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ANALYSIS OF THE WEAR TENACITY OF THE COXOFEMORAL JOINTS OF PATIENTS AFFECTED BY OSTEOPORUMSIS

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Abstract: In the Dominican Republic osteoporumsis is affecting many people. This disease attacks the structure of bone tissue causing a skeletal disorder characterized by loss of mass, wear and brittle fracture. In this study, the coxofemoral joints of women were analyzed because there is a relative movement between its elements, forming tribological systems that work with precision and efficiency; but, the efforts, friction and wear in this area affect its mobility and resistance. For this reason, through tribological methods, the wear resistance of the joints of 41 women was evaluated. As results, the wear rate and resistance to erosion and adhesion of hip joints were obtained. Observing that the rate of adhesive wear in the Patients is higher than the erosive rate and as these rates increase over time they reflect the conditions of osteopenia and osteoporumsis as a consequence. Therefore, the resistance of the tissues decreases.

Keywords: Wear toughness; wear rate; osteoporumsis; osteopenia; coxofemoral joints.

INTRODUCTION

Osteoporumsis affects the structure of bone tissue, causing a skeletal disorder characterized by wear and tear of tissue architecture, which consequently produces an increase in bone fragility and susceptibility to fracture. [1]. Fracture is the main complication, caused by low bone strength; this implies the analysis of said resistance because it is the force necessary to cause, under certain load conditions, the biomechanical failure of the bone [2]. This failure is also a product of the forces that act on the bone when its ability to maintain equilibrium is exceeded [2]. Bone quality refers to factors such as architecture, bone remodeling, cumulative damage that creates microcracks, and the degree of mineralization [1].

The problem presented is of interest to study because it affects the way in which friction phenomena, wear and the efforts that are caused in the hip joints are verified and their effect on the mobility of the system as a whole and resistance [3], [4], [5]. Therefore, the purpose of this research is to determine the wear tenacity of the hip joints of Patients affected by bone decalcification using tribology methods to calculate the rate and resistance to wear that will serve to evaluate the mechanical behavior of these joints. [5].

The World Health Organization first convened a group of experts in 1994 to assess the risk of fractures and its application to the detection of postmenopausal osteoporumsis. Osteoporumsis was defined based on bone mineral density using a standardized score, called T-score, to define the diagnostic categories, which are: Normal T-score ≥ -1; Osteopenia T-score between -1 and -2.5; Osteoporumsis T-score ≤ -2.5 and severe Osteoporumsis T-score ≤ -2.5 with a history of fracture [6].

Osteoporumsis is a common disease that affects populations of people throughout the world, so it is of great interest to study it in the Dominican Republic to find out the tolerable damage or wear that it produces in the hip joints [7]. Therefore, in the study of wear failures, it is usual to consider the wear processes defined with reference to the type and geometry of the relative movement between two surfaces in contact [8].

Each wear process is due to one (or more) wear mechanisms, among other factors [9]. In this case, erosive wear and sliding wear were addressed [10], [11], [12]. In the case of sliding rolling wear in the coxofemoral joints, the two surfaces or parts of the body, such as the hip and femur, will be in repeated contact [11]. In addition, erosion wear is present; which is produced when solid particles or liquid drops impact the surfaces, although other damaging parameters could be present [10]. The procedure of these tribological methods under standards is discussed in the next section to quantify the damage in bone tissues.

MATERIALS AND METHODS

MATERIALS

The materials used in this research are the images and numerical data obtained in the study by bone densitometry in female patients in the country. Likewise, to carry out this study, the GE Lunar Prodigy Advance DXA system manufactured by GE Medical Systems LUNAR [13] was used.

METHODOLOGY FOR THE TRIBOLOGICAL STUDY

The tribological study was carried out according to the ASTM G-137-97 Standard for the evaluation of adhesive wear due to sliding in the Block-on-ring configuration [11] and the ASTM-G-76-02 Standard. in the case of the analysis of wear by erosion of erosive solid particles [10].

