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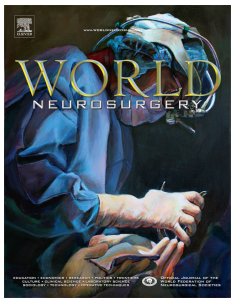

A Novel Approach to Percutaneous Lumbar Surgeries via Kambin's Triangle - A Radiographic and Surgical Planning Analysis with Nerve Segmentation Technology

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A Novel Approach to Percutaneous Lumbar Surgeries via Kambin's Triangle - A Radiographic and Surgical Planning Analysis with Nerve Segmentation Technology

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Short Title: Nerve Segmentation for percLIF Planning

Abstract:

Objective: While Kambin's triangle has become an ever more important anatomic window given its proximity to the exiting nerve root, there have been limited studies examining the effect of disease on the corridor. Our goal was to better understand how pathology can affect Kambin's triangle thereby altering laterality of approach for percutaneous lumbar interbody fusion (percLIF).

Methods: The authors performed a single-center retrospective review of patients evaluated for percLIF. The areas of Kambin's triangle were measured without and with nerve segmentation. For the latter, the lumbosacral nerve roots on 3D T2 MRI were manually segmented. Next, the borders of Kambin's triangle were delineated ensuring no overlap between the area and the nerve above.

Results: 15 patients (67.5 ± 9.7 years, 46.7% female) were retrospectively reviewed. 150 Kambin's triangles were measured. The mean areas from L1-S1 were 50.0 ± 12.3 mm2, 73.8 ± 12.5 mm2, 83.8 ± 12.2 mm2, 88.5 ± 19.0 mm2, and 116 ± 29.3 mm2, respectively. When pathology was present, the areas significantly decreased at L4-L5 ($p = 0.046$) and L5-S1 ($p = 0.049$). Higher spondylolisthesis and smaller posterior disc heights were linked with decreased areas via linear regression analysis ($p < 0.05$). When nerve segmentation was used, the areas were significantly smaller from L1-L5 ($p < 0.05$). Among 11 patients who underwent surgery, none suffered from postoperative neuropathies.

Conclusion: These results illustrate the feasibility of pre-operatively segmenting lumbosacral nerves and measuring Kambin's triangle to help guide surgical planning and determine the ideal laterality of approach for percLIF.

Introduction:

A procedure that has continued to gain traction for the treatment of degenerative spondylolisthesis or disc disease is the percutaneous lumbar interbody fusion (percLIF) through Kambin's triangle.[1,2] Kambin's triangle is an anatomical corridor that provides safe access to the disc space.[3-5] Currently, the triangle is defined as the exiting nerve root (ENR), superior endplate of the caudal vertebral body, and superior articulating process. However, there is still significant variation regarding the dimensions, angles of entry, and borders of Kambin's triangle.[6,7]

The importance of quantifying the size of Kambin's triangle is crucial since minimally invasive surgeries (MIS) have been linked with higher rates of nerve root injuries compared with conventional open surgery.[8] ENR injuries are the most common complication of the percLIF with rates as high as 20% having been reported in the literature.[8] A recent systematic review highlighted that at a pathologic level, there may be a significant decrease in the area of Kambin's triangle compared to healthy levels.[9] Thus, there is an ever-present risk for injury to the ENR, theca, and the dorsal root ganglion (DRG) during disc entry and endplate preparation.

Previous methods for the percLIF have relied heavily on fluoroscopy, computed tomography (CT) imaging, and triggered nerve stimulation. However, there remains no well-established strategies to plan a three-dimensional (3D) trajectory into the disc with knowledge of where the important neural structures are. Although still in its early technological stages, segmentation software was used in this small cohort study in an attempt to address these shortcomings with a novel technique of merging preoperatively segmented magnetic resonance imaging (MRI) with an intraoperative CT. This study's goals were 1) to better understand the dimensional trends in Kambin's triangle, 2) understand how segmentation of the ENR affects the area, 3) identify how pathologies can affect its area, and 4) illustrate the importance of

preoperatively visualizing the triangle in 3D to determine the ideal laterality of disc space entrance.

Materials and Methods

Study Design

The authors performed a single-center retrospective review of patients being evaluated for percLIF at a major academic research institution. From August 2021 - March 2023, patients were included according to the established indications for percLIF in the literature. Informed consent was obtained before every procedure. Patient permission to publish deidentified data was not necessary, as this study fell under the university's IRB's guidelines for "exempt" patient research. Data was collected via electronic health record review. Spondylolisthesis, anterior disc height (ADH), and posterior disc height (PDH) were measured using pre-operative radiographs.

Kambin's Triangle without ENR Segmentation

3D isotropic T2-weighted MRI sequences acquired at 1-mm slice thickness were used during the preoperative planning phase (Figure 1). The *Align* feature in BrainLab (BrainLab, Munich, Germany) was used to orient the images (coronal, axial, and sagittal) in the direction that maximized the cross-sectional area of Kambin's triangle. The triangle was then outlined using *Smartbrush* without the aid of the ENR (Figure 2). A board-certified neuroradiologist confirmed each segmentation. We used an approximation of the largest triangle that contained every part of the outlined space and calculated the area using the formula: 0.5 x base x height.

Kambin's Triangle with ENR Segmentation

In contrast to the prior method, individual ENRs were identified first in the axial and then sagittal plane with *Smartbrush* completing segmentation based on a region-growing algorithm (Figure 3). Each ENR was 'drawn out' bilaterally starting from where it exited the spinal cord to as far lateral as possible. Once the nerves were visualized, the *Align* feature was again used to orient the images to maximize the cross-sectional area of Kambin's triangle (Figure 4). Since the ENR had already been segmented, it helped ensure that we were not overlapping Kambin's triangle with any part of the nerve. To measure area, we used the same triangle approximation and formula stated above (Figure 5). BrainLab then generated a 3D representation of the structures to visualize spatial proximity (Figure 6).

