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System Analysis of the Human Femoral Bone: Applied Biophysical and Anatomical Correlations

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Abstract: Twenty-five linear and non-linear (angle) parameters were investigated by specially designed tool and caliper on a material of 166 macerated human femurs of adult individuals of both sexes. The absolute values were transformed into the relative one by the meaning of the transverse diameter of the femoral diaphysis and handled with the methods of descriptive statistics. By the value of variance (q^2), the results were distributed into four classes. The belonging of each group to the class was estimated in grades. According to this method, depending on the total grades the excerpt was distributed into four classes as well. The Pirson's coefficient in each class was calculated between the relative values of the investigated parameters. Two generations of system parameters were subsequently defined.

Key words: Anatomy, caliper, femur, pirson's coefficient, system analysis

INTRODUCTION

The kinematical chain of the low extremity can be designated as a crank mechanism, reciprocating the foot motion into rotary motion through the hip that in turn it's being transformed into the ascending variable directive torsion movements of the flexed sloping spiral of the spine.

While the human femur is an element of the non-linear system of the locomotor's apparatus (as the super system for the femur), functionally dependant upon the other elements of the super system, being some time a subsystem, the elements of which are epiphysis and diaphysis, the investigation of it's system organization has not only theoretical, but also direct practical significance (Gonzalez *et al*., 1999; Cumming *et al*., 1994; Lewinnek *et al*., 1978; Estok and Harris, 1994; Farmer *et al*., 1984).

Nowadays, not a single endoprotesis used for the replacement of the hip joint considers the constitutional, individual and other anatomical features of the patient's hip joint. This is why among other reasons there develop complications at various postoperative stages, which may affect the femoral component of the implant (Gonzalez *et al*., 1999; Lewinnek *et al*., 1978; Estok and Harris, 1994; Mc Collum and Gray, 1990; Morry, 1992; Noble, 1990; Noble *et al*., 1988; Turner, 1994). The more rare complication after the total replacement of the hip joint is the dislocation of the implant's head.

Considering the fact that the greater part of models has the fixed moment of the Shaft-Neck Angle (SNA) and the implant head's diameter is essentially less then that of the femur, the main prophylactic means is not only the creation of new implant models, but the creation of new methods of replacement, dependant on the individual anatomic peculiarities as well.

The femur is one of most investigated bones of the human skeleton. A great number of literatures are devoted to its anatomy, sexual polymorphism, race and age transformations (Cumming *et al*., 1994; Estok and Haris, 1994; Morrey, 1992; Noble *et al*.,1988). However, there is discrepancy as to the angle meanings of the parameters and its correlation to the linear characteristics of the femur. Thus, the size of the SNA according to Wagner varies from 125°3' up to 132°3′. According to Nikitiuk B.D., its size varies from 109° up to 153° and there is no angle

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meaning depending on sex. The scope of the angle meaning of the anteversion, according to numerous investigations, is roughly 74°. Also the literature data of the absolute meaning of the femur's head, other linear parameters, t ransformation age, etc., are unequal (Noble, 1990; Noble *et al*., 1988; Chiu, 2006; Spurijt, 2006).

Moreover, there are a great number of authors who consider that there is a group of factors (at the macro- and microscopic levels of the femur as a system) that influence the solidity of the proximal epiphysis and its stability towards the load and damage. The mechanism of this correlation has not been studied yet (Farmer *et al*., 1984; Morrey, 1992; Lubusky *et al*., 2006; Theodorou *et al*., 2006; Wisniewski and Grogg, 2006).

The lack of information about the correlation of the linear and angle parameters of the femur does not allow the determination of the anatomic structure of the femur as a unit of the non-linear system, thus functioning on the basis of the heuristic self-organization. Therefore, there is no possibility to describe the human femur as a subsystem of the locomotor's apparatus and, subsequently, the opportunity to create an adequate mathematical model of the whole skeleton is diminishing.

The aim of this investigation, necessarily, is to determine the group and level of the geometric system base parameters, thus analyzing the femur structure on the basis of a complex and thorough investigation.

