SCIENTIFIC ARTICLE

Effect of Percutaneous Endoscopic Lumbar Foraminoplasty of Different Facet Joint Portions on Lumbar Biomechanics: A Finite Element Analysis

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Objective: To evaluate the influence of percutaneous endoscopic lumbar foraminoplasty of different facet joint portions on segmental range of motion (ROM) and intradiscal pressure (IDP) of L_3/L_4 and L_4/L_5 motion segments by establishing three dimensional finite element (FE) model.

Method: Computed tomography images of a male adult volunteer of appropriate age and in good condition both mentally and physically. Obtained data was used in this study from July 2020 to December 2020, and an intact L_{3-5} three dimensional finite element model was successfully constructed using ANSYS and MIMICS software (model M1). The M1 was modified to simulate the foraminoplasty of different facet joint portions, with unilateral cylindrical excision (diameter = 0.75 cm) performed on the tip (model M2) and the base (model M3) of right L_5 superior facet elements along with surrounding capsular ligaments, respectively. Under the same loading conditions, the ROM and IDP of $L_3/_4$ and L_4/L_5 segments in states of forward flexion, backward extension, left lateral bending, right lateral bending, left axial rotation and right axial rotation were all compared.

Result: Compared with the intact model in backward extension, M2 increased the ROM of $L_{4/5}$ segment by 9.4% and IDP by 11.7%, while the ROM and IDP of M3 changed only slightly. In right axial rotation, M2 and M3 increased the ROM of $L_{4/5}$ segment by 17.9% and by 3.6%, respectively. In left axial rotation, M2 and M3 increased the ROM of L_4/L_5 segment by 7.14% and 3.6%, respectively. As for other states including forward flexion, left lateral bending, right lateral bending, the ROM and IDP were not significantly distinct between these two models. While focusing on L_3/L_4 segment, obviously changes in the ROM and IDP have not been presented and neither M2 nor M3 changed in any loading condition.

Conclusion: This study provides evidence that the base-facet foraminoplasty of L_5 superior facet provided a higher segmental stability compared with the tip-facet foraminoplasty in flexion and axial rotation. Meanwhile, it also shows the two types of foraminoplasty make few differences to the $L_{4/5}$ segmental biomechanics. Besides, it does not appear to impact the stability of L_3/L_4 in six states of forward flexion, backward extension, left lateral bending, right lateral bending, left axial rotation and right axial rotation when superior facet of L_5 was partially removed. These findings might be useful in understanding biomechanics of the lumbar spine after foraminoplasty performed on different portions of the facet, thus providing endoscopic surgeons a better reference for operational approach to maintain the function and mobility of the spine.

Key words: Biomechanics; Foraminoplasty; Lumbar percutaneous endoscopy; Three-dimensional finite element

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Introduction

Symptomatic lumbar disc herniation is a common etiology for spine surgery. Although open microdiscetomy is considered to be the gold standard method, the need for minimally invasive techniques and the improvements in the use of optics and surgical instruments have led to the utilization of percutaneous endoscopic transforaminal discectomy (PETD)[1]. Since the introduction of the concept of percutaneous posterolateral nucleotomy by Hijikata[2], Onik *et al.*[3], and Kambin[4], the technique of PETD has evolved over these years. PETD, by virtue of its transforaminal approach, offers several advantages over traditional open methods like shorter excision length, less blood loss, shorter hospital stay and cost, shorter recovery, lower complication rate, and lower infection rate[5, 6].

