Spinopelvic alignment and lumbar vertebral shape in children: associations with structural spinal abnormalities and body composition in the generation R study

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Abstract
Purpose To investigate the spinopelvic alignment and vertebral shape in children, and associations with body composition and structural spinal abnormalities on magnetic resonance imaging (MRI).

Methods We performed a cross-sectional study embedded in the Generation R Study, a prospective population-based birth cohort. Pelvic incidence and vertebral concavity ratios for each lumbar level were determined on sagittal MRI images in 9-year-old children, and structural spinal abnormalities were scored semi-quantitatively. The BMI-SD score was calculated, and body composition was assessed using DXA scans. Associations of pelvic incidence and vertebral concavity ratios with structural abnormalities and body composition measures were assessed using (multilevel) regression analyses.

Results This study included 522 participants (47.7% boys), aged 9.9 years (IQR 9.7–10.0). The mean pelvic incidence was 36.6° (SD 8.0). Vertebral concavity ratios ranged from 0.87 to 0.90, with significantly lower ratios for boys compared to girls. Associations were found for a larger pelvic incidence with decreased disc height [OR 1.03 (95% CI 1.02–1.05)], and a pelvic incidence in the lowest tertile with less disc bulging [OR 0.73 (95% CI 0.56–0.95)]. Increased vertebral concavity ratio was associated with decreased disc height [OR 14.16 (95% CI 1.28–157.13)]. Finally, increased fat-free mass index was associated with a smaller pelvic incidence [adjusted OR 0.85 (95% CI 0.07–1.63)].

Conclusion The mean pelvic incidence of 9-year-old children is 36.6° on supine MRI images, and a slightly concave shape of the lumbar vertebrae is seen. Spinopelvic alignment is associated with structural spinal abnormalities, and might itself be influenced by the children's body composition.

Keywords Child · MRI · Spine · Pelvic incidence · Vertebral shape

Introduction
The human standing posture involves a delicate balance between the spine and pelvis [1]. The positioning of the spine and pelvis determines the spinopelvic alignment, which can be described by parameters, like sacral slope, pelvic tilt, pelvic incidence, and lumbar lordosis. While most of these parameters depend on a person’s position, e.g. a standing or supine position, the pelvic incidence is described to be position-independent [1].

The spinal shape is largely determined during growth [2]. Several factors might influence this growth and development, among which is the loading on the spine. Overweight causes higher sustained loading in the lumbar vertebrae, influencing the stress distribution over the endplate [3]. Since the shape of the vertebrae is still developing in
children, the changed stress distribution might disrupt the normal formation of the vertebrae [4]. Furthermore, overweight or obesity may also disturb the normal spinopelvic development, as it forces adaptation of alignment, measured by e.g. the pelvic incidence, to keep the body balanced. A change in the spinopelvic alignment, spinal musculature, vertebral wedging, or disc health will affect the distribution of mechanical loading in the spine [5]. This can cause malalignment, which might cause other spinal pathologies and low back pain [6].

As structural spinal abnormalities already exist at a young age [7, 8], the aim of this study was to describe the sagittal spinopelvic alignment and lumbar vertebral shape of 9-year old children from a general population, using magnetic resonance imaging (MRI). Moreover, we aimed to investigate the associations of spinopelvic alignment and vertebral concavity with body composition parameters of these children and with the presence of structural spinal abnormalities seen on MRI.

Materials and methods

Study population This cross-sectional study was embedded in the Generation R Study, a prospective cohort study of 9778 children in Rotterdam, followed from early pregnancy to young adulthood [9]. All measurements within the Generation R Study have been approved by the Medical Ethics Committee of Erasmus MC University Medical Center Rotterdam, The Netherlands (MEC-2012–165). Written informed consent was obtained from parents or caretakers. At the age of 9 years, participants of the Generation R study were invited for two visits to the research center. The first visit included measurements of weight, height, and body composition, and the second visit an MRI scan. A random subsample (N = 894) was additionally invited for accelerometry data measurements for the purpose of a sleep study. This random study sample was used for the current study in Generation R. Out of this subsample, we included the participants of whom a T2-weighted MRI of the hips and lumbar spine was available and of sufficient quality for further analyses (Fig. 1).