MATERIALS AND METHODS

Approximately, 166 macerated human femurs of adult individuals of both sexes without visible symptoms of bone pathology taken from the anatomical museums of four Russian medical universities were investigated.

Twenty-five linear and angle parameters were investigated by a specially designed tool and caliper. The analysis pocket of the Excel XP was also used.

All the investigating parameters of the femur were divided into groups (Table 1), executing the motions of the hip joint, knee joint and the support function of the thigh.

The absolute values were transformed into relative values (the transverse diameter of the femoral diaphysis was chosen as the unit of measurement for every bone) and handled with the methods of descriptive statistics. By the value of variance (q^2), the results were distributed into four classes. The belonging of each group to the class was estimated in grades. According to this method depending on the total grades, the excerpt was distributed into four classes recurrently. The bones, having the total sum of grades less than M-2q^2 (M-expected value) were considered the 1st class, M-q^2 the 2nd class, M + q^2 the 3rd class and M + 2q^2 the 4th class.

Table 1: The presence of investigated parameters in the functional groups.

Groups	Types	Parameters	
Executing the motions of the hip joint	Linear	Head of the femur:	
		-Horizontal diameter	E
		-Vertical diameter	F
		-Neck of the femur:	
		-Horizontal diameter	G
		-Vertical diameter	H
		-Anterior length	I
		-Posterior length	J
		-Superior length	K
		-Inferior length	L
		-Transverse size of the proximal epiphysis	M
		-intertrochanteric distance	N
	Angular	-Diaphysis-neck angle	A
		-Anteversio of the neck	B
		-Rotatio of the head	C
Executing the motions of the knee joint	Linear	-The length of the lateral condyle	R
		-The length of the medial condyle	S
		-The transverse size of the patellar surface	T
		-Internal intercondylar distance	U
		-External intercondylar distance	V
Executing the support function	Linear	-Femoral obliquity	O
		-The anterior diameter of the diaphysis	P
		-The length of the femur	Q
	Angular	-Femoral declination	D

The Pirson's coefficient in each class was subsequently calculated between the relative values of the investigated parameters.

RESULTS AND DISCUSSION

For future analysis, the correlation ties with the Pirson's coefficient exceeding 0.6 were also taken (Table 2).

The first group (parameters marked as A-D) consists of angle parameters exclusively. It should be stated that there are no strong correlations between the angle and linear parameters in all of the classes. To our best knowledge, that indicates that the above stated angle parameters are the system creating features of the third rang, their influence on the morpho-functional characteristics of the femur as a total is minimal and their absolute meaning characterizes the individual variability in the limit specified by the supersystem.

The second group (parameters marked as E-N) determines the geometry of the proximal epiphysis of the femur. More importantly, is that the horizontal and vertical diameters of the femoral head are not only closely related parameters, but are strongly related to the length of the medial condyle because the above stated parameters execute the locomotor and thus support functions of the femur, simultaneously. Therefore, any derivative coefficient which is based on these parameters will characterize the quantity and quality of the femoral functional proportion and can also be used for the following classification of femoral bones.

Table 2: Correlation between measured parameters of the femoral bone

First class	Second class	Third class	Fourth class
parameters			
r_p	r_p	r_p	r_p
F_G 0.78	F_G 0.80	F_E 0.78	F_E 0.91
E_S 0.62	J_L 0.61	L_J 0.72	G_F 0.64
T_V 0.89	C_B 0.65	S_F 0.61	E 0.64
U0.92	S_G 0.72	E 0.62	H_E 0.71
U_V -0.83	F 0.72	V_R-0.74	N_K 0.62
R 0.95	V_N 0.70	N 0.65	J_L0.63
V_R -0.81	R 0.72	U_R 0.96	S_E 0.6
N 0.70	U_R 0.95	V -0.80	F 0.63
S_F0.66	V -0.74	T_R-0.9	V_N 0.66
T_V 0.92	N -0.61	V 0.84	S -0.59
U -0.89	T_N 0.63	U -0.93	U_R 0.9
R -0.84	R -0.890	Q_S 0.64	V -0.76
N 0.6	V 0.80		T_R -0.85
Q_S 0.6	U -0.95		V 0.84
			U -0.92
			M_F 0.73
			E 0.65
			N 0.65
			S 0.62
			P_U 0.61
			Q_M 0.75
			F 0.59