Operative Management

We have recently reported the perioperative outcomes of our first 5 patients.[10] Every patient had free running electromyography (EMG), which was monitored via electrodes placed in selected muscles of the bilateral lower extremities. Pedicle screws were placed at the proper levels using instrument-tracking previously described by our group (Figure 7).[11,12] A percutaneous patient reference array was then placed in the patient's posterior superior iliac crest (PSIS) using two 4 mm Schanz screws. An intraoperative CT (AIRO, Kalamazoo, Michigan) was then merged with the preoperative segmented MRI, with the help of a vendor representative from BrainLab. The CT scan, depending on the operative level, was done to include all five lumbar levels as well as portions of the sacrum to increase the accuracy of the fusion. A region of interest (ROI) was selected at the operative level, and the elastic fusion was centered around the accuracy of overlap in the ROI (Figure 8). This process focused the fusion on the most surgically-relevant level, given that the remaining vertebrae may have shifted due to the altering

in patient positioning from the supine preoperative MRI to the prone intraoperative CT. Having said this, all levels were lined up as accurately as possible during the elastic fusion process. Safe trajectories entering the disc space at the mid-pedicle point on coronal imaging were then planned (Figure 9). Based on the preoperative measurements of Kambin's triangle and the planned trajectory, an incision approximately 6 cm lateral of the midline was made based on which side had the larger triangle. A stimulating dilator (Spineology, St. Paul, MN) was then used to pierce into the annulus of the desired disc using the preplanned trajectory and BrainLab navigation (Figure 7). As long as no compound muscle action potentials in the lower extremities were recorded during activation of a threshold of 4 mA, it was felt that a 'safe' trajectory was used.[13,14] After appropriate discectomy, the ELITE expandable titanium cage (Spineology, St. Paul, MN) was placed and expanded. Bilateral rods connected the screws for fusion (Figure 7).

Statistical Analysis

For all continuous variables, a two sample t-test was conducted where $p < 0.05$ was considered statistically significant. For linear regressions, analysis was done with the built-in Excel® (Redmond, Washington) data analysis tool pack using an ANOVA model.

Results

Trends in Kambin's triangle with and without nerve segmentation

Fifteen patients (67.5 ± 9.7 years, 46.7% female, BMI 29.3 ± 5.22 kg/m^2) were included. In total, 150 Kambin's triangles were individually segmented and measured using the triangle approximation method. The mean areas at L1-L2, L2-L3, L3-L4, and L5-S1 were 50.0 ± 12.3 mm^2, 73.8 ± 12.5 mm^2, 83.8 ± 12.2 mm^2, 88.5 ± 19.0 mm^2, and 116 ± 29.3 mm^2, respectively

(Table 1). The data was uniformly distributed at each level. The dimensional trend of the area followed a linear regression model (p = 0.007, R^2 = 0.94) revealing a significant increase in size going down the lumbar spine. Upon comparing the two different approaches, the calculated areas of Kambin's triangle were significantly smaller from L1-L5 ($p < 0.05$), but not at L5-S1 (p = 0.29) when the triangle was outlined with the aid of the ENR segmentation (Figure 10).

Pathology can significantly reduce Kambin's triangle

The most common pathology was Grade 1 spondylolisthesis (80%), followed by foraminal stenosis (46.7%), and then Grade 2 spondylolisthesis (13.3%) (Table 2). When any of these pathologies were present, the area of Kambin's triangle significantly decreased at L4-L5 (p = 0.046) and L5-S1 (p = 0.049). (Table 3). At these pathologic operative levels, there was also a significant difference in sizes between the smaller and larger Kambin's triangle at the L4-L5 level. Among the 12 patients who had pathology at the L4-L5 level, the mean area for the smaller Kambin's triangle was 76.2 ± 14.5 mm^2 while the mean of the larger Kambin's triangle was 93.9 ± 15.9 mm^2, which was significantly larger (p = 0.0091) (Table 4). One patient had a conjoined nerve root of the right L5-S1 nerve (Figure 11). When comparing the right and left triangles at that level, the presence of the conjoined nerve root drastically reduced the area of Kambin's triangle by 46.4 mm^2 (38.3%).

Next, when plotting the radiographic variables against the area of Kambin's triangle, linear regression analysis revealed two key findings: 1) Higher values for spondylolisthesis were significantly associated with smaller areas of Kambin's triangle across all lumber levels (R^2 = 0.095, p = 0.0083); 2) lower measurements of PDH were also associated with smaller areas of the triangle (R^2 = 0.063, p = 0.033). ADH did not show any association with the area.

Peri- and Postoperative data

In terms of perioperative data, 11 (73.3%) patients from the total cohort have undergone their planned surgery at this point in time.[10] Among them, the most commonly operated on level was L4-L5 (81.8%). Only two patients underwent a multilevel fusion from L4-S1. 6 (54.5%) patients underwent 'awake' surgery while the remaining had general anesthesia. The mean estimated blood loss was 57.7 ± 47.8 mL, the median operative time was 174 minutes with a range of 140 – 210 minutes, and the mean length of stay in the hospital was 28.2 ± 11.2 hours. There were no intraoperative or postoperative complications noted for any of the cohort. None of the patients suffered from motor or sensory deficits at a mean postoperative follow-up of 8.90 ± 4.94 months (Table 5).

Discussion

An ENR can be injured in two main ways: (1) during blind manipulation while inserting a k-wire, obturator, or cannula, or (2) from excessive pressure exerted by the instruments. Morgenstern and Morgenstern reported a 32% postoperative complication rate consisting of ipsilateral dysesthesias and transitory muscle weakness following trans-Kambin procedures.[15] Similarly, studies have shown that postoperative dysesthesia should be expected in one-fifth of patients following transforaminal endoscopic decompression, which was attributed to DRG irritation.[16] More recent work has shown a decrease in the overall complication rate following percutaneous surgeries, but Choi et al. reported that the rate of ENR injury increased by 23% for each 1-mm decrease in distance from the nerve root to the facet joint of the lower level.[17,18] Of note, these previous studies that report ENR injury either did not measure the area

of Kambin's triangle preoperatively or measured it retrospectively after the operation. In order to reduce the prevalence of these injuries, our approach uses manual nerve root segmentation to both preoperatively measure Kambin's triangle and plan a safe path into the disc space.

MRI/CT fusion is the future of surgical planning

Over the last several years, researchers have begun testing the limits of MRI and CT 3D segmentation technology in both a manual and automated setting, the latter facilitated by advances in machine learning.[19] Although there has not been a comparable study in the literature that has measured all the lumbar levels using CT, Fan et al. used a CT deep-learning model specifically for the L5-S1 level.[20] Their mean area was ~150 mm^2, which was much larger than our mean area of 116 mm^2 for the same level. This lack of adequate ENR visualization on CT may result in an overestimation of the triangle's area thereby giving surgeons a false sense of security when entering the disc space. We attempted to test this hypothesis by performing our analysis of the triangle's area with and without ENR segmentation. As expected, when trying to locate the largest area for Kambin's triangle without the aid of the segmented nerve root acting as the hypotenuse, it is much more difficult to accurately pinpoint the appropriate borders when outlining the corridor. Especially when viewed in only two dimensions, it is challenging to ensure that the estimated area of the triangle does not overlap by more distal portions of the ENR as it traverses away from the spine. Although the surgical implications of this difference have not been studied, it is reasonable to speculate that using either CT or MRI scans without prior ENR segmentation may lead to an overestimation of the safe zone. This may thereby affect the dimensions of cannulas that can be safely used intraoperatively. Given the small cohort in this

work, these preliminary conclusions will need further testing using large scale prospective studies.

