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ORIGINAL ARTICLE

Movements of the lumbo-sacral nerve roots in the spinal canal induced by straight leg raising test: an anatomical study

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Abstract

Purpose The pain involved in the herniated discs could be generated by some mobility of the nerve roots during straight leg raising (SLR). SLR produces some movement of nerves, but the magnitude of this displacement needs to be thorough, that is why we have investigated lumbo-sacral nerve root displacement in the spinal canal during the passive straight leg raise (SLR).

Methods Fourteen cadavers underwent laminectomy to mark the nerve roots of L2–S1 with lead balls. X-rays were taken during different movements imposed on the body: bilateral hip extension, left SLR then right and bilateral SLR. By superimposing these images two by two, the displacement of the nerve roots is quantified numerically during the various SLR maneuvers with respect to the reference position corresponding to the bilateral hip extension.

Results The median range of the different nerve root movements ranged from 0.10 to 0.51 cm ($p<0.05$ except for the L2 root) when the left SLR is applied, from 0.26 to 0.48 cm ($p<0.05$) with the right SLR and from 0.30 to 0.65 cm ($p<0.05$) with a bilateral SLR. No statistically significant relationship was found between age and movement value.

Conclusions The lumbo-sacral nerve roots in the spinal canal region move statistically significantly in response to the clinically applied SLR test, except for L2 root during the left SLR. This movement is symmetric and greater when a bilateral SLR is applied. These anatomical results are correlated with those observed empirically in clinical practice.

Keywords Straight leg raising · Lasegue's test · Herniated disc · Movement nerve roots · Anatomy

Introduction

A key physical sign in the diagnosis of radiculalgia, amongst others caused by lumbar discs herniation, is the demonstration of nerve root tension signs [11, 13]. It should be noted that radiculopathy is frequent and responsible for lumbar pain with radicular irradiation in the lower limb. A herniated disc would compress the nerve roots [5] and accentuate the tensioning of the nerve [14] triggering pain.

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The nerve roots studied L2, L3, L4, L5 and S1 are often affected by protrusion of the nucleus pulposus in annulus fibrosus. The straight leg raising (SLR) test has a high sensitivity of 0.91 and a specificity of 0.26 in diagnosing herniated discs [4]. It has been shown that the population aged between 30 and 50 years was the most affected by lumbar disc herniation with a male to female ratio of 2:1 [10].

The compression of the nerve roots by the herniated disc would not be the only factor in the genesis of the pain. Indeed, the intervertebral disk contains inflammatory proteins that can irritate these nerve roots [3]. So, apart from the inflammatory and compressive mechanisms, a mobility of the nerve roots causing friction within the spinal canal would be responsible for the pain.

Passive SLR (Lasegue's test) will cause traction on the lumbo-sacral nerve roots through the spinal canal. Distances measured may amount between 1.4 and 4 mm as reported by Summers et al. in a clinical and radiologic investigation [19]. This study determines the anatomical source of the pain from MRI images in the low back pain cases: the anterior theca compressed by disc prolapse [19].

At the spinal canal level, movements of nerve roots could only be noticed when a leg elevation of some 20–30 degrees was achieved, with a stronger displacement after 60 degrees [8, 18]. All movements decrease, with proximity of spinal cord according to an old descriptive anatomical study [9]. These studies did not investigate contralateral nerve root movements during SLR.

The aim of this anatomical study is, therefore, to show that there is mobility of the lumbo-sacral roots on both sides in the spinal canal during the Lasegue's test.

Materials and methods

This prospective descriptive observational study was performed in the Anatomy Laboratory of the Faculty of Medicine in Grenoble Alpes University from May to July 2017. The anatomical dissections were performed on human cadavers, resulting from the body donation, embalmed with formalin solution. Cadavers with scoliosis were excluded. Rigor mortis had to be broken down by forcible ventroflexion of the hips and dorsiflexion of the knees.

The cadavers excluded from this study are those who have been operated on the spine identified by the presence of a lumbo-sacral scar, or the presence of surgical material in the lumbo-sacral spine.