As the key surgical procedure of PETD, percutaneous endoscopic foraminoplasty enables direct access to spinal canal with enlargement of foramen by resecting partial superior facet along with ablation of foraminal ligament[7, 8]. Since the introduction of the percutaneous discectomy by Kambin[4], transforaminal percutaneous endoscopic lumbar discectomy (PELD) has evolved over the years and is increasingly becoming a preferred choice of treatment for the management of lumbar disc herniation. Based on the posterolateral percutaneous lumbar disc decompression, some researchers have also developed percutaneous endoscopic techniques for treatment of various kind of lumbar disc diseases, using bone trephines or an endoscopic drill and side firing Holmium:yttrium-aluminum-garner laser[5]. Knight *et al.*[9] introduced laser foraminoplasty for chronic low back pain and associated sciatica, used a side-firing laser to ablate soft tissues such as foraminal ligaments and osteophytes compressing the exiting nerve root. Schubert and Hoogland[10] reported use of four-grade reamers (3.5 mm, 4.5 mm, 6.5 mm, and 7.5 mm) for expanding the foraminal window by removing the ventral portion of superior facet to approach migrated discs. Although most of the practical application of percutaneous endoscopic foraminoplasty has been limited to soft disc herniation, Yong Ahn *et al.*[11] have modified this technique and use for decompression of lumbar foraminal stenosis with a success rate of 81.8%. PETD provides sequential transforaminal passage by different size reamers, and afterwards cannula and endoscope are inserted carefully. According to relative reports on PETD[1,4,10,12], a 7.5-mm reamer is the most commonly used tool in clinic to ream away the superior facet joint and the ligamenta flava for enlargement of foramen.

Although much less anatomic damage was caused by transforminal approach when compared with traditional open methods, facet joints are partially removed to enlarge the stenotic foramen. However, an unfortunate but unavoidable downside to resecting anatomical structures of the spine is an altered load-bearing and motion environment. Many authors have reported on the biomechanical behavior of the spine after resecting partial facet using *in vitro* experimental studies. Abumi *et al.*[13] reported that only unilateral resection of total facet made the spine unstable, while removing supraspinous/interspinous ligaments or medial facet did not affect the range of motion. Zhou *et al.*[14] performed *in vitro* unilateral graded facetectomy on five cadavers and failed to find any significant negative effects to the lumbar stability until the range of graded facetectomy exceeded 50%. As most specimens are from elderly individuals with variations in bone quality and only motion parameters were calculated in these studies, finite element (FE) analysis, which is an alternative biomechanical model for *in vitro* models, has become a popular method for lumbar biomechanical investigations. Erbulut[15] established FE models of graded facetectomy (total left unilateral medial facetectomy, total bilateral facetectomy, 50% unilateral medial facetectomy, and 75% unilateral medial facetectomy) to evaluate the effect on lumbar ROM. In order to get a more comprehensive biomechanical understanding of the environment in the spine after graded facetectomy, Zeng *et al.*[16] did a further FE study which investigated the biomechanical effect of graded facetectomy on intervertebral ROM, intradiscal pressure, facet joint forces, and maximum von Mises equivalent stresses. However, these studies are based on traditional open microdiscetomy, which usually make more than half resection of facet joint, and only the effect of various resection proportion of facet joints on lumbar biomechanics was investigated. As the influence of different portions of foraminoplasty on the stability of lumbar segment is not widely explored, Yang *et al.*[17] has conducted a clinical trial and compared two groups (156 patients) obtained respective foraminoplasty at the tip and base of superior facet. Although no postoperative instability observed in the surgical spinal unit in the 2-year follow-up, foraminoplasty of the tip facet showed advantages in decreasing the incidence of postoperative neural dysfunction and reducing operation time.

In order to get access to spinal canal, endoscopic surgeons use graded reamers to open and enlarge the foramen by removing partial superior facet. Nevertheless, the facet joint portion where foraminoplasty is performed depends on aspects such as surgeon's experience and disc herniation location. To our knowledge, there are few reports of studies investigating biomechanical behavior of adjacent segments after foraminoplasty performed on different facet portions. In this article, we have simulated the lumbar percutaneous endoscopic surgery and built three models (M1, M2, M3) by FE method, thus analyzing the effect of lumbar percutaneous endoscopic foraminoplasty of different facet joint portions on ROM and IDP of L_4/L_5 and L_3/L_4 level.

Materials and Methods

Applicants Inclusion Criteria

The inclusion criteria are: (i) the age of applicant is between 20 and 60 years old in good health and he has a good spirit and intelligence; and (ii) he obeys the arrangement of the research group, accepts the treatment plan designed by the research group, and signs the informed consent.