As a result, research have begun shifting more towards MRI segmentation.[21] Pairaiturkar et al. used 3D MRI of Kambin's safe zone to find the maximum cannula diameter permissible for safe percutaneous endoscopic lumbar discectomy.[17] Although they did not directly calculate the areas of each triangle, their results paralleled ours. Mainly, they showed that the distance from the ENR to the facet joint increased going down the lumbar spine, further corroborating our data. Consequently, they concluded that the maximum diameter of an endoscopic cannula permissible through Kambin's triangle was highest at L5-S1 (6.11 mm) with the smallest diameter being at L1-L2 (4.03 mm). While they also measured both the right and left triangles, they did not mention any significant differences between the sides of entry or mention how pathology could affect the diameters.[17]

Presence of pathology can decrease Kambin's Triangle

Many of these prior works examining the efficacy of 3D segmentation concentrated on intact anatomy of Kambin's triangle, but there has yet to be a dedicated study examining the effect of disease on the dimensions of the triangle. We found that Kambin's triangle at a pathological level was significantly smaller than non-pathological levels, indicating that the presence of disease or degeneration could play a key factor in the variability of the area and should be taken into account during pre-operative planning. Specifically, there was a 23.3 mm^2 difference in average area between the diseased and healthy levels of L5-S1. This may be the explanation as to why some researchers have discouraged the percutaneous entrance into L5-S1 without foraminoplasty.[22,23] Our findings align appropriately with prior research done by Waguia

Kouam et al., who revealed similar trends in both the overall area and potential changes at the operative levels in their meta-analysis.[5] We took the analysis one step further by comparing the left and right Kambin's triangle at these diseased levels to determine if there was a significant difference between sides. At the L4-L5 level, which was the most commonly diseased, there was a 17.8 mm^2 (20.9%) difference between sides. This significant increase in area allowed the surgical team to preoperatively pick the laterality of approach that maximized the working zone they had to enter the disc space, thereby reducing the chance of ENR and DRG irritation. Hirayama et al. performed a similar analysis to determine the optimal angle of entry, but they did not speak on identifying the laterality of approach for an individual patient.[24]

Given that there is no current literature researching the possible association between radiographic variables and Kambin's triangle, we recorded spondylolisthesis, ADH, and PDH, which are all common factors measured during the pre-operative workup for patients. Our results illustrated a potential link between higher values for spondylolisthesis and lower values for PDH with smaller areas of Kambin's triangle. Anatomically, this association makes sense since the disc height is inherently built in as part of the medial border of Kambin's triangle. However, the effect of spondylolisthesis requires further investigation with larger cohorts, especially given that it was the most common pathology present among lumbar surgeries in general.[25,26]

Not only is there variability when pathology is present, but congenital malformations of the surrounding bony and neurovascular structures may increase the need for more accurate preoperative segmentation.[27] As illustrated in Figure 11, the presence of the conjoined nerve root significantly reduced the safe zone of Kambin's triangle by almost 50 mm^2. Haijiao et al. found a 17% incidence of nerve root anomalies out of 376 lumbar MRI scans, whereas prior studies relied mainly on CT scans, which only caught 2% of the conjoined roots.[28,29] Accordingly, there

would have been a risk of overlooking this anomaly if only CT imaging was used, thereby increasing the risk for ENR damage.

Limitations

This study had several limitations. First and foremost, the sample size was small, so making general conclusions about our work would require studies with larger cohorts. Likewise, the retrospective nature of the study brings inherent bias for both the data analysis and generalizability of our findings. The main reason for the small number of patients is the relative novelty of using this technique at our institution. To counterbalance this, all the lumbar levels for each patient were segmented bilaterally, which increased the number of total analyzed levels to 150 for heightened statistical power. This study aims to show the feasibility of implementing this nerve segmentation technology effectively in the operating room. Given that there have been no prior studies examining this topic, we believe that this work can be a stepping stone for future prospective studies looking at the correlation between segmentation, pathology, and the safe area of the triangle.

Second, although a board-certified neuroradiologist confirmed each of the segmentations, there is still inherent bias when segmenting the areas. It is also possible that patient positioning may impact the location of the ENR. It would be interesting to analyze the effects of patient positioning on Kambin's triangle, but this would require an intraoperative MRI prior to instrumentation placement. Third, we are limited by the length of follow-up for these patients, given that this technique was only recently adopted at our institution. In terms of operative time, these procedures did fall on the higher end of average when compared to their open and MIS single-level fusion counterparts, which have been estimated to last between 120 – 180 minutes.[30]

We hypothesize that with further experience and more cases performed, operative times will decrease as surgeons climb the learning curve.

Conclusion

In this small retrospective cohort study, we created 3D images by manually segmenting lumbar ENR from preoperative MRI using commercially available software and merging them with intraoperative CT images. The 3D images allowed us to preoperatively measure the area of Kambin's triangle without overlapping with the ENR, determine the ideal laterality of approach to maximize the safe zone, and plan a trajectory for percutaneous spinal surgery. We found that although there is a linear increase in the area going down the lumbar spine, the presence of pathology and using the preemptive nerve segmentation technique can significantly reduce the area of Kambin's triangle. Further prospective studies will be needed to corroborate our preliminary findings on a larger, more widespread scale.

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Figure Legends

Figure 1. 3D isotropic T2-weighted MRI. Sagittal (left) and axial (right) sequences were acquired at 1-mm slice thickness revealing a disc herniation at the L4-L5 level.

Figure 2. Kambin's Triangle (purple) was outlined using *Smartbrush* without the aid of the ENR acting as a boundary. We used the approximation of the largest triangle that contained every part of the outlined space (yellow outline) and calculated the area using the formula: 0.5 x base x height.

Figure 3. Individual ENRs (pink) were identified first in the axial (upper) and then sagittal (lower) plane with *Smartbrush* completing segmentation based on a region-growing algorithm. Each ENR was segmented bilaterally starting from where it exited the spinal cord to as far lateral as possible.

Figure 4. After the nerves were visualized, the *Align* feature was again used to orient the images in the direction that maximized the cross-sectional area of Kambin's triangle.

