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Elasticity Behaviour of a Healthy and Osteoarthritic Human Knee's Fresh Cancellous Bone

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Abstract

The aim of this paper is to evaluate the elasticity modulus of fresh human cancellous bone from the internal and external compartments segments of osteoarthritic and non-osteoarthritic knees. Cancellous bone samples of young and old subjects from both genders were collected. The measurements of the elasticity modulus were made only few hours after the samples were taken in through compression tests. The results show that the average value of elasticity modulus of the internal compartment (IC) (84.92 MPa) was the double of the external one (EC) (40.12 MPa). These values were found regardless of the gender and age factors. In osteoarthritic knees only the values of the internal compartment (121.88 MPa) increased, without significant variation of those of the external compartment (42.91 MPa). The results of this work need to be confirmed by other series. If they are validated, they would explain that the preferential site of osteoarthritis on the inner compartment of the knees is not only due to a static disorder, but that there is a structural bone factor. The confirmation of this new parameter will invite us to a review our anatomical, physiological, biomechanical knowledge of cancellous bone. The study was approved by the ethics Committee of Rabta Tunis Hospital, and all participants provided informed consent indicating their conscious and voluntary participation.

Keywords: Fresh cancellous bone; Knee; Elasticity modulus; Osteoarthritis; Decadent bones and joints

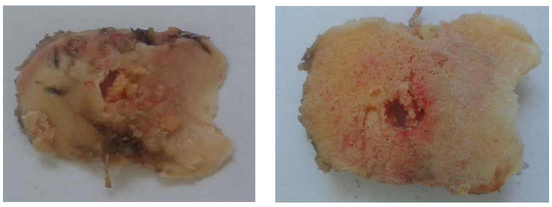
Introduction

In recent years, osteoarthritis has been the subject of numerous researches because of its social and economic repercussions [1]. The results of these researches are most often contradictory and make it impossible to understand either loads of observations such as the heterogeneity of the articular localizations, or the weak correlation between the radiographic changes and the clinical symptoms. That's the major purpose of this work; it's beginning on the internal compartment of the knees and not on the external one. We propose to know whether the preferential site of knee osteoarthritis on the internal compartment of the knees is determined by the various deviations of the knees [2], or if a bone parameter is associated with it, as the work of Martens et al. [3] seems to suggest. To approach this work, we chose to study among the large numbers of biomechanical parameters allowing characterizing the mechanical behaviour of the bone [4]. The most demonstrative parameter is the elasticity modulus. This module represents the relationship between a load applied to the section of a bone structure and the displacement induced in response to this load. If the values of the elasticity modulus of the materials are well known, we cannot say that about the bones. In a meta-analysis work, Goldstein [5] notes a very large disparity of results. He finds that the elasticity modulus varied between 1.1 MPa and 9800 MPa [5]. The causes of these differences are multiple and various. Some depend on the bone material [6], or its mode of preservation [7,8,9], embalming [7,8,10]. Others are the result of experimental protocols such as sample cutting plans [10]. This last factor is important in the bone because it considered as an anisotropic biomaterial and presented a heterogeneous structure.

Materials and Methods

Samples collection

This work is about the study of elasticity modulus of cancellous bone of the femoral condyles and tibial trays of 70 samples of healthy fresh bone and 26 samples of fresh bone osteoarthritis. The samples were obtained from amputated limbs or knees operated for knee osteoarthritis. Each sample was accompanied by an identification sheet (age, sex, side, anatomical site, time of collection and test time) as shown in Table 1. All these samples received the authorization of the ethics committee. These samples were divided into 18 samples from men (2 osteoarthritis and 16 non-osteoarthritis) and 78 samples from women (24 osteoarthritis and 54 non-osteoarthritis). The ages ranged from 19 to 83 for men and 46 to 82 for women. As for the anatomical site, 35 samples from the external compartment and 35 from the internal compartment for healthy bone are tested. While for osteoarthritic samples, 13 samples for each compartment are tested. The compartment is defined as the femoral condyle and try tibial. Macroscopically, the normal cancellous bone has a viscous aspect and reddish in color. It was covered by a thick white cartilage. Osteoarthritic cancellous bone was less red and less viscous, (Figure 1). The cartilage that overed it was thinner and denser



(a) (b)

Figure 1: Samples of osteoarthritic tibia: (a) view from above, (b) view from below External Tibial Compartment, Internal tibial compartment (IC): maximum densification zone.