Measurements

Height was measured with a Harpenden stadiometer (Hol-tain Limited, DYFED, U.K.) and weight was measured with a mechanical personal scale (SECA, Almere, the Netherlands). Body mass index (BMI; weight [kg]/height [m]^2) was calculated and age- and sex- adjusted standard deviation scores (SDS) for BMI were defined according to the Dutch reference growth charts [10]. Weight status was defined according to the cut-offs determined by the International Obesity Task Force (IOFT) [11]. A Dual-energy X-ray Absorptiometry (DXA) scan was performed (iDXA, Ge-Lunar, 2008, Madison, WI, USA) and used to calculate the fat mass index (FMI; fat mass [kg]/height [m]^2), fat free mass index (FFMI; fat free mass [kg]/height [m]^2), fat mass percentage (fat mass [kg]/total body mass [kg]*100), and fat free mass percentage (fat free mass [kg]/total body mass [kg]*100). Ethnicity of each child (Dutch, other-Western or non-Western) was based on the birth country of the parents. Skeletal age was obtained through the comparison of the maturity indicators estimated on hand DXA-scans with the standardized references provided in the Greulich and Pyle atlas [12].

MRI measures

During the second visit at the research center, MRI scans (3.0 Tesla MRI scanner (Discovery MR750w, GE Healthcare, Milwaukee, WI, USA)) of the hips and pelvic region, including the entire or major part of the lumbar spine, were acquired in supine position. The MRI protocol consisted of two matched three-dimensional (3D) acquisitions; a T2-weighted fat-suppressed 3D scan (T2FS Cube) and a mildly T1-weighted 2-point DIXON 3D gradient echo scan (LAVAFlex) providing two separate volumes rendering reconstructed water-only and fat-only images. Afterward, a 3D gradient de-warping algorithm was used to account for geometrical distortions from the large FOV selected. The sagittal T2-weighted images were used for further analyses. To calculate the pelvic incidence and vertebral concavity ratios, a widget called SpineMarker was developed within viewr software, developed by the Biomedical Imaging Group Rotterdam (BIGR). According to a standardized protocol, developed together with an experienced musculoskeletal radiologist (EO), markers were manually placed on predefined landmarks of the lumbar spine and hips (Appendix 1). Landmarks were automatically converted to coordinates, from which the pelvic incidence and vertebral concavity ratios were calculated (Fig. 2). The intraclass correlation coefficient for the inter-rater reliability was 0.759 for the pelvic incidence and varied between 0.189 (L1) and 0.758 (L2) for the vertebral concavity ratios. Structural abnormalities of the vertebrae and intervertebral discs, including disc degeneration and endplate irregularities, were scored semi-quantitatively according to a previously described standardized method [8]. The six most prevalent abnormalities were used for current analyses, i.e. signal intensity of the intervertebral disc, disc height, Pfirrmann grade, disc bulging, nuclear shape, and endplate irregularities, determined at each imaged vertebral level from L1 to S1 [8].
Data analysis

Descriptive statistics were used to assess child characteristics, pelvic incidence, and vertebral concavity ratios. For a better understanding of the distribution, the pelvic incidence was categorized into tertiles. Differences between boys and girls in alignment measures were assessed using a two-sample t-test. As the structural abnormalities and vertebral concavity ratios were scored for each lumbar level separately, multilevel logistic regression analyses were performed to determine associations of pelvic incidence and vertebral concavity ratios with the structural abnormalities. Linear regression was performed to assess associations between body weight measures and pelvic incidence and multilevel linear regression for associations between body weight measures and vertebral concavity ratios. Besides crude analyses, all analyses were adjusted for potential confounders as determined from literature: sex and skeletal age [13, 14]. Analyses on body weight measures were additionally adjusted for the time between the two visits at the research center (range 0–27 months). Results were presented as Odds Ratios (OR) and Beta’s (B) with 95% confidence intervals. All analyses were performed using SPSS Statistics version 25.0 (IBM, Armonk, NY, USA), and significance level was set at 0.05.

