Anatomical variations and congenital anomalies of the lumbar vertebrae: 64-slice MDCT appearance

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Learning objectives

To illustrate and briefly describe the anatomical variations and congenital anomalies of the lumbar vertebrae, as seen on 64-slice multidetector CT studies.
Background

Classic textbooks based on conventional radiography have offered and extensive account of many of these variations and anomalies. However, CT and MR imaging may provide a more precise assessment, particularly in complex cases.

Currently available 64-slice multidetector CT provides an excellent opportunity for reviewing the normal anatomy, anatomical variations and congenital anomalies of the lumbar vertebrae, given its excellent spatial resolution, multiplanar capabilities and volume renderings.

Variations and anomalies of the vertebral body, neural arch and its processes are reviewed, ranging from minor dysplastic findings to complex malformative features. Classic radiographic features are discussed, and their 64-slice multidetector CT counterparts are analyzed. New 64-slice multidetector CT signs are suggested, following a pattern recognition approach that may help characterize difficult cases. Finally, the presumed pathogenesis, clinical relevance and differential diagnosis of these conditions are briefly reviewed.
Imaging findings OR Procedure details

Introduction

The lumbar spine is formed by five separate vertebrae. Each lumbar vertebra has a vertebral body and a vertebral arch (Fig. 1) on page 10.

The vertebral body is the anterior part of the vertebra. The body of the lumbar vertebrae is much larger than those of the other vertebrae. The body is flattened or slightly concave above and below, concave behind, and shows deeply constricted anterior and lateral surfaces.

The neural arch is formed by a pair of pedicles and a pair of laminae, and supports four articular processes, two transverse processes, and one spinous process.

The vertebrae vary in size and other characteristics from one region to another, and to a lesser degree within each region. The first lumbar vertebra is a typical lumbar vertebra. However, the fifth lumbar vertebra is characterized by its body being much deeper in front than behind, which accords with the prominence of the sacrovertebral articulation; by the smaller size of its spinous process; by the wide interval between the inferior articular processes, and by the thickness of its transverse processes, which spring from the body as well as from the pedicles.

The lumbar vertebrae may present multiple anatomic variations and congenital anomalies. They result from alterations in the ossification process and commonly remain asymptomatic. A few of them may originate painful syndromes, or may be confused with fractures or dislocations.

Vertebral body

Hemivertebra is one of the most common vertebral anomalies. It results from unilateral failure of vertebral formation, in which only one half of the vertebra body develops. Hemivertebra is a common cause of congenital scoliosis. It can associate with other anomalies of the spine, ribs, heart and genitourinary tract. In spite of this, hemivertebra is commonly found as an asymptomatic incidental anomaly.

Butterfly vertebra is an uncommon spinal anomaly caused by a persistent sagittal cleft. It is usually asymptomatic, but may associate with other congenital anomalies. This anomaly should not be misinterpreted as a fracture (Fig. 2) on page 10.

The coronal cleft represents the result of embryonic arrest, with cartilage occupying the cleft between the anterior and posterior parts of the vertebral bodies.
Block vertebra is caused by a failure of the segmentation process during fetal development, leading to vertebral fusion. The fusion may be complete or partial, and usually involves the lumbar and cervical segments of the spine (Fig. 3) on page 11.

The posterior surface of the vertebral body is marked by one or more large holes known as nutrient foramina. These foramina transmit the nutrient arteries of the vertebral body and the basivertebral veins. The anterolateral surfaces of the vertebral body are marked by smaller foramina which transmit additional intraosseous arteries (Fig. 4 on page 12-5). The basivertebral veins are the principal veins of the vertebral body and run horizontally in the middle of the vertebral body, forming the Hahn’s canal (Fig. 6) on page 14.

A limbus vertebra results from an intrabody herniation of disk material at the junction of the endplate with the vertical bony rim of a vertebral body. The most common site is the lumbar region. The radiographic finding shows a defect in the anterior margin of the vertebral body usually at the superior margin in the lumbar vertebrae (Fig. 7 on page 15-8) on page 16. A Schmorl’s node is a contour defect in the endplate of a vertebra, resulting from central herniation of a portion of the disc into the adjacent vertebral body (Fig. 9) on page 17.

Hypoplasia and aplasia of the vertebral body are part of a spectrum of growth abnormalities of the centrum during the late stages of chondrification and ossification. Mild anterior wedging of the L1 vertebral body and posterior wedging of the L5 vertebral body are common findings (Fig. 10) on page 18. Hypoplasia of the L5 vertebral body may associate with bilateral spondylolysis.

