Determination of the Entry Point for Lower Lumbar Intradiscal Procedure Using Transforaminal Technique: Cross-Sectional Study Using Magnetic Resonance Imaging

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Abstract:

Introduction: Triangular working area otherwise known as the Kambin triangle is designated as a safe place to position the instrument during the operation, with minimal risk to exiting nerves. This study aims to improve understanding and increase the safety of various transforaminal intradiscal procedures at L3/L4, L4/L5, and L5/S1 levels.

Methods: A cross-sectional analysis involving 102 MRIs that met the inclusion criteria was obtained and analyzed at the L3/L4, L4/L5, and L5/S1 discs level. For each level, the Kambin triangle was measured. By evaluating those measurements, the viability of this method was determined.

Results: Safe working zone approach angles were consistently getting wider from L3 to S1 levels. It was statistically significant to be wider for the left side for the mean angle of lateral nucleus trajectory at the L4/L5 level and L5/S1. The entry point is at 32, 45, and 55-60 mm from the midline, and the instrument should be directed at 12°, 20°, and 27° medially for the lateral nucleus at L3/L4, L4/L5, and L5/S1, respectively. The center of the nucleus pulposus entry point is at 64, 77, and 85 mm from the midline with a medial inclination of 40°, 47°, and 52°, respectively, for L3/L4, L4/L5, and L5/S1. For the posterior nucleus pulposus, the skin should be pierced 90, 140, and 180 mm from the midline and directed medially at 53°, 61°, and 68°, respectively, for L3/L4, L4/L5, and L5/S1. The posterior annulus fibrosis entry point is 172, 355, and 450 mm with a medial inclination of 69°, 80°, and 84° at L3/L4, L4/L5, and L5/S1, respectively. The sagittal inclination is 3° cephalad at L3/L4, 10° caudally at L4/L5, and 27° caudally at L5/S1.

Conclusions: Preoperative MRI assessment is important to determine the angle of trajectory for the safe entry point for intradiscal procedure via transforaminal approach.

Keywords:

entry point lumbar, intradiscal procedure, transforaminal technique, Kambin's triangle, minimally invasive surgery, magnetic resonance imaging

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Introduction

It was estimated that approximately 60%-80% of the population will experience low back pain at some point in their working life[1)]. Low back pain tends to recur and results in prolonged sick leave and even early retirement[2,3)]. It is often overlooked and may attribute to the lack of uniformity in how low back pain is defined and treated[4)].

Disc degeneration with or without herniation is a prominent cause of low back pain, and much work has been done on treatments of disc degeneration[3)]. Surgical intervention via laminectomy or laminotomy is still widely performed to treat prolapsed intervertebral disc, with an acceptable incidence of complications[5,6)]. However, a considerable insult to the surrounding myoligamentous structures and the development of epidural and perineural fibrosis remain a concern[7)]. Minimal invasive surgical approach therefore becomes popular as the treatment method of choice for patients with a painful disc, including endoscopic surgical technique, percutaneous intradiscal laser, or radiofrequency ablation treatment[8,9)].

Understanding the radiographic and surface landmark of

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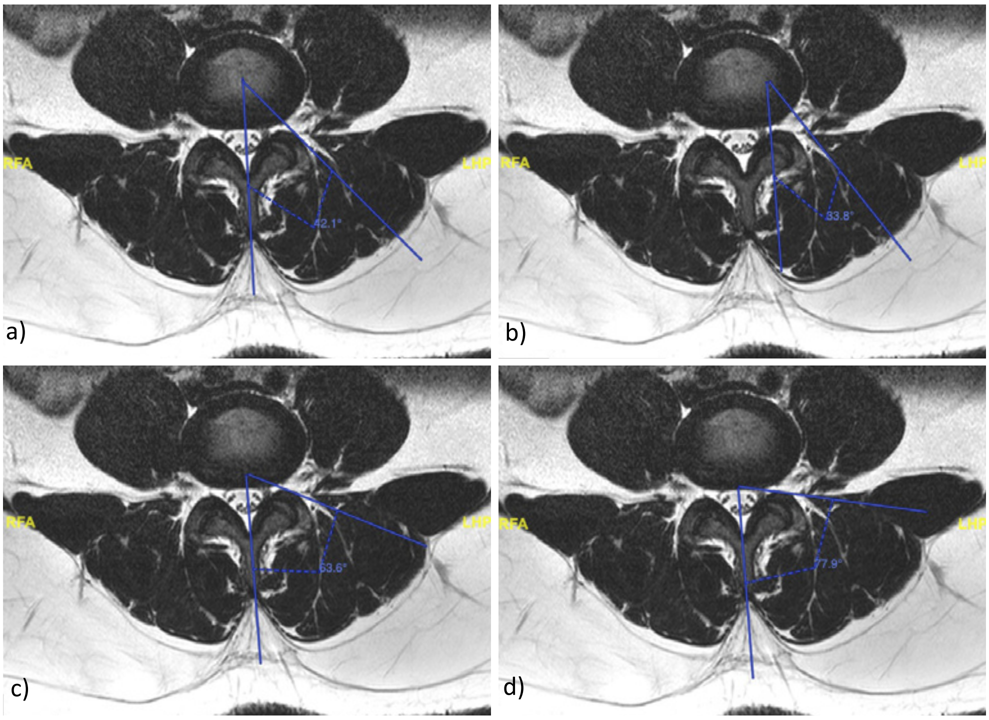