METHODOLOGY FOR THE ANALYSIS OF MEDICAL IMAGES BY BONE DENSITOMETRY (DXA)

First, a population of 40 female Patients between 42 and 75 years of age, affected by bone decalcification, was defined. Then, the bone densitometry test (DXA) was carried out in the Diagnostic centers and medical centers in the period from August 2011 to September 2021. This consisted of the quantitative analysis of the hip joint of each Patient and from there, the bone mineral content (BMC), bone mineral density (BMD) and the T-score and Z-score and the medical image of the analyzed area were obtained.

The T-score and Z-score express the severity of the disease in each Patient; the T-score is the value of the standard deviation of the bone mineral density with respect to a healthy 30-year-old person of the same sex, while the Z-score is the standard deviation of the bone density of a person with that of a average person of the same age and sex [6],[13],[14].

TRIBOLOGICAL METHODS FOR THE STUDY OF WEAR IN THE COXO-FEMORAL JOINTS OF PATIENTS WITH DECALCIFICATION OF BONE TISSUES

Due to the fact that in the hip joints there are mechanisms of wear due to sliding due to the movements of the Patient and/or erosive wear due to the decalcification of the bones, the tribological methods Block on Ring (Block-on-Ring) governed by the standard ASTM 137-97 [11] [15], [16] and Erosion by Solid Particles (Solid Particle Impingement) of the standard ASTM 76-02 [10], [15] to analyze the effects of decalcification in these bone tissues. In the research process; It began with the calculation of the tribological variables from the mass data of the bone densitometry analysis, using equation 1.

$$\mathbf{M}_{lost} = \frac{\Delta BMC}{\Delta t} \quad (1)$$

Where ΔBMC is the variation in bone mineral content and Δt is the time between bone densitometry analysis.

Second, in the case of the study of adhesive wear due to sliding presented in the coxofemoral joints, the equations of the Ring Block method were used, which consists of pressing a stationary block against the outer surface of a rotating ring and contact can occur when it starts. the sliding action between the elements in contact, either in a lubrication or scraping environment, allowing high contact pressures, as occurs in the coxofemoral joints [11]. So, the rate of adhesive wear was determined by the equation:

$$W = \frac{1}{F_N \cdot v \cdot \rho} \cdot \frac{\Delta m}{\Delta t} \quad (2)$$

FN is the normal force in the contact area exerted by the acetabulum on the femoral head, v is the average velocity of displacement of the femoral head in the acetabulum cup, and |p is the bone mineral density and m is the bone mass. Then, the adhesive wear resistance was determined:

$$R_{adhesive} = \frac{1}{W_{adhesive}} \quad (3)$$

The study of erosive wear of the hip joints was carried out according to the erosion test method that involves a gas stream with abrasive particles that impact the surface ("Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets" 2018) [10]. Then, the erosive wear rate (Q) was obtained by equation 4:

$$Q_{erosive} = \frac{M_{lost}}{t_{exp}} \quad (4)$$

Where, texp is the suffering time. Then, the resistance to erosion was determined through equation 5:

$$R_{erosive} = \frac{1}{Q_{erosive}} \quad (5)$$

Afterwards, the results and medical conditions of osteoporumsis, osteopenia and normal were analyzed.

RESULTS AND DISCUSSION

RESULTS OF THE ANALYSIS OF BONE DENSITOMETRY IN THE COXOFEMORAL JOINTS OF PATIENTS WITH DECALCIFICATION OF BONE TISSUES

The bone mineral density data (g/cm2) obtained by DXA in the hip of women between the ages of 42 and 75 years is presented in Table 1. Numerical values were obtained in the center of the hip joint, diaphysis of the femur. perpendicular to the transverse plane with internal rotation of approximately 15º to 25º, the neck of the femur, the head, and the greater trochanter.

