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REVIEW ARTICLE

MORPHOLOGY OF LUMBAR INTERVERTEBRAL FORAMINA AND ITS SIGNIFICANCE – LITERATURE REVIEW

MORFOLOGIA OTWORÓW MIĘDZYKRĘGOWYCH W ODCINKU LĘDŹWIOWYM I ICH ZNACZENIE – PRZEGLĄD LITERATURY

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ABSTRACT

Introduction

Lumbar foraminal stenosis is the main cause of low back or leg pain. Yet, radiological visualization of the radicular pathology remains a challenge. The fact it hardly correlates with clinical course only adds to the difficulty of understanding the pathomechanism of nerve root compression. Recently, researchers have revisited this problem by throwing more light on the foramen structure, its natural course, degenerative effect and dynamic morphological changes in the effort to better understand, hence diagnose and treat the related pathology.

Aim

The aim of this paper is to provide a most up-to-date and holistic review of available research on the morphology of lumbar intervertebral foramina and their related anatomy, which in light of recent research, has a yet unelucidated role in radiculopathy.

Material and methods

A PubMed search was conducted for original or review papers treating about lumbar intervertebral foramina including anatomical, morphometric, biomechanical, imaging, and dynamic studies. A total of 60 studies were selected and reviewed critically.

Results

The review shows that recent research focuses on difficulties with proper imaging of the lumbar intervertebral foramen with visualization of structures potentially involved in stenosis and on the investigation of biomechanics, which proves the lumbar intervertebral foramina to be very dynamic and complex structures. New perspectives are revealed for the possible role of foraminal structures in lumbar root stenosis.

Conclusions

Lumbar intervertebral foramen is a complex structure with varying anatomy at each level. More research is needed to better understand the etiology of radicular pain, where soft tissues seem to play a greater role than expected. Optimal imaging techniques need to be developed for soft tissue visualization inside the foramen to bring radiographic and clinical correlation of nerve root compression higher.

Keywords: intervertebral foramen, morphology, back pain, radiculopathy, imaging

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STRESZCZENIE

Wstęp

Stenoza otworów międzykręgowych jest jedną z głównych przyczyn bólu okolicy lędźwiowo-krzyżowej i/lub bólu nóg. Pomimo tego, diagnostyka obrazowa tego schorzenia pozostaje wyzwaniem. Brak korelacji objawów klinicznych z badaniami obrazowymi utrudnia zrozumienie patomechanizmu kompresji nerwów zlokalizowanych w lędźwiowych otworach międzykręgowych. Ostatnio naukowcy poszerzają wiedzę w tym temacie, kierując swoją uwagę na budowę otworów międzykręgowych, ich morfologię, wpływ na nią zmian degeneracyjnych, a także zmiany dynamiczne morfologii otworów w zależności od pozycji ciała. Nowe spojrzenie pozwoli lepiej zrozumieć i leczyć bóle korzeniowe.

Cel

Celem artykułu jest dostarczenie aktualnej i całościowej analizy dostępnych badań dotyczących morfologii kanałów międzykręgowych w odcinku lędźwiowym, która w świetle ostatnich badań ma kluczową rolę w radikulopatii. Naszym celem jest ułatwienie identyfikacji obszarów, które wymagają poszerzenia badań.

Materiał i metody

Poszukiwania przy pomocy bazy PubMed przeprowadzono w kierunku oryginalnych prac lub artykułów przeglądowych poświęconych otworom międzykręgowych w odcinku lędźwiowym, w tym badaniu anatomii, morfometrii, obrazowaniu oraz zmianom dynamicznym. Ogółem wyselekcjonowano 60 badań i poddano krytycznej analizie.

Wyniki

Przegląd pokazuje, że ostatnie badania koncentrują się na trudnościach z prawidłowym obrazowaniem otworu międzykręgowego w odcinku lędźwiowym, z wizualizacją struktur potencjalnie zaangażowanych w zwężenie. Analiza biomechaniki dowodzi, że otwory międzykręgowe w odcinku lędźwiowym są strukturami złożonymi i podatnymi na zmiany dynamiczne. Przedstawiono nowe spojrzenie na rolę struktur okolicy otworów międzykręgowych w zwężeniu odcinka lędźwiowego.