**Neural arch**

**1. Pedicles**

The pedicle is the segment of the vertebral arch between the transverse process and the vertebral body.

Congenital absence and hypoplasia of vertebral pedicles involve, in decreasing order of frequency, the lumbar, cervical and dorsal spine. Radiographic characterization of these two pedicle deficiencies may be difficult, given their overlapping manifestations. It has been suggested that many of the previously reported cases of lumbar absent pedicle may, in retrospect, represent hypoplasia.

On plain films, congenital absence of a dorsolumbar pedicle may be subtle or misleading, although associated features such as abnormal enlargement of the intervertebral foramen may help detect the anomaly. On axial MDCT images, congenital absence of a dorsolumbar pedicle typically associates with a small anteriorly displaced transverse
process. The anterior attachment of the transverse process can be interpreted as a hypoplastic pedicle, which may also occur. Additional features include dysplasia of ipsilateral superior articular facet, tilt of spinous process, contralateral arch hypertrophy and sclerosis, and rib abnormalities. A vertical cleft through the superior facet may be found. On oblique-sagittal MDCT reformations, this latter finding originates the previously undescribed "dog muzzle" sign (Fig. 11 on page 19-12). On page 20 When the absent pedicle coexists with segmentation anomalies, parasagittal and oblique-sagittal MDCT reformations help detect abnormal fusion of laminae and joint facets (Fig. 13). On page 21

2.-The pars interarticularis

The pars interarticularis or isthmus is located between the inferior and superior articular processes of the facet joint, anterior to the lamina and posterior to the pedicle.

A cleft through the pars interarticularis of a lumbar vertebra is termed isthmic spondylolysis. Isthmic spondylolysis may be congenital, although most defects of the pars interarticularis derive from acute or stress fracture. In fact, isthmic spondylolysis may be found in both dysplastic (developmental) and isthmic (adquired) spondylolisthesis, corresponding to types I and II of the Wiltse et al classification.

Dysplastic spondylolisthesis predominates at the L5/S1 level, and is caused by congenital insufficiency of the facet joints and disc complex. It may be classified as low and high dysplastic. High dysplastic spondylolisthesis tends to present with small and dysplastic articular processes, usually sagittally oriented and prone to anterior subluxation. The pars interarticularis is attenuated or elongated, but may also undergo spondylolysis (Fig. 14). On page 22 Additional findings include spina bifida occulta, posterior wedging of the L5 vertebral body, convexity at the superior sacral dome, and increased lumbosacral angle.

Isthmic spondylolisthesis implies a defect of the pars interarticularis. Isthmic spondylolysis may be identified on lateral radiographs, but is better seen on oblique views, originating the so-called "Scotty dog with collar" sign. Isthmic spondylolysis is also readily demonstrated on parasagittal reformatted MDCT images, although the classic radiographic sign at the L5 vertebra may be hard to reproduce on oblique-sagittal volume-rendered MDCT reformations (Fig. 15). On page 23

Unilateral isthmic spondylolysis is probably an acquired lesion, and usually remains asymptomatic. It may associate with sclerosis and hypertrophy of the contralateral neural arch, and may precipitate contralateral isthmic spondylolysis. It may also cause stress fracture of the contralateral pedicle (Fig. 16), on page 24 or associate with spina bifida occulta (Fig. 17). On page 25
3.- The laminae

The lamina is the flattened posterior portion of the vertebral arch from which the spinous process extends.

The retroisthmic cleft, one of the rarest forms of neural arch anomaly, involves the lamina immediately dorsal to the inferior articular process. Although a traumatic etiology has been suggested, it may associate with other congenital anomalies, such as ipsilateral deviation of the spinous process, ipsilateral facet dysplasia, and contralateral pedicle hypoplasia (Fig. 18). on page 26

Other anomalies of the laminae may found, such as agenesis (associated with segmental anomalies), hypoplasia or fusion.

4.- The spinous processes

The spinous process is the posterior extension of the lamina and it serve as a site of attachment for muscles and ligaments.

Spinal dysraphism implies a failure of fusion of the neural arch, and typically associates with central nervous system abnormalities. Spina bifida occulta, the closed and mild form of spinal dysraphism, usually involves the transitional levels of the spine, most commonly the L5 and S1 segments, and is generally regarded as an incidental finding. The term spina bifida occulta is used to describe midline defects of the neural arch, such as unfused spinous processes, laminae, or both (Fig. 19). on page 27 The spinous process may remain unattached, held by the ligamentum flavum, or may fuse with the contiguous spinous process, originating the so-called "clasp-knife deformity". The midline defect may also extend into the sacral canal (Fig. 20). on page 28 Spina bifida occulta may associate with skin abnormalities or tethered cord.