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Sample number	Sex	Age	Anatomical Location (Femur / Tibia)	Anatomical location (internal compartment IC or external compartment EC)	Nature of the sample	Cause of amputation	Degree of osteoarthritis	Young Modulus E (MPa)
1	Woman	46	Tibia	EC	non-osteoarthritis	road accident	-	40.73
2	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	43.07
3	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	42.51
4	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	44.21
5	Woman	78	Femur	EC	non-osteoarthritis	road accident	-	41.21
6	Woman	78	Femur	EC	non-osteoarthritis	road accident	-	41.29
7	Woman	78	Tibia	EC	non-osteoarthritis	road accident	-	43.23
8	Woman	78	Femur	EC	non-osteoarthritis	road accident	-	35.55
9	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	41.6
10	Woman	60	Femur	EC	non-osteoarthritis	road accident	-	40.29
11	Woman	60	Femur	EC	non-osteoarthritis	road accident	-	44.11
12	Woman	78	Tibia	EC	non-osteoarthritis	road accident	-	37.59
13	Woman	60	Femur	EC	non-osteoarthritis	road accident	-	36.57
14	Woman	78	Tibia	EC	non-osteoarthritis	road accident	-	40.22
15	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	42.91
16	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	42.61
17	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	36.14
18	Woman	65	Tibia	EC	non-osteoarthritis	road accident	-	38.68
19	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	45.89
20	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	37.03
21	Woman	65	Tibia	EC	non-osteoarthritis	road accident	-	44.28
22	Woman	60	Tibia	EC	non-osteoarthritis	road accident	-	38.22
23	Woman	65	Tibia	EC	non-osteoarthritis	road accident	-	37.59
24	Woman	65	Tibia	EC	non-osteoarthritis	road accident	-	36.57
25	Woman	78	Femur	EC	non-osteoarthritis	road accident	-	40.22
26	Man	24	Tibia	EC	non-osteoarthritis	road accident	-	27.86
27	Woman	60	Femur	EC	non-osteoarthritis	road accident	-	42.91
28	Woman	65	Tibia	EC	non-osteoarthritis	road accident	-	42.61
29	Woman	64	Femur	EC	non-osteoarthritis	road accident	-	36.14
30	Woman	64	Femur	EC	non-osteoarthritis	road accident	-	38.68
31	Man	30	Tibia	EC	non-osteoarthritis	road accident	-	28.32
32	Man	83	Tibia	EC	non-osteoarthritis	road accident	-	45.43
33	Man	30	Tibia	EC	non-osteoarthritis	road accident	-	47.9
34	Man	24	Tibia	EC	non-osteoarthritis	road accident	-	38.55
35	Man	22	Tibia	EC	non-osteoarthritis	road accident	-	43.64
36	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	91.85
37	Man	28	Tibia	IC	non-osteoarthritis	road accident	-	93.9
38	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	71.01
39	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	71.14
40	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	84.94
41	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	99.9
42	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	94.24
43	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	80.75
44	Man	83	Tibia	IC	non-osteoarthritis	road accident	-	78.81
45	Man	83	Femur	IC	non-osteoarthritis	road accident	-	77.32
46	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	91.85
47	Woman	65	femur	IC	non-osteoarthritis	road accident	-	72.63
48	Woman	65	Tibia	IC	non-osteoarthritis	road accident	-	97.14
49	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	70.94
50	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	92.51
51	Woman	78	Tibia	IC	non-osteoarthritis	road accident	-	70.06
52	Woman	78	Femur	IC	non-osteoarthritis	road accident	-	72.57
53	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	87.84
54	Man	28	Tibia	IC	non-osteoarthritis	road accident	-	88.25
55	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	99.47

