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Experimental forensic biometric study on the femur bone resitance as compared to the upper limb long bones resistance

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Abstract: The experimental study had the aim of comparing the femur resistance with the resistance of the tibia and the long bones of the upper limb (humerus, radius, ulna). The stretching, compression and bending biometrical forces were measured in 147 bone pieces, out of which 72 in compression, 21 in stretching and 53 in bending. The bone pieces were obtained through processing dead body material in 38 deceased people aged 60-70 years, after dissecting the bodies during the Anatomy and Embryology course at the Medicine, Pharmacy and Dentistry Faculty at "Vasile Goldiş" Western University in Arad. All the results were statistically processed in order to accuracy and precision for the study. There were significant differences between the stretching and bending forces and the cohort in which the compressions were done (p= 0,08). Significant differences were observed between the results of compressing the proximal and distal ends (femur, tibia and humerus). An F-test type analysis was done after the error elimination, establishing different correlation levels between the results obtained.
Key words: femur, bending, stretching, compressing, forces

Regarding the chemical composition, the bones are made of organic and inorganic non-homogenous materials, whose properties depend on the percentage ration that exist between them and the specific structure, being different, depending on the direction of the force. This is the reason why the bones of the elderly that have an osteoporosis degree and the trabecular matrix is thin and softened can be traumatized at small impact force velocity, corresponding to the normal walk speed. [5, 10, 11]

The lesions are situated preferentially at the proximal end of the bones, where the pronounced demineralization is the result of a continuous tension mechanism represented by the weight of the respective body and the osteoporosis process that affects the skeleton. In these regions the bone has a trabecular structure and the biomechanical properties are at a much lower level.

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Because the biological structure of the bone is not the same on transversal and longitudinal section, the bone properties are different when is charged with different electric charges on different incidences. The literature is rich in observations regarding the variation of the biomechanical properties, the born resistance being increased in athletes and the ones that perform sustained physical effort and have well developed muscles. Also, the correlation between the mechanical properties and the bone density was studied, the resistance diminishing with the decreasing of the bone density. [1, 2, 4]

The main objective of the study was the determination of the maximal compression, stretching and bending forces for certain bones of the upper and lower limb. The bone pieces that were studied, appertain to females or males aged 60-70 years.

The objectives were:

1. to obtain experimental results on real bones and to fill the database present in the literature
2. to be able to compare the behavior of different bones at variable mechanical forces
3. to compare the behavior at mechanical forces of the different parts of the same bone
4. to find analytical correlations capable of being used for the prognosis of the mechanical resistance in different test types, useful in the forensic expertise and crash tests.
5. to check and correlate the tests with literature

Material and method

The experimental study took place on several bone cohorts from the upper and lower limb skeleton. The bone pieces were prepared using the material obtained after dissection, appertaining to 60-70 years old people, in general in a bad nutrition state, so that as it regards the biological structure of the bone, these are generally demineralized.

The bone density was determined by the CT technique, using a Computer Tomograph Siemens Somatom Plus 4 in the Processing Images Laboratory from the Polytechnical University in Timisoara.

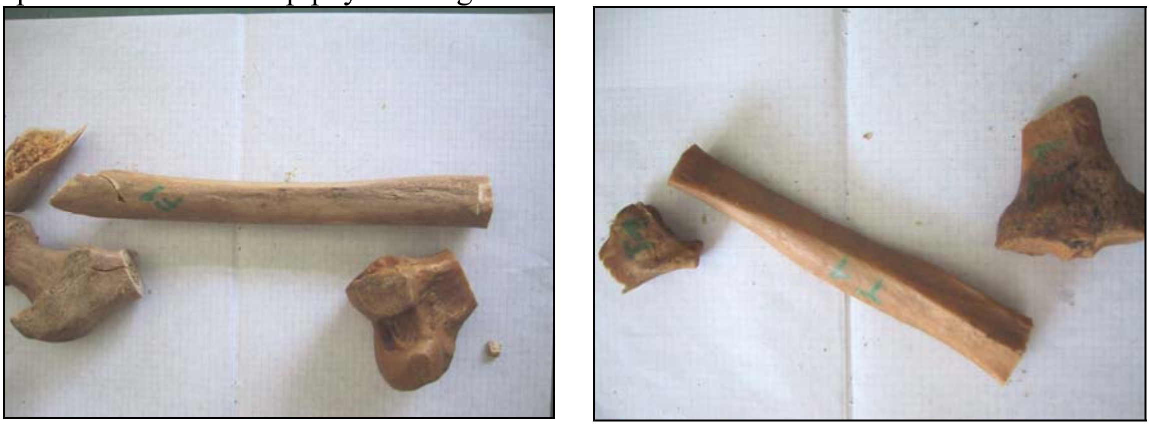
After measuring, the density value was detected in the interval 0,31 +/- 0,3 kg/cm^3(p = 0,01), on a 12 random pieces cohort form the bones tested for bending. [7, 13]