Figure 5. Kambin's triangle (orange) was segmented using its known anatomical boundaries. Since the ENR (blue) had already been segmented, it helped ensure that we were not overlapping Kambin's triangle with any part of the nerve. As before, we used an approximation of the largest triangle that contained every part of the outlined space (yellow outline) and calculated area using the formula: 0.5 x base x height.

Figure 6. 3D-generated representation of all the nerves and triangles to visualize spatial proximity for each lumbar level.

Figure 7. Intraoperative fluoroscopy images confirming accurate placement of instrumentation. A, Pedicle screws were placed bilaterally at the proper levels using instrument-tracking. B, A stimulating dilator (Spineology, St. Paul, MN) was then used to pierce through fascia and into the annulus of the desired disc using the preplanned trajectory and BrainLab navigation. C, An 8 mm portal was placed along the same trajectory through Kambin's Triangle. D, The verify balloon with omnipaque was done to ensure adequate discectomy. E, The cage was placed into the disc space and expanded to 13 mm. F, Bilateral rods were used to connect the screws.

Figure 8. MRI and CT elastic fusion done intraoperatively. A, the *Spy Glass* method was done to help with the alignment of the vertebrae within the range of interest (dotted white box). B, The *Blending* feature was used for further confirmation of an accurate image fusion.

Figure 9. Intraoperative CT with pre-operatively segmenting objects. The ENR (orange outline) and Kambin's Triangle (green outline) at the operative level were transferred over to the CT scan once image fusion was completed. This allowed for trajectory planning, illustrated by the screw in the top left panel.

Figure 10. Scatter line plots for both measurement techniques depicting an increase in Kambin's triangle area going down the lumbar spine, but with smaller areas when using ENR segmentation.

Figure 11. Segmentation images for the patient with a right conjoined L5-S1 nerve root. The unconjoined side (left) revealed a triangle (highlighted purple) with an area of 121 mm^2, as it was not inhibited by the lower S1 nerve root (orange). The conjoined side (right) revealed a

triangle (highlighted pink) with an area of 74.6 mm^2, as it was inhibited by both the lower S1 nerve root (green) and the superior L5 nerve (blue).

Table 1. Areas of Kambin's Triangle with Nerve Segmentation

Levels:	Average Area (mm^2)	SD	Median	IQR
L1-L2	50.0	12.3	51.6	15.3
L2-L3	73.8	12.5	74.0	13.4
L3-L4	83.8	12.2	87.3	13.9
L4-L5	88.5	19.0	88.7	27.3
L5-S1	116	29.3	112	44.0

Table 2. Demographic and Pathologic Data

Patient #	Age	BMI	Sex	# of Pathological Levels	Type of Pathology Present
1	76	31.6	F	2	Grade 1 Spondy and Foraminal Stenosis
2	68	21.6	F	1	Grade 1 Spondy and Foraminal Stenosis
3	61	29.7	M	1	Grade 1 Spondy and Foraminal Stenosis
4	67	23.6	F	1	Grade 1 Spondy
5	85	27.8	M	1	Grade 1 Spondy and Foraminal Stenosis
6	55	36.2	F	1	Grade 2 Spondy
7	65	31.8	M	1	Grade 1 Spondy and Canal Stenosis
8	73	33.8	M	1	Grade 1 Spondy
9	53	20.1	M	1	Grade 1 Spondy and Foraminal Stenosis
10	69	25.4	M	1	Grade 1 Spondy and Canal Stenosis
11	77	31.6	F	2	Grade 1 Spondy and Facet Cysts
12	52	28.5	M	2	Disc Protrusion and Conjoined Nerve Root
13	65	26.86	F	2	Grade 2 Spondy
14	66	38.74	F	1	Grade 1 Spondy and Foraminal Stenosis
15	80	31.87	M	2	Grade 1 Spondy and Foraminal Stenosis
Mean	67.2	28.2	-	-	-
SD	9.58	5.38	-	-	-

Table 3. Comparing the areas of Kambin's Triangle at pathologic vs. non-pathologic levels

Levels	Mean Pathological Area (mm^2)	Mean Non-Pathological Area (mm^2)	P values
L3-L4	82.4 ± 10.7	84.2 ± 12.7	0.75
L4-L5	85.0 ± 17.4	102 ± 20.2	0.046*
L5-S1	99.7 ± 34.6	122 ± 24.7	0.049*

*Significance was determined if p-value < 0.05

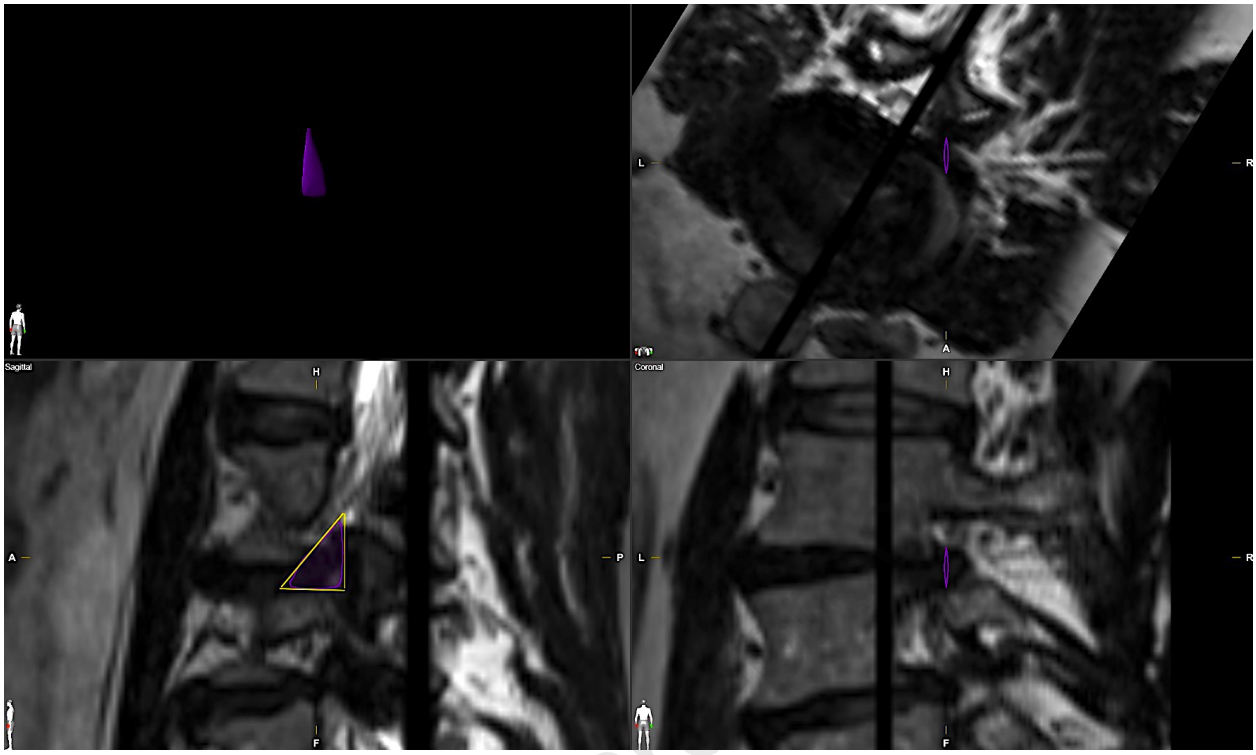
Table 4. Comparing the smaller and larger Kambin's Triangle at pathologic levels