Wnioski

Otwory międzykręgowe są strukturami złożonymi, a ich anatomia zmienia się w zależności od poziomu w odcinku lędźwiowym kręgosłupa. Potrzebne są dalsze badania, aby lepiej zrozumieć etiologię bólu korzeniowego, w którym tkanki miękkie wydają się odgrywać większą rolę niż zakładano. Należy opracować optymalne techniki obrazowania w celu wizualizacji tkanek miękkich w obrębie otworu, aby zwiększyć radiograficzną i kliniczną korelację kompresji korzenia nerwowego.

Słowa kluczowe: otwór międzykręgowy, morfologia, ból okolicy lędźwiowo-krzyżowej, radikulopatia, obrazowanie

Introduction

Lumbar spinal stenosis is a common source of leg and back pain. It refers to a narrowing in the central canal or laterally in the lumbar intervertebral foramen (IVF). When lateral recess or IVF are stenosed, symptoms of radiculopathy may be demonstrated. Yet, IVF stenosis is too much of an umbrella term as the exact location of radicular stenosis may be extraforaminal (exit zone), intraforaminal (hidden in the midzone) or even in the entry zone or the lateral recess. The fact that there is no universally accepted definition of lateral lumbar spinal stenosis, and that there is no generally accepted radiologic diagnostic criteria for nerve root compression, only adds to the confusion. Moreover, proper diagnosis of foraminal stenosis in the lumbosacral region is well known to be difficult as radiologic imaging does not always yield convincing findings and does not correlate clinically.

The radicular pathology is thought to originate from stenosis that can be caused directly by mechanical compression or indirectly by inflammation-induced swelling of IVF structures like in degenerative spondylosis (Orita *et al.,* 2016), which is associated with intervertebral disc protrusion or herniation, osteophyte formation, facet hypertrophy or synovial cyst, ligamentumflavum hypertrophy or other IVF structure, the roles of which remain not fully elucidated (Fig.1).

Despite a double digit radiologic prevalence of IVF stenosis that increases with age, clinical diagnosis is often missed, which may account for approximately 60% of failed back surgery syndromes with continued post-operative symptoms. This shows how the understanding of IVF morphology, natural course and related structures is a prerequisite to future investigation of radicular pathomechanism, as well as to improve the diagnosis and treatment of lumbar IVF-related pathologies.

Aim

The aim of this paper is to provide a most up-to-date review of available research on the morphology of lumbar intervertebral foramina and their related anatomy, which in light of recently increased research has shown a potential role in radiculopathy that remains yet unelucidated. We aim at facilitating the identification of areas that require more investigation.

Material and methods

A PubMed search was conducted for papers up to 2019 using the following search strategy:

1. intervertebral foram*[Title/Abstract] – 854 results
2. (spin*[MeSH Terms]) AND morphology*[Title/Abstract] – 1851 results
3. (spin*[MeSH Terms]) AND morphometr*[Title/Abstract] – 985 results
4. ((spine[Title/Abstract]) AND dynamic*[Title/Abstract]) AND biomechanic*[Title/Abstract] – 545 results
5. ("back pain"[Title/Abstract]) AND radiculopath*[Title/Abstract] – 1081 results
6. imag*[Title/Abstract] AND spine[Title/Abstract] AND lumbar[Title/Abstract] – 6067 results

To the total of 11.383 papers exclusion criteria were applied (Table 1) to yield 89 papers.

Next, each of the authors have scrutinized individually for relevance a symmetrical proportion of the remaining abstracts narrowing the result down to 60 papers. Finally, the studies were divided into 3 categories depending on the focus: anatomic studies (irrespectively of method), studies assessing the modalities of IVF imaging and those investigating IVF morphological changes (wheather dynamic, position-dependent or natural course). Thus, the review follows such categorization accordingly.

