Fetal magnetic resonance imaging of lumbar spine development in vivo: a retrospective study

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Abstract
Objective The aim of this study is to describe MR imaging appearances of the fetal lumbar spine in vivo at different gestational ages (GAs).
Methods This retrospective study was approved by the Third Affiliated Hospital of Zhengzhou University. We collected MR images and clinical data of 93 fetuses in our hospital. All the MR images were obtained by 3-T MR. All had the mid-sagittal plane of steady state free precession sequence (Trufi) of the lumbar spine, which could show the lumbar vertebra and conus medullaris (CM). Regression analysis was made between GA and heights of lumbar vertebral body ossification center (LVBOC), lengths of LVBOC, and heights of intervertebral gap (IVG).
Results There were good linear correlations between the heights of LVBOC and GA (P < 0.001), lengths of LVBOC and GA (P < 0.001), and heights of IVG and GA (P < 0.001).
Conclusion We showed the different development of each LVBOC and IVG which caused the difference of the shape of LVBOC and IVG.

Keywords Fetus · Magnetic resonance imaging · Spine

Introduction
Because of more detailed information obtained by the MR, fetal MR could be very useful for the diagnosis and treatment of fetal disease [1–5]. Before evaluating the fetal spine, it is important to understand the development of fetal spine at different GAs [4, 6]. We find few of published dates on the appearances of vertebrae and intervertebral space, and most of them were postmortem [7–13]. The aim of this study is to describe MR imaging appearances of the fetal lumbar spine in vivo at different GAs [14, 15].

Material and methods
This retrospective study was approved in the Third Affiliated Hospital of Zhengzhou University. Between September 2017 and March 2021, 353 fetuses were examined in our hospital which due to the abnormality of the central nervous system indicated by ultrasound, which included mild ventriculomegaly and abnormal width of the cavum septum pellucidum, and their central nervous system abnormalities were confirmed by the MR, and none of them had other positive findings in ultrasound and MR, and all of them had MR images of fetal head and spine. Mild ventriculomegaly (ventricle width of 10–12 mm) without other systemic malformations is usually considered to have normal neurodevelopmental processes [16]. Without of aneuploidy and other associated fetal abnormalities, the neurodevelopment appears to be normal in the abnormal width of the CSP prenatally [17]. Because of the prognosis, these fetuses were considered to be low risk and selected in the study. Reasons for exclusion included blurry images due to fetal movement (n = 138), no mid-sagittal image of fetal lumbar spine images (n = 107), and inability to identify the L5 position (n = 15), and 93 fetuses, from 22 to 37 gestational weeks (median, 27.1 gestational weeks) were collected.

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in our study in the end. The GA was estimated by the date of woman’s last menstrual period \((n=82)\) or the assessments made by sonography \((n=11)\).

All the MR images were obtained by 3-T MR (Skyra, Siemens Medical Systems, Germany) with an eight-channel body surface coil. Pregnant women were placed in the supine position, and those who were difficult to examine in the supine position could be placed in the left lateral position. There was no fetal sedation, and if fetal movement was obvious, the pregnant woman would have rest, then we continued to examine. Three-plane imaging of T2WI of fetal spines was acquired. All had the mid-sagittal plane of steady-state free precession sequence (Trufi, repetition time/echo time = 740/2.4 ms; field of view, 35×45 cm; thickness, 3 mm; −0.6 mm gap; voxel size, 1.1×1.1×3.0 mm; FA, 58°; NEX, 1) of the lumbar spine, which could show the lumbar vertebra and CM. The other sequences consisted of the T2WI half-Fourier acquisition single-shot turbo spin echo sequence (HASTE, repetition time/echo time = 1400/63 ms; field of view, 40×40 cm; thickness, 4 mm; 0.8-mm gap; FA, 120°; NEX, 1), T1WI fast-low angle shot (repetition time/echo time = 120/2.4 ms; field of view, 35×40 cm; thickness, 4 mm; 0.8 mm gap; FA, 70°; NEX, 1), and susceptibility-weighted imaging (SWI, repetition time/echo time = 10/5 ms; field of view, 35×35 cm; thickness, 3 mm; 0 mm gap; FA, 15°; NEX, 1). All the MR images were transferred to PACS (Synapse, Fujifilm medical system, Japan).