TABLE 1 Unit attribute of lumbar L_3–L_5 finite element model

Component	Type	Elements	Nodes
Cortical bone	Solid187	112846	191873
Cancellous bone	Solid187	142718	286745
Cartilage endplate	Solid187	32783	65534
Annulus ground	Solid187	27584	65534
Nucleus pulposus	Solid187	30245	53317
Articular cartilage	Targel170/Contal174	1175	2637
ALL	Link10	24	32
PLL	Link10	20	30
LF	Link10	12	18
ISL	Link10	12	24
SSL	Link10	10	20
TL	Link10	14	28
CL	Link10	18	36

Applicants Exclusion Criteria

The exclusion criteria are: participant suffered from severe spinal degeneration or severe irreversible damage of multiple spinal columns such as spinal tuberculosis and tumor.

Ethics Statement

This study was conducted based on the principle of voluntary participation and was in accordance with the protocols proposed by the committee of our hospital. The patient involved in this study signed written informed consent prior to the study. The participant knew well about the study prior to the experiment and had the capability to complete all plans (Table 1).

Finite Element Model of L_3–L_5

A 30-year-old young male volunteer was selected and examined with radiograph scanning to exclude deformity or disc degeneration in his lumbar spine. The volunteer stood at a height of 175 cm and weighed 68 kg. The scanning was conducted by Siemens Somatom Sensation 64 multi-sliced spiral CT (MSCT), and the patient was posed in the supine position. The scanning table was adjusted to locate the scanning area, with the L_3–L_5 spinal segments being observed with a scanning thickness of 0.625 mm. The CT images were obtained and saved as digital imaging and communications in medicine format. The final two-dimensional images were obtained with effect noise on the CT image, and unnecessary bone area was excluded. Then editing and removal procedures were performed on the images using Minics software. After segmentation, feature extraction, smoothing, the elements and nodes were imported to ANSYS software for remesh and obtained the finite element model of L_3–L_5 (M1). The model is shown in Fig. 1.

The intact model consisted of 63,8146 elements and 34,7461 nodes. In the modeling, the data for the basic geometries of the intervertebral discs were taken from average literature values[18], and all the important spinal components, such as cortical bone, cancellous bone, posterior elements, disc annulus, disc nucleus, and endplate were also appropriately simulated. The anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), intertransverse ligament (TL), ligamenta flava (LF), interspinal ligament (ISL), supraspinal ligament (SSL), and capsular ligament (CL) were integrated according to their anatomical positions and were represented by tension-only spring elements with nonlinear material properties. Furthermore, the four facet joint articulations through L_3 to L_5 were simulated as surface-to-surface contact elements, a thin cartilaginous layer was created for each facet articular surface. The coefficient of friction was set at 0.1. Material properties used in the models are listed in Table 2, the material properties of the various spinal components were derived from a previous study[19].

Model Validation

The intact L_3–L_5 FE model was validated against the results of a previously published study by Shim *et al.*[20]. M1 was validated by the cadaveric studies previously conducted in the laboratory for a 7.5 Nm moment alone in various loading

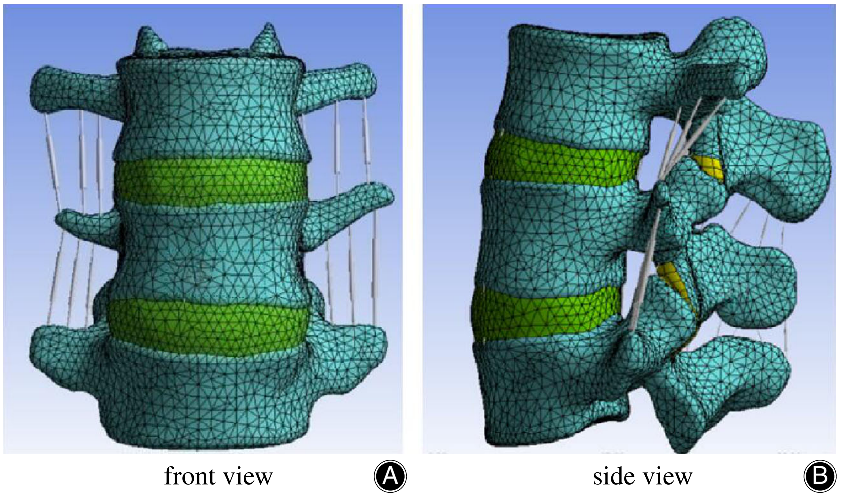

Fig. 1 The finite element model of $L_{3–5}$ (M1) is established by scanning the lumbar of a 30-year-old young male volunteer through Siemens Somatom Sensation64 multi-sliced spiral CT (MSCT) and constructing using ANSYS and MIMICS software.