Results and discussion

Morphology of Lumbar Intervertebral Foramina – Imaging studies

The intervertebral foramina (IVF) are points of exit for the nerve roots. A single IVF has two joints as part of its boundaries i.e., the inter-vertebral joint anteriorly and the facet joint posteriorly. The compact bone of the deep arch of the inferior vertebral notch from the vertebra above and the shallow superior vertebral notch from the vertebra below form the superior and inferior boundaries respectively (Gilchrist *et al.,* 2002).

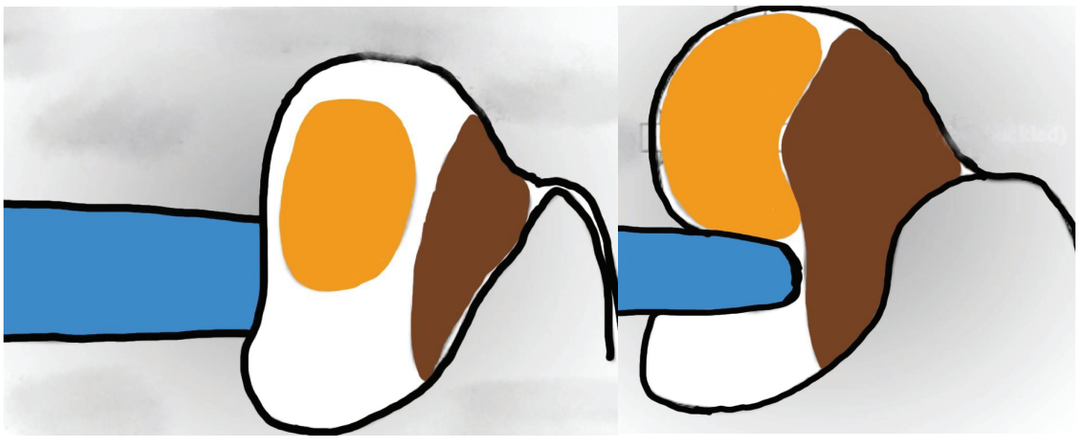

Figure 1. Visualization of spondylosis in lumbar intervertebral foramen where changed disk (blue) and ligamentumflavum (brown) leads to nerve root (yellow) compression. A modified figure based on illustration from Orita *et al.* 2016.

Table 1. Papers' search exclusion criteria.

Exclusion criteria:
▪ studies published earlier than 1990, unless cadaveric ▪ papers not in English ▪ spine segment other than lumbar ▪ publication type: other than original or review ▪ stenosis other than foraminal ▪ studies assessing treatment (open surgical, endoscopic, conservative) ▪ foraminal stenosis related to pathology other than degenerative (idiopathic scoliosis, schwannoma, etc.) ▪ lack of full-text availability

The upper part of the foramen has a broader antero-posterior dimension than the lower part at all lumbar levels except L5/S1 where the reverse occurs (Cramer *et al.,* 2003; Devi *et al.,* 2005).

Overall, the shape of IVFs is oval and resembles an inverted pear with the bigger belly being its greatest horizontal dimension (Cramer *et al.,* 2003). Yet, the IVF shapes may vary. A total of 4 morphological types of IVF shape were identified including elliptical, reniform, pyriform, and teardrop (Bulyshchenko *et al.,* 2018).

A lumbar IVF vertical dimension stretches between the vertebral notches of respective vertebral pedicles and a horizontal dimension stretches between the inferior-posterior margin of the upper vertebra ventrally and the superior articular process of the facet joint dorsally. The ratio of these dimensions is around 2:1 and remains fixed along the lumbar levels except L5-S1, which has a slightly different IVF morphology resembling an inverted egg (Cramer *et al.,* 2003).

The size of the lumbar IVF is symmetrical when it comes to sides (Cramer *et al.,* 2003). In turn, IVF dimensions may vary slightly per each lumbar level. According to MRI studies of Cramer *et al.,* the average lumbar IVF dimension across L1-L5 levels varies from 20.2 (±SD 2.0) to 17.0 (±SD 2.5) [mm] vertically and from 10.9 (±SD 2.0) to 9.4 (±SD 1.6) [mm] horizontally. In a multispiral CT study of Bulyschchenko *et al.* (2018), all IVF parameters including the foraminal height were found do decrease from upper lumbar segment down to the lumbosacral junction. Other study reports same trend except the vertical dimension is largest at L2 and decreases until L5 where it is the smallest. In contrast, the horizontal dimension remains about the same (Cramer *et al.* 2003).