Figure 1. Measurement of (a) center of nucleus trajectory angle (CNA), (b) lateral nucleus trajectory angle (LNA), (c) posterior nucleus trajectory angle (PNA), and (d) posterior annulus trajectory angle (PAA).

the instrument trajectory is essential for the efficacy and safety of these techniques. The triangular working zone (Kambin triangle) was proved to be safe as the channel and for positioning of the instrument during the procedure, with minimal injury risk to the exiting nerves[10]. During the procedure, the cannula should be placed as close as possible to the facet joint to avoid neural injury, especially at the upper lumbar. Choe et al reported that neural complication was reduced by 23% per 1 mm increase in this distance[11]. "Accurate landing," which means accurate entry through the foraminal window to the target area in the disc, is the most important key to success and preventing complications. The principle is that the landing point should be as close as possible to the disc lesion and the exiting nerve root should not be disturbed[12].

Currently, there are no clinical or radiological studies to recommend the appropriate entry point and its trajectory angle to approach the disc in our population. Previous studies will hopefully improve our understanding and increpriase the safety of various transforaminal intradiscal procedures at L3/L4, L4/L5, and L5/S1 levels[13,14].

Materials and Methods

This is a cross-sectional study that was conducted at a tertiary teaching hospital. The reference population was the Malay population who underwent an MRI examination for a spinal assessment and who were otherwise reported to have normal lumbar spines. The number of sample sizes was determined using Power and Sample Size software sample size calculator on the basis of a study by Lee DH et al[15]. The MRI images of the patients who had previous lumbar spine surgeries, spinal tumors or metastasis, congenital abnormalities, trauma or infection, scoliosis (Cobb angle>10°), and other abnormalities were excluded from the study.

The MRI images which fulfilled the inclusion criteria were randomly selected using purposive randomization and analyzed. Standard axial and sagittal plane MRI images, with 3.0-3.5 mm slice thickness were taken from L3/4, L4/5, and L5/S1 disc levels (Philips Achieva TX 3.0 Tesla Magnetic Resonance system, General Electric, Milwaukee, USA). All images were appropriately angled to the disc space and measured using Picture Archiving & Communication Systems software computer digitizer. Eight relevant parameters related to the working zone were measured.

The methods of measurement were described (Fig. 1, 2) and the parameters measured on the axial plane were as follows:

i. Center of nucleus trajectory angle (CNA): Angle between the midline of the vertebral body and a line drawn from the center point of nucleus pulposus to the lateral edge of superior articular process (SAP).
ii. Lateral nucleus trajectory angle (LNA): Angle between the midline of the vertebral body and a line drawn from the lateral edge of the nucleus pulposus to the lateral edge of SAP.
iii. Posterior nucleus trajectory angle (PNA): Angle between the midline of the vertebral body and a line drawn from the mid-posterior edge of the nucleus pulposus to the lateral edge of SAP.