Dissection protocol

First, the specimen was placed in the ventral decubitus position with the arms along the body. The zone to be studied is delimited by palpation of the spines of the second lumbar vertebra at the first sacral vertebra. Then, an opening of the previously marked zone is effected by a median incision with a scalpel, along the line of the spinous processes, bordered by two transverse incisions. To access the vertebral blades, paravertebral muscles and adipose tissue are removed. A laminectomy with posterior approach can then begin. The purpose is to reach the contents of the spinal canal and, therefore, the dural sac. Thereafter, the dura mater is incised along its length, allowing the access to the left and right nerve roots L2, L3, L4, L5 and S1. The nerves studied are identified by their respective emergence at the level of the intervertebral foramen.

These nerves are marked by lead balls (Caperlan®) to a few centimeters of their emergence (Fig. 1). Concerning the characteristic of the lead balls, they measure 6 mm in diameter and weigh 1.25 g. A screw is inserted on a stable bone level to be used as a reference point for determining the laterality of the anatomical specimen. The lead balls are placed using only our nerve roots as a marker and measured movement does not take into account the bone frame so that the bone does not influence our landmarks.

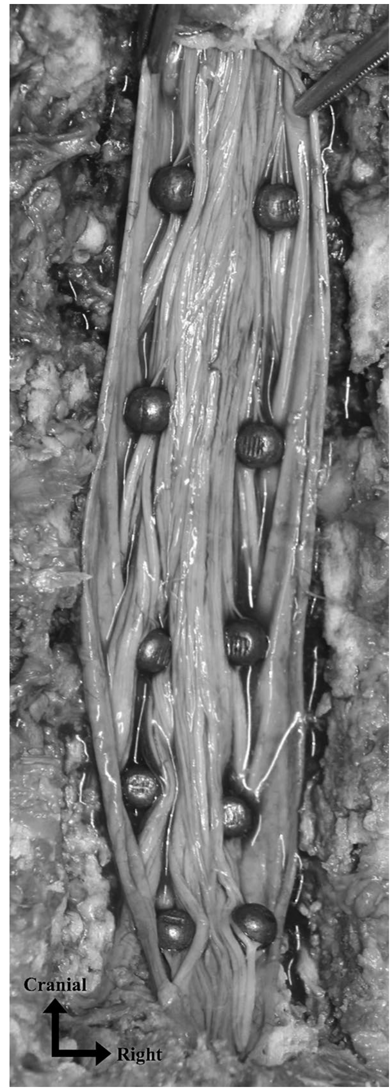

Fig. 1 Left and right nerve roots from L2 to S1, located in the spinal canal, marked by lead balls

Under the X-ray image intensifier (Siemens Arcadis Avantic®), the anatomical specimen is placed in a ventral decubitus position at the edge of the table, legs dangling.

A 7-cm-long metal ruler is placed close to the body for future calibration.

To quantify the different movements of the nerve roots within the spinal canal, several X-ray images are taken according to the movements imposed on the body.

The movements made are as follows: bilateral hip extension, bilateral hip flexion (bilateral straight leg raising), left straight leg raising (left SLR) and right straight leg raising (right SLR). During this procedure, we kept the bodies firmly in the ventral decubitus position with an external mechanical device.

The X-rays are stored on a USB stick and transferred to a computer with Gimp 2.8® software (version 2.8.22). This software allows the superposition of two X-ray images to study the different movements of the nerve roots via the lead ball (Fig. 2). We have previously made comparisons between the measurements obtained electronically and those that could be obtained with a millimetric surgical rule and several operators. This allowed us to attest to the accuracy of the software.