Spinous process deviation may reflect rotation of the entire vertebra or developmental asymmetry of the neural arch. This latter variant may cause confusion in the interpretation of anteroposterior radiographs of the spine, and simulate vertebral body malalignment. In this setting, MDCT may be used to establish the correct diagnosis.

Hypoplasia of the spinous process may occur. Persistent ossification centers of the spinous process may also be found. These have smooth round borders, resembling typical accessory ossicles which should not be confused with fractures.

5.- Articular processes
The articular processes arise from the junction of the pedicles and laminae. Their shape and orientation show regional differences throughout the spine, with transition points around C6 and T11. The change of orientation is gradual from cervical to thoracic region, and rather sudden from thoracic to lumbar region.

The mammillary process is a normal elevation at the posterior margin of the superior articular facet (1-3). It arises from a secondary ossification center, and may persist into adult life. A prominent mammillary process may be hard to identify on anteroposterior radiographs of the lumbar spine. On a radiographic oblique view, it is seen as a ring-shaped opacity adjacent to the pedicle. This feature, termed the "two-eyed Scotty dog", may be easily reproduced on oblique-sagittal volume-rendered MDCT images (Fig. 21 on page 29-22). on page 30

A vertical cleft through the superior articular process may occur. It can associate with a hypoplastic pedicle or a dysplastic facet joint (Fig. 23). on page 31 A horizontal cleft through the inferior articular process originates the "Oppenheimer ossicle" (Fig. 24), on page 32 which may be mistaken for a facet fracture. Accessory ossicles at the superior joint facet may also occur.

Articular processes may be hypoplastic (Fig. 24b) on page 32 or absent. Fused facet joints may be seen in segmental anomalies and various neural arch malformations. Absent facet joints may associate with conjoined nerve root and cause low back pain.

Facet tropism is defined as asymmetry at the facet joint angles of the lumbosacral region. Some individuals show asymmetric facet joint angles (Fig. 25), on page 33 but the definition of excessive tropism is arbitrary. It has been suggested that facet joint tropism does not significantly affect the risk of facet joint osteoarthritis or disc degeneration. However, both facet joints tend to be more sagittally oriented in patients with degenerative spondylolisthesis.

6.- Transverse processes

The transverse processes of the dorsal spine are thick, strong, and considerably long, particularly at D1. They have no foramen transversarium, and end in a clubbed extremity. They have a costal facet from D1 to D10, but this may be absent at D10. They adopt a transitional tripartite configuration at D12 (occasionally at D10, D11 or L1). Persistent secondary ossification centers may occur (Fig. 26A). on page 34 These have smooth round borders, resembling typical accessory ossicles. These features help differentiate these anomalies from fractures.
The L1, L2 and L3 transverse processes are slender and horizontal. The L1 transverse processes lose the D12 tripartite configuration, as the superior, lateral and inferior tubercles turn into mamillary, transverse and accessory processes. However, the L1 transverse process may retain a tripartite configuration (Fig. 26B) on page 34 remain ununited, or support a small lumbar rib (Fig. 26C) on page 34.

The accessory processes are found at the posterior aspect of the transverse processes (Fig. 27) on page 35. On rare occasions, they may be particularly prominent. Accessory and mammillary processes may join into a bony bridge, forming a foramen transversarium. Anomalous articulations between contiguous transverse processes may occur (Fig. 28) on page 36.

The L4 and L5 transverse processes arise from the pedicles and posterior parts of the vertebral bodies, and incline a little upward. The L5 transverse processes may be abnormally enlarged and articulate with the sacrum or the iliac bone (Fig. 29) on page 37. Bertolotti's syndrome refers to the occurrence of a transverse mega-apophysis in a transitional lumbosacral vertebra, which has been considered a possible cause of low back pain.
Fig. 0: Normal anatomy of a typical lumbar vertebra.

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**Fig. 0:** Butterfly vertebra. Coronal reformatted (A) and anterior coronal volume-rendered MDCT (B) images demonstrate a sagittal cleft within the L5 vertebral body.

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Fig. 0: Block vertebra. Sagittal reformatted (A) and anterior coronal volume rendered MDCT (B) images show L3-L4 block vertebra.

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Fig. 0: Vascular foramina in the anterior border of the vertebral body.