The wear study was carried out in the region of the femoral neck, trochanteric region, Ward's Triangle, the diaphysis and the global region of interest, considering that there is loss of bone mass when the parts are in contact or not. Then, from the bone mineral density (g/cm2), bone mineral content (g), projected area (cm2), t-score and z-score, osteopenia, osteoporumsis or normal misclassification were detected in the Patients. This classification obeys the standardized score called T-score, for the diagnostic categories, which establishes: Normal T-score ≥ −1; Osteopenia T-score between −1 and −2.5; Osteoporumsis T-score ≤ −2.5 and Severe Osteoporumsis T-score ≤ −2.5 with a history of fracture [6], [17].

RESULTS OF THE ANALYSIS OF EROSIVE WEAR IN THE HIP JOINTS OF PATIENTS

Table 2 shows the results of the erosive wear study in the femoral neck region of Patients with bone decalcification in normal condition, such as the rate of wear (Qerosive), the resistance to wear (Rerosive) and the volume lost (Vperd)..

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Women	NBMD	TBMD	TOBMD	t-sc	z-sc	NBMC	PESO (kg)	COND
P2BM	1.017	0.785	1.046	-0.2	1.7	4.90	63.50	Normal
P3CM	0.943	0.881	1.062	0.7	0.3	4.38	72.57	Normal
P4CR	0.874	0.89	1.052	-1.2	0.7	3.96	77.11	Osteopenia
P5CG	0.709	0.645	0.776	-2.4	-1	3.38	58.97	Osteopenia
P6DLO	0.804	0.896	0.982	-1.7	-1.1	4.56	77.11	Osteopenia
P7DLSM	0.949	0.778	1.021	-0.6	-0.1	3.82	63.05	Normal
P8DLM	1.002	0.726	1.004	-0.2	0.8	5.33	74.84	Normal
P9DD	0.862	0.649	0.87	-1.3	-0.2	3.36	72.57	Osteopenia
P10EA	0.823	0.665	0.833	-1.5	-0.2	4.36	72.57	Osteopenia
P11FI	0.829	0.661	0.861	-1.5	-0.6	3.45	63.50	Osteopenia
P12FC	1.145	0.784	1.096	0.8	1.7	4.70	64.86	Normal
P13FA	0.924	0.859	1.069	0.8	-0.2	4.31	72.57	Normal
P14GA	0.835	0.822	0.926	-1.5	-1.4	5.37	77.11	Osteopenia
P15GS	1.302	0.685	0.907	1.9	2.7	8.61	99.79	Normal
P16LRA	1.585	0.804	1.048	3.3	6.1	10.06	77.11	Normal
P17MM	1.098	0.844	1.067	0.4	0.8	4.54	72.57	Normal
P18PC	0.735	0.746	0.853	-2.2	-0.5	3.95	65.77	Osteopenia
P19PC	0.856	0.779	0.977	-1.3	-0.3	3.43	72.57	Osteopenia
P20SS	1.141	0.991	1.268	0.7	1.8	5.47	91.63	Normal
P21VL	1.678	0.674	0.964	4.5	5.3	14.69	58.97	Normal
P22ZR	0.695	0.619	0.726	-2.4	-0.7	3.19	63.05	Osteopenia
P23AL	0.845	0.744	0.912	-1.4	-0.6	3.71	75.75	Osteopenia
P24AY	0.899	0.743	0.964	-1	-0.1	4.23	90.72	Normal
P25AMY	1.241	1.065	1.363	1.5	2.9	7.48	73.48	Normal
P26AC	0.733	0.638	0.792	-2.2	-0.6	2.67	64.86	Osteopenia
P27AH	0.956	0.699	0.901	-0.6	0.2	4.75	58.97	Normal
P28AO	1.267	0.759	0.983	1.7	3.4	7.74	78.93	Normal
P29AL	0.913	0.749	0.913	-0.9	-0.3	4.36	92.53	Normal
P30AH	0.829	0.514	0.755	-1.5	0.4	3.58	57.61	Osteopenia
P31AH	0.725	0.514	0.687	-2.3	-0.4	2.54	57.61	Osteopenia
P32ADR	0.937	0.864	1.036	-0.7	0.6	4.62	72.57	Normal
P33AK	1.164	0.937	1.151	0.9	1	6.70	56.70	Normal
P34AK	0.619	0.504	0.627	-2.7	-1.4	2.02	97.52	Osteoporum
P35AK	0.612	0.483	0.64	-3.1	-1.5	1.50	97.52	
P36AJ	0.778	0.543	0.714	-1.9	-1.6	3.06	72.57	Osteopenia
P37AJ	0.708	0.506	0.673	-2.4	-2.1	2.41	72.57	Osteopenia
P38AAJ	1.101	0.82	1.099	0.5	1.5	6.18	72.57	Normal
P39AR	1.317	0.566	0.902	2	3.2	8.13	63.05	Normal
P40AS	1.092	0.892	1.102	0.4	0.4	6.05	63.50	Normal
P41ALS	0.943	0.833	1.04	-0.7	0.5	4.62	77.56	Normal