First, the X-ray images taken in bilateral hip extension and in bilateral SLR are superimposed one on top of the other. The coordinates X and Y of the metal ruler are determined on these two ends. The Pythagorean theorem is applied to determine the length of the metal ruler in pixels (root of $((x1-x2)^2+(y1-y2)^2)$). Thanks to a cross product and knowledge of the ruler measures of 7 cm, the conversion factor pixel in centimeters can be determined. These formulas are integrated in an Excel table (Microsoft Office 2017, version 15.36)®. Results are adjusted to the nearest cent per unit. The coordinates X and Y are determined at the center of each lead ball by taking the intersection of two orthogonal ball diameters. The coordinates $x1$ and $y1$ correspond to the nerve roots in bilateral hip extension and the coordinates $x2$ and $y2$ to those in bilateral SLR. These coordinates are entered in the Excel table and thus, thanks to the formula, the motion made by each nerve root can be quantified. These manipulations are repeated for the superposition of X-ray images in bilateral hip extension and in left SLR, then in bilateral hip extension and in right SLR, where $x1$ and $y1$ represent the coordinates of the lead balls in bilateral hip extension and $x2$ and $y2$ represent those in left or right SLR. These different steps are performed for each anatomical specimen.

All dissections have been carried out by the two same operators. The measurements were carried out by one of the two operators and then checked by the second one. If a discrepancy between the two measurements was found, the average of the two values was retained.

Statistical analysis

STATA 12.0® (StataCorp. 2011. Stata Statistical Software: Release 12. College Station, TX: StataCorp LP.) was used for statistical analysis. The mean and the Student's *t* test could not be realized because the distribution of data did not obey the normal law, and we did not have equality of variances.

The median, and the first and the third quartiles were calculated for each nerve root, according to each movement performed.

A nonparametric test of mean comparison on matched data was carried out: Wilcoxon test. The displacement of each nerve root was compared to the value of 0.10, if it was greater than 0.10 it was considered a notorious root movement. This value was chosen taking into account the precision of our measurements, so we consider that this is the margin of acceptable error. We calculated that a sample size of 14 cadavers would give a power of 80% with an alpha risk of 5%.

The variance movement expected was 0.27 centimeters (mean of the results obtained in a study: 0.14 and 0.4 cm [19]) with a tolerated gap of 0.10. Moreover, we have compared the results obtained between subjects aged 75 and

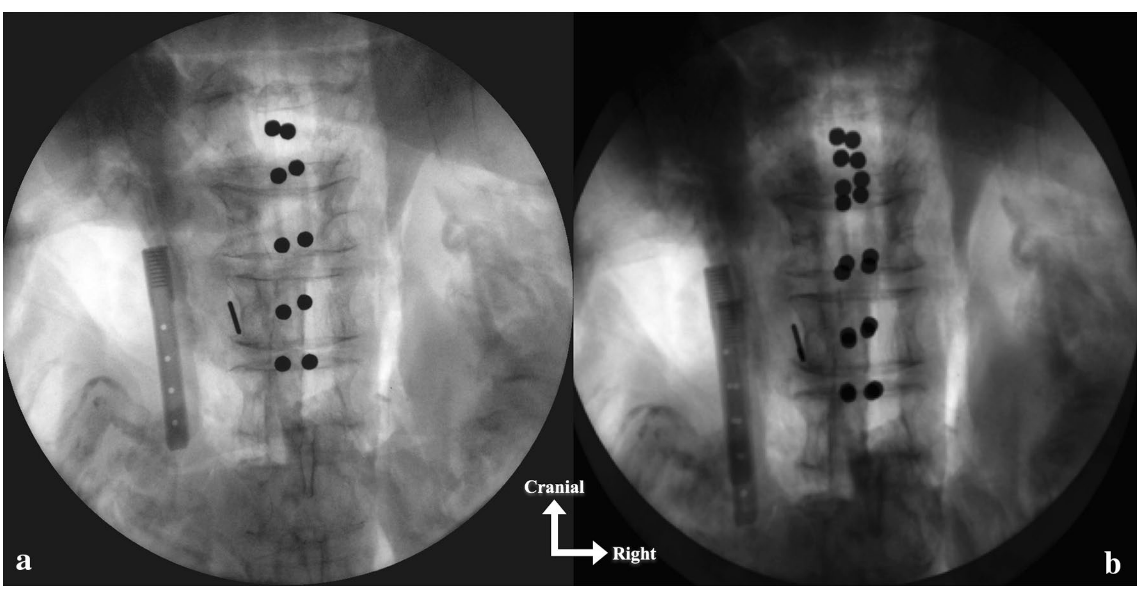

Fig. 2 X-ray image. **a** Image of an anatomical part in bilateral SLR. **b** Superposition of two images (bilateral SLR on bilateral hip extension) by Gimp® software

lesser to those aged over 75 years. A p value < 0.05 was considered statistically significant.