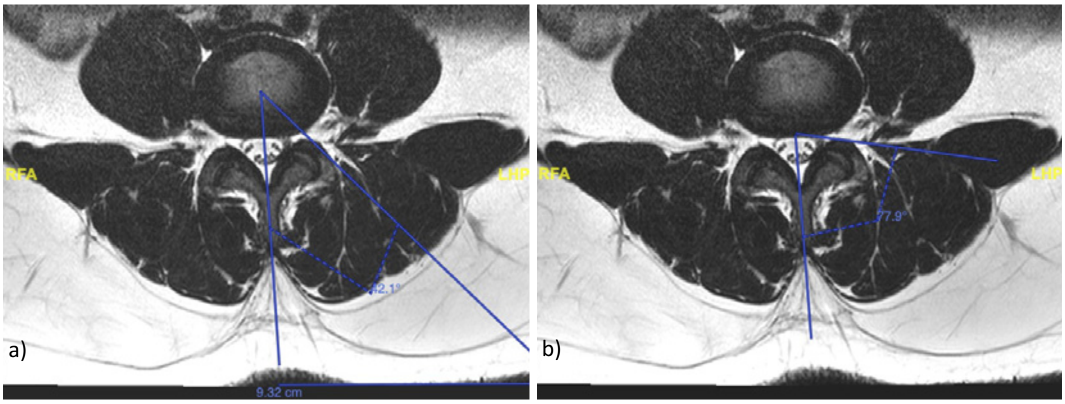

Figure 2. (a) Measurement of surface distance between spinous process and center of nucleus pulposus trajectory, center of nucleus trajectory distance (CND, LND). The measurement of other distances (PND, PAD) is determined via mathematical calculation. (b) Measurement of PAD and PND at certain disc levels is impossible because the distance between the entry points and the midline is far outside the MRI images and located at the side of the body. The entry points are therefore categorized as “require posterolateral approach.”

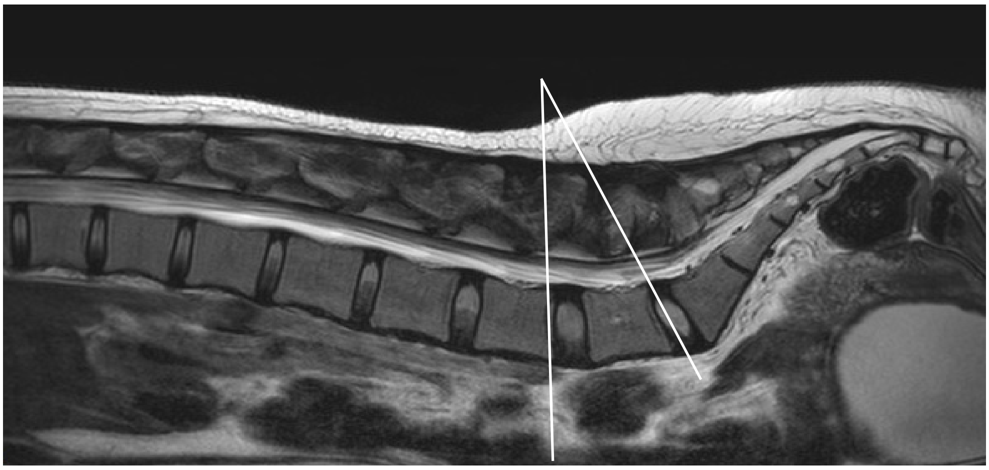

Figure 3. Measurement of sagittal inclination angle (SIA) between the mid-sagittal line of the disc and the trajectory line from the skin.

iv. Posterior annulus trajectory angle (PAA): Angle between the midline of the vertebral body and a line from the mid-posterior edge of annulus fibrosis to the lateral edge of SAP.

v. Lateral nucleus pulposus trajectory distance (LND): Surface distance between the spinous process and lateral nucleus trajectory.

vi. Center of nucleus trajectory distance (CND): Surface distance between spinous process and center of nucleus pulposus trajectory.

vii. Posterior nucleus trajectory distance (PND): Surface distance between spinous process and posterior nucleus trajectory.

viii. Posterior annulus trajectory distance (PAD): Surface distance between spinous process and posterior annulus trajectory.

ix. Sagittal inclination angle (SIA) was measured between the mid-sagittal line of the disc and the trajectory line from the skin. It was measured at the mid-sagittal level of L3/L4, L4/L5, and L5/S1 discs. (Fig. 3).