56	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	100.03
57	Woman	65	Tibia	IC	non-osteoarthritis	road accident	-	72.63
58	Woman	65	Tibia	IC	non-osteoarthritis	road accident	-	96.02
59	Woman	65	Tibia	IC	non-osteoarthritis	road accident	-	70.93
60	Woman	64	Tibia	IC	non-osteoarthritis	road accident	-	93.74
61	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	100.52
62	Woman	60	Tibia	IC	non-osteoarthritis	road accident	-	70.06
63	Woman	64	Tibia	IC	non-osteoarthritis	road accident	-	72.56
64	Man	28	Tibia	IC	non-osteoarthritis	road accident	-	79.79
65	Woman	46	Tibia	IC	non-osteoarthritis	road accident	-	84.78
66	Man	35	Tibia	IC	non-osteoarthritis	road accident	-	100.59
67	Man	30	Tibia	IC	non-osteoarthritis	road accident	-	88.15
68	Man	24	Tibia	IC	non-osteoarthritis	road accident	-	88.43
69	Man	28	Tibia	IC	non-osteoarthritis	road accident	-	77.94
70	Man	19	Tibia	IC	non-osteoarthritis	road accident	-	86.82
71	Woman	60	Tibia	EC	osteoarthritis	-	++	40,45
72	Woman	60	Tibia	EC	osteoarthritis	-	+++	46,68
73	Woman	60	Tibia	EC	osteoarthritis	-	+	41,6
74	Woman	78	Tibia	EC	osteoarthritis	-	++	46,73
75	Woman	64	Tibia	EC	osteoarthritis	-	+++	44,3
76	Woman	60	Tibia	EC	osteoarthritis	-	++	48,94
77	Man	83	Tibia	EC	osteoarthritis	-	+++	49,53
78	Woman	78	Tibia	EC	osteoarthritis	-	++	45,7
79	Woman	60	Tibia	EC	osteoarthritis	-	+	41,63
80	Woman	61	Tibia	EC	osteoarthritis	-	+++	45
81	Woman	62	Tibia	EC	osteoarthritis	-	++	41,32
82	Woman	62	Tibia	EC	osteoarthritis	-	+	29,24
83	Woman	60	Tibia	EC	osteoarthritis	-	++	36,74
84	Woman	60	Tibia	IC	osteoarthritis	-	+	105,68
85	Woman	60	Tibia	IC	osteoarthritis	-	++	110,17
86	Woman	60	Tibia	IC	osteoarthritis	-	+++	135,81
87	Woman	78	Tibia	IC	osteoarthritis	-	+	107,31
88	Woman	60	Tibia	IC	osteoarthritis	-	++	110,16
89	Woman	60	Tibia	IC	osteoarthritis	-	++	119,52
90	Man	83	Tibia	IC	osteoarthritis	-	+++	124,53
91	Woman	78	Tibia	IC	osteoarthritis	-	++	100,52
92	Woman	60	Tibia	IC	osteoarthritis	-	+++	136,88
93	Woman	62	Tibia	IC	osteoarthritis	-	++	119
94	Woman	60	Tibia	IC	osteoarthritis	-	++	117,24
95	Woman	61	Tibia	IC	osteoarthritis	-	+++	134,3
96	Woman	64	Tibia	IC	osteoarthritis	-	+++	163,43

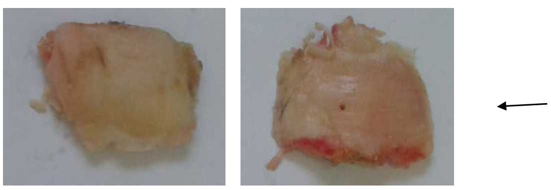
Legend : Degree of osteoarthritis :

+ : Osteoarthritis in the early stage

++ : Osteoarthritis in an advanced stage

+++ : Osteoarthritis in a more advanced stage (Total erosion of cartilage)

Table 1: Samples informations.



(a) (b)

Figure 2: Samples of osteoarthuric femur: (a) External condyle (thick cartilage), (b) Internal condyle (thin cartilage), Reduced cartilage and appearance of cancellous bone.

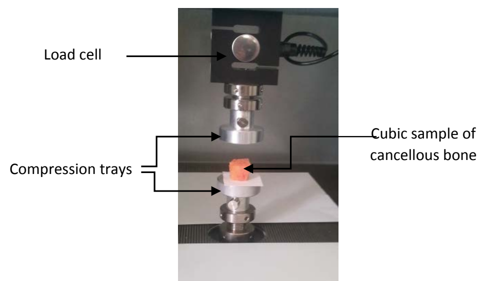


Figure 3: Tensile / compression testing machine with compression trays.

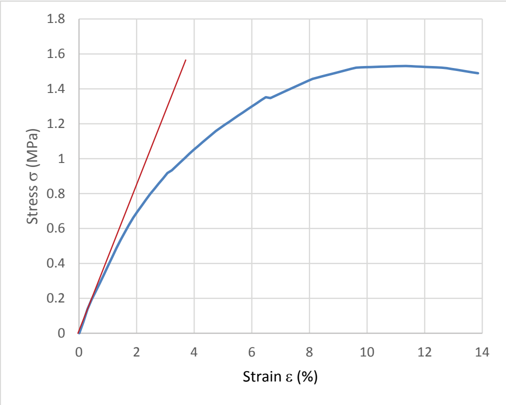


Figure 4: Stress/strain curve of a cancellous bone of the external compartment of the tray tibial of 60 years old woman.