All the measurements were carried on the mid-sagittal plane of Trufi (Fig. 1). Lumbar ossification centers are defined as hypointensity in the spinal vertebral region of the Trufi sequence. Localizing the iliolumbar ligament was been used to determine the lumbar vertebral level, and counting down from C2 might be a supplement, although more difficult since cervical vertebral ossification centers were extremely small and it was difficult to get the mid-sagittal images of the whole spine. If localization was still difficult, the case would be removed. Before independent measurements were performed by two pediatric radiologists (10 years of clinical work experience in our hospital), they had to make an agreement on the location of the L5. The mean of the two measurements was then used for further analysis. SPSS 20.0 was used for the data analysis. Simple linear regression analysis was made between GA and heights of lumbar vertebra body ossification center (LVBOC), lengths of LVBOC, and heights of intervertebral gap (IVG).

**Results**

There was a good inter-rater agreement on the measurements of heights of LVBOC, lengths of LVBOC, and heights of IVG \((P < 0.001)\). There were good linear correlations

**Table 1** Linear correlation between the heights of LVBOC and GA

|        | R²  | P       | Constant | Slope |
|--------|-----|---------|----------|-------|
| Height of L1 | 0.716 | <0.001 | −1.660  | 0.220 |
| Height of L2 | 0.667 | <0.001 | −1.580  | 0.219 |
| Height of L3 | 0.681 | <0.001 | −1.516  | 0.215 |
| Height of L4 | 0.646 | <0.001 | −2.049  | 0.23  |
| Height of L5 | 0.585 | <0.001 | −1.209  | 0.185 |

**Table 2** Linear correlation between the lengths of LVBOC and GA

|        | R²  | P       | Constant | Slope |
|--------|-----|---------|----------|-------|
| Length of L1 | 0.670 | <0.001 | −1.488  | 0.243 |
| Length of L2 | 0.654 | <0.001 | −1.193  | 0.241 |
| Length of L3 | 0.652 | <0.001 | −1.488  | 0.250 |
| Length of L4 | 0.674 | <0.001 | −1.366  | 0.248 |
| Length of L5 | 0.658 | <0.001 | −2.092  | 0.267 |

**Table 3** Linear correlation between the heights of lumbar IVG and GA

|        | R²  | P       | Constant | Slope |
|--------|-----|---------|----------|-------|
| Height of L1–2 | 0.210 | <0.001 | 1.102   | 0.038 |
| Height of L2–3 | 0.333 | <0.001 | 0.591   | 0.062 |
| Height of L3–4 | 0.431 | <0.001 | 0.423   | 0.071 |
| Height of L4–5 | 0.373 | <0.001 | 0.587   | 0.067 |
Fig. 2 Scatter plot shows a linear relation between the heights of LVBOC and GA (a, L1H, L2H, L3H, L4H, and L5H stand for heights of LVBOC of L1, L2, L3, L4, and L5), the lengths of LVBOC and GA (b, L1L, L2L, L3L, L4L, and L5L stand for lengths of LVBOC of L1, L2, L3, L4, and L5), and the heights of IVP and GA (c, L12, L23, L34, and L45 stand for heights of IVP of L12, L23, L34, and L45).
between the heights of LVBOC and GA \((P < 0.001)\), lengths of LVBOC and GA \((P < 0.001)\), and heights of IVG and GA \((P < 0.001)\). The results of the correlation are shown in Tables 1, 2, and 3. Scatter plots are shown in Fig. 2a, b, and c.

**Discussion**

The development of the spine includes 6 periods: (1) formation of the somitic mesoderm and notochord, (2) formation of the somites, (3) formation of the dermomyotome and sclerotome, (4) the membranous phase, (5) vertebral chondrification, and (6) vertebral ossification [18, 19]. The ossification of the vertebra begins from the thoracolumbar junction [18]. Generally, at present, fetal MR is imaged after 18 gestational weeks, and at this time, all the lumbar ossification centers could be seen [1, 20]. Many diseases can cause changes in the height of the vertebral body, such as the wedge vertebra (Fig. 3). Wedge vertebra is a cause of scoliosis. Wedge vertebra usually does not cause obvious scoliosis [1, 20], but the height of the vertebral body usually decreases on one side [19].

The steady-state free precession sequence (Fig. 4) is the major sequence for the fetal spine MR, which shows the vertebral ossification center better than the single-shot turbo spin echo sequence, and the contrast signal to noise ratio between the vertebral ossification center and intervertebral space is better [1, 21–23]. The single-shot turbo spin echo sequence (Fig. 5) shows better of the soft tissue and spinal cord [1, 21–23]. SWI sequence (Fig. 3a) shows vertebral ossification center is better than the steady state free precession sequence, especially MIP images can be performed to display ossification centers of the spine and thorax, but the soft tissue and spinal cord cannot be displayed [4]. Since the SWI images are often blurry because of fetal movement and maternal respiration, they are only used as a secondary means in our hospital [4].

