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ANATOMY

Femoral Nerve Strain at L4–L5 Is Minimized by Hip Flexion and Increased by Table Break When Performing Lateral Interbody Fusion

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Study Design. Anatomic studies have demonstrated that nerves and blood vessels have excursion with extremity range of motion. We have measured femoral nerve excursion with the lateral lumbar transpsoas interbody fusion (LLIF) procedure with changes in table flexion and ipsilateral hip flexion on both sides of 5 cadavers.

Objective. To determine the effect of hip range of motion on femoral nerve strain near the L4–L5 disc space because it pertains to the LLIF procedure.

Summary of Background Data. Postoperative thigh symptoms are common after the LLIF procedure. Although nerve strain in general has been shown to impair function, it has not been tested specifically with LLIF.

Methods. Five cadavers were placed in the lateral position as though undergoing the L4–L5 LLIF procedure. Radiographical markers were implanted into the femoral nerve. Lateral and anteroposterior fluoroscopic images were recorded with 0° initial table flexion and the hip at 0, 20, 40, and 60° flexion. The table was flexed to 40°, and the process repeated. Examination was repeated on the contralateral side and nerve strain and excursion were calculated.

Results. Table flexion results in preloading the femoral nerve when approaching L4–L5. Nerve strain was highest with the table flexed to 40° and the hip at 0° (average, 6%–7%). Strain in the femoral nerve decreased with increasing hip flexion for both table flexion angles. Anterior displacement of the nerve by approximately 1.5 mm was noted at 40° table flexion compared with 0°.

Conclusion. Strain values with table flexion of 40° approached those associated with reduced neural blood flow in animal studies. Table flexion should be minimized to the extent possible when performing L4–L5 LLIF. Additionally, hip flexion to 60° can neutralize the neural strain that occurs with aggressive table flexion.

Key words: XLIF, LLIF, femoral nerve, strain, dysesthetic leg pain, minimally invasive fusion, iliopsoas, table break, hip flexion, lateral decubitus, neural conduction, neural blood flow.

Level of Evidence: N/A

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Anatomic studies have demonstrated that nerves and blood vessels have excursion with extremity range of motion. Gilbert *et al*[1] demonstrated that intracanal nerves move with extremity range of motion, in particular when the hip is flexed more than 60°. Subsequently, Kim *et al*[2] showed that tension on the abdominal aorta may be reduced up to 20% with hip flexion when performing anterior lumbar interbody fusion.

Lateral lumbar transpsoas interbody fusion (LLIF) at L4–L5 has been successfully performed and reported by a number of surgeons.[3–7] Among the factors that influence success are postoperative dysesthetic thigh pain and the potential for nerve palsy.[8–10] Intraoperative nerve tension may add to neural injury when combined with retraction.

Nerve tension has been documented in the clinical setting as a pain generator. For instance, the femoral nerve stretch test,[11] straight leg raise,[12] and Lasegue test[13] all can cause pain in patients who have lumbar disc herniation. Anatomic studies have shown extremity range of motion does cause neural displacement up to 10 mm.[14] Furthermore, nerve excursion during straight leg raise tends to displace intrathecal nerve roots laterally, toward a posterolateral disc herniation.[15] Although the intraspinal neural motion has been found to be limited to under 5 mm because of ligamentous attachments within the foramen,[15] extraforaminal neural motion within the psoas has not been studied.

Animal models have shown that the viscoelastic properties of nerves can predict blood flow and neural damage.[16] The term tension can more appropriately be described in physical terms. Stress is defined as a deforming force per unit

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area (F/A) (5). Strain is defined as unit deformation (ΔL/L). Tension is the magnitude of pulling force. Strain can be used describe how tensile stress can affect nerves. Studies of rat sciatic nerves have shown that strains of 6% to 8% decrease neural blood flow, whereas strains of 14% to 16% completely block blood flow.[17,18]

The purpose of this study is to determine the effect of lower extremity range of motion on the lumbar plexus as it pertains to the LLIF procedure. In particular, it is our hypothesis that hip flexion greater than 20° will relax (decrease tension and intraneural strain) the femoral nerve near the L4–L5 disc space within the psoas. Additionally, table flexion (to move the rib cage away from the iliac crest on the upside of the patient) and nerve position will be examined during this experiment. The data from this study may guide clinical practice by making recommendations on preoperative positioning for L4–L5 LLIF surgery.