TABLE 2 Material properties used to represent various components in the model

Component	Young's modulus (MPa)	Passion ratio
Cortical bone	12000	0.3
Cancellous bone	100	0.3
Cartilage endplate	25	0.4
Nucleus pulposus	1	0.49
Annulus ground	4.2	0.45
ALL	7.8	0.30
PLL	10	0.30
LF	15	0.30
TL	10	0.30
CL	7.5	0.30
ISL	10	0.30
SSL	8	0.30

directions, with 400 N compression follower preload. After several adjustments, the ROM of the cadaver biomechanical study and M1 were compared, the ROM of M1 was always within one standard deviation of the results derived from the biomechanical cadaver measurements. Therefore, the M1 was proved to be valid and reliable (Table 3).

FE models with foraminoplasty of different facet joint portions were established

In order to get models with foraminoplasty performed on different facet joint portions, the intact model was modified to simulate M2 and M3 at L_4/L_5 level. This level was chosen due to its higher prevalence in individuals suffering from disc degenerative disease, which is the mostly performed level of transforaminal endoscopic surgery. In order to remove partial facet, surrounding CL had to be removed since they encapsulate the facets. The tip and base portion of the right L5 superior facet were marked as target points, afterwards a cylindrical excision (diameter = 0.75 cm) was made on the tip and base portions separately, which is at an angle of 30° with the coronal plane and horizontal plane, respectively. The three-dimensional FE models and meshed FE models with foraminoplasty performed on different facet joint portions are shown in Fig. 2.

Load Applied and Boundary Conditions

In this research, the inferior surface of the L_5 vertebra remained immobilized throughout the load simulation. The L_3 segment was physiologically loaded with 400 N. Afterward, a bending moment of 7.5 Nm was applied to the L_3 vertebra to recreate extension, flexion, left and right lateral bending, and left and right axial rotation. All loads were chosen according to Shim *et al.*[20].

Results

Range of Motion

The ROM of $L_{4/5}$ was 4.6°, 3.2°, 3.4°, 3.4°, 2.8°, and 2.8° under the six conditions of flexion, extension, left and right bending, and left and right rotation in the M1 (Model 1, The intact L_3–L_5 FE model); the ROM of $L_{4/5}$ was 4.6°, 3.5°, 3.5°, 3.5°, 3.3°, and 3.0° under the six conditions of M2 (Model 2, Three-dimensional FE model after tip foraminoplasty); the ROM of $L_{4/5}$ was 4.6°, 3.2°, 3.4°, 3.4°, 2.9°, 2.9° under the six conditions of M3 (Model 3,Three-dimensional FE model after basement foraminoplasty) (shown in Table 4, Fig. 3).

The ROM of $L_{3/4}$ were 3.9°, 3.3°, 3.5°, 3.5°, 2.7°, and 2.7°, respectively, under the six conditions of flexion, extension, left and right bending, and left and right rotation of M1 (Model 1, The intact L_3–L_5 FE model); the ROM of $L_{3/4}$ were 3.9°, 3.4°, 3.5°, 3.5°, 2.8°, and 2.8°, respectively, under the six conditions of M2 (Model 2, Three-dimensional FE model after tip foraminoplasty); the ROM of $L_{3/4}$ under the six conditions of M3 (Model 3, Three-dimensional FE model after basement foraminoplasty) were 3.9°, 3.4°, 3.5°, 3.5°, 2.8°, 2.8°, respectively (Table 5, Fig. 4).