Results

Numbers of dissections

This anatomical study concerns the analysis of 14 adult cadavers, 6 males and 8 females. The mean age was 77.07 ± 11.37, the weight 52.14 kg ± 9.14, the size 160.93 ± 10.51 cm and the BMI 20.07 kg/m^2 ± 2.47.

Movement of the nerve roots during the transition from bilateral hip extension to bilateral SLR

We can notice that the movement carried out, within the spinal canal for each nerve root studied, is statistically significant at the threshold of 5% (Table 1). Moreover, the movement made by the left nerve roots is identical to that of the right nerve roots for S1–L3, and is similar for the nerve roots L2 left and right. We can observe in Fig. 3, where each box plot represents a nerve root, that the movement of the different nerve roots within the spinal canal is decreasing from S1 to L2. The median of the observed movement for the nerve root S1 is 0.64 cm for the left and 0.65 cm for the right side. While the observed motion for the nerve root L2 is 0.32 cm on the left, it is 0.36 cm on the right side.

We note that this movement of the nerve roots S1–L2 during the transition from bilateral hip extension to bilateral SLR, within the spinal canal, is more pronounced than that observed by these same nerve roots during the movement between the bilateral hip extension and left or right SLR.

Table 1 Median and p values of nerve root movements

Nerve roots	Transition from bilateral hip extension to bilateral SLR		Transition from bilateral hip extension to left SLR		Transition from bilateral hip extension to right SLR	
	Right	Left	Right	Left	Right	Left
S1	0.65 (0.001)	0.64 (0.001)	0.52 (0.001)	0.51 (0.001)	0.49 (0.001)	0.48 (0.001)
L5	0.49 (0.001)	0.46 (0.001)	0.39 (0.002)	0.35 (0.001)	0.32 (0.001)	0.38 (0.001)
L4	0.39 (0.001)	0.35 (0.002)	0.28 (0.002)	0.28 (0.002)	0.33 (0.005)	0.30 (0.006)
L3	0.32 (0.001)	0.30 (0.001)	0.26 (0.022)	0.21 (0.005)	0.26 (0.011)	0.30 (0.022)
L2	0.36 (0.006)	0.32 (0.005)	0.15 (0.120)	0.10 (0.390)	0.27 (0.004)	0.26 (0.004)