There is no sex difference in the IVF dimensions except minimally larger vertical dimension in males (Cramer *et al.,* 2003). As per weight, horizontal dimensions of the IVFs were found to decrease as body weight increased. As per aging, the height of the IVF shrinks with age, which is most probably due to degenerative changes involving disc or vertebral body narrowing

(Yusof *et al.,* 2018). Also, the vertical dimension was found to increase with body height (Cramer *et al.,* 2003). Yet, a study using 3D-CT models of 59 healthy subjects reports that while the lumbar foraminal height decreases with age at all spinal levels, it concerns only males. Females had a non-uniform distribution of foraminal height shrinkage (Senoo *et al.,* 2014). Yet, the same study confirms that foraminal height is significantly larger in upper lumbar levels for both genders.

The width of the foramina in males is reported to be significantly smaller than in females for all age groups and it decreases with age at all levels. Similarly to the vertical dimension, the width remains significantly larger on the upper levels of the lumbar spine (Senoo *et al.,* 2014).

A more detailed CT study (Zhang *et al.,* 2018) confirms the shrinking of IVF height with age by showing a decreased disc height of adjacent vertebra of L3/4 to L5/S1. The study took measurements at 3 different sagittal slices around the pedicle to assess the IVF anatomy at the nerve root entry point, middle point and the exit point from the IVF. It was found that the IVF height decreases gradually from the entry to the exit of foramen at L3/4 and L4/5. In turn, at L5/S1 it decreases at midpoint from entry to increase at exit.

In turn, the horizontal dimension decreases gradually from the entry to the exit all the way from L3/4 to L5/S1. On the other hand, a CT study on L4/5 IVF and aging showed no decrease in width at this level in any of the sagittal slices while it confirms the IVF height decrease (Wang *et al.,* 2018).

When the IVF surface area delineated by the bony boundaries is measured, it shows a decrease with age across all lumbar segments (L3/4-L5/S1) at each sagittal slice with the highest drop in the area at L5/S1 level between middle age and old age group of males (Zhang *et al.,* 2018). Also the lumbar vertebral bodies change with age as their endplates become more concave and the prevalence of osteophytes increases (Shao *et al.* 2002).

Morphology of Lumbar Intervertebral Foramina – cadaveric studies

Overall, cadaveric studies show basic IVFs dimensions such as foraminal heights, widths, and their relationship across the lumbar levels to be very similar with the findings of the imaging studies. However, the cadaveric results remain quite inconsistent (Devi *et al.,* 2005; Hasegawa *et al.* 1995; Sunday *et al.* 2018). Interestingly, a cadaveric study defined a critical posterior disc height of ≤4 [mm] and a lumbar IVF height of ≤15 [mm] to yield anatomically evident nerve-root compression (in 8 of 10 foramina and in 4 out of 5 foramina, respectively) (Hasegawa *et al.,* 1995).

However, it should be taken into account that cadaveric studies have a number of inherent limitations that make generalizations and comparison very difficult. Small sample numbers usually give insignificant results, different cadaver handling may influence the anatomy (various fixation techniques or effects of freezing and defrosting) and manual measurements with Vernier calipers cannot discriminate between the bone and the adherent soft tissues such as ligaments. Finally, there is lack of inter and intra observer reliability tests that are often performed with CT or MRI studies and the results have no clinical correlation, especially in terms of IVF compression on the nerve root.

Anatomy of Lumbar Intervertebral Foramina – soft tissues

Numerous structures pass through the lumbar IVFs including the root of each spinal nerve, segmental spinal arteries and veins, lymphatics, and two to four recurrent meningeal nerves (Gilchrist *et al.,* 2002). Yet, apart from the bony frame of IVF, multiple soft tissue structures are involved in bounding the foramen: the intervertebral disc, lateral expansion of the posterior longitudinal ligament and the anterior longitudinal venous sinus anteriorly and lateral prolongation of ligamentumflavum posteriorly.