Statistical analyses were performed using SPSS Windows version 22 (SPSS Inc., Chicago, IL, USA). Parametric data were analyzed using descriptive analysis (test), and the results were presented in a standard table as mean values and their standard deviation. An independent t-test was performed for numerical data. A P value of <0.05 was considered significant.

This study was approved by the Human Research Ethics Committee.

Results

One hundred two patients’ MRI images were enrolled in this analysis. The subjects comprised 58 male patients with a mean age of 35 (SD 9.2) years and 44 female patients with a mean age of 30 (SD 8.1) years. Their mean age was

Table 1. Measurements of LNA, CNA, PNA, and PAA at L3/L4, L4/L5, and L5/S1 of Both Sides.

	Measurements (°)		Mean difference (95%CI)	t statistic (df)	P value
	Right Mean (SD)	Left Mean (SD)			
Lateral nucleus trajectory (LNA)					
L3/L4 (n=93)	11.70 (4.94)	12.89 (4.90)	−1.19 (−2.61, 0.23)	−1.65 (184)	0.1
L4/L5 (n=92)	19.22 (5.62)	20.98 (5.70)	−1.761 (−3.40, −0.11)	−2.11 (182)	0.036
L5/S1 (n=78)	26.24 (5.93)	28.63 (5.33)	−2.385 (−4.17, −5.98)	−2.63 (154)	0.009
Center of nucleus trajectory (CNA)					
L3/L4 (n=93)	40.40 (5.37)	40.87 (3.52)	−0.473 (−1.57, 0.62)	−0.84 (184)	0.397
L4/L5 (n=92)	47.74 (4.54)	47.38 (4.54)	0.349 (−0.96, 1.68)	0.54 (182)	0.593
L5/S1 (n=78)	52.47 (4.28)	52.14 (4.06)	0.333 (−0.98, 1.65)	0.49 (154)	0.619
Posterior nucleus trajectory (PNA)					
L3/L4 (n=93)	52.90 (5.37)	53.57 (5.35)	−0.667 (−2.21, 0.88)	−0.19 (184)	0.849
L4/L5 (n=92)	61.90 (6.12)	61.65 (5.85)	0.250 (−1.49, 1.99)	0.28 (182)	0.778
L5/S1 (n=78)	68.05 (6.15)	67.88 (6.10)	0.167 (−1.77, 2.10)	0.17 (154)	0.865
Posterior annulus trajectory (PAA)					
L3/L4 (n=93)	68.89 (7.04)	69.09 (6.80)	−0.194 (−2.19, 1.81)	−0.84 (184)	0.397
L4/L5 (n=92)	80.77 (6.79)	79.96 (6.31)	0.815 (−1.09, 2.72)	0.84 (182)	0.400
L5/S1 (n=78)	84.32 (6.42)	83.60 (5.95)	0.718 (−1.24, 2.67)	0.72 (154)	0.470

CAN=central nucleus angle, LNA=lateral nucleus angle, PNA=posterior nucleus angle, and PAA=posterior annulus angle

Table 2. Measurements of PND, CND, PND, and PAD at L3/L4, L4/L5, and L5/S1 of Both Sides.

Axial plane distance (mm)	Measurements (mm)		Mean difference (95%CI)	t statistic (df)	P value
	Right Mean (SD)	Left Mean (SD)			
Lateral nucleus trajectory (PND)					
L3/L4 (n=74)	31.27 (6.03)	32.55 (7.16)	−1.281 (−3.43, 0.87)	−1.17 (146)	0.241
L4/L5 (n=75)	44.29 (9.22)	46.71 (10.27)	−2.467 (−5.63, 0.69)	−1.54 (147)	0.125
L5/S1 (n=63)	55.37 (10.44)	59.42 (11.00)	−4.04 (−7.84, −0.25)	−2.11 (123)	0.037
Center of nucleus trajectory (CND)					
L3/L4 (n=71)	64.03 (11.69)	64.11 (11.16)	−0.823 (−3.87, 3.71)	−0.43 (140)	0.966
L4/L5 (n=56)	76.93 (12.59)	77.75 (13.02)	−0.819 (−5.71, 4.07)	−0.33 (106)	0.741
L5/S1 (n=32)	84.65 (12.39)	85.65 (12.29)	−1.01 (−7.09, 5.05)	−0.33 (64)	0.739
Posterior nucleus trajectory (PND)					
L3/L4 (n=80)	90.52 (25.25)	94.00 (29.24)	−3.478 (−12.05, 5.10)	−0.80 (156)	0.424
L4/L5 (n=76)	139.62 (44.94)	140.00 (47.57)	−0.374 (−15.20, 14.58)	−0.50 (150)	0.960
L5/S1 (n=60)	179.43 (60.86)	172.66 (53.12)	6.768 (−13.88, 27.42)	0.64 (118)	0.518
Posterior annulus trajectory (PAD)					
L3/L4 (n=77)	175.25 (68.48)	179.95 (73.61)	−4.693 (−27.33, 17.94)	−0.41 (152)	0.68
L4/L5 (n=62)	355.20 (176.03)	347.25 (166.40)	7.943 (−53.19, 69.08)	0.83 (121)	0.79
L5/S1 (n=38)	499.86 (196.46)	469.85 (224.09)	−19.993 (−117.34, 77.35)	−0.40 (73)	0.68