Results

Participant characteristics

Of the 9747 live-born children included in the Generation R Study, 7392 participated in the follow-up measurements at the age of 9 years, and in 3231 of those MRI scans of the spine were made. The final study sample consisted of 522 participants of which both MRI images of sufficient quality and accelerometry data were available (Fig. 1). The included participants had a median age of 9.9 (IQR 9.7–10.0) years, 47.7% were boys, and the majority of the children had a Dutch ethnicity (84.1%) and a normal weight (83.5%) (Table 1).
Pelvic incidence and vertebral concavity

The average pelvic incidence angle among the included participants was 36.6° (SD 8.0), and no differences were seen between boys and girls. The distribution of the pelvic incidence is visualized in Fig. 3, with the limits for three equal tertiles set at 32.30° and 39.52°. Vertebral concavity ratios ranged between 0.87 and 0.90, with slightly lower ratios for boys compared to girls (Table 2).

Pelvic incidence, vertebral concavity, and the presence of structural abnormalities

A larger pelvic incidence angle was associated with decreased disc height [adjusted OR 1.03 (95% CI 1.02–1.05)]. Moreover, the pelvic incidence angle in the upper tertile was associated with decreased disc height, with an adjusted OR of 2.39 (95% CI 1.69–3.37). The pelvic incidence angles in the lower tertile were associated with less disc bulging [adjusted OR 0.73 (95% CI 0.56–0.95)]. No associations were found between the pelvic incidence and other structural abnormalities. An increased vertebral concavity ratio was associated with the presence of a decreased disc height [adjusted OR 14.16 (95% CI 1.28–157.13)] (Table 3).

Body composition measurements and the pelvic incidence and vertebral concavity

An increased fat-free mass index was associated with a smaller pelvic incidence [adjusted OR 0.85 (95% CI 0.07–1.63)]. None of the other body composition measurements were associated with the pelvic incidence nor with the vertebral concavity ratio (Table 4).
Discussion

In this study including 522 participants with a median age of 9.9 years, we found a mean pelvic incidence of 36.6° (SD 8.0), with a normal distribution, without any difference between boys and girls. The vertebral concavity ratio indicated mild concave vertebrae at all levels, with lower ratios for boys compared to girls. Both a larger pelvic incidence angle and a larger vertebral concavity ratio were associated with a decreased disc height, and a smaller pelvic incidence was associated with less disc bulging. A higher fat-free mass index was associated with a smaller pelvic incidence, while none of the body composition measures were associated with the vertebral concavity ratio.

Spinopelvic alignment develops during childhood, and the morphology of the spinopelvic setting is fixed at the end of skeletal growth [15]. The pelvic incidence found in the present study population was somewhat smaller compared to previous studies in children within the same age range [16, 17]. This difference might be explained by the difference in position of the participants: the MRI’s in the present study were performed in supine position, while participants in the other studies underwent standing lateral radiographs. Although the pelvic incidence is described to be independent of measurement position, an overestimation of the pelvic incidence on standing radiographs or an unstable sacroiliac joint in certain patients has been suggested [18]. The vertebral shape measure used, i.e. vertebral concavity ratios, showed a mild concave shape of the vertebrae at all lumbar levels in the present study, which indicates that this is a normal vertebral shape in children aged nine years old. We found significant differences in the vertebral concavity ratios between boys and girls, which is in contrast to studies in adults that showed no differences in vertebral concavity between sexes [19, 20]. The children in our study population were in their growth, with different growth patterns for boys and girls. This seems reflected in cervical vertebrae measures [21] and may disappear after further development towards adulthood. With the follow-up measurements of the present longitudinal cohort study, future analyses will enable us to get more insight into these differences of development between sexes.

