greater if the components for sliding were close to that area. This was observed perfectly in the studies assessing displacement of the sciatic nerve at the posterior surface of the thigh. In this case, two types of mobilisation were chosen in the main: from the slump test, with the cervical and knee components,[52,57] or combining hip flexion with knee flexion and hip extension with knee extension.[45,59] In these cases, greater displacement of the sciatic nerve was observed in the studies that used the components of the lower limb to generate displacement. When components that were very distant from the measurement area were chosen (e.g. cervical flexion for sciatic nerve sliding in the thigh) the displacement was very slight.[52]

In the study by Kasehagen et al.,[51] evaluating supracondylar radial nerve excursion from active and passive movement of the wrist towards palmar flexion or ulnar deviation, it is significant that there is greater nerve excursion with the forearm in supination rather than in pronation, which is different from the ULNT2b description for the radial nerve, which describes the test based on forearm pronation.[9,15] In this same study, greater excursion was also observed from passive mobilisations than from active mobilisations, due to the greater range of motion generated.

**Table 1** Peripheral nerve displacement. Affected nerve and control group comparison.

| Author | Sample size | Patient's position | Site of sample | Movement requested | Result |
|---|---|---|---|---|---|
| Erel (2003) | 17 carpal tunnel syndrome; 19 control group | Supine position with 45° and 90° GH abduction, elbow extension and supination | Distal 1/3 of forearm | MTCP extension (from 90° flexion to 0°) | 2.62 mm distal sliding control group, 2.20 mm CTS |
| Greening (2005) | 9 patients with whiplash/8 control group/8 patients non-specific arm pain/7 control group | Supine position 30° GH ABD, elbow extension and forearm in supination | Middle 1/3 forearm | Maximum inhalation | Whiplash: .38 mm/CG: 1.32 mm. Non-specific arm pain .49 mm/CG: 1.55 mm |
| Dilley (2007) | 18 non-specific arm pain; 39 control group | *Wrist extension:* 45°ABD with external rotation, elbow extension and supination *MTCP extension:* 90° ABD, elbow and wrist in extension. *Elbow extension:* 90°ABD and neutral position of the wrist | Middle 1/3 of forearm and distal 1/3 arm | Extension of wrist, MTCP extension, elbow extension | No significant differences in movement were observed between the intervention group and the control group. |
| Erel (2010) | 10 (3 females 7 males) with median nerve suture | Supine position, 45° GH ABD elbow extension and supination | 5–15 cm proximal to the wrist fold | MTCP extension of 90° flexion to neutral position | 2.15 mm affected nerve; 2.54 mm healthy side. Correlation between reduction of sliding and time between lesion and surgical intervention |
| Boyd (2012) | 5 type-2 diabetes patients. 5 healthy people | Lateral position, with hip at 20° flexion and knee extension. Lateral position with hip flexion until the point of sensitive response, knee extension. | Popliteal fossa | Dorsal flexion of ankle of 30° plantar flexion to neutral position | In *20° flexion:* 2.18 mm CG, .83 mm diabetes. *Max. hip flexion:* .66 mm CG, .42 mm diabetes |
| Ridehalg, C. (2015) | 18 asymptomatic people. 67 people with referred pain to the lower limb | Lateral position, with 30° and 60° hip flexion and 90° knee flexion | Posterior surface of thigh | Knee extension in 3 phases: from 90° to 45°, from 45° to 20° and from 20° to full extension | No significant difference between the control group and the referred pain group (10 mm and 10.3 mm). Slight reduction of displacement in the radiculopathy and radicular pain groups (9.4 mm and 8.8 mm) |

The studies analysed corroborate different principles on which neurodynamics is based. Nerve displacement is observed with respect to the adjacent tissues, which is more or less significant in each and every one of the studies. Nerve excursion travels in the direction of the joint which elongates the nerve bed through which the nerve runs; therefore, the joint that increases the tension on the nerve.