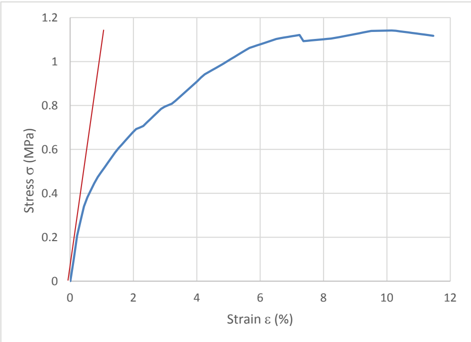


Figure 5: Stress/strain curve of a cancellous bone of the internal compartment of the tray tibial of a 60 years old woman.

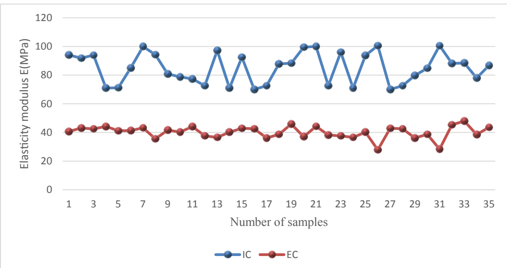


Figure 6: Evolution of elasticity modulus according to the number of samples of healthy human cancellous bone of the two internal and external compartments. (IC: Internal Compartment, EC: External Compartment).

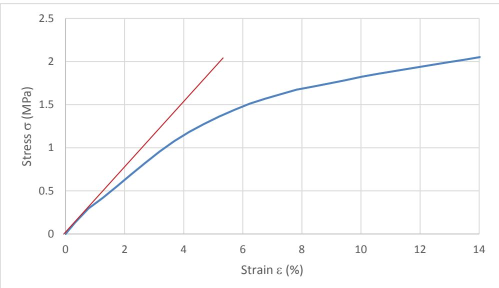


Figure 7: Stress/strain curve of a cancellous bone of the outer compartment of the tibial tray of a 60 years old osteoarthritis patient.

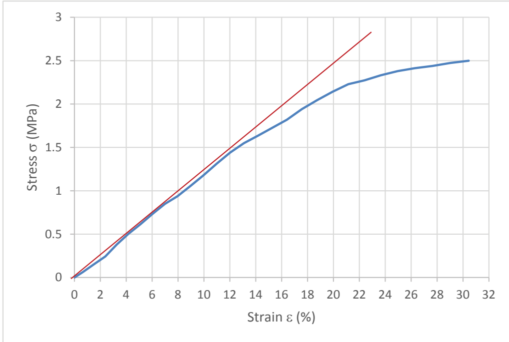


Figure 8: Stress/strain curve of a cancelous bone of the internal compartment of the tibial tray of a 60 years old osteoarthritis patient.

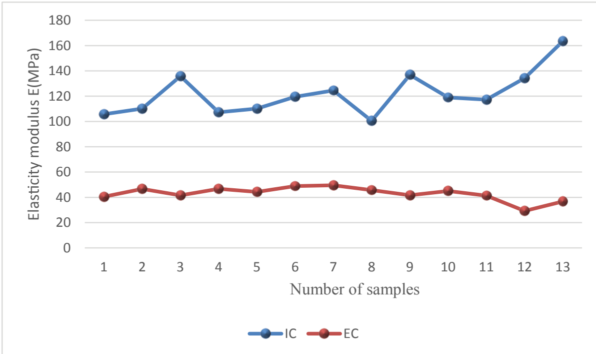


Figure 9: Elasticity modulus of osteoarthritic human cancellous bone of the two internal and external compartments of the knee. (IC: Internal Compartment, EC: External Compartment).

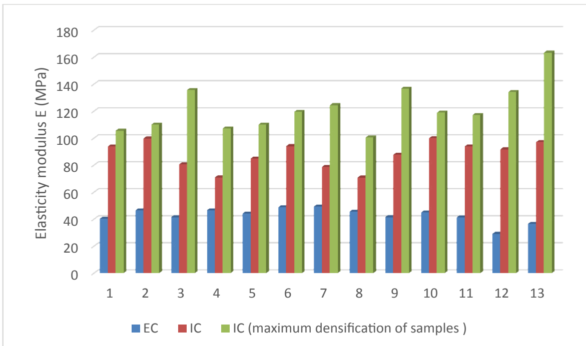


Figure 10: Distribution of the elasticity modulus values of osteoarthritis cancellous bone.

(Figure 2). In the old osteoarthritis, the osteocartilaginous lesions were found extended to the external compartment.

Experimental Conditions

Preparation

The epiphyseal cancellous bone, separated with the scalpel from its articular cartilage, was cut with a diamond saw into small cubes of 20 mm of edges measured with a digital caliper.