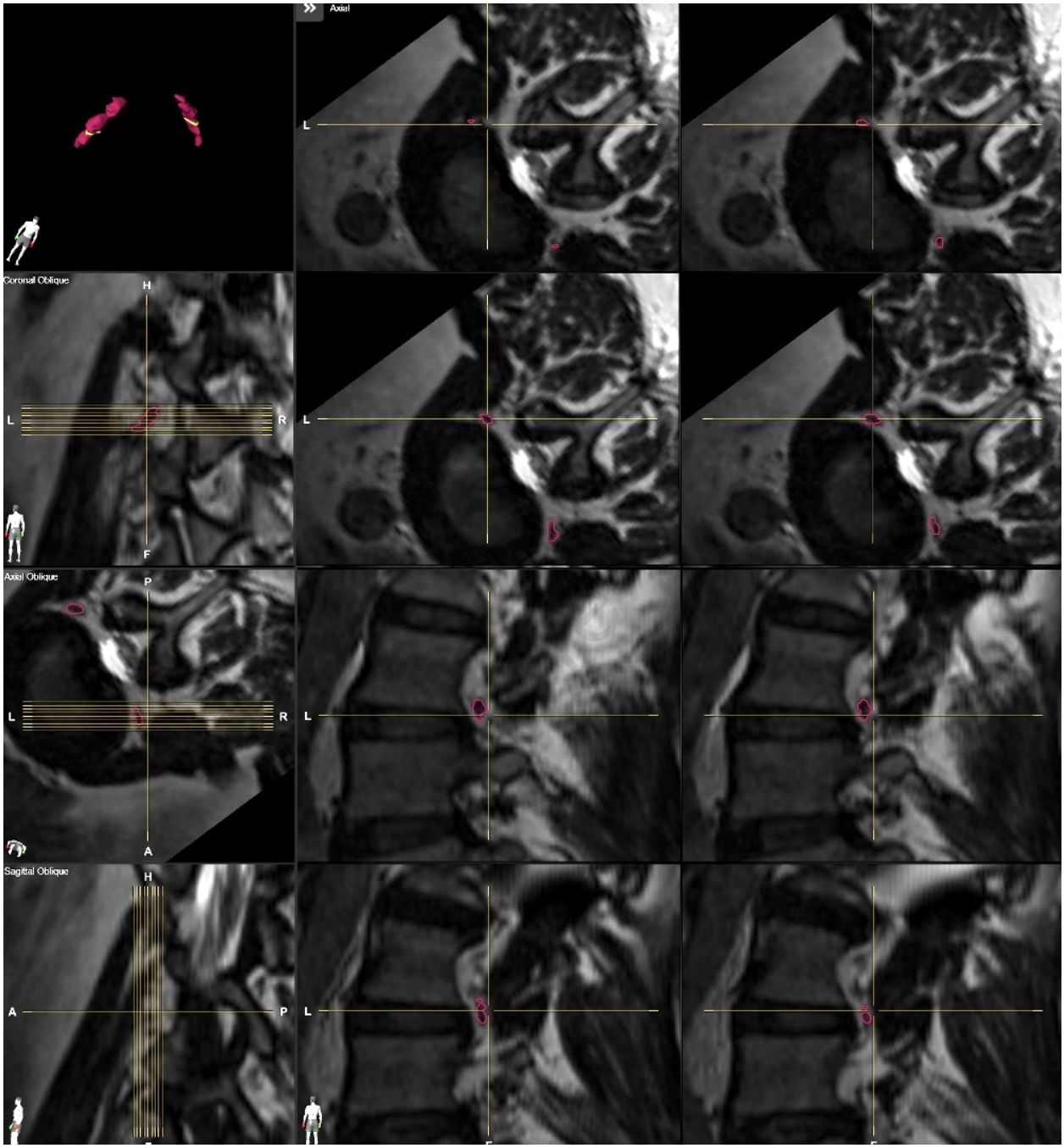
Levels	Laterality	Mean Pathologic Area (mm^2)	P Values
L3-L4	Small Side	79.6 ± 8.7	0.58
	Large Side	85.2 ± 13.7	
L4-L5	Small Side	76.2 ± 14.5	0.0091*
	Large Side	93.9 ± 15.9	
L5-S1	Small Side	85.1 ± 30.8	0.26
	Large Side	114 ± 35.8	

*Significance was determined if p-value < 0.05

Table 5. Peri and Postoperative Data

Patient #	Anesthesia Type	LOS (hours)	Blood Loss (ml)	Operative Time (mins)	Months to Follow-Up
1	Awake	12	50	180	16.5
2	General	24	10	183	1.9
3	Awake	14	25	160	13.3
4	Awake	14	50	140	12.5
5	Awake	34	25	184	14.6
6	General	33	50	182	8.2
7	Awake	27	50	193	9.9
8	General	48	150	210	6.7
9	General	35	25	150	5.8
10	Awake	36	50	147	7.3
11	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA
13	General	33	150	193	1.5
14	NA	NA	NA	NA	NA
15	NA	NA	NA	NA	NA
Mean	-	28.2	57.7	174	8.9
SD	-	11.2	47.8	22.2	4.9