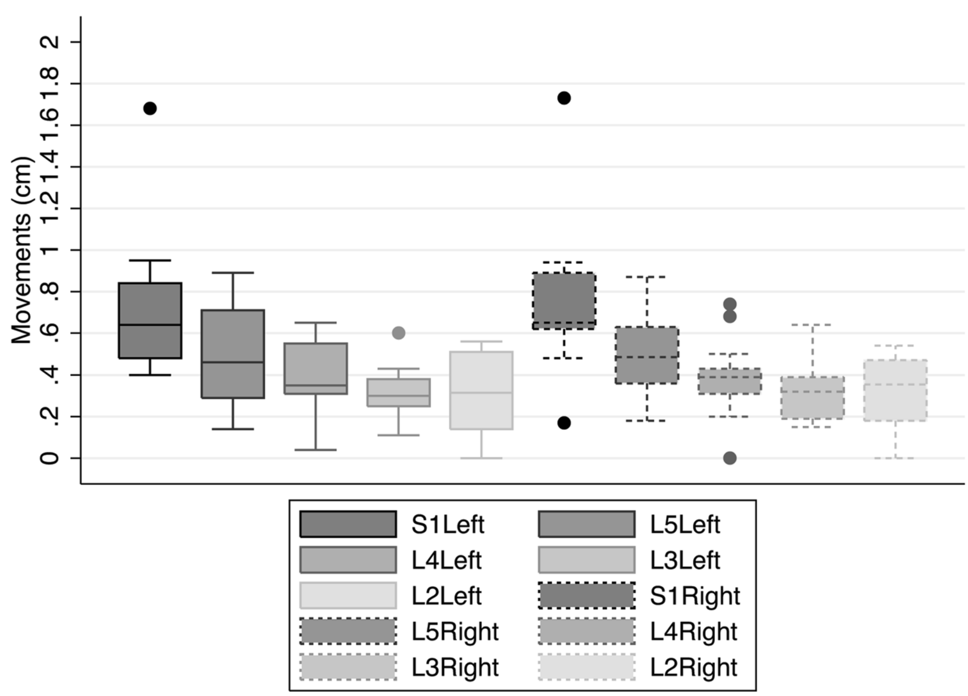

Fig. 3 Box plot of movement of the left and right nerve roots during the transition from bilateral hip extension to bilateral SLR

Movement of the nerve roots during the transition from bilateral hip extension to left SLR

We can observe that the movement performed by the left nerve roots S1–L3 in the spinal canal for each nerve root studied is statistically significant ($p < 0.05$). For the left nerve root L2, we can also observe a certain degree of movement, but this last one is not statistically significant ($p = 0.39$).

However, we can see that when this movement is made, the right nerve roots S1–L3 also perform a statistically significant movement ($p < 0.05$) within the spinal canal. We find the same amplitude of motion on the left and right nerve roots belonging to the same lumbar or sacral level.

This movement is also decreasing from the caudal nerve roots to the cranial nerve roots (Fig. 4).

Movement of the nerve roots during the transition from bilateral hip extension to right SLR

We can see that the right nerve roots S1–L2 make a statistically significant movement ($p < 0.05$).

As in the movement between the passage of the bilateral hip extension and the left SLR, we can see that the contralateral nerve roots to the movement carry out a movement of the same scale belonging to the same lumbar or sacral level. This movement is statistically significant ($p < 0.05$).

Moreover, it is also decreasing in the nerve roots S1–L2, on the left and right sides (Fig. 5).

Movement of the nerve roots according to age: less than or equal to 75 years and more than 75 years

This value of 75 years was chosen following the study of Goddard [9], which shows a greater movement after the age of 75 years. The movement obtained in subjects older than 75 years is greater than that obtained in subjects aged 75 years or less for the majority of the nerve roots; however, we did not demonstrate a statistically significant difference (Table 2) for the movement bilateral hip extension–bilateral SLR between the two groups.

There was also no statistically significant difference ($p > 0.05$) between the two groups for movement of the nerve roots during the transition from bilateral hip extension to right or left SLR.

Discussion

The range of movement recorded in the spinal canal is higher than those found in other studies [6, 9]. A displacement between 1.4 and 4 mm [19] was expected, but in this case, the median measurements ranged from 0.10 to 0.51 cm ($p < 0.05$; except for the L2 root $p > 0.05$) when the left SLR is applied, from 0.26 to 0.48 cm ($p < 0.05$) with the right SLR. The best displacement is showed when bilateral SLR is applied with a range of movement from 0.30 to 0.65 cm ($p < 0.05$). This can be explained by the use of a different measurement method compared to