The third group (parameters marked as O-Q) determines the geometry of the femoral shaft. Amongst them the length of the femur closely related to the length of he edial condyle in the 1st and 3rd classes; in the 4th class, the parameter is related to the vertical diameter of the head and the transverse size of the proximal epiphysis. The forth group characterizes the 3D cross relations of anatomical structures of the distal epiphysis.

As shown in Fig. 1, in all of the investigated classes of the femoral bones the strong correlations are stated between parameters of the forth group. This is an illustration of the functional proportion of the distal epiphysis. Similarly, the length of the lateral condyle correlates with the parameters T, U and V. This phenomenon confirms the hypothesis that the medial condyle executes the supporting function mainly.

Analysis of the correlations in the first class confirms the assumption that the proximal epiphysis is the lever system acting according to the weight vector, which is generated at the intertrochanteric area.

Furthermore, investigating the biomechanics of the hip joint, Nechaev has inferred that the femur can supinate at the knee joint independently of other segments of the lower extremity. This is confirmed by 3D relationships between condyles and provided by SNA and the geometry of the femoral neck.

However, we were unable to find a strong relationship between SNA and linear parameters of both

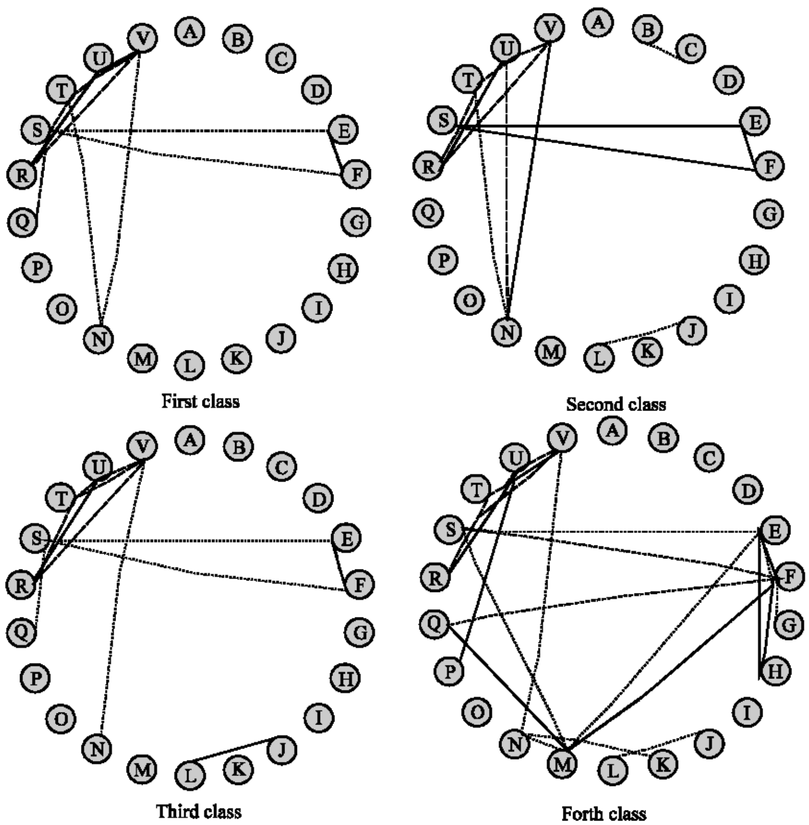

Fig. 1: Correlations between investigated parameters in four distributed classes of femoral bones. Pirson's coefficient 0.6-0.69 (dotted line), 0,7 and above (straight line-positive meaning, broken line-negative meaning)

epiphyses in the first, third and forth classes. Therefore, the correlation between the length of the medial condyle and the horizontal diameter of the femoral neck confirms the capability of the isolated femoral supination.

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