Adolescent idiopathic scoliosis young female rib hump: normative biomechanical data study

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1. Introduction

In adolescent idiopathic scoliosis (AIS), several investigations (Lee et al. 2005; Lam et al. 2011) demonstrated that low bone mineral density (BMD) is a systematic disorder in AIS which can be persistent. In a biomechanical view, a low BMD is associated with low bone strength. To our knowledge, in the case of scoliotic rib, no specific mechanical data are available to model scoliotic rib cage (Descrimes et al. 1995). From human surgery wastes (gibbectomy), cortical part of scoliotic ribs has been tested using an ultrasonic device to get elastic properties (Young's modulus, Poisson's ratio); CT scan has been used to get BMD added to an histomorphometric analysis to evaluate the porosity of the cortical area. The aim of this study was to provide normative mechanical data for ribs, components of the rib hump, by establishing BMD and elastic properties associated with histomorphometric observation. This study offers normative biomechanical information of scoliotic ribs and leads us to use these data in AIS rib cage finite element modelling

2. Methods

Two patients (F15 and F17, respectively, female of 15 and 17 years old) with severe deformities (more than 40° of Cobb angle) were treated to correct the rib hump deformity and 4 or 5 parts of these ribs were extracted. After the cutting process, the proximal part (1 cm length) of each rib was embedded in methyl methacrylate, which allows a histomorphometric evaluation with ImageJ® providing the porosity and the osteonal orientation. A CT scan was carried out on sticks designed in the remaining part, and on phantoms (Cirs 62) containing various concentrations of hydroxyapatite (HA; 200, 800, 1000, 1250 and 1750 mg/cm^3). This process allows to relate the CT Hounsfield units (HU) to mineral content (linear equation). Rectangular region of interests determined on each sample, with Mimics® (Materialise NV), leads to their own BMD (matrix 512 × 512 pixel size 215 μm in the cut plane). A specific ultrasound device (Figure 1), which is able to study a small sample, has been designed to obtain transversal and longitudinal velocities (VLs) using 7 MHz transducer. In the longitudinal direction and if the density values are known, it is possible to get Young's modulus.

3. Results and discussion

Porosity of cortical part is lower than 2.18%. Medium value is 1.35% with a standard deviation of 0.52. Tissue morphology of AIS ribs cross section shows a usual adult cortical bone morphology, lamellar and osteonal organisation. Each sample can be considered as non-porous material, thus to calculate the longitudinal Young's modulus E, we can use the following equation:

$$E = \rho \times v^2,$$

where ρ is the sample density and v the longitudinal wave velocity.

Upon condition that the wavelength of the ultrasonic wave used (0.22 mm) was 10 times lower than slides thickness.

Owing to the curve of each rib of the rib hump, seven rectangular samples were cut from F15's ribs and eight from F17. The linear equation obtained with HA phantom, (BMD = 0.8565HU + 224.23; $R^2 = 0.991$) leads us to an average value of 2204 mgHA cm^{-3} for F15 and 2500 for F17. These values of BMD are original, to our knowledge there is no similar data in the literature.

For the F15's ribs samples, average VL is 2575 m/s^{-1} (ranged from 2079 to 3103 m/s^{-1}) and average value for transversal velocity (VT) is 1660.62 m/s^{-1} (ranged from 1598 to 1746 m/s). Considering the F17's ribs, average VL: 2711 m/s^{-1} (ranged from 1799 to 3516 m/s); average VT: 1796 m/s^{-1} (ranged from 1576 to 2009 m/s; Figures 2 and 3).

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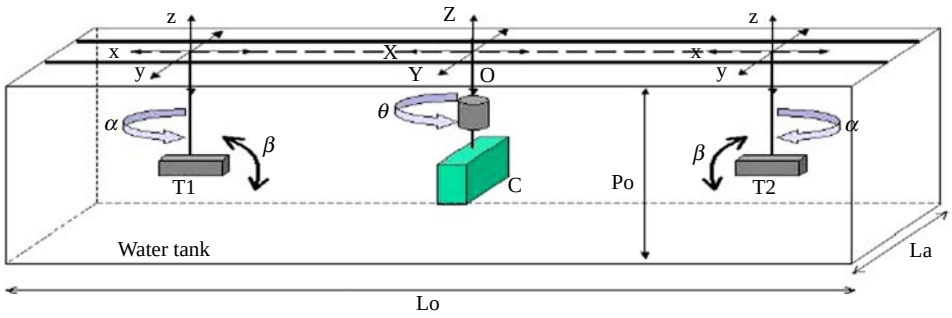

Figure 1. Acoustic bench (7 MHz).

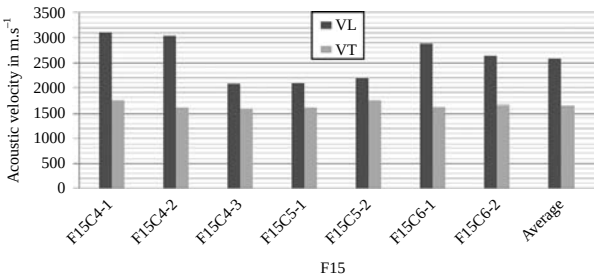

Figure 2. Acoustic velocity values for 15 year old females. ($Ci - j$; rib number: i and sample number: j).

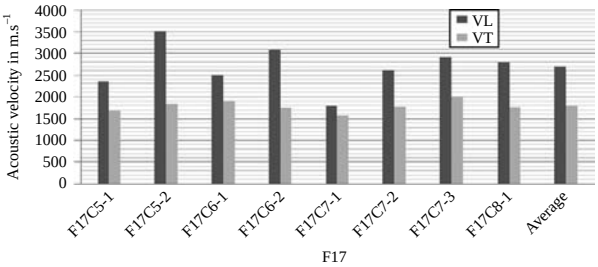

Figure 3. Acoustic velocity values for 17 year old females. ($Ci - j$; rib number: i and sample number: j).

Literature data for cortical part of human bone are 2700–3800 m/s (Katz et al. 1984) and 3550–4180 m/s (Yoon and Katz 1976), though to our knowledge, there is no human ribs evaluated using ultrasonic experimentation. Considering the Young modulus, $E3$ average value for F15 and F17 was, respectively, 12.1 ± 4.3 and 13.5 ± 2.5 GPa. These data are far away from the value (5 GPa; Descrimes et al. 1995) used in most of the finite element model of scoliosis. Though it is a value for cortical and trabecular part and from a study of a global vertebro-costal complex. In accidentology, the ribs Young's modulus correponds to a global value for a whole bone. That is why we cannot compare with normal young female cortical rib samples, and the lack of reference in paediatric population bone's data leads us to consider these as a reference.

4. Conclusions

This study gives an experimental ultrasonic scan and CT scan evaluation which provides normative data of cortical sample from scoliotic ribs. Models of spinal scoliotic deformity optimise brace or surgical treatment, their reliability is an important issue of biomechanical modelling; these new data could lead to improve their biofidelity. Evaluating the sensibility of mechanical properties could lead to a new numerical experimentation process. A new goal could be to analyse anisotropy by determining with other mechanical tests (such as compression) the Young modulus in other directions.

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