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Anatomical Study

Patterns of Rib Growth in the Human Child

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Abstract

Introduction: Whereas there is substantial information on the changes of the rib cage during childhood and asymmetry of the thorax in children with scoliosis, there are virtually no normative data on the growth of individual ribs throughout childhood.

Methods: The Hamann−Todd (HT) Osteological Collection provided the bones of 32 human specimens aged 1−18 years. A total of 6,226 individual photographs of all vertebral bodies and ribs were obtained from these specimens. Quantitative measurements were taken with image analysis software and the results of 2 of the measurements, the outer costal length (OCL) and the base diameter (BD), are presented here.

Results: With the exception of the ribs at T12, both the OCL and BD showed linear, statistically significant growth with age for all ribs. The relationship of OCL and BD to each other within each rib was obtained by multiplying and dividing these 2 measurements. The BD × OCL product indicates that the ribs grow through coupled symmetry, by which ribs in the upper and lower thorax start at the same size and grow at the same rate within the pair; ribs 1 and 12, 2 and 11, and 3 and 10. Each rib pair grows at a significantly different rate from all other pairs. Measurements of BD and OCL from a specimen with scoliosis from the collection compared with these normative values were greatly different. The principle that ribs resemble a known geometric form, called the logarithmic spiral, is introduced.

Conclusions: This article is 1 of the first studies of the change in length and shape of normal ribs in an osteology collection of a wide age range of pediatric specimens. The data provide a framework for determining the difference between ribs from normal children and those with scoliosis.

Keywords: Thorax; Chest; Rib; Growth; Scoliosis

Introduction

Rib growth in the human child is important for the proper development and functioning of many of the critical internal structures, including the heart, lungs, and abdominal organs, as well as providing a stable attachment for the diaphragm. During human evolution the rib cage transitioned from a triangular funnel shape to a more barrel-shaped chest in *Homo erectus* approximately 1.6 million years ago. Canavese and Dimeglio [1] provided contemporary information on how the chest grows in volume during childhood. The neonate has approximately 6% of eventual adult chest volume. The 10-year-old child has 50% of eventual adult chest volume. Although the 10-year-old child is nearing adult height, by maturity there is a doubling of chest volume.

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The changing length and shape of the rib creates a greater cross-section of the thorax that, when added to the increase in thoracic height, rib separation, and costo-sternal growth, contributes to overall thoracic volume [1]. There is little detailed information on how the neonate with a triangular-shaped thorax assumes the barrel shape transition to adulthood. The infant chest is both more funnel-shaped as well as circular in cross-section compared with the adult. With increasing age the chest becomes more barrel-shaped, with greater transverse width in the mid-thoracic spine at ribs 6 and 7. A deeper understanding of rib growth is useful to understand thoracic growth, especially for the surgeon who cares for children with complex spine and chest deformities.

There is little published information on normal rib growth. Most studies have described abnormalities of rib or thorax growth and asymmetry in children with scoliosis [1-5]. Rib deformities created in experimental animals have demonstrated that abnormal thoracic development is a common feature of scoliosis [6,7]. Experimental rib measurements have included angular rotation [8], laterality differences between left and right [8-10], the centroid of the rib [11] and the slope index of the ribs [12]. In some studies, rib abnormalities have been limited to rib fusions or chest wall defects rather than specific defects in the rib [13,14].

In contrast to the ribs, the basic growth of the long bones is well described [15]. In the human femur, 70% of the growth occurs distally (approximately 1 cm/year) with 30% of growth occurring proximally. For the humerus, 80% of linear growth is proximal and 20% is distal. However, for ribs, the contribution to linear growth of the vertebral versus the costal end is unknown. Introducing standardized definitions of the dimensions of the rib might allow normative data to be used to describe how the rib appears to grow during childhood. Since the rib shape appeared to define an enclosed area, 2 measurements that represented this space were defined. The outer costal length (OCL) is the total curved length of the rib, and the base diameter (BD) is the linear distance connecting one end of the rib to the other. These 2 measurements influence the shape and size of the chest and therefore are considered 2 of the key parameters in thorax growth and development. The purpose of this study was to describe normative data of rib growth during childhood in human specimens from the Hamann−Todd (HT) Osteological Collection. This would then allow inferences to be made about the unique shape and growth pattern of pediatric ribs and determine how the growth of the rib contributes to the volume and shape of the developing pediatric thorax.

Materials and Methods

The HT Osteology Collection is housed in the Cleveland Museum of Natural History and contains over 3,100 human specimens, including 62 cataloged pediatric specimens aged 1−18 years. Most of these specimens are over age 10 years and there are no 2- or 9-year-old specimens in the collection. A total of 32 of the most complete specimens representing age 1−18 years were selected. At least 1 specimen from each available age group was selected to provide a cross-section of a growing population. The collection was visited twice to determine the best method for taking measurements of the growing spine and ribs. High-quality digital photographs with a background grid provided the most reliable information, because there were no transcription errors and any discrepancy or outlying value could be re-measured directly from the photographs.

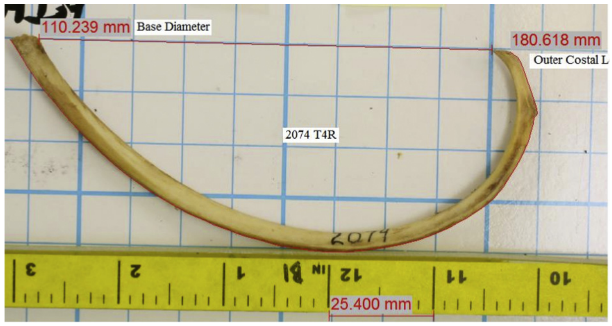

Fig. 1. Rib measurements. The grid pattern in the background is at 12.7-mm intervals. For the rib shown, the image was calibrated from the ruler (which is physically higher than the background). Physical measurements for the outer costal length and base diameter are indicated.

Five pediatric spine surgeons sorted the bones from each subject whereas 4 separate camera stations took a total of 6,226 high-definition photographs of ribs and vertebrae of the 32 pediatric specimens. Ribs were sorted right to left and proximal to distal, ribs 1−12. All available ribs and spines from the specimens were photographed. Spinal segments C1 to the sacrum and all available ribs were imaged in 6 different views from 3 orthogonal angles with the digital camera mounted on a tripod. Each photograph was then calibrated from the background grid and quantitative measurements were taken. The OCL was measured as the total curved length of the rib. The BD was the linear distance connecting one end of the rib to the other (Fig. 1). Scandium Image Analysis Software (Olympus, Soft Imaging Solutions, GmbH, Munster, Germany) was used for all measurements, reported to 0.1 mm. The final data set resulted in over 32,000 separate measurements. Of the 768 potential ribs, 714 were actually measured. Fifty-four of the ribs were missing and in 2 specimens the ribs were cut off, so they were excluded from the analysis. Linear regression correlation coefficients and 2 sampled t tests were used for statistical evaluation.

The authors also report on the ribs of 1 specimen from the collection with congenital scoliosis and compare the OCL and BD of an apical rib from this specimen to the 32 study HT specimens.

Results

Rib growth with age

The OCL BD was plotted against age; as an example, Figure 2 shows results only for the fourth ribs. Linear regressions demonstrated correlation coefficients (r^2) of 0.840