With regard to the studies that compare excursion between healthy people and people with a peripheral neuropathy, no significant results were observed to confirm that having a neuropathy will cause a reduction in nerve movement around the adjacent structures. Ridehalgh et al.[45] observed a slight reduction in sliding in the radiculopathy and radicular pain subgroups, but they did not observe

**Table 2** Peripheral nerve excursion in healthy patients.

| Author | Sample size | Patient's position | Sample site | Movement requested | Result |
|---|---|---|---|---|---|
| Dilley (2001) | 10 (3 wrist/7 index) | Supine position.<br>*Wrist:* GH ABD 201, elbow extension and forearm in supination<br>*Index:* same as in wrist but with 45° ABD | 6–12 cm above the wrist | *Wrist:* passive radiocarpal extension from 0° to 30°.<br>*Index:* Passive mov. of maximum flexion at 30° MTCP extension | 2.8–3.9 mm of excursion on passive radiocarpal extension; 1.6–4.5 mm (SD ± .4 mm) on passive extension of the index |
| Dilley (2003) | 34 (23 females/11 male) | *Radiocarpal extension:* GH ABD at 30°–45°–90° with full extension of 90° elbow flexion. Forearm in supination.<br>*GH abduction:* 10° GH ABD with elbow extension and forearm in supination.<br>*Elbow extension:* 90° GH ABD and radiocarpal in neutral position or 45° extension.<br>*Contralateral cervical tilt:* GH ABD at 30° and 90° with elbow extension and forearm in supination | Distal 1/3 of forearm, distal 1/3 of arm and proximal 1/3 of forearm | *Radiocarpal extension:* from 60° flexion to 40° extension.<br>*GH abduction:* from 10° to 90°.<br>*Elbow extension:* from 90° flexion to 0°.<br>*Contralateral cervical tilt* | On radiocarpal extension distal sliding of the median nerve was observed. There was a reduction of 20% of sliding with the arm in 90° ABD compared to 45° ABD. With the elbow in 90° flexion on performing radiocarpal extension no relative movement was observed at the level of the arm but it was observed at the level of the forearm. Sliding of the nerve towards the joint generating tension was observed. |
| Julius (2004) | 14(9 females/5 males) | *Trunk antepulsion and flexion:* 90° GH flexion and GH ABD 20°, elbow extension and supination.<br>*Contralateral cervical tilt:* GH ABD 90°, elbow in extension and forearm in supination | Forearm | Cervical antepulsion, trunk flexion and contralateral cervical tilt | Of the three movements, contralateral cervical tilt generated greater displacement (2.3 mm at the level of the arm and 1.5 mm at the level of the forearm). Shoulder antepulsion reduced the displacement |
| Echigo (2008) | 34 females | Supine position and glenohumeral abduction of 30° | Proximal 1/3 of forearm | *Passive extension of the wrist and fingers* in different combinations of position of the elbow and forearm.<br>Active PIP and DIP flexion movement and triple IP and MTCP flexion | Passive mobilisation generates greater nerve displacement in all its variants than active mobilisation. Nerve displacement is distal in the passive movement of wrist and finger extension. By contrast, it is proximal in the active movement of finger flexion. |
| Coppieters (2009) | 15 (8 females/7 males) | Supine position with 90° abduction and external GH rotation | 7–10 cm proximal to medial epicondyle | Sliding: elbow extension + homolateral tilt.<br>Tension: elbow extension + contralateral cervical tilt | Slider mobilisation generates greater nerve displacement than tensioner mobilisation (10.2 mm and 1.8 mm, respectively) |