PND=posterior nucleus distance, CND=central nucleus distance, PND=posterior nucleus distance, and PAD=posterior annulus distance

Table 3. Measurements of SIA at L3/L4, L4/L5, and L5/S1.

Sagittal inclination angle (SIA)	Measurements (°) Mean (SD)	Range (°)
L3/L4 (n=88)	2.73 (3.36)	−8 to 11
L4/L5 (n=90)	−9.68 (4.61)	−29 to −1
L5/S1 (n=82)	−26.82 (5.02)	−37 to −14

SIA=sagittal inclination angle

32.8 years (SD 9.0). All the measurements were summarized (Table 1, 2, 3).

L3/4 level

The measurements of angles of interest at L3/L4 were obtained from 93 MRI images (Fig. 1). LNA was 11.7° (SD 4.9°) and 12.9° (SD 4.9°) on the right and left sides, respectively. CNA was 40.4° and 40.9° (SD 3.5°) (SD 5.4°) on the right and left sides, respectively. PNA was 52.9° (SD 5.4°) and 53.6° (SD 5.4°) on the right and left sides, respectively. PAA was 68.9° (SD 7.0°) and 69.1° (SD 6.8°) on the right and left sides, respectively.

At L3/L4, the measurements of distance parameters were obtained from 74 MRI images (Fig. 2a). Mean LND were

31.3 mm (SD 6.0 mm) and 32.6 mm (SD 7.2 mm) on the right and left sides, respectively. CND was 64.0 mm (SD 11.7 mm) and 64.1 mm (SD 11.2 mm) on the right and left sides, respectively. PND was 90.1 mm (SD 25.1 mm) and 94.4 mm (SD 29.2 mm) on the right and left sides, respectively (Fig. 2b). PAD was 175.3 mm (SD 68.5 mm) and 179.9 mm (SD 73.6 mm) on the right and left sides, respectively.

Inclination angle (SIA) was measured in 88 MRI images with a mean value of 2.7° (SD 3.4°) cephalad (Fig. 3).

L4/5 level

The measurements of the angle of interest at L4/L5 were obtained from 92 MRI images. Mean LNA was 19.2° (SD 5.6°) and 20.9° (SD 5.7°) on the right and left sides, respectively. The difference between both sides was statistically significant. CNA was 47.7° (SD 4.5°) and 47.4° (SD 4.5 °) on the right and left sides, respectively. PNA was 61.9° (SD 6.1°) and 61.7° (SD 5.9°) on the right and left sides, respectively. PAA was 80.8° (SD 6.8°) and 79.9° (SD 6.3°) on the right and left sides, respectively.

Mean LND was 44.3 mm (SD 9.2 mm) and 46.71 mm (SD 10.3 mm) on the right and left sides, respectively. CND was 76.9 mm (SD 12.6 mm) and 77.8 mm (SD 13.0 mm) on the right and left sides, respectively. PND was 139.6 mm (SD 44.9 mm) and 140.0 mm (SD 47.6) on the right and left sides, respectively. PAD was 355.2 mm (SD 176.0 mm) and 347.3 mm (SD 166.4 mm) on the right and left sides, respectively.

Inclination angle (SIA) was measured in 90 MRI images with a mean value of 9.7° (SD 4.6°) caudal.