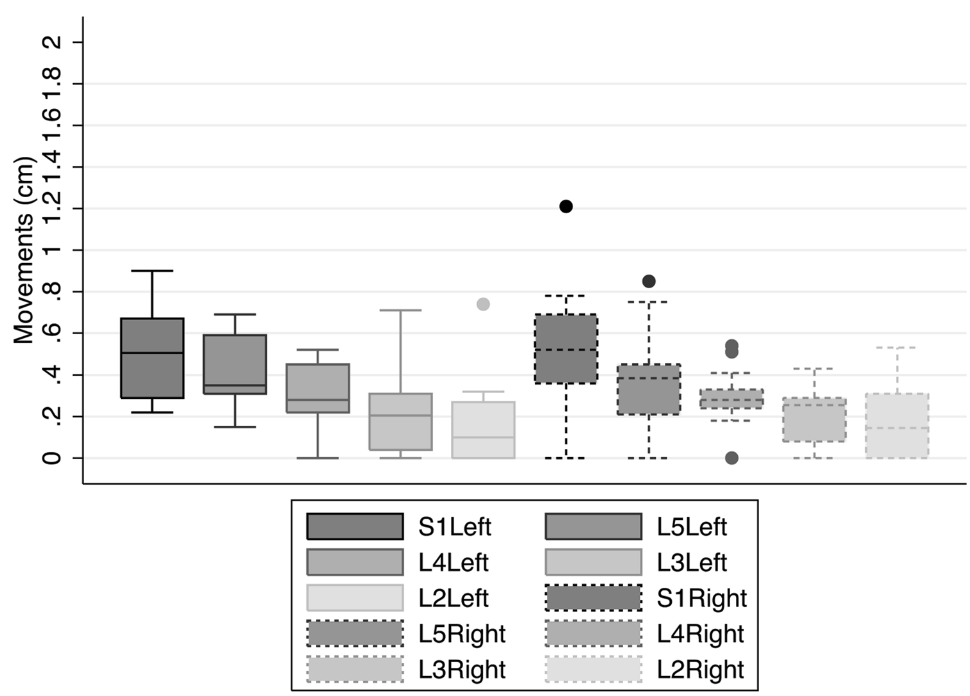

Fig. 4 Box plot of movement of the left and right nerve roots during the transition from bilateral hip extension to left SLR

Fig. 5 Median and quartiles of movement of the left and right nerve roots during the transition from bilateral hip extension to right SLR

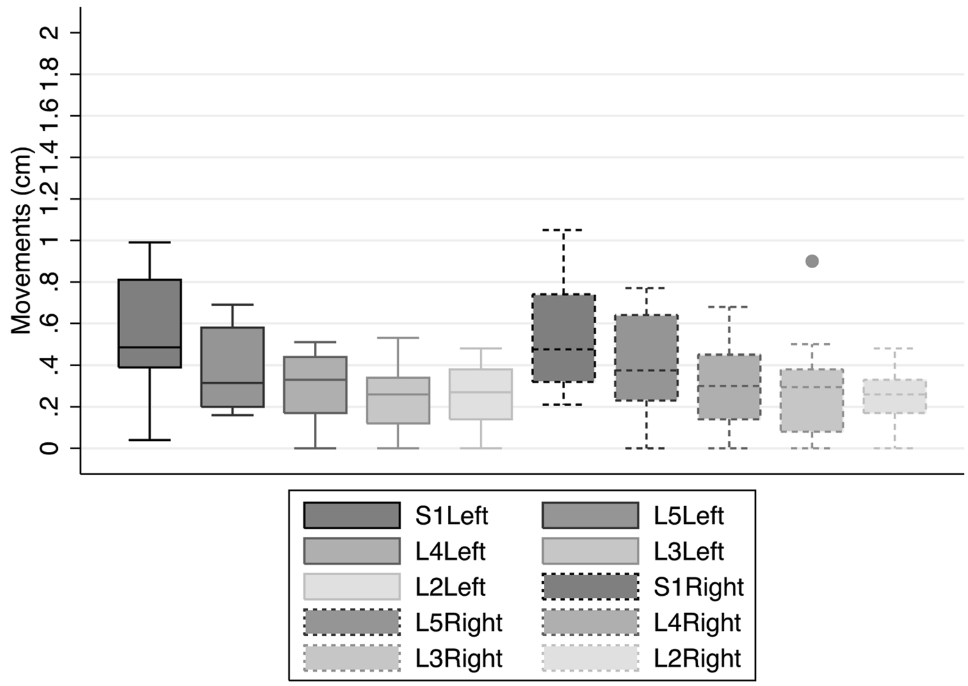

Table 2 p value obtained when comparing the different movements between the two groups: aged 75 years or less vs aged over 75 years

