INTRODUCTION
In recent computed tomography (CT) studies we demonstrated the presence of a preexistent axial rotation in the normal non-scoliotic spine. Although certainly less in magnitude, the observed rotational patterns were comparable to the convexity of the curve in idiopathic scoliosis. Asymmetrical growth of the neurocentral junctions (NCJs) may play an essential role in the preexistent rotational patterns of the spine, because the NCJs are responsible for the growth of vertebral bodies and arches. To our knowledge, no studies systematically analyzed the closure and asymmetry of the NCJs in relation with the preexistent rotational patterns in the normal growing spine. The authors hypothesize that the preexistent rotational patterns are a result of an asymmetrical closure of the NCJs in the normal children’s spine. The purpose of this study is to evaluate the closure and possible asymmetry of the NCJs in relation to the preexistent rotational patterns in the normal thoracic and lumbar spine and the convexity of the curve in idiopathic scoliosis.

METHODS
Between January 2005 and February 2011, 599 children underwent CT of the thorax (and abdomen) for several indications; e.g. recurrent pulmonary infections or prior to bone marrow transplantation. Exclusion criteria were: spinal pathology or trauma, anatomical abnormalities and syndromes affecting growth. Additionally, scans with poor quality; artifacts or consisting of too few slices were excluded. The exclusion of a total of 400 (67%) children, led to an inclusion of 199 children (36% girls) and a total of 4992 NCJs. Categorization into 52 infantile (0-3 years old), 69 juvenile (4-9 years old), and 78 adolescent (10-16 years old) children was based upon the classification of idiopathic scoliosis by the Scoliosis Research Society.

On the transversal CT-slice of each vertebra from level T2 to L5 at which both pedicles were best visible, measurements were performed semi-automatically, using in-house developed software. For vertebral rotation, the same measurement method was used, as in our previous studies; vertebral rotation was defined as the angle between the longitudinal axis of the vertebra and a midline through the thorax in the transversal plane (Figure 1A). Age of closure of the NCJs was defined as the age at which fifty percent of the NCJs were determined as closed. Semi-automatically, absolute area data of all NCJs were collected (Figure 1B) and the angle between the longitudinal axis of the vertebra and the ‘best-fit’ line through a NCJ was calculated (Figure 1C). A P value <0.05 was considered to be statistically significant.

RESULTS
Intra-class correlation coefficients for inter- and intraobserver reliability for the measurement of NCJ area and NCJ angle, were 0.96 (95% CI: 0.95-0.96) and 0.99 (95% CI: 0.98-1.00) and 0.85 (95% CI: 0.80-0.88) and 0.88 (95% CI: 0.85-0.91), respectively.

Analyses of the age of closure of the NCJs showed that lumbar levels close first, at an average age of 4-5 years old, followed by high thoracic levels (T2-T4) at the age of 6-8 years old; and at last mid thoracic levels (T5-T12) at the age of 8-9 years old.

Asymmetry in the mean surface area of the NCJ was significantly different between the age cohorts (P=0.008). At the infantile age, the right NCJ was predominantly larger than the left NCJ and at the juvenile age the left NCJ was larger than the right NCJ. At the adolescent age most levels were closed. Post hoc analysis showed a statistically significant difference in NCJ asymmetry between the infantile and juvenile cohorts (P=0.037). There were no significant differences in asymmetry of the angle between the NCJ and the longitudinal axis of the vertebra between the age cohorts.

Mean vertebral rotation was significantly different between the age cohorts (P<0.001). The high thoracic spine was rotated to the left in all cohorts. The mid thoracic spine (T6-T12) was predominantly rotated to the left at the infantile age (P=0.05) and to the right at the juvenile and adolescent age (P=0.035 and P=0.004, respectively). The lumbar spine was rotated to the left in infants (P=0.05), and in the midline in juveniles and adolescents. No statistical significant differences in vertebral rotation were seen between the genders (P=0.076).

DISCUSSION
The role of the NCJ in the etiopathogenesis of idiopathic scoliosis has been frequently discussed in the literature. This study showed significant differences in NCJ asymmetry in the mid thoracic spine between non-scoliotic infantile, juvenile, and adolescent children, matching the convexity of the curve in idiopathic scoliosis. In the mid thoracic spine, the right NCJ was predominantly larger in infants, the left NCJ in juveniles, and no asymmetrical pattern of the NCJ was observed in adolescents, because most NCJs were already closed.

Previous results of preexistent rotational patterns in the normal spine were confirmed by this study. The mid thoracic spine was predominantly rotated to the left in infants, and to the right in juvenile and adolescent children. The presence of asymmetrical closure of the NCJs in the normal spine possibly results in a preexistent rotation at the same spinal levels, by providing asymmetrical growth of the pedicles and/or of the vertebral body. In the literature, the symmetry of the NCJs in the normal spine has been discussed by cadaver studies or the analysis of the length the NCJs in a small population.3 Because every NCJ has other morphometric characteristics, semi-automatic NCJ analysis using segmentation software in a large population provides more representative data.

In conclusion, the asymmetrical closure pattern of the NCJs matches the preexistent rotational pattern of the normal, non-scoliotic spine and the convexity of the curve in idiopathic scoliosis. This study supports the hypothesis that once an idiopathic scoliosis develops, it follows a preexistent rotational pattern, caused by the asymmetry of the NCJs in the normal spine.

SIGNIFICANCE: This study contributes to the knowledge of the basic anatomy of the growing spine. Additionally, it supports a hypothesis about the convexity of the curve in idiopathic scoliosis.

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