For the pieces sectioned at both ends, used in the lots exposed to compression forces, the density was 0,175 +/- 0,01 kg/ cm^3 (p = 0,03). [7, 13]

The bones preparation protocol of the bones comprised the following stages: the bodies were injected with 10% formaldehyde solution and kept 4-6 months dived in formaldehyde. After another 6 months dissection period, the limbs were taken out from the articulations and put in water for 48 hours, to dilute the formaldehyde present in the tissues and that prevented the removal of these tissues through boiling. During this time, the water was changed 3-4 times to dilute and extract better the formaldehyde. After this operation, the bone pieces covered with muscular tissue were boiled until the tissues detached alone. In the end, the bone pieces were washed in warm water and then in 19% NaOH solution and again warm water and kept to dry at room temperature without sun exposure.

Several bone lots were tried at a universal testing machine with a progression charging rate of 0,001 s^{-1}, respecting the conditions imposed to a static test. In order to obtain the bones pieces for the experiment, there were sectioned the proximal and distal epiphysis. The breaking forces and the area of the fracture point were measured in order to establish the breaking behavior. [7, 10, 12]

To obtain the pieces exposed to the test, the one samples were sectioned at both ends, the proximal and distal epiphysis being removed.



a. *Femur – piece no.1* b. *Tibia - piece no.1*

Fig. 1 Bones after the first sectioning

For the compression lot, the values of the section surfaces were obtained approximating the section surface as being trapezoidal.

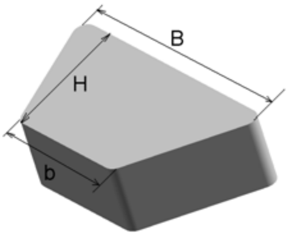


Fig. 2 The section surface in the compression lot

Fig. 3 The section surface in the bending lot

Fig. 4 Testing the stretching resistance – probe no. 2

Fig. 5 Testing the bending resistance – probe no. 3

For the bending and stretching tests, the length of the bone pieces was variable, over passing 150 mm in all cases, length that represents the distance between the mechanical supports. Except for the femur, whose section surface was compared in the middle third with a cvasicirculary, for all the others the section surface was considered triangular and the sides being precisely measured. [7]

As an example, in table 1 the measured there can be observed the measured values correspondent to the geometrical figures represented in figure 2 and 3.

The compression and stretching tests were done along the longitudinal axis of the bone (figure 4) and the bending ones were done perpendicular on this axis (figure 5). In the last lot, the bone pieces suffered a charge at both ends and at the middle third (three points charge). [6, 7, 8]

The charge was determined through dividing the registered force value to the section area of each studied piece. The charging values were processed using statistical calculations to obtain useful conclusions regarding the mechanical properties of the bones of the elderly.

The critical values found experimentally were analyzed first using the Chauvenet criteria. [7, 8, 11, 12]

Table 1 The geometry of the bone surfaces resulted through sectioning

Piece no.	Femur							
	b [mm]	B [mm]	H [mm]	$A_{trapeze}$ [mm^2]	L1 [mm]	L2 [mm]	L3 [mm]	$A_{triangle}$ [mm2]
1	43.0	83.0	59.0	3717	29.5	30.0	30.0	299.35
2	41.0	77.0	65.0	3835	27.5	29.0	27.0	269.76
3	37.0	67.0	61.0	3172	28.0	26.5	27.5	262.52
4	37.0	77.0	56.0	3192	28.5	26.0	27.5	262.52
	Tibia							
1	38.0	41.9	41.6	1661.92	19.0	27.0	25.0	211.5157
2	38.7	46.3	43.0	1827.50	25.0	22.5	29.5	238.88
3	35.9	42.6	44.8	1758.40	23.5	25.5	20.5	204.84
4	41.0	48.8	49.7	2231.53	30.5	26.5	31.5	294.35
5	33.2	42.0	43.6	1639.36	18.5	23.5	17.0	160.22
6	38.0	41.9	41.6	1661.92	19.0	27.0	25.0	211.51

Bone studied	Test	No. of pieces	Tension [MPa]	Standard deviation [MPa]	Statistical confident [MPa]	Variant [MPa]^2
Femur	Compression the proximal extremity	12	1.6005	1.0364	1.7046	1.0740
	Compression the distal extremity	12	1.6828	1.1403	1.8756	1.3002
	Stretching	7	4.4168	1.9974	1.1488	3.9895
	Bending	11	4.0218	2.3957	1.9703	5.7395
Tibia	Compression the proximal extremity	13	0.6506	0.3706	0.0740	0.1373
	Compression the distal extremity	13	1.5224	0.7172	0.8251	0.5144
	Stretching	6	1.4872	0.4914	0.0154	0.2414
	Bending	10	4.2616	1.9592	1.6113	3.8384
Humerus	Compression the proximal extremity	11	1.2348	0.6284	1.0336	0.6351
	Compression the distal extremity	11	1.4593	0.7369	1.2121	0.7005
	Stretching	8	3.0035	1.6932	1.1246	3.9545
	Bending	10	2.0971	2.5682	2.0890	6.2033
Radius	Bending	11	2.2988	1.0205	1.1870	1.0415
Ulna	Bending	12	4.4310	2.3989	1.9730	5.7549

Table 2 Results of compression and stretching tests

Results

The most complex and resistant bones of the human skeleton, femur, tibia and humerus, were tested in order to measure the compression, stretching and bending resistance.