The medial canal border contains the dural sleeve while the lateral border contains a facial sheet and overlying psoas muscle (Gilchrist *et al.,* 2002). Finally, numerous ligaments have been identified to transverse the lumbar IVF, of which many are associated with neurovascular structures and may contribute to their compression (Fig.2).

Golub and Silverman (Golub *et al.,* 1969) in a 1969 cadaveric study identified an inconsistent

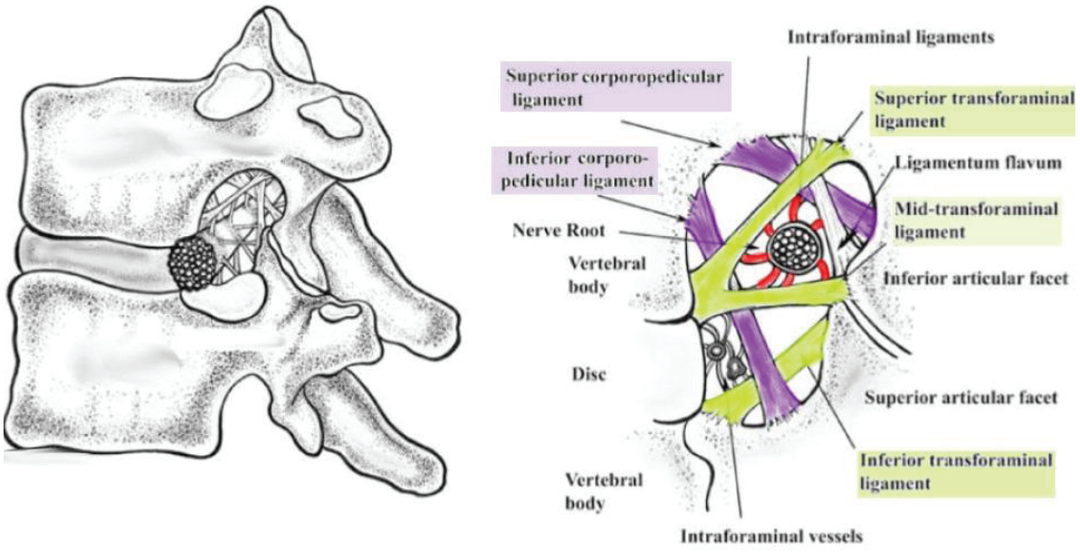

Figure 2. Lumbar intervertebral foramen ligaments.

presence of many ligamentous bands across the IVFs of all lumbar levels, especially at L1-L2 foramina. Five major transforaminal ligaments were identified: obliquely running superior and inferior corporotransverse ligaments and transversely running superior, mid- and inferior transforaminal ligaments. Considered anomalous structures at the beginning, the authors of subsequent cadaveric studies supported the findings but the ligaments were particularly abundant at fifth lumbar foramen. Generally, ligaments are thicker in the upper lumbar levels compared to lower levels and they run in three different zones: internal (entry), intraforaminal and external (exit).

The internal ligaments are dense at the lower part of foramen medial surface and form a subcompartment rich in venous plexus (Amonoo-Kuofi *et al.,* 1988). There are 3 types of intraforaminal ligaments: (1) deep anterior forming subcompartment with recurrent meningeal nerve and branch of spinal artery, (2) superior oblique forming anterosuperiorsubcompartment with large branch of segmental artery, (3) horizontal mid-transforaminal ligament, over which spinal nerves can be extended (Amonoo-Kuofi *et al.,* 1988). The external ligaments are corporotransverse ligaments that together with the associated internal and intraforaminal ligaments divide the IVF into compartments with a network constituting a fixing, protective and supporting role on one hand and a contribution to stenosis on the other.

The literature reports a very diverse rate of occurrence of ligaments (from about 3% to 100%) depending on the criteria for identification and classification, which differs greatly among the studies (Amonoo-Kuofi *et al.,* 1988; Bakkum *et al.* 1994; Min *et al.* 2005; Zhao *et al.* 2016; Zhong *et al.* 2017; Zhong *et al.* 2018).