NBMD: mineral density in the femoral neck; TBMD: mineral density in the trochanteric region; BMD: mineral density in Ward's triangle; DBMD: mineral density in the diaphysis; TOBMD: mineral density in the global region of the hip; t – sc: t-score; z – sc: z-score; HLT: height. Mineral density measurements in (g/cm2). Source: self-made.

Table 1. Results of the analysis of bone densitometry in the coxofemoral joints of women who present decalcification of the bone tissues.

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Patients	NBMC (g)	NBMC _0 (g)	NBMD_0 g/cm²	Q*erosive* (g/year)	R*erosive* (year/g)	V ol *perd* (cm³)
P2BM	4.900	3.027	0.629	0.489	2.047	0.522
P3CM	4.380	3.345	0.737	0.281	3.562	0.788
P4CR	3.960	2.823	0.623	0.237	4.216	0.345
P5CG	3.380	3.227	0.677	0.076	13.107	0.038
P6DLO	4.560	4.464	0.786	0.015	67.418	-0.018
P7DLSM	3.820	3.182	0.790	0.124	8.091	0.116
P8DLM	5.330	3.887	0.732	0.271	3.691	0.374
P9DD	3.360	2.761	0.721	0.121	8.238	0.509
P12FC	4.700	3.261	0.757	0.498	2.006	-0.794
P13FA	4.310	3.564	0.780	0.152	6.587	0.661
P15GS	8.610	4.974	0.753	0.360	2.776	0.633
P16LRA	10.060	3.812	0.600	0.602	1.660	1.072
P17MM	4.540	3.684	0.819	0.091	11.038	-1.750
P20SS	5.470	3.551	0.741	0.288	3.475	0.397
P21VL	14.690	5.140	0.761	1.148	0.871	11.801
P24AY	4.231	3.549	0.743	0.378	2.648	-0.180
P25AMY	7.478	3.875	0.716	0.708	1.413	3.858
P27AH	4.750	3.696	0.758	0.107	9.348	0.722
P28AO	7.737	3.734	0.683	0.375	2.667	4.103
P29AL	4.361	3.734	0.778	0.100	9.952	0.027
P32ADR	4.621	3.390	0.699	0.466	2.146	0.726
P33AK	6.698	4.598	0.874	0.276	3.621	2.936
P38AAJ	6.179	3.818	0.740	0.443	2.256	2.843
P39AR	8.127	4.089	0.738	0.398	2.512	3.975
P40AS	6.049	4.486	0.874	0.291	3.442	2.404
P41ALS	4.621	3.444	0.710	0.121	8.269	0.544

Table 2. Values of the erosive wear of the coxofemoral joints-femoral neck region, of women with decalcification in normal condition.