Intradiscal Pressure

The IDP of $L_{4/5}$ intervertebral disc in the M1 (Model 1, The intact L_3–L_5 FE model) were 0.372 MPa, 0.486 MPa, 0.434 MPa, 0.421 MPa, 0.463 MPa, and 0.463 MPa, respectively, under the six conditions of flexion, extension, left and right bending and left and right rotation; the IDP of $L_{4/5}$ intervertebral disc in the M2 (Model 2, Three-dimensional FE model after tip foraminoplasty) were 0.387 MPa, 0.543 MPa, 0.446 MPa, 0.427 MPa, 0.510 MPa and 0.510 MPa, respectively, under the six conditions; the von Mises stress

TABLE 3 Validation of the finite element model

	Range of motion (mean ± standard deviation)			
	$L_{3/4}$ level		$L_{4/5}$ level	
Working condition	Shim *et al.*[4]	M1	Shim *et al.*[4]	M1
Flexion	4.3 ± 0.8	3.9	5.5 ± 0.9	4.6
Extension	3.0 ± 0.4	3.3	2.8 ± 0.4	3.2
Left lateral bending	3.5 ± 0.7	3.5	4.4 ± 1.0	3.4
Right lateral bending	3.5 ± 0.7	3.5	4.4 ± 1.0	3.4
Left axial bending	2.9 ± 0.6	2.7	3.8 ± 1.0	2.8
Right axial bending	2.9 ± 0.6	2.7	3.8 ± 1.0	2.8

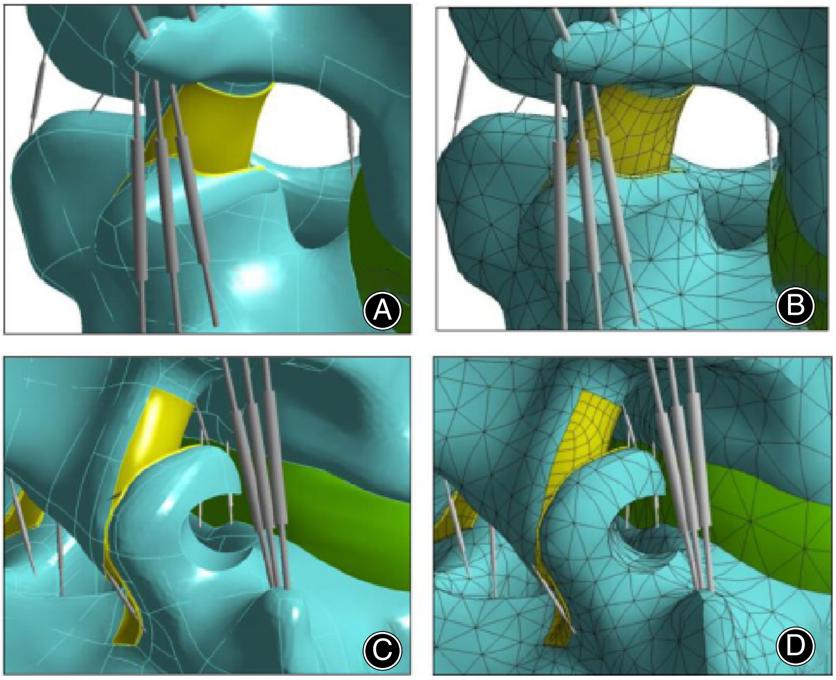

Fig. 2 (A) Three-dimensional FE model after tip foraminoplasty; (B) meshed FE model after tip foraminoplasty; (C) three-dimensional FE model after basement foraminoplasty; (D) meshed FE model after basement foraminoplasty.

extremes of $L_{4/5}$ intervertebral disc in the M3 (Model 3, Three-dimensional FE model after basement foraminoplasty) under six working conditions were 0.375 MPa, 0.492 MPa, 0.442 MPa, 0.426 MPa, 0.487 MPa, and 0.482 MPa (Table 6, Fig. 5).