The entrance zone of L1-L5 has predominantly radiating ligaments (over 96% of IVFs) and some transforaminal ligaments (about 3% of IVS) while their length varies from 0.59 to 11.92 [mm] with highest abundance in the superior aspect of the entrance zone (Zhong *et al.,* 2018). The most common type of ligament is the superior corporotransverse ligament (Amonoo-Kuofi *et al.,* 1988) and the most common intraforaminal ligament is the oblique inferior (Min *et al.* 2005).

Many authors interpret the location of transforaminal ligaments as potential cause of root entrapment as they diminish the space available for the nerve to pass. The transforaminal ligaments were found to occupy on average 28.5% ±18.8% of IVF area (Min *et al.,* 2005) and to decrease the vertical dimension of the compartment containing ventral ramus of spinal nerve by 31.5% (Bakkun *et al.,* 1994).

Finally, there are ligaments extending radially from nerve root sleeve into four directions with the most prominent nerve root attachment to the facet capsule posteriorly (Grimes *et al.,* 2000). Other ligaments fan out with attachments inferiorly and superiorly to the adjacent pedicles and anteriorly to the intervertebral disc. These ligaments are hypothesised to limit motion along the nerve root as biomechanical studies showed significant increase in strength at failure with axial traction, which progresses from L3 to L5 (Grimes *et al.,* 2000). They have also been shown to prevent damage evoked by spinal nerve traction since a graded decrease in the displacement proximal to the extraforaminal ligaments was seen from the levels L1-L4 when pulling nerve roots at different angles (Kraan *et al.,* 2010). Thus, the proximal attachments secure a spinal nerve position central in the intervertebral foramen and also reduce longitudinal tension.

Radiating ligaments medially in the entrance zone may contribute to dura laceration and epidural hemorrhage during surgical or endoscopic procedures (Zhao *et al.,* 2016). Same complications may arise from procedures that remove the lamina or ligamentumflavum due to the meningovertebral ligaments that fix the dural sac in the lumbosacral region of the spinal canal. Such ligaments were found in nearly all specimens at L5-S1 level (Shi *et al.,* 2012). The attachment points involve more commonly the ligamentumflavum compared to the lamina and the ligaments vary in length from around 5 to 40 [mm] extending caudally from the origin on the dura (Shi *et al.,* 2012).

At the lumbosacral junction a lumbosacral ligament extends from the transverse process of L5 and the L5-S1 disk to the sacral ala, forming the roof of the lumbosacral tunnel through which the L5 spinal nerve passes. This may be the site of extraforaminal entrapment if lateral disk herniations, osteophytes, or tumor metastasis are present (Golub *et al.,* 1969; Transfeldt *et al.,* 1994).

Lumbar IVF position-dependent and dynamic changes

The spine can perform the movement of flexion, extension, bending, and rotation, all of which can change the in vivo anatomic congruence and dimensions of lumbar IVFs.

A number of studies report that during dynamic activity of lifting from flexed position to extension, the IVFs' area, width and in some studies also height decrease significantly and monotonically, except L5-S1 (Fujiwara *et al.,* 2001; Infusa *et al.,* 1996; Iwata *et al.,* 2013; Schmid *et al.,* 1999; Ren *et al.,* 2017; Zhong *et al.,* 2015). The reverse happens during flexion. This is useful for patient positioning during injections or surgeries as position-dependent variation in cross-sectional area of the neural foramina can reach 44.4% (Schmid *et al.,* 1999).

Lateral bending significantly decreases the foraminal width, height and area at the bending side, with opposite effects contralaterally (Fujiwara *et al.,* 2001). This lends rationale to the fact that radiculopathy is more frequent on the concave side of the degenerative lumbar scoliosis (Fu *et al.,* 2011). Kaneko *et al.* used multidetector row CT and found significantly smaller IVF height, area and posterior disc height at lower vs upper lumbar levels and on the concave vs convex side of degenerative scoliosis (Kaneko *et al.,* 2012).