Figure 1. The LLIF approach: an open retroperitoneal dissection with the LLIF retractor in place. The femoral nerve is behind the LLIF retractor blade and is marked with an asterisk (*). Posterior is to the left of the image; anterior is demarcated by an "A." The K-wire is pointing to the L4–L5 disc. LLIF indicates lateral lumbar transpsoas interbody fusion.

MATERIALS AND METHODS

Specimen Characteristics

Five fresh-frozen cadaveric specimens were used (torso to midfemur). Three were female and 2 were male and average age was 72 years (range, 61–77 yr). Specimens were kept frozen until experimentation at −20°C and were thawed at room temperature for 1 day prior to experimentation. This article is exempt from IRB approval because it is a cadaveric study.

Specimen Preparation

Both sides of the cadaveric spines were used for a total of 10 sets of data. The cadavers were positioned on an articulating radiolucent operating table (Amsco 3085 General Surgical Table, Steris Corp., Mentor, OH) as though being treated with a L4–L5 LLIF. Stabilizing pins were placed into the sacrum and the anterior-superior iliac spine. The pins were mounted to the table, and the ribcage was taped down. A standard retroperitoneal approach was performed and the trunk of the femoral nerve identified within the substance of the psoas. A small aperture was made in the psoas to see the femoral nerve. We specifically did not disrupt any connective tissue or interneural connections to minimize the Heisenberg Uncertainty principle of observation—the notion that one changes an object by observing it.

Figure 1 depicts a more extensive dissection. It is designed to show the femoral nerve in relation to the retractor. The K-wire is pointing to the L4–L5 disc.

Four 1.5-mm metallic beads were implanted using suture into the femoral nerve (Figure 2). A 12.7-mm spherical metallic scaling marker was implanted into the L5 vertebral body in a location that did not obscure the 1.5-mm beads. The 12.7-mm spherical reference marker was used to scale the location of the 1.5-mm beads because fluoroscopic image magnification varies on the basis of the distance from the x-ray source.

Experimental Data Sets, Recording, and Analysis

The table flexion was measured by a goniometer mounted to the table and positioned at 0° and 40° to create 2 data sets. Hip flexion was 0, 20, 40, and 60° for each table flexion angle and measured by a second goniometer. Table orientation was performed to provide true anteroposterior (AP) and lateral C-arm fluoroscopy with respect to the L5 vertebral body (pedicles equidistant from the spinous process; parallel to the L5 superior endplate). Digital fluoroscopy images (OEC 9900 Elite, GE Medical Systems, Fairfield, CT) were recorded for each table position and hip flexion angle and then imported into Matlab (The MathWorks, Inc., Natick, MA) and digitized (Figure 3A–E). Binary images were initially created and edge detection was performed to locate the 12.7-mm scaling marker. The original grayscale images were scaled on the basis of the known diameter of the scaling marker. A local coordinate system based on the L5 vertebral body was then created on the scaled fluoroscopy images. The horizontal axis (lateral

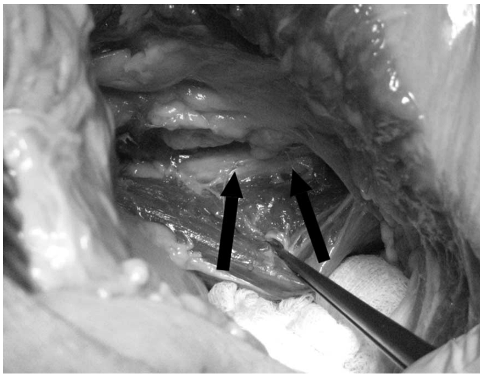

Figure 2. Femoral nerve with arrows pointing to the implanted metal beads.