In the M1 (Model 1, The intact L_3–L_5 FE model), the IDP of $L_{3/4}$ intervertebral disc was 0.365 MPa, 0.474 MPa, 0.435 MPa, 0.424 MPa, 0.456 MPa, and 0.447 MPa under the six conditions of flexion, extension, left and right bending, and left and right rotation, respectively; the IDP of $L_{3/4}$ intervertebral disc under the six conditions of the M2 (Model 2, Three-dimensional FE model after tip foraminoplasty) was 0.369 MPa, 0.479 MPa, 0.439 MPa, 0.428 MPa, 0.462 MPa, and 0.452 MPa, respectively. The IDP of $L_{3/4}$ disc in the M3 (Model 3, Three-dimensional FE model after basement foraminoplasty) under six working conditions are 0.366 MPa, 0.476 MPa, 0.437 MPa, 0.426 MPa, 0.459 MPa, and 0.449 MPa, respectively (Table 7 and Fig. 6).

Discussion

Biomechanical Significance

Compared with traditional open microdiscetomy, PETD, with its advantages of minimal anatomic damage, less facet

TABLE 4 The ROM of $L_{4/5}$ segment after different parts of formation on L_5 facet joint (°)

Model	Condition					
	Flexion	Extension	Left bending	Right bending	Left rotation	Right rotation
M1	4.6	3.2	3.4	3.4	2.8	2.8
M2	4.6	3.5	3.5	3.5	3.3	3.0
M3	4.6	3.2	3.4	3.4	2.9	2.9

TABLE 5 The ROM of $L_{3/4}$ segment after different parts of formation on L_5 facet joint (°)

Model	Condition					
	Flexion	Extension	Left bending	Right bending	Left rotation	Right rotation
M1	3.9	3.3	3.5	3.5	2.7	2.7
M2	3.9	3.4	3.5	3.5	2.8	2.8
M3	3.9	3.4	3.5	3.5	2.8	2.8

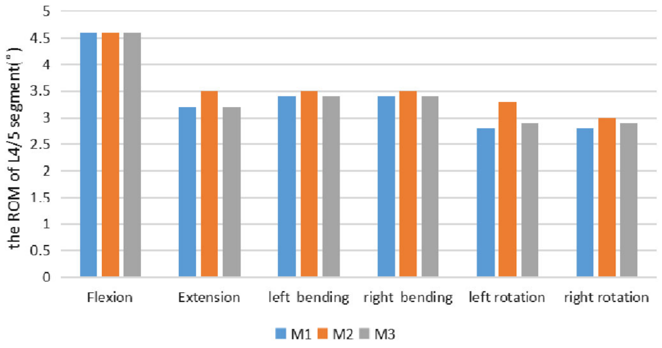

Fig. 3 It shows the comparison of the ROM of L_4/L_5 segment in the M1 against M2 and M3 under a torque of 7.5 Nm in flexion, extension, left bending, right bending, left rotation and right rotation. According to results obtained by our study, for extension, M2 increased the ROM of L_4/L_5 segment by 9.4%, while the ROM of M3 little changed. In left axial rotation, M2 and M3 increased the ROM of L_4/L_5 segment by 7.14% and 3.6%, respectively. In right axial rotation, After foraminoplasty performed on the tip facet, M2 notably increased the ROM of L_4/L_5 segment by 17.9%, and this was the largest increase at L_4/L_5 motion segment among all loading cases.

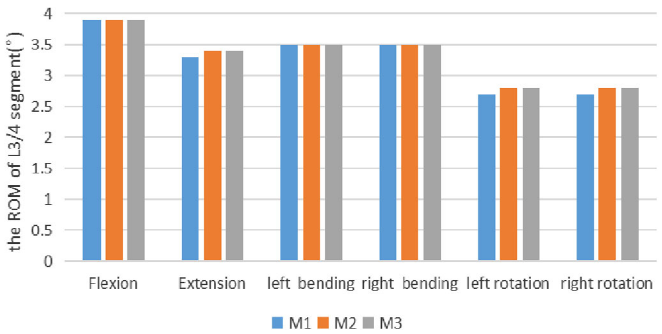

Fig. 4 It shows the comparison of the ROM of L_3/L_4 segment in the M1 against M2 and M3 under a torque of 7.5 Nm in flexion, extension, left bending, right bending, left rotation and right rotation. As it is shown in figure, neither M2 nor M3 increased the the ROM of L_3/L_4.