L5/S1 level

The measurements of the angle of interest at L5/S1were obtained from 78 MRI images. LNA was 26.2° (SD 5.9°) and 28.6° (SD 5.3°) on the right and left sides, respectively. The difference in the measurement was statistically significant. CNA was 52.5° (SD 4.3°) and 52.1° (SD 4.1°) on the right and left sides, respectively. PNA was 68.1° (SD 6.2°) and 67.9° (SD 6.1°) on the right and left sides, respectively. PAA was 84.3° (SD 6.4°) and 83.6 ° (SD 5.9°) on the right and left sides, respectively.

Mean LND was 55.4 mm (SD 10.4 mm) and 59.4 mm (SD 11.00 mm) on the right and left sides, respectively. The difference was also statistically significant. CND was 84.7 mm (SD 12.4 mm) and 85.7 mm (SD 12.3 mm) on the right and left sides, respectively. PND was 179.4 mm (SD 60.9 mm) and 172.7 mm (SD 53.1 mm) on the right and left sides, respectively. PAD was 499.9 mm (SD 196.5 mm) and 469.9 mm (SD 224.1 mm) on the right and left sides, respectively.

Inclination angle (SIA) was measured in 82 MRI images with a mean value of 26.8° (SD 5.0°) caudal.

PND and PAD at L3/L4, L4/L5, and L5/S1 disc were determined via mathematical calculation, using a formula based on the trajectory angles (PNA and PAA). The measurements could not be performed directly on the MRI images because the trajectory lines on the skin were located far outside the range of the MRI images.

Discussion

In 1973, Kambin and Gellmann developed a nonvisualized posterolateral percutaneous central nucleotomy for resection and evacuation of nucleus tissue via a posterolateral approach[16]. Many minimally invasive pain procedures had been developed recently to improve patients' outcomes including shortened operating time, less bleeding, improved patients' recovery[13], minimized perineural and epidural scar formation, reduced incidence of injury, and denervation of paraspinal muscles[10]. However, perioperative complications especially exiting nerve root injuries, ranging from 1% to 8.9%, were still reported with this technique[16].

The safe zone was defined by Kambin in 1973, and it is a right-angle triangle over the dorsolateral disc. It is formed by a hypotenuse (the medial border of the nerve root as it exits from the intervertebral foramen), base (superior border of the caudal vertebra), and its height (the dura or traversing vertebra)[17].

Mirkovic and Min published the dimensions of the Kambin triangle in their cadaveric studies[13,18]. They measured the anatomical dimension on the coronal and sagittal plane and described the triangle as 18.9 mm wide and 12.3 mm high, which increase distally[18]. Based on these studies, an ideal endoscope size can be developed for clinical usage.

Xiao et al reported their analysis of this working zone in 32 individuals based on magnetic resonance neurography[19]. They highlighted the limited distance between nerve root and lower facet which may increase the risk of neural injury. Choi et al reported that neural complication was reduced by 23% per 1 mm increase in this distance[11], which means that the diameter of the triangle is much smaller at the upper level and becomes wider distally. Therefore, to avoid neural injury, the cannula should be placed as close as possible to the facet joint instead. Previous studies help evolve our understanding and increase the safety of PELD[13,14] and other similar procedures using the transforaminal approach.

Lumbar disc herniation can be classified based on anatomical location: central, subarticular, foraminal, and extraforaminal. "Accurate landing," which means accurate entry through the foraminal window to the target area at the disc is the most important key to achieving a successful procedure and minimizing complications.

The center of nucleus pulposus is a common target for discography procedure, nucleoplasty, radiofrequency treatment, and steroid injection, especially at L4/L5 and L5S1. CNA and CND were measured in this study to locate the appropriate entry and trajectory angle for the instruments used in the procedures.

LNA and LND were measured to locate the working area for other types of annulopasty (e.g., biaculopasty), where two probes are inserted to thermocoagulate the posterior annulus for discogenic pain without herniation.

Posterolateral and posterocentral parts of the disc are common areas for herniation. Minimally invasive discectomy and percutaneous discectomy are commonly performed to remove disc herniation using the transforaminal approach. PAA, PAD, PNA, and PND were measured to assist the surgeons to locate the correct entry and trajectory angle of the instruments for these procedures.