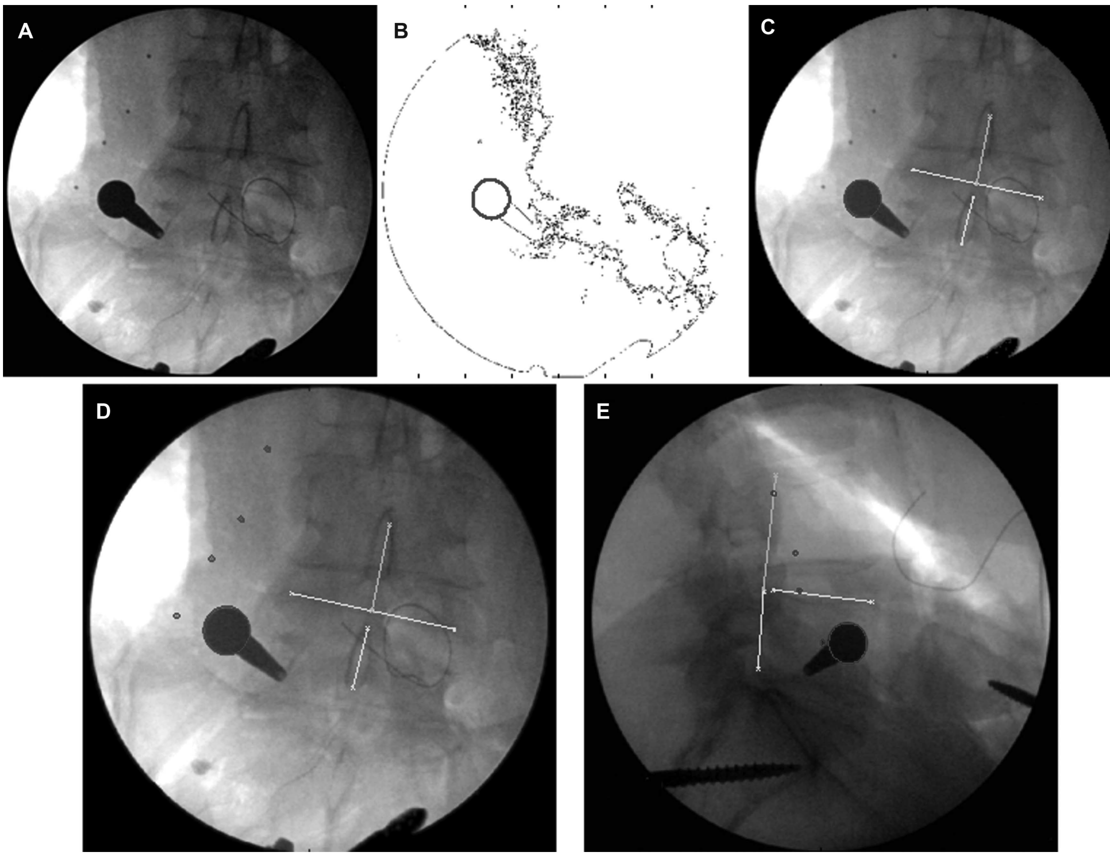

Figure 3. Fluoroscopic image analysis to determine location and distance between nerve markers: (**A**) AP image imported to Matlab; (**B**) AP image converted to binary and edge detection of 12.7-mm spherical scaling marker; (**C**) AP image with creation of local coordinate system; (**D**) final AP image showing registration of metal femoral nerve beads with bead location calculated in scaled local coordinate system; (**E**) final lateral image showing registration of metal beads (same process A–C for generating image). AP indicates anteroposterior.

fluoro view: AP axis; AP view: lateral axis) was created from the superior endplate of L5. In the AP fluoro view, the vertical axis (cephalad-caudal axis) was created from the midpoints of the L4 and L5 spinous processes. In the lateralfluoro view, the vertical axis (cephalad-caudal axis) was created from the posterior margin of the L5 vertebral body. The 4 metallic beads were then registered in each view and their positions were transformed into the L5 coordinate system. Analysis was performed in both the AP and lateral planes.