The wear that occurs in the hip joints is associated with the loss of bone mass on the surface of the femoral head that joins the pelvis in the acetabulum. Decalcification is the product of different factors and the degree of the disease indicates the normal condition due to the little loss of bone mass compared to osteopenia and osteoporumsis [18], [19]. These wear results are shown in table 2 and table 3.

In table 3, the last two rows of data correspond to the two Patients suffering from osteoporumsis, the rest of the rows of data correspond to the Patients with osteopenia. The effect of the degradation of the bone mass in the neck of the femur that reflects these diseases or pathologies can be observed in Figure 1.

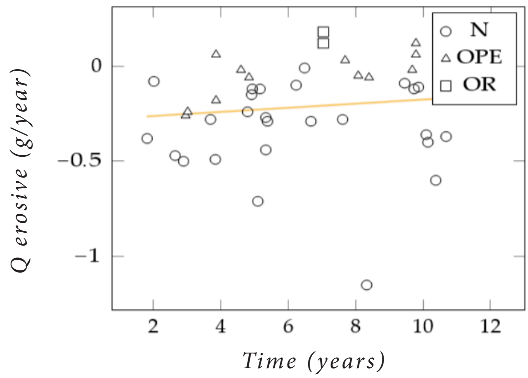

Figure 1. Erosive Wear Rate (f(x) = 0.0108x – 0.2841; R2 = 0.0138) in Patients: Normal Medical Condition N; OPE: Osteopenia; OR: Osteoporumsis.

Figure 1 shows the quantification of erosive wear from the moment the Patients began to lose bone mass in the hip joint up to the degree of advancement. The pathological

Patient	NBMC (g)	NBMC_0 (g)	NBMD_0 g/cm²	Q*erosive* (g/year)	R*erosive* (year/g)	V ol*perd* (cm³)
P1BE	3.520	2.742	0.648	0.264	3.785	0.266
P10EA	4.360	3.628	0.686	0.244	4.105	0.252
P11FI	3.450	3.072	0.738	0.047	21.317	0.110
P14GA	5.370	4.543	0.837	0.056	17.928	5.385
P18PC	3.950	3.437	0.640	0.061	16.341	0.198
P19PC	3.430	3.334	0.728	0.021	47.703	-2.932
P22ZR	3.190	2.868	0.626	0.028	35.493	0.170
P23AL	3.711	3.547	0.759	0.017	58.825	-1.398
P26AC	2.672	2.900	0.649	-0.030	-33.751	-4.262
P30AH	3.582	2.878	0.620	0.183	5.466	-1.440
P37AJ	2.413	3.546	0.803	-0.116	-8.628	-5.503
P34AK	2.023	2.838	0.654	-0.116	-8.635	-5.742
P35AK	1.504	2.768	0.654	-0.180	-5.565	-9.513

Table 3. Values of tribological variables that quantify the erosive wear of the coxofemoral joints of women suffering from osteopenia and osteoporumsis.

condition is reflected by the volume lost and the rate of wear. In this graph, the relationship of the wear rate is presented as a function of the elapsed time of the deterioration of the evaluated surface according to the z-score data by densitometry [18]. The calculated relationship has a coefficient of determination of R2 = 0.0138, implying a weak Pearson correlation coefficient (r = 0.1174). Therefore, the gradual loss of bone material can be seen at the interface of the components of hip joints in contact, which over time progresses the phenomenon of wear [19], [20]. Consequently, mild wear is observed in Patients with onset of tissue mass loss. Then, the wear of the Patients who are in the condition of osteopenia is seen with remarkable effect and on the other hand, some Patients have the rate of erosive wear much higher; indicating the condition of osteoporumsis.

In the tribological study of the Patients, it is interesting to study beyond the integrity of bone mass in the hip joint, the resistance presented by the neck area of the femur and can be seen in Figure 2. The graph shows the model that relates the resistance of the hips with the time in which the wear occurred. This model has a coefficient of R2 = 0.0065, which is equivalent to a Pearson correlation of r = 0.0806, which is a weak correlation [21].