	p (extension–flexion movement)	p (extension–left SLR movement)	p (extension–right SLR movement)
Left S1	0.61	0.61	0.31
Right S1	1	0.18	0.31
Left L5	0.40	0.18	0.24
Right L5	0.40	0.35	0.61
Left L4	0.50	0.06	0.87
Right L4	0.50	0.50	1
Left L3	0.87	0.31	0.13
Right L3	0.93	0.93	0.61
Left L2	0.45	0.8	0.09
Right L2	0.18	0.20	0.24

subsequent studies. Use of X-ray images makes it possible to show a more precise movement, including what was not visible to the naked eye.

This measurement method is reliable and reproducible. Moreover, the analysis of the measurements by two operators limits the margins of measurement errors because if there is a measurement discrepancy, the mean of the two is retained.

However, there is a persistent margin of error, even if it is taken into account in the calculations and partly controlled, linked to the positioning of the cursor giving the coordinates of the center of the lead ball.

As we can see in this study, nerve roots shifting is noticed with a movement that becomes progressively higher from L2 to S1.

In Goddard's study, we can also see a better amplitude of movement of the nerve when one moves away from its emergence [9]. The presence of fibrous adhesions and particularly those in the spinal canal can justify this growing movement. If these adherences are broken, more movement can be obtained on straight leg raising, but the degree of natural movement is affected. Therefore, we have to note that during the dissection some fibrous adhesions were damaged. They may be at the origin of a probable increase in the measured movement.

Furthermore, density of adhesions seems to be age related [9], leading to increased mobility with age. This postulate found in the study carried out by Goddard could not be confirmed in this study.

Indeed, to eliminate any influence of age on the movement, we decided to compare the results between cadavers aged 75 years or more versus those aged under 75 years. There was no statistically significant difference in movement because, as described in Table 1, the average age of the cadavers remains high, with an age range from 60 to 97 years. However, a clinical study proves that age has an effect on result of SLR test in patients suffering lumbar disc herniation [20].

To our knowledge, the physiological movement of nerve roots has never been studied dynamically on a living patient. During our experiments, intra-dural factors were removed by dural section and extra-dural factors by section of the posterior vertebral arch. The external factors that may be pathological and compromise the movement were removed during the dissection, to be closer to a physiological situation. However, the limits inherent to the use of cadavers (in particular rigidity, high age, dissection removing many anatomical structures) could limit comparability with living patients.

Concerning the size of the lead balls, it allowed them to be large enough to encompass the majority of the nerve and the smallest possible to exert the least pressure on the latter. The lead balls were placed at a few centimeters from the exit of the nerves to not impede the normal course of the nerve in the spinal canal and to avoid that the lead balls come against the bone forming the foramen.

Otherwise, the direction of movement was not the same from one body to another. The logic would be that when the sign of Lasegue is applied, the nerves move downwards through their respective foramina like found in other studies [6, 9]. However, in a certain number of cases, we have found a paradoxical movement of the nerves that go up in the cranial direction during SLR. However, our movements are observed via X-ray images in a 2D plan. In addition, a ventro-dorsal movement was observed and filmed. Thus, these two parameters can explain this illusion of such paradoxical movement.

To see the importance of this ventro-dorsal movement, we made a profile radiographic imaging on two cadavers. This was not conclusive because the image quality was not powerful enough to allow the visualization of this displacement. This is why we chose not to quantify this movement in our study, to focus on the movements in the axis studied here.

This projection in a 2D plan can, therefore, only induce an underestimation of the measured movements.

The straight leg raising can cause a large movement of the different nerve roots.

