Subject-Specific Bone Mechanical Properties: Is There An Alternative To X-Rays Modalities?

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1. Introduction

To build subject-specific models, non-invasive techniques applicable *in vivo* should be developed. To give an example this study focuses on the thorax. Thoracic injuries are one of the major causes for fatalities and injuries in car crashes. In order to improve users' safety a better knowledge of the ribcage biomechanics is requested[1,2,3]. This knowledge allows numerical models of the thorax to be built. Up to now such models represent standard individuals. However there is a need for improving the protection of the entire population of car users. Thus specific thorax models should be developed (e.g. for children at various ages and for adult taking into account the ageing effect). For health applications such as scoliosis correction using brace, patient-specific models are requested to improve treatment outcome. In both cases (safety of car users and *in silico* medicine for scoliosis), the geometry of the ribcage can be obtained from medical imaging and in particular using a low dose imaging technique[4,5].

One scientific bottleneck is related to the mechanical properties of the bone. How the apparent mechanical properties of the ribs can be measured non-invasively? Today quantitative computed-tomography is the only clinical modality that allows rib cage density measurement to derive rib apparent elasticity. This approach is based on the hypothesis that the relationships between density assessed using quantitative computed tomography and elasticity (as previously obtained on vertebral cancellous bone[6] or femoral cortical bone[7]) can be also found on the ribs. However the main drawback is the radiation dose of this imaging modality. To overcome this limit, ultrasound techniques could be an interesting alternative. Ultrasound axial transmission was developed to assess *in vivo* health status of long bones (radius, tibia) at peripheral skeletal sites[8] and could be applied to the ribs that look like a long bone and are close to the skin. Before considering *in vivo* application on the ribs, the goal of this study was to assess *in vitro* relationships between ultrasonic measurements and apparent elastic properties of ribs.

2. Methods

This approach was already performed on 9 human rib specimens (6 and 8 levels), from 5 subjects (67 to 80 years old) provided by the Departement Universitaire d'Anatomie Rockefeller (Lyon, France) through the French program on voluntary corpse donation to science. Rib segment (120 mm long) were cut from the midsection of each rib to perform three complementary measurements. First high-resolution peripheral computed tomography (HR-pQCT) (Xtreme CT, Scanco Medical, Brüttisellen, Switzerland) was considered (pixel size: 82 µm) to define the rib cortical thickness and the 3D geometry of the ribs. Then specimens were measured using ultrasound. A probe of 1 MHz with two emitters positioned on either side of a group of receivers was used for axial transmission ultrasound measurements. The measured parameter was the ultrasound propagation velocity from the first arriving signal (VFAS)[7]. The measurements were performed on the central area of the samples: 3 times (with repositioning of the probe) on the internal ($VFAS_{int}$) and external ($VFAS_{ext}$) sides.

Finally, three-points bending experiments were performed until failure. A servo-hydraulic testing machine was used (INSTRON 8802, High Wycombe, England). The loading speed was 0.5 $m.s^{-1}$. The apparent Young's modulus and the maximal bending strength were computed by two ways: firstly analytically using cross-section measurements from HR-pQCT and secondly using a numerical model and an inverse approach. The geometry of the numerical model was derived from the HR-pQCT images. The Young's modulus and the maximal strength

were identified using an inverse approach combining a finite element model of the rib and its corresponding experiment (load-displacement curve).
For the statistical analysis, the Wilcoxon-test was used for paired comparisons and the Spearman-test to study the correlations between variables.

3. Results

The influence of the rib level was analysed with a Wilcoxon test, and shows that the ribs 6 and 8 have equivalent mechanical, geometrical and ultrasonic properties (p>0.10). The correlations were found statistically significant between VFAS (internal and external sides) and both mechanical parameters (Young's modulus (analytical and numerical) and maximal strength). As an example the Spearman- coefficient was 0.87 (p<0.02) for the correlation between the $VFAS_{ext}$ and the Young's modulus obtained from the inverse method (Figure 1).

4. Discussion

The experimental values obtained are globally consistent with those reported in the literature. Ultrasonic velocity measurements are comparable to those measured at the radius by Muller et al[9]. Mechanical properties (Young's modulus and maximal strength) are in accordance with those obtained by Stitzel et al.[1] when comparing anterior sample locations. No relationship between ultrasound measurement on the ribs and the mechanical properties was reported previously. Such results open the way for non-invasive assessment of input data for numerical model of the thorax for various ages in the population.

5. Conclusion

This study on the ribs showed a highly significant relationship between the speed of the first arriving signal issued from ultrasound axial transmission and the mechanical properties (elasticity and maximal strength) obtained from bending experiments. This preliminary study opens the way to a non-invasive assessment of rib properties. This is a first step towards *in vivo* studies to get subject-specific rib properties.

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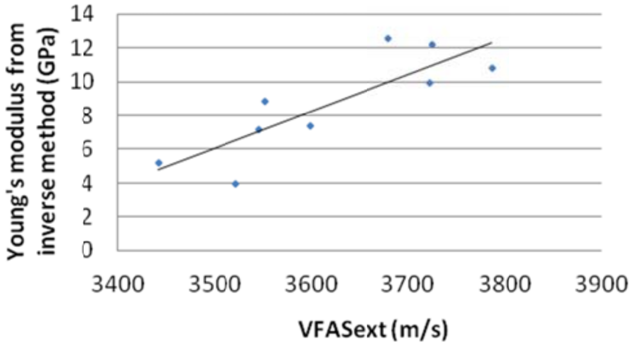

Figure 1 – Relationship between Young's modulus of the ribs (6^{th} & 8^{th}) and the velocity of the first arriving signal, r_{sp}=0.87, p<0.02 **(VFAS).**

7. References

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