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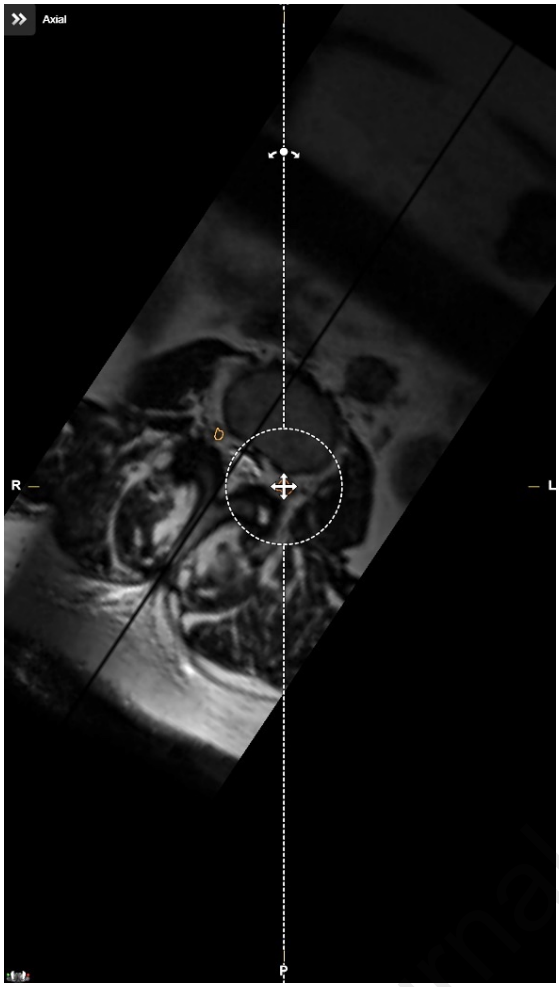