Symptomatic disc problem requiring pain control procedure at L3/L4 is not uncommon. If disc procedure is indicated, the entry point for the lateral part of the nucleus is approximately 30 mm from the midline and the instrument should be directed at approximately 10° medially. For the center of nucleus pulposus entry, the entry point is approximately 65 mm from the midline and the instrument should be directed at 40° medially. For posterior nucleus pulposus entry, the entry point is approximately 90 mm from the midline and the instrument should be directed at 55° medially. For posterior annulus entry, the entry point is approximately 175 mm from the midline and the instrument should be directed at 70° medially. The sagittal inclination for all disc entries at L3/L4 was slightly cephalad.

L4/L5 disc problem is probably the most common. At L4/L5, the entry point for the lateral part of nucleus is approximately 45 mm from the midline and the instrument should be directed at 20° medially. For the center of nucleus pulposus entry, the entry point is approximately 80 mm from the midline and the instrument should be directed at 50° medially. For posterior nucleus pulposus entry, the entry point is approximately 140 mm from the midline and the instrument should be directed at 60° medially. For posterior annulus entry, the entry point is approximately 350 mm from the midline and the instrument should be directed at 80° medially. The sagittal inclination for all disc entries at L3/L4 was approximately 10° caudally.

At L5/S1, the entry point for the lateral part of the nucleus is approximately 55 mm from the midline and the instrument should be directed at 25° medially. For the center of nucleus pulposus entry, the entry point is approximately 85 mm from the midline and the instrument should be directed at 50° medially. For posterior nucleus pulposus entry, the entry point is approximately 180 mm from the midline and the instrument should be directed at 70° medially. For posterior annulus entry, the entry point is approximately 50 cm from the midline and the instrument should be directed at 85° medially. The sagittal inclination for all disc entries at L3/L4 was approximately 30° caudally. The transforaminal approach might be difficult and may limit the use of this approach at the L5/S1 disc due to some anatomical constraints, namely, high-riding iliac crest and large L5 transverse processes[8].

Measurement of certain entry point distances at certain disc levels was done indirectly via mathematical calculation because the distance between entry points and the midline is far outside the MRI images and located at the side of the body (Fig. 2b). We found that PND and PAD at L3/L4, L4/L5, and L5/S1 disc were under this category. Since the entry points to the targeted area in the disc were located at the side of the body, the entry points, therefore, we categorized them as “require lateral approach.”

There are a few limitations of this study. The patients' body weight and size (BMI) may affect the entry point especially in a very big size patient where it will be laterally shifted, although trajectory angles may not change. The absence of intraoperative data using these measurements in our study is another limitation that we need to improve in the future study. Another limitation identified is that measurements were performed in a supine position as all MRIs were done in this position. The entry point may differ in prone position during the procedure.

Understanding the entry point and trajectory angles to reach the working area in the disc is imperative for surgeons for safety and efficacy. Entry points to L3/L4, L4/L5, and L5/S1 discs are between 30-60 mm from the midline and 10°-30° medially for the lateral nucleus (LND). For the posterior nucleus and for the posterior annulus, entry points were 50°-70° and 70°-85° medially respectively and both require a lateral approach. The sagittal inclination for disc entries was between 3° cephalic to 30° caudally.

Conclusion

The percutaneous transforaminal approach is probably the most common approach for intervertebral disc procedures because of its safety and efficiency. Understanding the entry point and trajectory angles to reach the working area in the disc is imperative for the surgeons for safety and efficacy. The entry point to the L3/L4, L4/L5, and L5/S1 discs are between 30 mm and 60 mm from the midline and 10°-30° medially for the lateral nucleus, 60-85 mm from the midline and 40°-50° medially for the center of nucleus pulposus, 90-180 mm from the midline and 50°-70° medially for posterior nucleus pulposus, and 170-450 mm and 70°-85° medially for posterior annulus fibrosus. The sagittal inclination is from 3° cephalic to 30° caudally.

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Author Contributions: Mohd Imran Yusof-study design, manuscript editing

Azizul Akram Salim-manuscript writing

Joehaimey Johari-manuscript writing

Allan Ravi Rajagopal-data collection and initial draft

Ethical Approval: This study was approved by Universiti Sains Malaysia research and ethics committee (USM/JEPeM/16110415).

Informed Consent: Informed consent was obtained by all participants in this study.

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