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Fig. 0: Vascular foramina in the anterior border of the vertebral body. (Coronal volume rendered (a), axial (b) and coronal reformatted (c) images).

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**Fig. 0:** Hahn's canal. Sagittal (a) and axial (b) volume-rendered MDCT images show a horizontal fissure on the posterior aspect of the vertebral body.

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Fig. 0: Limbus vertebra. Lateral radiograph (a) and sagittal thin slab reformatted MDCT images (b,c) show the defect at the anterosuperior border of L4.

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Fig. 0: Limbus vertebra. Axial MDCT image (a) and oblique volume rendered images (b) show a limbus vertebra.

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**Fig. 0:** Schmorl's node. Sagittal reformatted (a) and axial (b,c) MDCT images show a contour defect at the anterior-superior endplate of L5. Note the sclerotic margin subjacent to the defect.

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**Fig. 0:** Sagittal reformatted MDCT and lateral radiographs images show normal anterior wedging of D12 (a) and posterior wedging of L5 (b) vertebral bodies.

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**Fig. 0:** Absent or hypoplastic lumbar pedicle in a 45-year-old man who presented with long-standing low back pain. Anteroposterior (a) and lateral (b) radiographs show normal left L1 and L3 pedicles (dotted arrows), absence of a normal left L2 pedicle, a vertical cleft through the left L2 neural arch (arrowhead), and abnormal left L2 transverse process (curved arrow).

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**Fig. 0:** Axial (c) and coronal (d) thin-slab volume-rendered and oblique-sagittal reformatted (e) MDCT images show absence or hypoplasia of left L2 pedicle (circle), anterior attachment of left L2 transverse process (curved arrow), vertical cleft through the left L2 superior articular process (white arrowhead), dysplasia of the left L1 inferior articular process (black dotted arrow), dysplasia of the left L1 retroisthmic arch (black arrow), and sclerosis with hypertrophy of the right L2 neural arch (black arrowhead). At the oblique-sagittal reformation, a "dog muzzle" sign is appreciated.

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**Fig. 0:** Absent or hypoplastic lumbar pedicle in a 52-year-old woman who was referred for characterization of an adnexal mass. Axial thin-slab volume-rendered MDCT image (a) demonstrate absence or hypoplasia of the right L4 pedicle (circle). Right (R) and left (L) oblique-sagittal (b) and right and left parasagittal (c) reformatted MDCT images demonstrate associated segmentation anomalies, consisting of fusion of the right L4/L5 laminae (black arrow), and right L4/5 joint facets (white arrow). A small accessory bone (arrowhead) is also seen.

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Fig. 0: L4-L5 dysplastic spondylolisthesis and sacralization of L5 in a 32-year-old woman who presented with leg paresthesias. Midsagittal (a) and parasagittal (b) reformatted, oblique-axial reformatted (c), and posterior coronal volume-rendered (d) MDCT images show dysplastic spondylolisthesis, with posterior L5 wedging (large arrow), convexity of the superior sacral dome (white arrowhead), slender but otherwise preserved pars interarticularis (black arrowhead), dysplastic L4-L5 facet joints (small arrows), and mild spinal disraphism (star).

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**Fig. 0:** Isthmic spondylolisthesis in a 53-year-old man who presented with low-back pain that radiated into the right lower extremity. Lateral radiograph (a) and parasagittal reformatted (b) MDCT images show L5-S1 spondylolisthesis with isthmic spondylolysis (circles). The classical radiographic sign of the "Scotty dog with collar" is hard to reproduce on oblique-sagittal thin-slab volume-rendered MDCT images (c), although parasagittal reformations allow an adequate interpretation in most cases.

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**Fig. O:** Unilateral spondylolysis with contralateral pedicle stress fracture in a 21-year-old man who presented with low back pain. Anteroposterior radiograph (a), coronal reformatted (b) and axial thin section (c) MDCT image show left L4 spondylolysis (arrowheads). A stress fracture of right L4 pedicle (arrow in c) is also shown.

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**Fig. 0:** Unilateral spondylolysis and spina bifida occulta in a 24-year-old man who presented with long-standing low back pain. Axial thin-section MDCT image shows right L5 spondylolysis (arrowhead) and spina bifida occulta (arrow).

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**Fig. 0:** Left L3 retroisthmic cleft in a 40-year-old man who presented with right sciatic pain. Anteroposterior radiograph (a), axial thin-section (b), oblique-sagittal reformatted (c) and posterior coronal volume-rendered (d) MDCT images show a left L3 retroisthmic cleft (white arrows), mild hypoplasia of the right L3 pedicle (arrowhead), and dysplasia of the left L3/4 facet joint (dotted arrow).

