Characterization of the difference in fracture mechanics between children and adult cortical bone

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1 Introduction

Clinical literature describes a specific type of children bone fracture, known as “greenstick facture” which is never encountered for adult bone. Concerning children bone, there is a tremendous lack of mechanical references. Indeed, the few studies which explored the mechanical characteristics of growing process in bone dealt with samples close to cancerous cells [1], or with samples from cadavers [2]. These studies gave dispersive results and did not provide insights to the two different kinds of fracture (i.e. brittle for mature bone and plastic for growing bone).

Part of the answer could lie in the evolution of the biochemical composition of cortical bone; indeed, Bala et al. [3] have shown that the elasticity depends on the mineral part of the bone matrix and the plasticity on the organic part (collagen 1).

This organic part of cortical bone seems to differ between adult and children. Saito et al. [4] have shown that the main non enzymatic crosslinks in mature bone (PYD+DPD) are different from those of growing bone (DHLNL+HLNL). It seems to us that the difference between plastic growing bone fractures and brittle adult bone fractures could be explained by this difference in the non enzymatic collagen crosslinking.

We performed three point microbending tests on children and adult bone to evaluate the mechanical Young’s modulus (E_m) and the plastic strain energy (ω_p). The results are in agreement with the clinical observations. The goal of this study is to explain these differences in mechanical behaviour between children and adult bone by using a biochemical analysis of the organic part quantifying the composition of the collagen.

2 Material and Methods

From a Marseilles hospital population, we studied non-pathological children cortical bone. Indeed in paediatric surgery, a whole autotransplant is extracted from the bottom of the fibula (5 cm up to the ankle) and the unused part (wastes) is included in this study. The adult bone samples of the same anatomic site were extracted from the cadaver population of the INSERM 1033 Unit (Lyon – France). A total of 29 parallelepipedic samples were obtained and their dimensions are from 15 to 35 mm long (bone axis direction), from 10 to 20 mm wide and from 2 to 3.5 mm thick (transverse directions). Furthermore, we have respected a ratio of 10:1 between span and thickness for the three points microbending. After size fitting, each sample had to have a weight upper than 1g to be included in the biochemical analysis of this study. Each sample is sorted in two groups: on one hand, 15 samples (4 to 16 year old) in children group and to other hand 14 samples (+/- 75 year old) in adult group.

A three point microbending test till fracture has been carried out to compare the mechanical behaviour of children and adult cortical bone. The span to depth ratio has been fixed to 10:1. Two parameters were estimated: the Young's modulus E_m and the plastic strain energy ω_p .The broken samples were then prepared to make a biochemical analysis quantifying the ratio between the two most important non enzymatic cross links (PYD + DPD) and (DHLNL + HLNL), called here R_{PONT} .

3 Results and Discussion

Spatz et al. [5] have established that the minimal span to depth ratio in three-point bending is around 20:1 (preferably 25:1) to estimate the Young's modulus of bone material. The ratio applied in this study (10:1) is imposed by the very short dimensions of the surgical wastes and may induce an underestimation of the mechanical Young's modulus. Nevertheless the values reported in Table 1 are in quite good accordance with the results published by Currey (1975).

Samples	n	Plastic Strain Energy ω_p (GPa)	R_{PONT}
Children	14	5.45 ± 2.38	0.23 ± 0.23
Adult	15	1.18 ± 0.67	0.63 ± 0.23
T-Test Student		$p \ll 0.001$	$p \ll 0.001$
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Table 1. Mechanical and biochemical results.

The experimental results of the microbending test show a statistic difference (T test, p***) between children and adult for ω_p . These results are in agreement with the clinical observations.
To gain insights on this difference in plastic strain energy, we have evaluated the organic matrix of the bone by an HPLC analysis.
We have found a difference between children and adult for the R_{PONT} value (p***) in agreement with Saito and al. [4] study. These results are shown in Table 1. In brief, it seems that two parameters are influenced by ageing process: the plastic strain energy ω_p and the R_{PONT} value. The relationship between these two parameters (ω_p and R_{PONT}) is a significant negative exponential correlation (R^2 = 0, 65) (Figure 1). The main feature of this result is the gap existing at 0.5 for R_{PONT}. Indeed, all adult samples (ω_p lower than roughly 2 MPa) are up to 0.5 for R_{PONT}. On the contrary, all children samples (ω_p higher than roughly 2 MPa) are down to this 0.5 gap. Our results show that a cortical bone a lower plastic strain energy that means a lower ability of the material to deform plastically (*brittle fracture*) has a R_{PONT} value lower than 0.5, and on the contrary, a cortical bone with a greater plastic deformation ability (*greenstick fracture*) has a R_{PONT} value higher than 0.5.

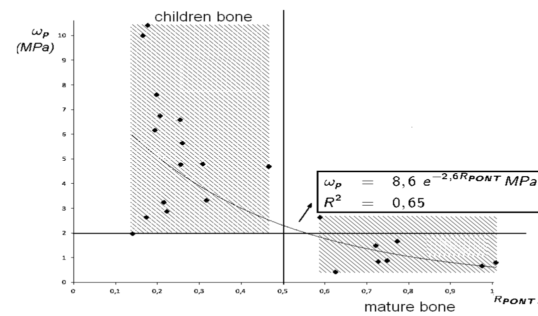

Figure 1. Correlation between ω_p and R_{PONT}.

4 Conclusion

The aim of this study is to compare the fracture mechanical properties of children and adult bone and to try to explain the differences found by analysing the collagen matrix. This study shows a link between plastic behaviour and subnanostructural organisation of the organic matrix in cortical bone during the ageing process.

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