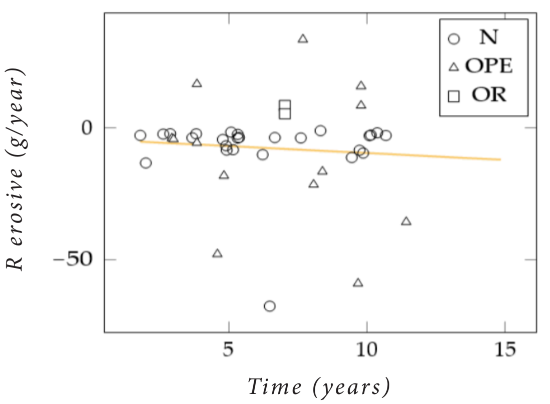

Figure 2. Erosive Wear Resistance (f(x) = −0.5264x − 4.1205; R2 = 0.0065) in Patients: Normal Medical Condition N, OPE: Osteopenia, OR: Osteoporumsis.

Figure 2 shows the resistance offered by the hip bones to the gradual loss of bone material in the evaluated areas, and it can be seen that resistance and integrity decrease over time as wear due to disqualification progresses [20], [twenty-one].

From the mathematical models of linear regression determined for the rate of erosion and for the resistance to erosive wear of the surface of the neck of the femur of each Patient, it can be said that the coefficient of determination is the proportion of the total variance of the variables explained by the regression. In the case of this type of wear, the determination coefficient reflects the goodness of fit of the models to the variables that have been explained in Figure 1 and Figure 2.

When evaluating the resistance of the Patients' hips, the probabilistic behavior is studied by means of a Gaussian distribution model, which is shown in Figure 3.

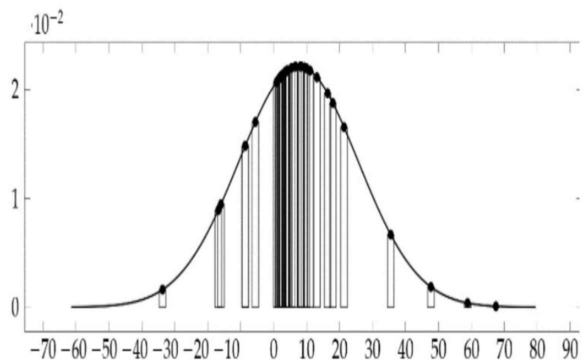

Figure 3. Distribution of resistance to erosive wear in all Patients in normal medical N condition of bone decay, OPE: Osteopenia, OR: Osteoporumsis.

Figure 3 shows the distribution of the resistance to erosive wear in the Patients in the different progressive stages of bone decalcification, that is, decalcification in normal condition, osteopenia and osteoporumsis; in detail, it has a mean of 7.5269 (year/g), with a relative asymmetry coefficient of 1.4757 (> 1) implying that there is a concentration of Patients with

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more resistance towards the right side of the distribution and a kurtosis of 4.08901 (> 3) indicating a leptokurtic distribution, more pointed and with wide ends than a normal distribution, which evaluates the conditions of the Patients in the presence of diseases; therefore, this problem reflects a concern in the Dominican Republic [20], [22], [23].

ADHESIVE WEAR ANALYSIS RESULTS BY SLIDING AT THE HIP JOINTS

In the case of the quantification of the adhesive wear studied in the area of the head of the femur, there are results of the phenomenon of wear due to the effect of decalcification and at the same time due to the sliding action in the contact area of the elements that make up the hip joints of the Patients [20], [21].

The tribological variables corresponding to the adhesive wear of the hip joints imply evaluating the global region of the hip joints [21], for which the bone mineral density in the global region of the hip was determined as shown in table 4.

Table 4 contains the data on the mineral content and bone density, among other results obtained from the densitometry analysis and from which the adhesive wear due to sliding in the head of the femur in relation to the acetabulum was determined in patients with a normal medical condition. in the presence of decalcification of its bone mass.