Ulna and radius were tested for bending because they are bones whose compression resistance role is decreased after applying the Chauvenet criteria, the results were processed and the following parameters were processed: the average charge, the standard deviation. [7, 8, 12]

The charging values were compared and brought up global information about the testing lots (Table 2). Representing the maximal values for the femur, tibia and humerus in this way, it is clear the fact that:

- at distal ends the values were higher than at proximal, for the same bone taken in part, the differences being very important for tibia and humerus
- at distal ends of the bones the compression extreme values were not significantly different.

Comparing the charging values in the case of stretching and bending tests with the compression ones, they were found statistically different (p = 0,08). [3]

This is probably a result of the fact that the bone pieces exposed to compression were sectioned at the level of the junction of the superior and inferior epiphysis where the trabecular structures are predominant as compared to the pieces used in stretching and bending probes that were sectioned and in which the cortical layer is thinner and more homogenous. [13, 14, 15]

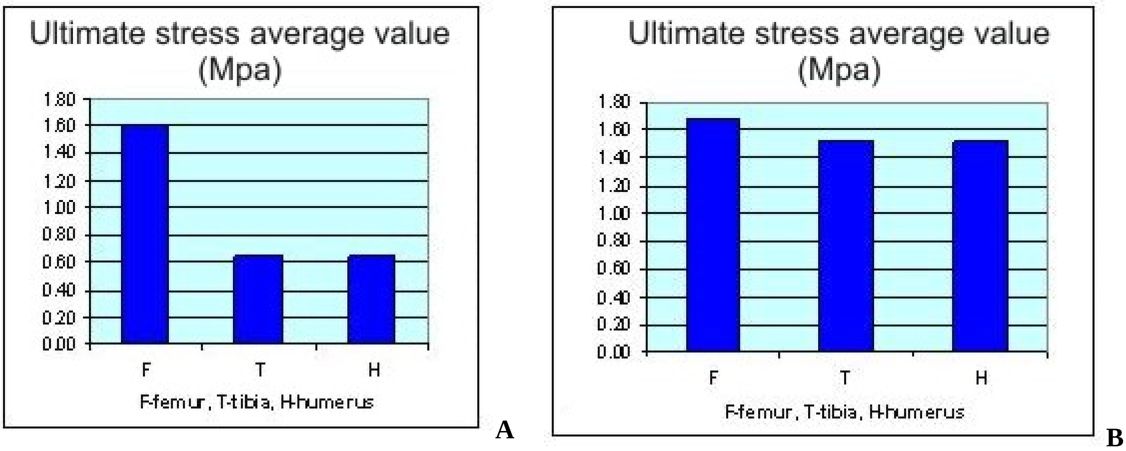


Fig. 6 Comparison between the average results in the compression trial: A) proximal end ; B) distal end

Conclusions

1. The fracture of the femoral diaphysis represents a major trauma where it always have to be considered the possibility of associated lesions, the 4.0218 MPa tension developing high kinetic energy.
2. The fractures of the diaphysis are usually transversal through direct mechanism (hit, fall) or spiral. The treatment is the surgical osteosynthesis, with plaque or rod and proves the necessity of using some supporting and osteosynthesis materials, considering the compression forces both at the proximal and distal end, as well as the stretching and bending that act in this bone.
3. Even if they are the consequence of strong trauma, of high energy, the open bone femur fractures have a much lower incidence than in the case of other segments (foot, leg), due to the very resistant bone structure, the tension for femoral diaphysis breakage being 4.4168 MPa in the case of stretching forces and 4.0218 MPa in the case of bending.

4. To use the experimental results for the femur and to predict its mechanical behavior there were established polynomial regressions with the value of R^2

Bone	Test	Polynomial regression	R^2
Femur	Compressing - Proximal	y = -0.0011x6 + 0.0318x5 - 0.3625x4 + 2.0207x3 - 5.6654x2 + 7.4168x - 2.6765	0.9959
	Compressing - Distal	y = -0.0015x6 + 0.0448x5 - 0.5053x4 + 2.7783x3 - 7.6581x2 + 9.9582x - 4.1842	0.9928
	Stretching	y = -0.0444x5 + 0.8322x4 - 5.8237x3 + 18.749x2 - 26.356x + 13.15	1
	Bending	y = -0.0761x3 + 1.2293x2 - 2.8043x + 3.7155	1

An R^2 value close to 1 proofs a precision of the polynomial functions established for the variation limits of the maximal tension, being a 99%- 99,98% objectivity factor for all the testing lots, can be useful in forensic expertise with crash tests.

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