joint removal, and operative instability, has gradually become one of the most acceptable treatments for disc herniation[20]. However, since facet joints and foraminal ligament are partially removed to enlarge the stenotic foramen by transforaminal approach, PETD still have an effect on the biomechanical property of adjacent segments to some degree[8]. For foraminoplasty, various range of proportions and portions of facet joints could be removed, depending on the surgical approaches, surgical technique, surgeons and foraminoplasty way. Although many groups[13–16] have investigated the effect of various resection proportion of facet joints on lumbar biomechanics, and reported that lumbar stability was not significantly affected only if the range of graded facetectomy exceeded 50%, there have been few studies comparing the biomechanical behavior of adjacent segments after foraminoplasty was performed on different facet portions.

In this research, an intact FE model (M1) of L_3–L_5 was constructed in this study, and ROM of the model was calculated for validation study. The intact lumbar model was validated against *in vitro* experimental studies[21] to ensure suitability of model for further analysis. In order to investigate effect of foraminoplasty of different facet portions on segmental stability of lumbar, the M1 was modified to simulate foraminoplasty of different facet portions, by performing 0.75 cm cylindrical excision on the tip and the basement of right L_5 superior facet elements along with surrounding capsular ligament separately. The effect of percutaneous endoscopic lumbar foraminoplasty of different facet joint portions on segmental range of motion (ROM) and intradiscal pressure (IDP) of L_3/L_4 and L_4/L_5 motion was segmentally analyzed for all six loading conditions.

This study demonstrated that the base foraminoplasty of L_5 superior facet provided a higher segmental stability compared with the tip-facet foraminoplasty in extension and axial rotation. According to results obtained by our study, for extension, M2 increased the ROM of L_4/L_5 segment by 9.4%, while little changed in the ROM of M3. In left axial rotation, M2 and M3 increased the ROM of L_4/L_5 segment by 7.14% and 3.6%, respectively. In right axial rotation, after foraminoplasty was performed on the tip facet, M2 notably increased the ROM of L_4/L_5 segment by 17.9%, and this was the largest increase at L_4/L_5 motion segment among all loading cases. This is similar to *in vitro* results reported by Abumi *et al.*[13] where ROM increased significantly for axial rotation, and increase in ROM occurs in opposite direction for axial rotation. Our predicted results also show similar behavior in axial rotation. Our model predicted that base-facet foraminoplasty also had less impact on the IDP of L_4/L_5 level in extension and axial

TABLE 6 The IDP of $L_{4/5}$ intervertebral disc after different parts of formation on L_5 facet joint (MPa)

	Condition					
Model	Flexion	Extension	Left bending	Right bending	Left rotation	Right rotation
M1	0.372	0.486	0.434	0.421	0.463	0.463
M2	0.387	0.543	0.446	0.427	0.510	0.501
M3	0.375	0.492	0.442	0.426	0.487	0.482

TABLE 7 The IDP of $L_{3/4}$ intervertebral disc after different parts of formation on L_5 facet joint (MPa)

	Condition					
Model	Flexion	Extension	Left bending	Right bending	Left rotation	Right rotation
M1	0.365	0.474	0.435	0.424	0.456	0.447
M2	0.369	0.479	0.439	0.428	0.462	0.452
M3	0.366	0.476	0.437	0.426	0.459	0.449

rotation. In extension, M2 increased the IDP of L_4/L_5 level by 11.7% while M3 little increased the IDP. For left axial rotation, M2 and M3 increased the IDP by 10% and 5.2%, and M2 and M3 increased the IDP of L_4/L_5 level by 8.2% and 4.1% in right axial rotation. Compared with M3, the increased ROM and IDP in M2 indicated more loss of stability and a greater load through the intervertebral disc of L_4–L_5. This would inevitably lead to a greater risk of lumbar degeneration. Besides, neither M2 nor M3 increased the IDP or ROM of the L_3/L_4 segment in any loading condition.