Likewise, axial rotation decreases the foraminal width and area at the rotation side with opposite effects on the contralateral side (Fujiwara *et al.,* 2001). These findings are very much in line with the analogous effect that axial torsion has on the lumbar disc height, which increases (by 1.52 [mm]) in its posterior and right zones during rotation to the right, whereas the left, anterior, and central zone decreases (Espinoza *et al.,* 2016). Further support is lended by Al-Omairi *et al.* reporting parallel results for both IVFs and disc heights during rotation (Al-Omairi *et al.,* 2017). Yet, in patients with degenerative disc disease compared to normal subjects, both dynamic and position-dependent changes of IFV dimensions were found to be significantly smaller at L3/4 with overall IVF area shrinking by 32.8% and 33.6% at L4/5 and L5/S1, respectively (Cha *et al.,* 2017).

When it comes to spine flexion, it was shown to increase the foraminal width, height and area while decreasing the bulging of discs and thickness of ligamentumflavum Fujiwara *et al.,* 2001).

The ligament has maximum thickness in extended position (Schmid *et al.,* 1999).

Interestingly, one study reports a 0.7 [mm] facet joint gapping in lumbar side-posture spinal adjusting and a lesser gapping during side-posture positioning in the MRI scanner (Cramer *et al.,* 2000). The posture-dependent imaging results bear important clinical meaning. In conventional imaging the patient is examined in the supine position, where lumbar lordosis is physiologically reduced with relief or at least a reduction in pain, which must be the consequence of increased foraminal dimensions (Splendiani *et al.,* 2014). Thus, examinations in orthostatic conditions would enable a "functional" evaluation of the column. The foraminal area was found to be 13.3% and 21% smaller in respective upright and upright+hyperlordotic position when compared to supine MRI (Lang *et al.,* 2018).

Comparison of the imaging studies

Although IVF morphology studies on cadavers are of great value, only imaging in vivo offers the advantage of clinical correlation and interpreting the IVF as a whole thanks to 3D reconstruction.

CT is more accessible, cheaper and superior bone discriminating tool compared to MRI (Khami *et al.,* 2014). Also, degenerative, erosive and destructive changes of the facet joints as well as facet orientation and spondylolysis are better visualized by CT (Adama *et al.,* 2014; Eun *et al.,* 2012). On the other hand, MRI has the advantage of not using ionizing radiation and superior visualizing capacity for soft tissues (Kim *et al.,* 2018).

Yet, regarding ionizing radiation, It has been reported that ultra low dose CT can lower the amount of radiation by 60–68% and patients with BMI lower than 25 [kg/m^2] can undergo ultra low dose CT while keeping good image quality and precision of diagnosis (Lee *et al.,* 2018).

Measuring volume of lumbar IVF in young asymptomatic adults using CT has yielded values between 1.17 and 1.29 [mm^3] with excellent reproducibility (intra-observer correlation coefficients) between 0.90 and 0.99 and with very good inter-observer correlation coefficients between 0.77 and 0.8. Consequently, CT studies prove an excellent and reliable imaging technique for IVF evaluation with average differences in intra- and inter-observer measurements regardless of the evaluator group of only 1 [mm] (Khami *et al.,* 2014). Measurements of IVFs using MRI yields same excellent reliability and reproducibility results (all above 0.94) (Cramer *et al.,* 2003). In a study comparing the IVF sagittal measurements using MRI and CT, the results were clinically and statistically reliable and valid for both methods but measurements made from the MRI scans were found to be more accurate (Cramer *et al.,* 1994).

In general, many studies regard CT and MRI as complementary methods for imaging bony and soft tissues of the spine. Recommendations include the acquisition of high-resolution multiplanar CT reconstructions and fat-suppressed T2 weighted fast-spin- or turbo-spin-echo sequence MRI in at least one plane in every examination of the lumbar spine. (Eun *et al.,* 2012; Jenkins, 2004). Also, a study comparing CT sans, MR imaging and corresponding microtome sections of 18 cadavers has proved that the ligaments originating from the posterolateral margin of the intervertebral disk that are attaching to the inferior pedicle, superior articular process, transverse process or ligamentumflavum are effectively depicted by CT or MRI as linear structures with distinct attenuation coefficient or signal intensity compared to adjacent fat and areolar tissue (Nowicki *et al.,* 1992).