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Fig. 0: Spina bifida occulta in a 66-year-old man with lung cancer. Axial (a, b) and coronal (c) thin-slab and posterior coronal (d) volume-rendered MDCT images reveal a complex variant of spina bifida occulta, consisting of unfused L1 spinous process (arrows) and left L1 lamina (stars). A dysplastic left L1/2 facet joint (arrowhead in B) is also seen.

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**Fig. 0:** Defect of the posterior wall of the sacral canal in a 13-year-old boy who presented with long-standing low back pain. Posterior coronal volume-rendered MDCT image shows a wide defect of the posterior wall of the sacral canal.

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**Fig. 0:** Prominent L2 mammillary processes in a 44-year-old woman who presented with low back and right sciatic pain. Anteroposterior radiograph (a), axial thin-slab volume-rendered (b) and posterior coronal volume-rendered (c) MDCT images show prominent mammillary proccess (arrows).

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**Fig. 0:** Thin-slab oblique-sagittal volume-rendered (d) reproduces the classic radiographic "Scotty dog". Within its head, the nose corresponds to the transverse process (tp), the eye to the pedicle (p) and the ear to the superior facet (sf). Oblique-sagittal volume-rendered (e) displays the so-called "two-eyed Scotty dog", where the prominent mammillary process (arrow) superimposes within the contour of the dog's head, suggesting a "dog's eye". The left L2 transverse process shows a distal downward projection (arrowhead), which has been described as the "pig's snout pedicle" sign on plain films.

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Fig. 0: Dysplastic right L5/S1 facet joint in a 43-year-old woman who presented with low back and right sciatic pain. Axial thin-section (a) and posterior coronal volume-rendered MDCT image (b) show a dysplastic right L5/S1 facet joint (arrow). An abnormal cleft through the right superior S1 articular process (arrowhead) is seen.

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**Fig. 0:** Oppenheimer's ossicle in a 39-year-old man who presented with low back and right sciatic pain. Anteroposterior radiograph (a), coronal reformatted (b) and left parasagittal reformatted (c) MDCT images show an Oppenheimer's ossicle (arrow) at the caudal aspect of the left inferior L3 articular process. The right inferior L3 articular process shows slight hypoplasia (arrowhead).

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Fig. 0: Facet tropism in a 38-year-old man who presented with left sciatic pain. Anteroposterior radiograph shows sagittally oriented left L4/5 facet joint (thick arrow) in a patient with L5 sacralization. Axial thin-slab volume-rendered MDCT images show symmetric L2/3 facet joints (arrowheads in b), mild L3/4 tropism (thin arrow in c), and marked L4/5 tropism (thick arrow in d). Posterior coronal volume-rendered MDCT image (e) shows excellent correlation with plain film.

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Fig. 0: A) Persistent ossification center in a 25-year-old woman who presented with dorsal pain after minor trauma. Axial thin-section MDCT image shows a persistent ossification center at the right D12 transverse process (arrow). Spina bifida oculta (arrowhead) is also noted. B) Tripartite configuration of right L1 transverse process in a 53-year-old man who presented with right sciatic pain. Axial thin-section MDCT image shows persistent tripartite configuration of the right L1 transverse process (arrow), and a small lumbar rib (arrowhead). C) Lumbar ribs in an 88-year-old man with stable aneurysm of the abdominal aorta. Axial thin-section MDCT image shows persistent tripartite configuration of L1 transverse processes (arrows), and small lumbar ribs (arrowheads).

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Fig. 0: Accessory processes in a 34-year-old woman who presented with low back pain. Axial thin-section (a) and coronal volume-rendered (b) MDCT images show accessory processes (arrows) at the posterior aspect of L3 transverse processes.

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**Fig. 0:** Anomalous joint between transverse processes in a 46-year-old woman who suffered left sciatic pain. Anteroposterior radiograph (a), coronal reformatted (b) and coronal volume-rendered (c) MDCT images show an abnormal articulation between left L1 and L2 transverse processes (arrowhead).

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**Fig. 0:** L5 transitional vertebra in a 40-year-old woman who presented with left-sciatic pain. Axial thin-section (a) and coronal volume-rendered (b) MDCT images show a transitional lumbosacral vertebra, with a left hypertrophic transverse process (arrow) that articulates with the ilium and sacrum.

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Conclusion

64-slice multidetector CT is an optimal modality for the comprehensive evaluation of the anatomical variations and congenital anomalies of the lumbar vertebrae.
References