At the spinal canal level, movements of nerve roots could only be noticed when a leg elevation of some 20 to 30 degrees was achieved. A greater displacement of the nerve roots was observed after a leg elevation of about 60 degrees [11]. We showed thanks to our box plots that the movements of the nerve roots were all the more important because the nerve root comes from a lower level. We think this is due to the length of the nerve roots which is more important as we descend down the spine.

There is a risk of potential error in the reproducibility of the execution of the Lasegue maneuver even if the latter is minimized because it is carried out by the same operator.

When performing the unilateral Lasegue sign, a contralateral motion was highlighted.

Moreover, the amplitude of this displacement was often the same on both sides. It is true that for some patients with important disc herniation, the sign of Lasegue is found positive on the opposite side to the protrusion of the disc. This phenomenon can be explained by a bilateral displacement of the spinal roots whichever side the SLR is applied. We think that the sign of Lasegue can be positive in the contralateral part of compressed nerve root because a movement of contralateral nerve roots occurs during the sign of Lasegue.

Spengler and Freeman defined the crossed SLR test as a much more specific criterion for disc protrusion [17]. Indeed, a positive crossed SLR is found for 87% of these patients. The specificity of crossed SLR is estimated at 0.88 whereas that of SLR is 0.26 [4].

Furthermore, we note that the movement of nerve roots was more important when a bilateral Lasegue was applied [15]. It would be interesting to perform this bilateral maneuver for patients suspected of disc herniation because by increasing the displacement of the nerves we increase the probability of triggering the pain. One study [17] even evaluated the effectiveness of this sign after intervertebral disc surgery. A positive SLR at 4 months after lumbar intervertebral disc surgery predicted a poor post-operative result, and a negative 4-month SLR predicted an excellent outcome.

The visualization of a movement generated by the Lasegue's sign and of a physiological friction of the nerves against bones of the spinal canal raises the question of the mechanism by which prolapsed discs induce pain.

We have shown a variability of nerve root movement with an average inter-quartile gap of about 0.3 cm, which may explain in part the inter-individual variability of pain perception in patients with disc herniation.

In patient with herniated disc, the tension in the nerve roots increases, after the Lasegue's test, resulting in a low back pain associated with a leg pain. Some studies have looked at the mechanisms involved, among the factors mentioned, the compression of nerve roots by prolapse disc would cause pain in the lower limbs [1, 5, 16, 21]. In addition to this phenomenon, Begg and Falconer have found congestion and swelling of the cauda equina, in the presence of disc protrusion [6]. Reduced blood flow to the nerve roots during the SLR test in patients with lumbar disc herniation was also noted [2, 12].

All these results suggest a multifactorial origin of the pain induced by the straight leg raising. There would be a mechanical cause with a tension of the nerve, from its emergence to its termination. But, there would be also inflammatory mechanism generating edema of the nerve [7].

The sign of Lasegue remains the main clinical sign of a herniated disc, so the fact of knowing the mechanisms involved makes it possible to improve its clinical application.

Movement of the nerve roots during the transition from bilateral hip extension to bilateral SLR within the spinal canal is statistically significant ($p < 0.05$). We can see the same movement when the right SLR is applied ($p < 0.05$). When the left SLR is performed there is statistically significant nerve root movement ($p < 0.05$) with the exception of root L2 ($p = 0.39$ on the left side and $p = 0.12$ on the right side). Note that the movement is increasing from root L2 to S1. The caudal displacement of the lumbo-sacral nerve roots was significantly greater with the bilateral SLR than the unilateral SLR.

Furthermore, we can see that the contralateral nerve roots of the side where the SLR is applied carry out a movement of the same amplitude belonging to the same lumbar or sacral level. This movement is not influenced by age. These results explain the pain often found empirically during a contralateral maneuver to the lesion. Our study, therefore, makes it possible to link clinical data to anatomical reality.

Author contributions AB: data analysis, manuscript writing, and manuscript editing; AL: data collection or management, and manuscript writing; LT: data collection or management, and manuscript writing; YR: manuscript writing and manuscript editing; PC: manuscript writing and manuscript editing; OP: protocol/project development and manuscript editing.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institution and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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