INTRODUCTION

In Adolescent Idiopathic Scoliosis, several investigations [1-2] demonstrated that low bone mineral density (BMD) is a systematic disorder which can be persistent. However, unlike vertebrae, no specific scoliotic ribs data are available in literature neither for internal morphometric data nor for mechanical properties and mineral distribution. To model scoliotic rib cage, realistic data are necessary. Focusing on specific scoliotic's ribs characteristics at the rib hump level is the aim of this paper. Ribs from human surgery wastes (gibbectomy) were studied to assess cross sectional dimensions, BMD and mechanical properties (Young’s modulus). A three-step method was developed: firstly, we evaluated the porosity of cortical bone by histology, secondly we processed a Ct-scan evaluation, on whole ribs for cross section dimensions, and on cortical sticks extracted for BMD. Finally, an ultrasonic experimentation provided mechanical values.

METHODS

On the last two years at the children’s hospital, two patients (F15 and F17, respectively female of 15 and 17 years old) without any exclusion criterion (chronic use of medicine, genetic or neuronal disorder, minimum calcium daily amount, …) and with severe deformities (more than 40° of Cobb angle) were studied. Gibbectomy of ribs 4 to 9 was done, and then the proximal part (1cm length) of each was embedded in methyl metacrylate and sectionned (8µm thick sections) to process an histomorphometric evaluation with ImageJ®. A CT-scan (Siemens 64 dual source, Siemens AG, Erlangen, Germany) was carried out to assess the morphology of each rib, cortical thickness was measured at 4 locations (top, bottom, anterior and posterior) and the torsion (alpha angle) of the cortical shell was measured along ribs axis (Fig 1). On cortical sticks, another CT-scan process allowed to relate the CT Hounsfield units (HU) (linear equation) to their own BMD.

Figure 1: morphometric rib analysis

A specific ultrasound device was designed to obtain longitudinal and transversal velocities (VL and VT) using 7 MHz transducer. In longitudinal direction and knowing the density value (ρ), Young modulus (E) is obtained.
RESULTS AND DISCUSSION

Porosity of cortical part is lower than 2.18 %, average value is 1.35 % +/- 0.52 (Results are presented as: mean +/- standard deviation). The histological images show a classical cortical bone organization (lamellar bone with osteon). Cross sectional dimensions are shown on table 1, the three first ribs (R4, R5, R6) got similar alpha rotation angle. The standard deviation does not allow to give normative morphometric data, more subject are expected for.

Because of the curve of each ribs extracted, only 7 rectangular samples were cut from F15’s ribs and 8 for F17. The linear equation obtained with HydroxyApatite (HA) phantom, (BMD = 0.8565HU + 224.23; R² = 0.991) lead us to an average value for F15 of 2204 mgHA.cm⁻³ and 2500 mgHA.cm⁻³ for F17.

Considering condition that the wavelength of the ultrasonic wave (0.22 mm) is ten times lower than slides thickness, we can calculate the longitudinal Young modulus using a law for non-porous material. For the F15’s ribs samples, VL is 2575 m.s⁻¹ (ranged from 2079 to 3103 m.s⁻¹) and VT is 16601 m.s⁻¹ (ranged from 1598 to 1746 m.s⁻¹). Considering the F17’s ribs, VL: 2711m.s⁻¹ (ranged from 1799 to 3516 m.s⁻¹) and VT: 1796 m.s⁻¹ (ranged from 1576 to 2009 m.s⁻¹). In literature, VL values for cortical part of human bone are 2700 - 3800 m.s⁻¹ [3] and 3550 - 4180 m.s⁻¹ [4]. To our knowledge up to date, there is no human ribs evaluated using ultrasonic experimentation.

Considering the Young’s modulus (E) for F15 and F17 is respectively 12.1 +/- 4.3 GPa and 13.5 +/- 2.5 GPa. They are different from the range value (5GPa for E) used in most of the finite element models [5]. We cannot compare them because these values are from a global vertebro-costal complex study and models of scoliosis mimics ribs as if it was one entity. Furthermore, we cannot compare our results to 15/17-year-old non scoliotic female rib due to the lack of reference in pediatric population bone’s data.

CONCLUSIONS

This study is a preleminary histological, Ct-scan and ultrasonic experimental evaluation which provides normative data of cortical sample from scoliotic ribs. In order to provide relevant statistic more samples are necessary. Due to the drastic inclusion criteria, a long term project is planned to study a sufficient number of subjects. Patient specific numerical models of spinal scoliotic deformity optimize brace or surgical treatment, their reliability is an important issue of biomechanical modeling; these new data could improve their biofidelity.

REFERENCES


Table 1: Cortical thickness (mm) of the ribs (Ri) measured at four locations (Top, Post, Bottom and Ant) are presented as mean +/- SD, length of each piece of rib is reported as well as angle alpha (in degrees).