Measuring devices

A tensile/compression testing machine "LLOYd EZ50" was used for carrying out compression tests. This machine is equipped with a load cell of 5KN. Two special small size cylindrical compressing trays were designed using aluminium material as shown in Figure 3. All samples were transported the same day to the biomechanics laboratory and studied. In practical terms, we placed the samples one by one between the trays of the machine, then, progressively applied a compressive force along the longitudinal axis of the bone until they were broken. The cross-head speed was 1 mm/mn.

Results and Discussion

Determination of elasticity modulus of healthy knee joint of both internal and external compartments

The elasticity modulus values are obtained from the slope at the origin of the stress/strain curves as shown in Figure 4. The obtained average values are 84.92 MPa for the internal compartment and 40.12 MPa see for the external compartment.

With:

Stress $\sigma = F/S0$,

F: Force applied in N,

S0: Initial section of the sample in mm^2,

Strain: $\varepsilon = \Delta L/L0 = (L0-L) / L0$ (L: measured length, L0: initial length)

This difference between the two compartments was constant regardless of gender, age and the sampling area femur or tibia of the same compartment. The varied curve of the elasticity modulus of the internal compartment has more fluctuations than the external compartment (Figure 5).

A statistical analysis of the averages was made by a comparison T-test for independent samples using the SPSS software. The number of samples was sufficient. Indeed, 70 samples of normal cancellous bone including 35 of the external compartment of the knee and 35 of the internal compartment. The average values 84.92 MPa for the internal compartment and 40.12 MPa for the external compartment. The p-value 1,48189E -20 < 0.05 and the test is significant. The internal compartment elasticity modulus is greater than the external compartment E (IC) > E (EC). The elasticity modulus of cancellous bone is classified according to anatomical site of the internal and external compartment. The elasticity modulus of cancellous bone of internal compartment is twice as large as that of external compartment.

According to the sex, the elasticity modulus of internal compartment of the bone has an average of 37.28 MPa for men and 41.61 MPa for women. The p-value =0.32 >0.05. For the internal compartment, the average elasticity modulus found is 84.34 MPa for men and 84.81 MPa for women. The p-value = 0.88 >0.05. It can be seen that sex does not intervene in the classification of the elasticity modulus of cancellous bone.

Determination of the elasticity modulus of the articulation of internal and external compartments of the osteoarthritic knees

The elasticity modulus of cancellous bone for 26 arthrosic samples from 12 postmenopausal women and one man are determined. The results of the compression tests are represented by the stress/strain curves in Figure 4. Like healthy cancellous bone, the elasticity modulus of cancellous osteoarthritis bone, is classified according to the anatomical site: the internal and external compartment of the knee.

The elastic modulus curve of the internal compartment shows very large fluctuations with respect to the external compartment (Figure 5). The average elastic modulus of the external compartment is 42.91 MPa and that of the internal compartment is 121.88 MPa. A significance T-test was performed to validate the classification of osteo-cancellous bone samples according to the anatomical site, the p-value 9,90962E -09 < 0.05. The elasticity modulus of the external compartment of healthy and osteoarthritic individuals is similar while the elasticity of the osteoarthritic internal compartment is higher than that of healthy persons. The osteoarthritic cancellous bone has two values of the modulus of elasticity at the level of the internal compartment according to the state of the sample. The samples in the maximum densification zone have a higher value see Figures 6-10.

Conclusion

In this work, the study of compression tests of the knee's cancellous bone shows many peculiarities. The overall results of the elasticity modulus found are different from those published [8]. Does this difference lie in the choice to work on fresh and unsecured cancellous bone? This bone has anisotropic properties according to the anatomical location of the internal or external compartment of the knee joint. The highest modulus of elasticity is located in the internal knee compartment: (external compartment 40.12 MPa, internal compartment 84.92 MPa.). This difference is not only significant, but is independent of sex. In this study, there were no differences found in the modulus of elasticity between men and women. For the external compartment, it is 37.28 MPa for men and 41.61 MPa for women. For the internal compartment it is 84.34 MPa for men and 84.81 MPa for women. What's the cause that can explain the greater female frequency of osteoarthritis? In the osteoarthritic knees, only the values of the elasticity modules of the internal compartments are increased. It is noted that osteoarthritis occurs more frequently in single women. These results, if validated by other studies, would allow us to reconsider our reading and teaching of anatomy in general and of the musculoskeletal system in particular, and thus answer the repeated calls of many teams, [6,11-26] to better understand and treat a variety or multitude of orthopedic pathologies?

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