Intraneural strain was calculated as the change in distance (L) between the markers divided by the initial distance as follows:

$$\varepsilon = \frac{\Delta L}{L_{\text{initial}}}$$

Because the shortest distances between the markers were found at 0° table flexion and 60° hip flexion, the distances from this table/hip position were considered to be the initial distances (L_{initial}) for all strain calculations. Therefore strain at 0° table flexion and 60° hip flexion was always equal to zero. Strain was summed across the 3 intermarker distances to provide the total intraneural strain as follows:

$$\varepsilon_T = \varepsilon_{1-2} + \varepsilon_{2-3} + \varepsilon_{3-4}$$

Means, standard deviations, and maximum and minimum strain values were calculated for each table flexion and hip flexion angle. Lateral and AP strains were compared for the various table and hip flexion angles using repeated-measures analysis of variance and Holm Sidak paired comparisons with significance set at $P < 0.05$.

Nerve position along the L5 superior vertebral endplate was assessed by finding the intersection on the lateral fluoroscopy images between the line connecting the nerve markers and the AP (horizontal) local coordinate axis. The position was measured from the origin of the coordinate system, which is aligned with the posterior vertebral body margin. Similar to strain, the means, standard deviations, and maximum and minimum position values were calculated for each table flexion and hip flexion angle and compared using repeated-measures analysis of variance with significance set at $P < 0.05$.

RESULTS

Intraneural Strain

Femoral nerve strain was found to increase with increasing table flexion angle (Figure 4A, B; Table 1). In contrast, nerve strain was normalized with increasing hip flexion. Therefore, both position of the limb and table flexion can "preload" the nerve with strain. In particular, 40° of table flexion and hip extension (0° hip flexion) can create the most preload.

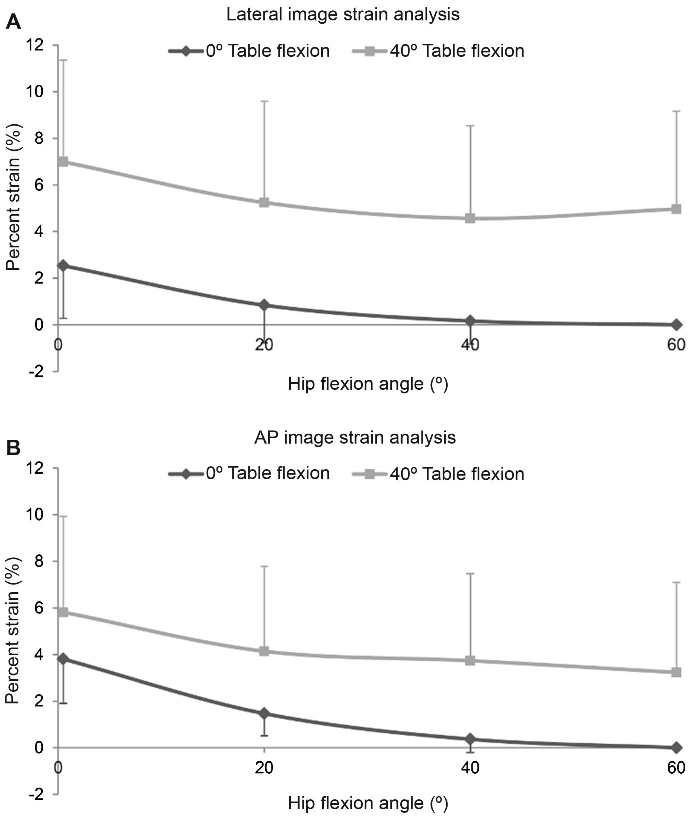

Figure 4. Strain values in the lateral (**A**) and AP planes (**B**) with different table breaks and degrees of hip flexion. The error bars represent 1 standard deviation of error. AP indicates anteroposterior.