Each centrum is fused by the inferior half and the superior half of the sclerotomes, so the intersegmental vessels are located in the center of the vertebral bodies [4]. On fetal MR T2WI, the vertebral ossification center is usually shown as a hypointensity in the spinal vertebral region [24]. The hyperintensity in the central vertebral ossification center due to the intersegmental vessels is rare in MR in vivo. The morphology of the fetal vertebral ossification center can be manifested as biconvex, bullet-like, rectangular hypointensity on T2WI images [24]. The intervertebral disc showed uniform hyperintensity on T2WI images [24]. The intervertebral disc showed uniform hyperintensity on T2WI images [24]. In the axial images, the ossification centers of the lumbar vertebrae appear as round-shaped T2 hypointensity. The ossification centers of lumbar vertebral arches are distributed on both sides and no fusion occurred [6]. Oblique axial scanning was usually required to observe the ossification center of the vertebral body and the bilateral vertebral arches.

![Fig. 3 24 weeks of gestation, SWI (a) and Trufi (b) showed that T10 (red arrow) was a wedged vertebra, and the spine was slight scoliosis. The chromosome karyotyping and chromosome microarray analysis report fetal trisomy 18 (not included in study cases)](image)
Localization of lumbar vertebral is difficult in some cases in vivo examinations. Due to the influence of maternal respiration and fetal movement in the examination, it cannot locate the lumbar vertebral in sagittal position by 12th rib in coronal position or L5 nerve in axial image [25]. Localizing the iliolumbar ligament is the most commonly used method in the sagittal position [26]. This method is not very accurate. It is more accurate to count down from C2, and as discussed previously, it is more difficult because of the small cervical vertebral ossification centers, and it was difficult to get the mid-sagittal images of the whole spine.

In our study, we find the linear relationship between the heights of LVBOC and GA, lengths of LVBOC and GA, and heights of IVG and GA. The slopes of the linear relationship between heights of LVBOC from L1 to L4 and GA are very similar, and the slope of L5 is the minimum. The slopes of the linear relationship between the lengths of every LVBOC and GA are very similar. Due to the asynchrony of their development, the size and shape of the vertebral bodies are ultimately different [11, 12, 18, 27]. The height slope of the lumbar IVG is inconsistent, indicating that their development is not synchronized, L3-4 grows the fastest and L1–2 the slowest [12, 18].

There are limitations to our study. Since this is a retrospective study and no MR follow-up was performed in our cases on the spine after birth, we are unable to evaluate the lumbar spine after birth yet. Further studies to evaluate the association between prenatal and postnatal study, as well as the long-term follow-up, are needed, and we intend to use the 3D software to describe values of lumbar vertebra based on the 3D sequence in the future.

**Conclusion**

We demonstrate a good linear relationship between the development of the lumbar spine and gestational age in vivo by MR.

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**Declarations**

**Conflict of interest** The authors declare no competing interests.

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**Fig. 4** The same fetus was examined at 28 (a) and 36 (b) weeks of gestation. Trufi images of the mid-sagittal plane of the spine showed the development of heights and lengths of LVBOC and heights of IVP. Note the development of the cerebral cortex

**Fig. 5** Half-Fourier acquisition single-shot turbo spin echo sequence (HASTE) of lumbar spine shows the spinal canal, cerebrospinal fluid, and lumbar spinal cord (red arrow)
References