Analysis of the results

As a part of the three-column structure of vertebrae, facet joints play a significant role in maintaining the stability of spinal motion. Facets transfer load through spinal column and restrict the motion of vertebrae, especially in the direction of extension and rotation[22]. These facet joints are typical diarthrodial joints with cartilage covering the articular surfaces, as well as ligamentous capsules that guide, couple, and limit the relative translations and rotations of adjacent vertebrae. For the tip-facet foraminoplasty, partial bony structure was resected along with cartilage and CL, thereby violating the anatomic integrity of articulating joint, an increase of ROM and IDP is found in extension and rotation. Jun-Song Yang *et al.*[17] believed that, besides preserving the anatomic integrity of the lumbar spine, a nearly complete reservation of ligamental and muscular structure is beneficial for maintaining the spinal stability. Choi *et al.*[5] has laso suggested that the resection should not involve the articular surface as preserving a larger articular surface is important for maintaining spinal stability.

Based on finite element modeling, this study demonstrated that the base-foraminoplasty of facet provided a higher segmental stability compared with the tip-facet foraminoplasty in extension and axial rotation. Our model predictions provide the clinician better understanding of lumbar biomechanics after percutaneous endoscopic foraminoplasty performed on different facet joint portions, and provide endoscopic surgeons a better reference for operational approach to maintain the function and mobility of the spine.

Limitation of the Study

This study is more likely to be a basic study on the biomechanical effects of foraminoplasty through PETD. Therefore, it has its own limitations. In future further studies, the clinical research could embark on three-dimensional finite element analysis of the biomechanical comparison between the preoperative and postoperative lumbar spine of patients with lumbar disc herniation undergoing PETD, which will be more valuable for clinical guidance.

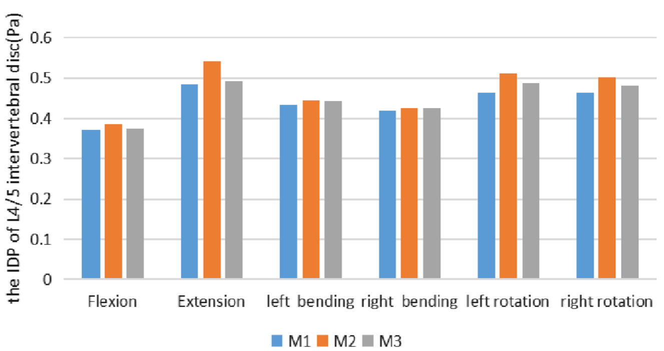

Fig. 5 It shows the comparison of the IDP of L_4/L_5 segment in the M1 against M2 and M3 under a torque of 7.5 Nm in flexion, extension, left bending, right bending, left rotation and right rotation. As it depicted, in extension, M2 increased the IDP of L_4/L_5 level by 11.7% while M3 little increased the IDP. For left axial rotation, M2 and M3 increased the IDP by 10% and 5.2%, and M2 and M3 increased the IDP of L_4/L_5 level by 8.2% and 4.1% in right axial rotation.

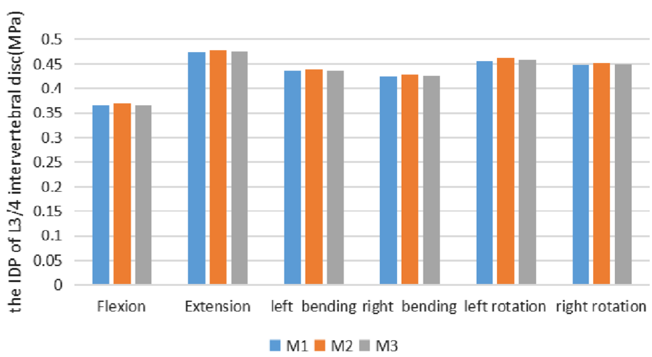

Fig. 6 It shows comparison of the IDP of L_3/L_4 segment in the M1 against M2 and M3 under a torque of 7.5 Nm in flexion, extension, left bending, right bending, left rotation and right rotation. According to the Figure, neither M2 nor M3 increased the IDP of L_3/L_4 segment.

Competing Interests

The authors have declared that no competing interests exist.

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