The lateral plane analysis showed greatest strain values at 40° table flexion, ranging from 4.57 ± 3.98% at 40° hip flexion to 6.99 ± 4.36% at 0° hip flexion. However, there were no significant differences between strains for different hip flexion angles at this table position ($P \geq 0.569$; Table 2). All average strains at 40° table flexion were greater than at 0°. At 0° table flexion, there was a trend toward higher strain as hip flexion angle was reduced (2.53 ± 2.25% at 0°); however, the difference was not statistically significant from 60° hip flexion ($P = 0.390$). There were also no significant differences from 60° hip flexion at intermediate hip flexion angles (40°: $P = 0.890$, 20°: $P = 0.980$).

The AP plane analysis showed similar results to the lateral plane analysis with greatest stain values again occurring at 40° table flexion and 0° hip flexion (5.81 ± 4.12%). In this case however, the 0° table flexion strains at 0° and 20° hip flexion were greater than the 40° table flexion strains at 40° and 60° hip flexion. The lowest strain condition (0° table flexion, 60° hip flexion) was statistically significant from all 40° table flexion results ($P \leq 0.031$) as well as the 0° table flexion condition with the hip extended ($P = 0.006$).

Nerve Position

Nerve position varied with extremity range of motion as well as table flexion (Figure 5; Table 3). Table flexion from 0° to 40° demonstrated the greatest change in position of the nerve at the L4–L5 disc space, with an average of 2.6- to 3.2-mm anterior movement of the nerve for various hip flexion angles (60° and 0°, respectively). Increasing hip flexion also influenced nerve position, but most notably with the table position at 0°, where the nerve moved anteriorly from 8.5 ± 4.9 to 9.1 ± 7.5 mm. At 60° table flexion, the nerve movement was negligible with hip flexion (position of 11.6–11.7 mm at all angles). Despite some numerical differences in nerve position, no statistically significant differences were detected between any combinations of table or hip flexion angles ($P = 0.101$).

DISCUSSION

Minimally invasive spine surgery is a rapidly growing field. A standard component, the LLIF procedure, allows the surgeon to access the anterior spine through a transpsoas, retroperitoneal approach.[19] Intuitively, positioning the patient with a flexed hip would seem to relax tension on the muscle and nearby lumbar nerve plexus. In their description, Ozgur *et al*[19] also recommended using the table flexion to facilitate access past the iliac crest or rib cage. However, the authors are unaware of any studies that quantify nerve tension with either ipsilateral hip flexion or table flexion.

This study shows that table flexion results in preloading the femoral nerve with intraneural strain when approaching

TABLE 1. Percent Strain Values for Hip Flexion Angles of 0°, 20°, 40°, and 60° at Table Flexion Angles of 0° and 40° From Analysis of Lateral and AP Fluoroscopy Images

		Strain (%) (Mean ± Std Dev [Min, Max])			
		60° Hip Flexion Angle	40° Hip Flexion Angle	20° Hip Flexion Angle	0° Hip Flexion Angle
Lateral image analysis					
Table flexion angle	0°	0.00 ± 0.00 [0.00, 0.00]	0.16 ± 0.99 [−1.21, 2.52]	0.84 ± 1.62 [−0.58, 4.46]	2.53 ± 2.25 [0.02, 6.07]
	40°	4.96 ± 4.20 [−0.05, 13.6]	4.57 ± 3.98 [0.25, 12.8]	5.24 ± 4.34 [−1.01, 13.5]	6.99 ± 4.36 [0.37, 15.3]
AP image analysis					
Table flexion angle	0°	0.00 ± 0.00 [0.00, 0.00]	0.36 ± 0.57 [−0.30, 1.20]	1.47 ± 0.96 [0.19, 3.02]	3.80 ± 1.90 [0.85, 6.56]
	40°	3.23 ± 3.86 [−2.45, 9.26]	3.73 ± 3.73 [−1.98, 9.25]	4.14 ± 3.64 [−1.54, 9.57]	5.81 ± 4.12 [−0.37, 11.8]

AP indicates anteroposterior.