1. Coblenz AC, Teixeira SR, Mirsky DM et al (2020) How to read a fetal magnetic resonance image 101. Pediat Radiol 50(13):1810–1829
2. Bekiesińska-Figatowska M, Romaniszuk-Doroszewska A, Bragoszewska H et al (2018) Seventeen years of prenatal magnetic resonance imaging at the Institute of Mother and Child in Warsaw. Pol J Radiol 83:94–102
3. Wang J, Zhou Q, Fu Z et al (2021) MRI evaluation of fetal tethered-cord syndrome: correlation with ultrasound findings and clinical follow-up after birth. Clin Radiol 76(4):314.e1-314.e8
4. Abouglihalia H, Noda S, Chapman T et al (2021) Multimodality Imaging evaluation of fetal spine anomalies with postnatal correlation. Radiographics 41(7):2176–2192
5. Passias PG, Poorman GW, Jalai CM et al (2019) Incidence of congenital spinal abnormalities among pediatric patients and their association with scoliosis and systemic anomalies. J Pediatr Orthoped 1
6. Baumgart M, Wiśniewski M, Grzonkowska M et al (2016) Digital image analysis of ossification centers in the axial dens and body in the human fetus. Surg Radiol Anat 38(10):1195–1203
7. Matsubara Y, Higaki T, Tani C et al (2020) Demonstration of human fetal bone morphology with mr imaging: a preliminary study. Magn Reson Med Sci 19(4):310–317
8. Lemire GT, Beauregard Lacroix É, Campeau PM et al (2020) Retrospective analysis of fetal vertebral defects: associated anomalies, etiologies, and outcome. Am J Med Genet A 182(4):664–672
9. Xu T, Wang X, Yu H, Zhao F (2020) Twin pregnancy complicated with congenital Hemivertebra: report of two cases and literature review. Bmc Pregnancy Childb 20(1)
10. Jian N, Lin N, Tian M et al (2019) Normal development of costal element ossification centers of sacral vertebrae in the fetal spine: a postmortem magnetic resonance imaging study. Neuroradiology 61(2):183–193
11. Miao M, Lin X, Zhang Z, Zhao H (2019) Normal development of the fetal spinal canal and spinal cord at T12 on 3.0-T MRI. Acta Radiol 60(5):623–627
12. Szpinda M, Baumgart M, Szpinda A et al (2013) Morphometric study of the T6 vertebra and its three ossification centers in the human fetus. Surg Radiol Anat 35(10):901–916
13. Chabert S, Villalobos M, Ulloa P et al (2012) Quantitative description of the morphology and ossification center in the axial skeleton of 20-week gestation formalin-fixed human fetuses using magnetic resonance images. Prenat Diagn 32(3):252–258
14. Gilligan LA, Calvo-Garcia MA, Weaver KN, Kline-Fath BM (2020) Fetal magnetic resonance imaging of skeletal dysplasias. Pediat Radiol 50(2):224–233
15. Sun Y, Ning G, Li X, Qu H, Zeng J (2020) MRI characteristics of the fetal tethered spinal cord: a comparative study. Int J Neurosci 1–10
16. Fox NS, Monteagudo A, Kuller JA et al (2018) Mild fetal ventriculomegaly: diagnosis, evaluation, and management. Am J Obstet Gynecol 219(1):B2–B9
17. Cooper S, Katorza E, Berkenstadt M et al (2018) Prenatal abnormal width of the cavum septum pellucidum - MRI features and neurodevelopmental outcome. J Matern Fetal Neonatal Med 31(22):3043–3050
18. Williams S, Alkhatib B, Serra R (2019) Development of the axial skeleton and intervertebral disc. Curr Top Dev Biol 133:49–90
19. Dias MS (2007) Normal and abnormal development of the spine. Neurosurg Clin N Am 18(3):415–429
20. Prayer D, Malinger G, Brugger PC et al (2017) ISUOG Practice Guidelines: performance of fetal magnetic resonance imaging. Ultrasound Obstet Gynecol 49(5):671–680
21. Victoria T, Johnson AM, Edgar JC et al (2016) Comparison between 1.5-T and 3-T MRI for fetal imaging: is there an advantage to imaging with a higher field strength? AJR Am J Roentgenol 206(1):195–201
22. Reddy UM, Abuhamad AZ, Levine D, Saade GR (2014) Fetal imaging. J Ultras Med 33(5):745–757
23. Nagaraj UD, Bierbrauer KS, Stevenson CB et al (2018) Spinal imaging findings of open spinal dysraphisms on fetal and postnatal MRI. Am J Neuroradiol 39(10):1947–1952
24. Widjaja E, Whiby EH, Paley MNJ, Griffiths PD (2006) Normal fetal lumbar spine on postmortem MR imaging. American journal of neuroradiology : AJNR 27(3):553–559
25. Peckham ME, Hutchins TA, Stilwill SE et al (2017) Localizing the L5 vertebra using nerve morphology on MRI: an accurate and reliable technique. Am J Neuroradiol 38(10):2008–2014
26. Beek FJ, van Leeuwen MS, Bax NM et al (1994) A method for sonographic counting of the lower vertebral bodies in newborns and infants. AJNR Am J Neuroradiol 15(3):445–449
27. Szpinda M, Baumgart M, Szpinda A et al (2013) Cross-sectional study of the ossification center of the C1–S5 vertebral bodies. Surg Radiol Anat 35(5):395–402

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