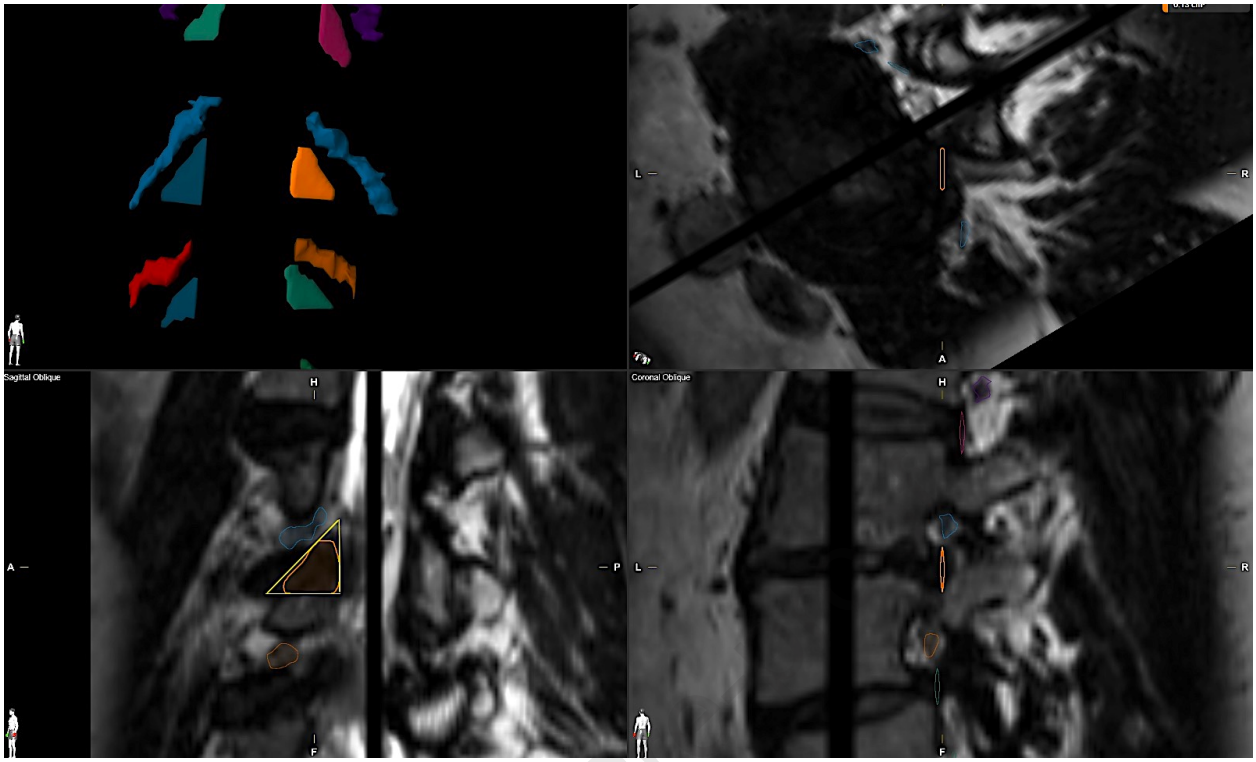

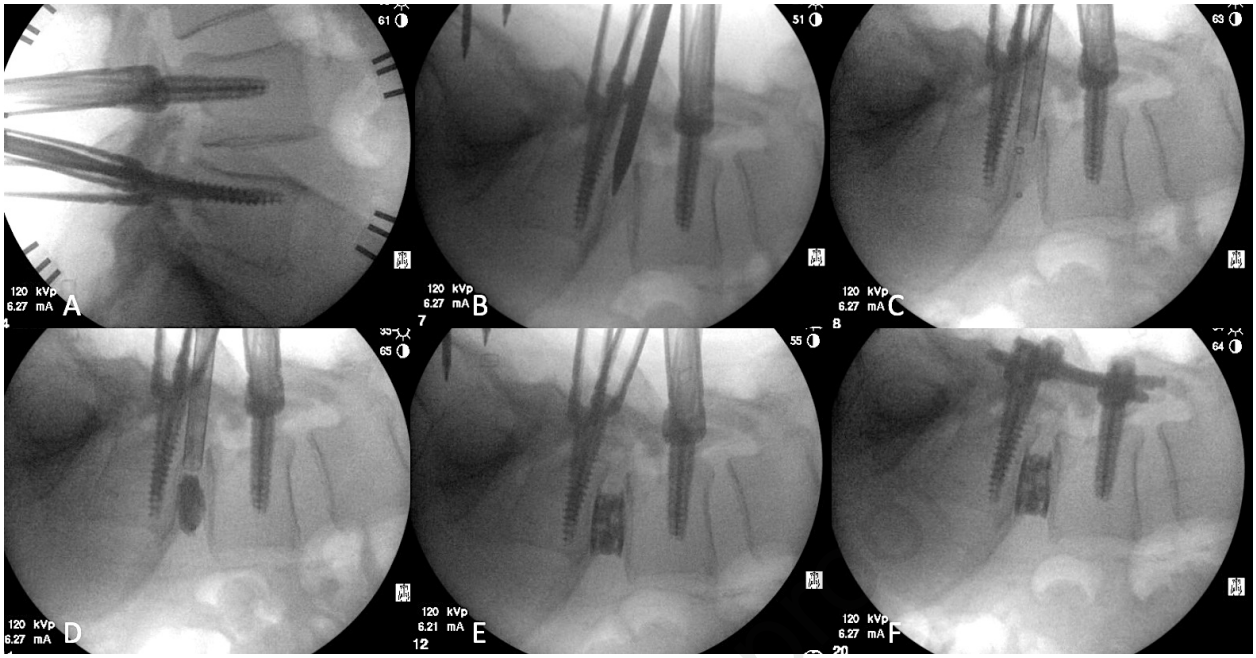

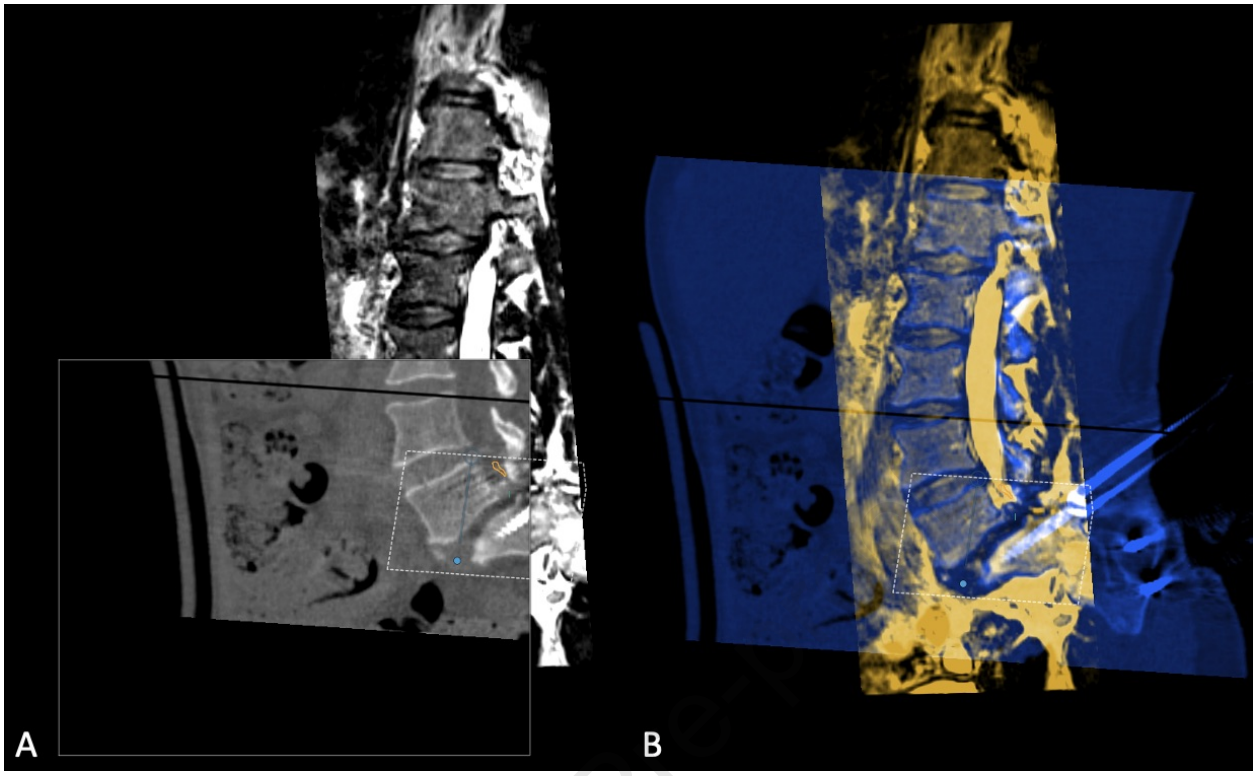

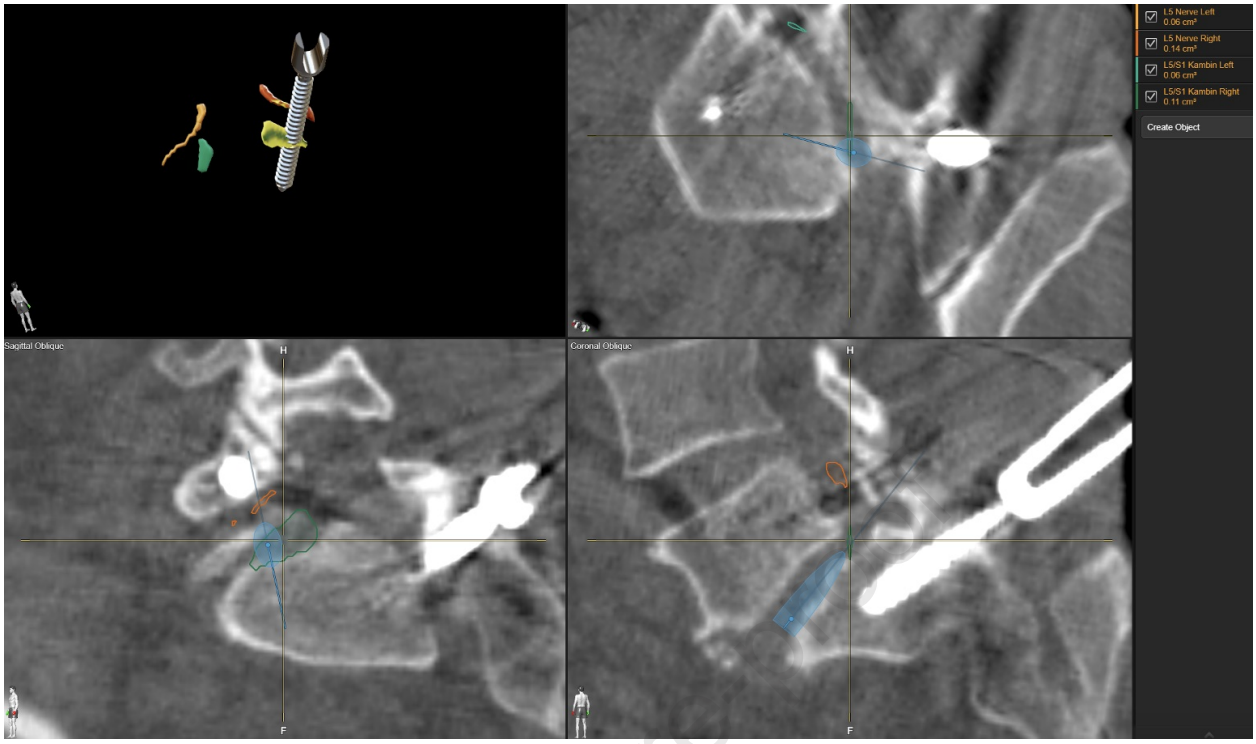

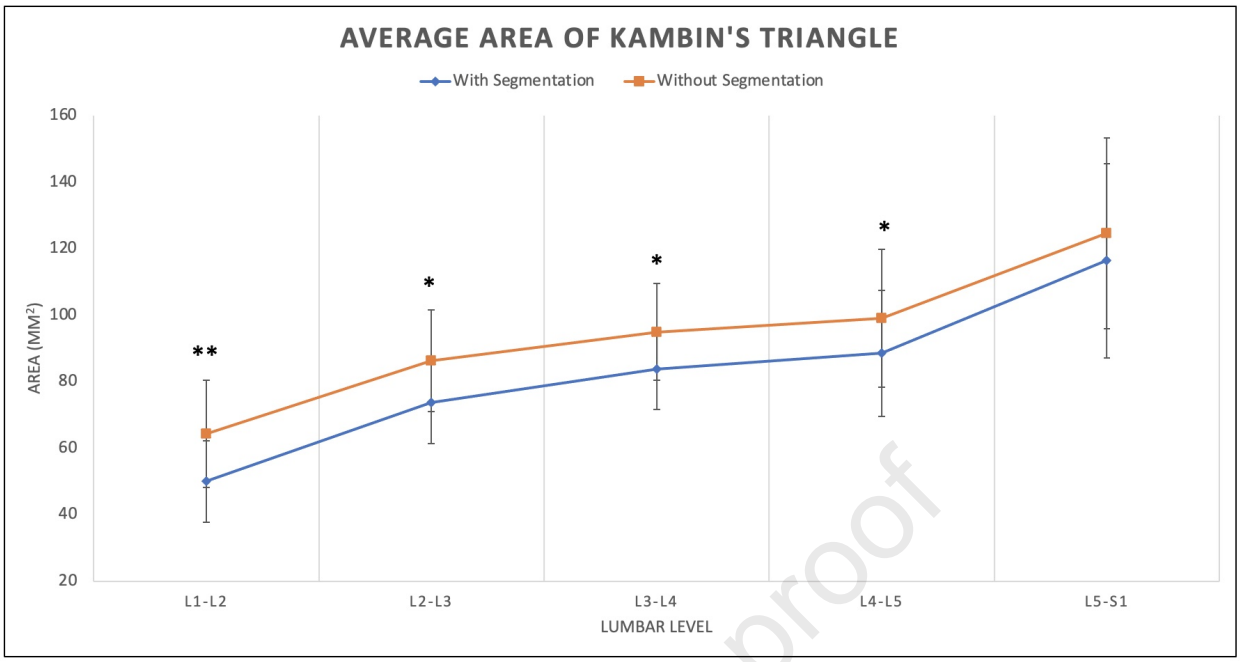

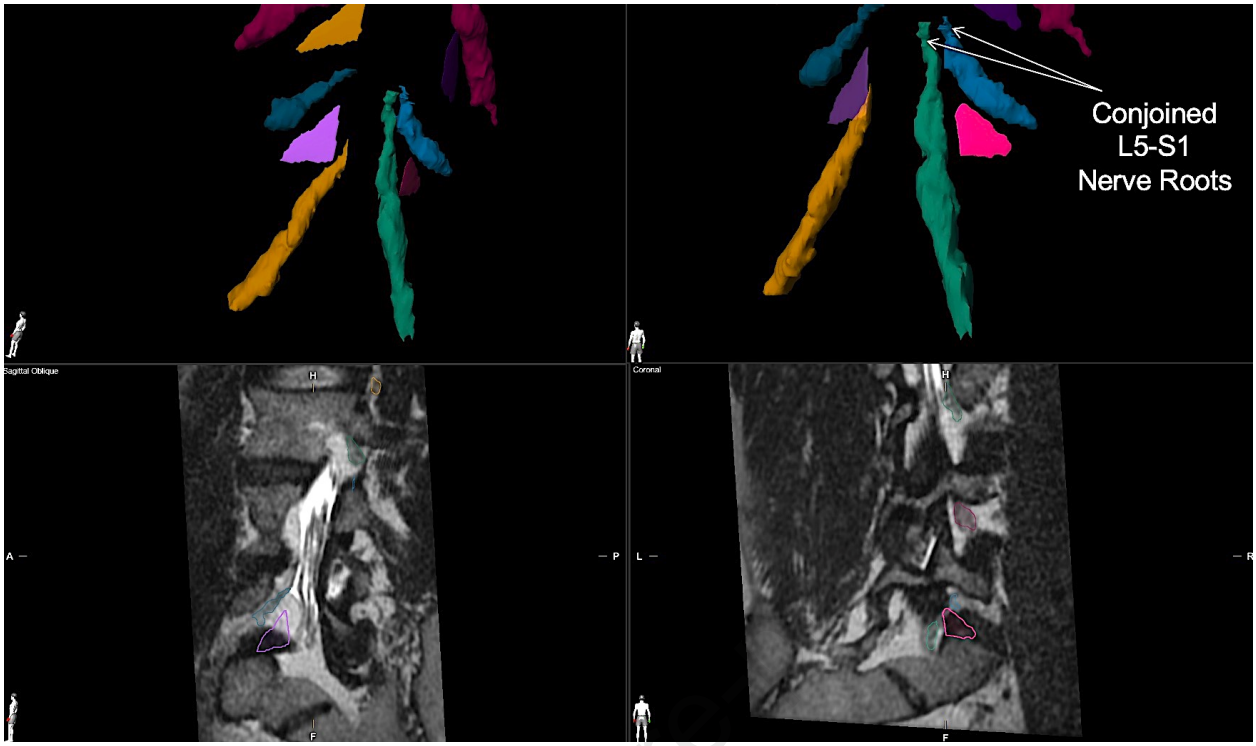

Abbreviations: percutaneous lumbar interbody fusion (percLIF), minimally invasive surgeries (MIS), exiting nerve root (ENR), computed tomography (CT), three-dimensional (3D), magnetic resonance imaging (MRI), electromyography (EMG), dorsal root ganglion (DRG), anterior disc height (ADH), posterior disc height (PDH)

Disclosures

Muhammad M. Abd-El-Barr is a consultant for Depuy Synthes, TrackX, and Spineology.

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