TABLE 2. ***P* Values From Repeated-Measures ANOVA and Holm Sidak Paired Comparisons Between Test Conditions**

Comparison	Lateral Image Analysis	AP Image Analysis
0° Table flexion, 60° hip flexion *vs*.		
0° Table flexion, 40° hip flexion	0.890	0.976
0° Table flexion, 20° hip flexion	0.980	0.743
0° Table flexion, 0° hip flexion	0.390	**0.006**
40° Table flexion, 60° hip flexion	**0.002**	**0.031**
40° Table flexion, 40° hip flexion	**0.005**	**0.007**
40° Table flexion, 20° hip flexion	**0.001**	**0.002**
40° Table flexion, 0° hip flexion	**<0.001**	**<0.001**
0° Table flexion, 40° hip flexion *vs*.		
0° Table flexion, 20° hip flexion	0.985	0.916
0° Table flexion, 0° hip flexion	0.415	**0.018**
40° Table flexion, 60° hip flexion	**0.003**	0.084
40° Table flexion, 40° hip flexion	**0.007**	**0.021**
40° Table flexion, 20° hip flexion	**0.001**	**0.007**
40° Table flexion, 0° hip flexion	**<0.001**	**<0.001**
0° Table flexion, 20° hip flexion *vs*.		
0° Table flexion, 0° hip flexion	0.689	0.264
40° Table flexion, 60° hip flexion	**0.014**	0.585
40° Table flexion, 40° hip flexion	**0.036**	0.291
40° Table flexion, 20° hip flexion	**0.007**	0.133
40° Table flexion, 0° hip flexion	**<0.001**	**0.001**
0° Table flexion, 0° hip flexion *vs*.		
40° Table flexion, 60° hip flexion	0.430	0.993
40° Table flexion, 40° hip flexion	0.601	0.941
40° Table flexion, 20° hip flexion	0.308	0.930
40° Table flexion, 0° hip flexion	**0.007**	0.423
40° Table flexion, 60° hip flexion *vs*.		
40° Table flexion, 40° hip flexion	0.982	0.991
40° Table flexion, 20° hip flexion	0.965	0.956
40° Table flexion, 0° hip flexion	0.569	0.158
40° Table flexion, 40° hip flexion *vs*.		
40° Table flexion, 20° hip flexion	0.965	0.990
40° Table flexion, 0° hip flexion	0.411	0.394
40° Table flexion, 20° hip flexion *vs*.		
40° Table flexion, 0° hip flexion	0.705	0.622

Values in bold typeface represent statistically significant differences (P < 0.05). ANOVA indicates analysis of variance; AP, anteroposterior.

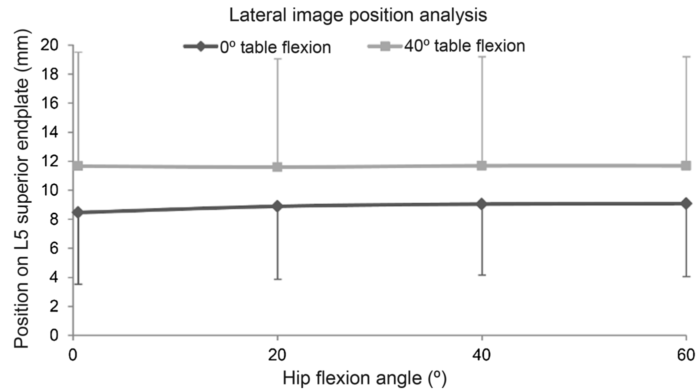

Figure 5. Position of the nerve along the L5 superior endplate in the lateral plane with different table breaks and degrees of hip flexion. The error bars represent 1 standard deviation. Position is measured from the posterior vertebral margin of L5.