Jung-Ha Kim *et al.,* (2018) reviewed 14 studies about diagnostic accuracy of imaging for lumbar disc herniation to conclude that specificities and sensitivities of MRI, CT and Myelography were all comparable. However, high number of false positive and false negative results were pointed out including the fact that available research uses old imaging techniques since all but one study were published before 1995. Similar results were obtained by T. Maus (2010) who stated that sensitivity and specificity of CT, CT myelography and MRI in diagnosing lumbar spine stenosis and disc herniation is similar.

As per MRI itself, it has its own advocates that call MRI a "gold standard" for diagnostics of lumbar spine. It's recommended for example in

diagnostics of radiculopathy in cases where regular conservative treatment fails or in lumbar spinal stenosis. Patient with contraindications for MRI should undergo CT (Adams *et al.,* 2014; Rao *et al.,* 2018). MRI is also a very helpful modality in preoperative planning like in case of MRI based 4-point grading system of IVF stenosis proposed by T.S. Jeong *et al.,* (2017). A novel diagnostic parameter discriminating for surgery - a Foraminal Stenotic Ratio - was developed and assessed by Yamada *et al.* using 3D MRI. The ratio was significantly different between conservative and surgical groups and was proved to determine lower lumbar IVF stenosis that requires surgery in symptomatic patients with a moderate accuracy. Interestingly, foramina occupied in ≥50% by fat obliteration were likely to fail conservative treatment, with a positive predictive value of 75% (Yamada *et al.,* 2017).

Manabe *et al.,* (2019) used a novel diffusion-weighted magnetic resonance neurography technique for visualizing nerve tract in the lumbosacral region and found that 36.6% of lumbar radiculopathy patients had a high nerve root take-off angle (≥60°) at the IVF caused by degenerative changes, which shows a new MRI potential for indirect radicular diagnosis.

Myelography is generally of little use because it provides little information regarding lateral pathology due to the dural sac terminating at the lateral aspect of the midzone, preventing significant contrast-filling of the distal nerve root sheaths. Yet, it was found that Myelo-CT is superior in assessing patients who had previous surgical procedures. Diffuse and lateral recess stenosis was better appreciated on the myelogram and myelo-CT compared to noncontrast CT or MRI alone (Epstein *et al.* 1990). Also, MR imaging and CT myelography underestimates root compression caused by degenerative changes in the lateral recess in about 30% of surgically confirmed cases compared to only 5% to 7% with conventional myelography that correctly predicts impingement in 93% to 95% (Bartynski *et al.,* 2003). This makes conventional myelography a crucial supplemental study when stenosis of lateral recess is a suspected cause of radiculopathy.

However, the limitation of imaging is that they have hardly comparable poor diagnostic value (de Graaf *et al.,* 2006) and that approximately 90% of low back pain is non-specific (unidentified pathological mechanism) with very poor correlation between imaging findings and the clinical presentation or course (Adams *et al.,* 2014; Eun *et al.,* 2012; Khami *et al.,* 2014; Maus, 2010; Rao *et al.,* 2018) . In asymptomatic patients, abnormal findings appear on CT or MR in 4–28% of cases, most commonly among elderly (Kent *et al.,* 1992). For this reason it is often underlined in research and campaigns that physicians should be judicious when referring patient with low back pain to MRI or CT (Levinson *et al.,* 2015). Also, there are studies we have reviewed in the previous section that point to the role of IVF dynamic changes depending on positioning. J.R. Jinkins underlines that such posture-dependent changes in visualized IVFs can be seen in MRI and CT for both asymptomatic and low back pain patients (Jinkins, 2004).

Moreover, studies comparing MRI, CT and Myelography done in supine and upright position concludes that upright position is a better choice as it allows more accurate information on location of compression and reveals a more pronounced pathology (Ido *et al.,* 2002; Lang *et al.,* 2018; Splendiani *et al.,* 2014).

Conclusions

Lumbar intervertebral foramen is a complex structure with varying anatomy at each level. More research is needed to better understand the etiology of radicular pain, where soft tissues seem to play a greater role than expected. Optimal imaging techniques need to be developed for soft tissue visualization inside the foramen to bring radiographic and clinical correlation of nerve root compression higher.

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