**Table 2** (*Continued*)

| Author | Sample size | Patient's position | Sample site | Movement requested | Result |
|---|---|---|---|---|---|
| Brochwicz, B. (2013) | 11 (6 females and 5 males) and 9 (5 females and 4 males) | Supine position with 30° ABD + RE GH and elbow extension | Forearm | Cervical translation and cervical tilt | 3.3 mm displacement on translation. 2.3 mm on tilt |
| Kasehagen, B. (2016) | 30 (18 females and 12 males) | Supine position 45° ABD, elbow extension and MTCP at 30° flexion. | 1–5 cm proximal to the humeroulnar joint. | Flexion and ulnar deviation of wrist both active and passive in pronation and supination of the forearm | The radial nerve presents greater displacement with the forearm in supination than in pronation (1.41 mm vs. 1.06 mm) Passive movement generates greater run than active movement 1.42 mm vs. 1.04 mm) |
| Ellis, R. (2008) | 27 (14 female and 13 males) | SLUMP test position with 90° hip flexion and 50° knee flexion | Posterior surface of thigh and popliteal fossa | From maximum cervical flexion and plantar flexion to active cervical extension and passive dorsal flexion of the ankle | 3.47 mm posterior surface of the hip, 5.22 mm in the popliteal fossa. |
| Ellis, R. (2012) | 31 (22 females 9 males) | SLUMP test position with 90° hip flexion | Middle 1/3 posterior surface of the thigh | Cervical extension and knee extension (from 80° to 20° flexion), mobilisation in tension. | 3.2 mm displacement on sliding. 2.6 mm in tension. If only the cervical component moves, there is little displacement at the level of the thigh (.1 mm) |
| Carroll, M. (2012) | 16 (10 females and 6 men) | Standing with a foot on a mobile platform that performs dorsal flexion of the ankle from 10° plantar flexion to 20° dorsal flexion. | Tibial retromalleolar region | Dorsal flexion of the ankle | 3 mm in a caudal direction |
| Shum, G. (2013) | 25(14 females and 11 males) | Standing with knee extension | Popliteal fossa | Trunk and hip flexion | 12.2 mm in a proximal direction |
| Ridehalgh, C. (2014) | 18 (9 females and 9 males) | Lateral position with hip at 30° and 60° flexion | 10 cm distal to the gluteal fold | Knee extension in 3 phases: from 90° flexion to 45°, from 45° to 20° and from 20° to 0° | In 30° hip flexion: 9.9–10.1 mm. In 60° flexion: 12.4–12.5 mm |
| Coppieters, M. (2015) | 15 (9 females and 6 males) | Lateral position. | Posterior surface of the thigh in the area where less transversal displacement is observed | Different combinations of hip and knee movements | Slider mobilisation presents a greater run than the rest, up to 17 mm. Tensioner mobilisation generates 3.2 mm displacement. |
| Ellis, R. (2016) | 16 females and 18 males) | Seated in SLUMP or upright position. 90° hip flexion. | Middle 1/3 posterior surface of the thigh | Slider and tensioner mobilisations combining cervical and knee movements | Greater displacement in the erect than in the SLUMP position although not significant (6.9–6.4 mm respectively) |

differences in the somatic referred pain group. Therefore other aspects must be taken into account, not only anatomopathological changes, in pain generation in a peripheral neuropathy, such as reduced blood flow or intraneural oedema generation and activation of the immune system.

After nerve repair by section a significant reduction of nerve movement was observed compared to the healthy people, and there was also a direct correlation between the reduction of excursion and the delay before surgery. There is less excursion the longer intervention is delayed.

The main limitation of ultrasound for evaluating longitudinal peripheral nerve movement is the transversal movement of the structure itself, which causes the structure to be assessed to leave the image plane in the study of longitudinal displacement. In order to minimise this, some of the studies describe areas where this lateral displacement is very reduced.[52,55,58,59]

Future research studies should approach the observation of nerve mobility in people with other types of musculoskeletal disorders, such as muscle lesions and their relationship with adjacent nerves. Thus, recovery work should include the implementation of specific work on the nerve, if a reduction in its sliding is observed with respect to the adjacent structures.

## Conflict of interests

The authors have no conflict of interests to declare.

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