L4–L5 for LLIF surgery. Femoral nerve strain was highest with the table broken to 40° and the hip at 0° (average, 6%–7%). In animal models, strain has been shown to impair neural conduction directly. Tibial nerve conduction was decreased to 70% with 7% strain and completely blocked at 12% strain.[20] In the study by Wall *et al*,[20] the conduction ability was regained after relaxation in 1 hour in the 7% group but did not completely return in the 12% group. As such, prolonged neural strain levels may also cause dysesthetic nerve pain from impaired sensory function.

The strain values achieved with maximum table flexion without hip flexion have been shown in animal studies to decrease neural blood flow.[20] Moreover, human studies have shown that neural blood flow decreases with increased nerve tension in the setting of a disc herniation.[21] As such, nerve tension during the LLIF procedure may indirectly impair nerve function through nutrient deprivation. Because of both the direct and indirect influences of nerve strain, one may consider decreasing table flexion to the minimum needed to accomplish longer LLIF surgical procedures. For shorter procedures, this finding may be less of a consideration.

Minimization of strain was seen with hip range of motion. Strain in the femoral nerve decreased with increasing hip flexion for both table flexion angles. Hip flexion can reduce the preload on the femoral nerve in cases where the table is broken to 40° for access to L4–L5. However, residual strain may exist unless table flexion is reduced. Anterior displacement of the nerve by approximately 1.5 mm was noted at 40° table flexion compared with 0°. These findings reinforce the notion that hip flexion on the upside is desirable.

It is important to note that minimizing nerve tension does not eliminate the potential for neurological complications. In a retrospective review of 59 patients, Cummock *et al*[22] noted a 62.7% prevalence of thigh symptoms, of which approximately 50% persisted at 3-month follow-up, and 10% at 1-year follow-up. More seriously, the femoral nerve injury has been reported at 4.8% at the L4–L5 level.[10] Case reports even document contralateral femoral nerve injury in deformity correction.[23] The reported high complication rates underscore the need to minimize neurological risk in the LLIF procedure.

TABLE 3. Position Where Nerve Crosses L5 Superior Endplate Measured From Posterior Margin of Vertebral Body From Analysis of Lateral Fluoroscopy Images for Hip Flexion Angles of 0°, 20°, 40°, and 60° at Table Flexion Angles of 0° and 40°

		Position on L5 Superior Endplate (mm) (Mean ± Std Dev [Min, Max])			
		60° Hip Flexion Angle	40° Hip Flexion Angle	20° Hip Flexion Angle	0° Hip Flexion Angle
Table flexion angle	0°	9.1 ± 5.0 [0.2, 14.2]	9.0 ± 4.9 [0.1, 13.8]	8.9 ± 5.0 [0.1, 13.4]	8.5 ± 4.9 [−0.3, 12.6]
	40°	11.7 ± 7.5 [0.9, 23.1]	11.7 ± 7.5 [1.3, 23.4]	11.6 ± 7.5 [1.0, 23.2]	11.7 ± 7.9 [1.2, 24.4]

CONCLUSION

Our anatomic findings suggest that hip flexion and lower table flexion may be protective against nerve injury by decreasing strain and anterior nerve displacement. Although table flexion is often needed for disc access, we suggest that surgeons minimize table flexion as much as allowed. Further clinical studies are needed to verify the clinical impact of the laboratory findings of this article.

➢ Key Points

- ❑ Table flexion of 40° increased intraneural strain.
- ❑ Hip flexion to 40° to 60° neutralizes intraneural strain caused by table flexion.
- ❑ Surgeons may consider minimizing table flexion and maximizing hip flexion to decrease the intraneural strain during lateral transpsoas interbody fusion.

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