In literature, a lower pelvic incidence or smaller lordosis is associated with more disc degeneration in adults [22]. In our study, no association between pelvic incidence and disc degeneration was found. This difference is likely due to the fact that we studied a group of children in whom these abnormalities are relatively rare and it might be too early.

| Table 1 Characteristics of the included participants (N=522) |
|-------------------------------------------------------------|
| Age (years) 9.9 (9.7–10.0) |
| Sex (boys) 249 (47.7) |
| Ethnicity                                                   |
| Dutch 439 (84.1) |
| Other-Western 31 (5.9) |
| Non-Western 52 (10.0) |
| Weight status                                               |
| Underweight 35 (6.7) |
| Normal weight 436 (83.5) |
| Overweight 45 (8.6) |
| Obese 6 (1.1) |
| BMI (SD-score) 0.08 (0.9) |
| Fat mass index (kg/m²) 3.9 (3.3–5.0) |
| Fat free mass index (kg/m²) 12.5 (11.8–13.2) |
| Fat free mass (%) 24.0 (20.5–28.7) |
| Fat free mass (%) 76.0 (71.3–79.5) |
| Height (SD-score) −0.07 (0.9) |
| Skeletal age (years) 9.2 (1.2) |

Values are means with standard deviations, or medians with interquartile range for continuous variables, and numbers with percentage for categorical variables. This table is based on non-imputed data; there was 1 missing value (0.2%) for skeletal age.

BMI Body Mass Index, FMI Fat Mass Index, FFMI Fat-Free Mass Index.

Fig. 3 Distribution of the pelvic incidence angle in 9-year-old children. The three equal tertiles are represented by the different colors: blue for pelvic incidence < 32.30°, green for pelvic incidence ≥ 32.30° and < 39.52°, and orange for pelvic incidence ≥ 39.52°.
in the development to identify these associations. However, a larger pelvic incidence is associated with decreased disc height. An increased pelvic incidence indicates an increase in lumbar lordosis. This may cause more compression and shear forces on the intervertebral discs, resulting in decreased disc height. However, this is purely suggestive, since our analyses are based on cross-sectional data and no causal relationship can be determined. A negative association was found between a lower pelvic incidence and the presence of disc bulging, which indicates less posterior disc bulging in children with a more straight spine. So these findings indicate that spinopelvic alignment already seems to play a role in the presence of structural spinal abnormalities in childhood.

The positive association of the vertebral concavity ratio with the presence of a decreased disc height found in our study population seems logical, as a greater ratio indicates the vertebra to be more flat or even somewhat convex, which results in a smaller disc height of the adjacent intervertebral disc. As no other associations were found between any of the structural abnormalities and vertebral shape, the role of the vertebral shape in the presence of structural spinal abnormalities seems unlikely.

Associations of body weight and composition with structural spinal abnormalities have been described in adults, adolescents, and children [8, 23–25]. Jankowicz-Szymanska et al. (2019), recently showed that excessive body weight is associated with the sagittal shape of the lumbar spine in children aged 10–12 years [13]. In the present study, we found an association of the BMI-SD score with the pelvic incidence, but this association did not remain after adjustment for potential confounders. However, the association of the fat-free mass index with the pelvic incidence did remain significant after adjustment. It is difficult to interpret and

### Table 2 Pelvic incidence and vertebral concavity ratio’s in the study population, with sex differences

| Values are means with standard deviations for continuous variables, and number with percentage for categorical variables. This table is based on non-imputed data; missings on concavity ratio were 397 for L1, 150 for L2, 30 for L3, 7 for L4, and 1 for L5. Bold values are statistically significant |
|---|
| **Pelvic incidence (degrees)** |
| Angle (°) | Total (n = 522) | Boys (n = 249) | Girls (n = 273) | p-value |
| 36.6 (8.0) | 36.7 (7.8) | 36.5 (8.3) | 0.795 |
| <32.30° | 174 (33.3%) | 82 (32.9%) | 92 (33.7%) | 0.741 |
| 32.30–39.52° | 174 (33.3%) | 87 (34.9%) | 87 (31.9%) |
| ≥39.52° | 174 (33.3%) | 80 (32.1%) | 94 (34.4%) |
| **Vertebral concavity ratio** |
| L1 | 0.90 (0.06) | 0.89 (0.06) | 0.92 (0.06) | 0.001 |
| L2 | 0.87 (0.06) | 0.86 (0.06) | 0.88 (0.06) | 0.001 |
| L3 | 0.87 (0.06) | 0.85 (0.06) | 0.88 (0.06) | <0.001 |
| L4 | 0.89 (0.06) | 0.88 (0.06) | 0.90 (0.05) | <0.001 |
| L5 | 0.88 (0.06) | 0.86 (0.05) | 0.89 (0.06) | <0.001 |

### Table 3 Associations between pelvic incidence, vertebral concavity ratio, and structural abnormalities

| Signal intensity | Disc height | Pfirrmann Grade | Disc bulging | Nuclear shape | Endplate irregularities |
|---|---|---|---|---|---|
| Abnormal (n = 125) | Decreased (n = 185) | Abnormal (n = 17) | Yes (n = 362) | Abnormal (n = 147) | Yes (n = 196) |
| Pelvic incidence |
| Angle Crude | 1.02 (1.00; 1.04) | **1.03 (1.02; 1.05)** | 1.00 (0.97; 1.03) | 1.01 (1.00; 1.03) | 1.02 (0.99; 1.04) | 1.00 (0.98; 1.02) |
| Adjusted<sup>a</sup> | 1.02 (1.00; 1.04) | **1.03 (1.02; 1.05)** | 1.00 (0.97; 1.03) | 1.01 (1.00; 1.03) | 1.02 (0.99; 1.04) | 1.00 (0.98; 1.02) |
| <32.30° Crude | 0.93 (0.63; 1.39) | 1.24 (0.85; 1.80) | 1.12 (0.63; 1.98) | **0.72 (0.55; 0.94)** | 0.83 (0.54; 1.28) | 0.95 (0.66; 1.37) |
| Adjusted<sup>a</sup> | 0.93 (0.62; 1.39) | 1.28 (0.87; 1.86) | 1.12 (0.63; 1.99) | **0.73 (0.56; 0.95)** | 0.86 (0.56; 1.31) | 0.96 (0.67; 1.38) |
| 32.30–39.52° Crude | Reference | Reference | Reference | Reference | Reference | Reference |
| Adjusted<sup>a</sup> | Reference | Reference | Reference | Reference | Reference | Reference |
| ≥39.52° Crude | 1.15 (0.79; 1.69) | **2.32 (1.66; 3.26)** | 1.14 (0.65; 2.00) | 0.82 (0.63; 1.07) | 1.00 (0.66; 1.51) | 1.04 (0.73; 1.48) |
| Adjusted<sup>a</sup> | 1.12 (0.76; 1.64) | **2.39 (1.69; 3.37)** | 1.13 (0.64; 1.99) | 0.85 (0.65; 1.11) | 1.02 (0.68; 1.55) | 0.99 (0.69; 1.42) |
| Vertebral concavity ratio L1 to L5 Crude | 2.10 (0.14; 32.42) | **10.40 (1.00; 108.06)** | 2.64 (0.04; 159.25) | **0.14 (0.03; 0.79)** | 2.41 (0.16; 37.13) | 0.24 (0.02; 2.50) |
| Adjusted<sup>a</sup> | 1.15 (0.07; 18.91) | **14.16 (1.28; 157.13)** | 2.40 (0.04; 160.19) | 0.27 (0.05; 1.52) | 2.40 (0.15; 39.84) | 0.17 (0.02; 1.86) |

Values are Odds Ratios with 95% confidence intervals. Multilevel analyses are based on complete cases.

<sup>a</sup>Adjusted for sex and skeletal age. Bold values are statistically significant.
explain the mechanism behind and meaning of this association, especially since we did not find any associations of the other body composition measurements with the pelvic incidence. The association we found might be a coincident finding. However, it might also be the case that especially the fat-free mass, and not the fat mass, plays a role in the spinal development in children. Therefore, further research is needed to investigate how this relation between the fat-free mass and pelvic incidence develops towards adulthood.

Strengths and limitations

The major strength of this study is the large sample size of children from a general population, in which we were able to assess the children’s spines on MRI and additionally retrieved extensive information on their body composition. Additionally, we were able to adjust the analyses for the skeletal age. However, some limitations should be taken into account. First, to reduce the risk of inaccuracy of the MRI measures, annotations were only made if the landmarks were clearly visible. Unfortunately, this caused missing values in some of the images, but these are likely to be random and therefore not introducing any bias. Also, the calculated pelvic incidence and vertebral concavity ratios were very sensitive for small variations in the manual annotations. These variations were limited by following the standard protocol and only two people working on the annotations. Furthermore, the subsample of the study cohort we used included more children with a Dutch ethnicity and less children with overweight or obesity compared to the total study cohort, even though the selection was intended to be random [8]. Therefore, caution should be made in the interpretation of the study results, as the study sample is not fully representative of the Dutch and worldwide population of children.

In conclusion, the pelvic incidence of the 9-year-old children in this study follows a normal distribution with a mean of 36.6° on supine MRI images, and a slightly concave shape of the lumbar vertebrae is seen. Spinopelvic alignment seems to be associated with structural spinal abnormalities, already at this young age, and might itself be influenced by the children’s body composition. Longitudinal studies are needed to further assess the relations between body composition, pelvic incidence, and structural abnormalities, and their development and influence on complaints later in life.

Appendix 1–Landmarks on spinal MRI images

See Figs. 4, 5.
Fig. 4  Markers placed on landmarks of the lumbar spine: corners and center of the upper and lower endplate of each lumbar vertebra and sacral plate, and anterior and posterior borders of the sacral canal at each lumber level.
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Author contributions All authors contributed to the study’s conception and design. Measurement software was developed by Hakim C. Achterberg, in collaboration with Marleen M. van den Heuvel. Data analysis were performed by Marleen M. van den Heuvel and Nathalie E. Griffioen. The manuscript was written by Marleen M. van den Heuvel, Nathalie E. Griffioen, and Marieke van Middelkoop, and all authors read and approved the final manuscript.

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Availability of data and material The datasets generated during and/or analyzed during the current study are not publicly available due to privacy reasons but are available from the corresponding author on reasonable request.

Fig. 5 Markers placed on the center of the femoral heads, determined by placing a circle around the femoral heads, both in coronal and sagittal plane.

Declarations

Conflict of interest SB reports consulting fees from Pfizer, personal fees from OARSI Congress, personal fees from Osteoarthritis & Cartilage, grants from The Netherlands Organisation for Health Research and Development, and grants from Dutch Arthritis Association, outside the submitted work. Other authors declare no conflict of interest.

Code availability ViewR Code. Available at: https://gitlab.com/radiology/infrastructure/viewr/. ViewR Documentation. Available at: https://viewr.readthedocs.io/en/latest/.

Ethics approval All measurements within the Generation R Study have been approved by the Medical Ethics Committee of Erasmus Medical Center Rotterdam, The Netherlands (MEC-2012–165).

Consent to participate Written informed consent was obtained from all parents or legal caretakers.

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