From the tribological methods to determine the wear present in the hip joints, the wear parameters were calculated, such as the loss of bone mineral content in the global region of the hip joint (Mperd), the rate of adhesive wear by sliding (Wadh), the resistance to adhesive wear (Radh) and the effort produced by friction (σt), which are presented in table 5, [12], [21].

In table 5, it can be seen that the Patients present decalcification of the tissues in different degrees. The hip joints present an adhesive wear providing in their bone mass variable with respect to the densitometry data.

Patients who present less mass loss have greater physical resistance in their tissues, but in all Patients the amount of mass lost is within a normal range without reaching the degree of osteopenia pathology. In the case of osteopenia and osteoporumsis, Table 6 contains the results of the bone densitometry analysis.

Table 7 shows the data of the adhesive wear due to sliding in the patients that resulted in loss of bone mineral content. For the calculation of adhesive wear, the load supported by the femoral head and the average sliding speed experienced by a person were considered [24].

Figure 4 presents the rate of sliding adhesive wear for all patients as a function of time expressed in a mathematical model [23]. The graph shows a relationship with a coefficient of determination of R2 = 0.0045, which indicates that these variables are not strongly correlated.

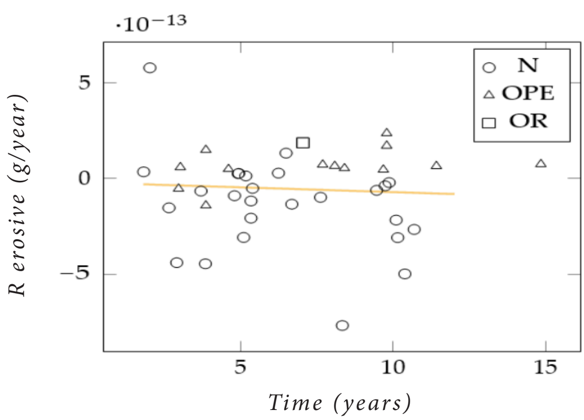

Figure 4. Rate of adhesive wear by sliding (f (x) = −5 × 10−15x − 2 × 10−14; R2 = 0.0045). N: Normal medical condition, OPE: Osteopenia, OR: Osteoporumsis.

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Patient	t-score	z-score	AG (cm^2)	TOBMC (g)	TOBMC_0 (g)	T OBMC*loss* (g)
P2BM	-0.90	1.70	33.80	33.56	25.12	-8.45
P3CM	2.00	0.30	33.02	33.31	31.93	-1.38
P4CR	-0.70	0.70	25.14	25.11	22.53	-2.59
P5CG	-0.70	-1.00	28.14	20.51	24.42	3.91
P6DLO	-0.70	-1.10	33.25	30.94	35.80	4.86
P7DLSM	-0.70	-0.10	25.93	25.11	25.46	0.34
P8DLM	-0.70	0.80	31.36	29.85	26.36	-3.49
P9DD	-0.70	-0.20	25.32	20.78	21.41	0.63
P12FC	0.80	1.70	28.43	29.62	22.91	-6.72
P13FA	0.80	-0.20	27.74	28.17	28.91	0.74
P15GS	1.90	2.70	39.11	33.52	18.84	-14.68
P16LRA	3.30	6.10	34.67	34.50	3.41	-31.09
P17MM	0.40	0.80	29.90	30.31	26.98	-3.32
P20SS	0.70	1.80	31.10	37.64	29.86	-7.78
P21VL	4.50	5.30	38.25	34.91	7.95	-26.96
P24AY	-1.00	-0.10	29.86	27.26	27.67	0.42
P25AMY	1.50	2.90	32.47	42.32	30.55	-11.77
P27AH	-0.60	0.20	30.28	25.77	24.97	-0.81
P28AO	1.70	3.40	32.68	30.43	14.10	-16.33
P29AL	-0.90	-0.30	29.97	25.86	26.98	1.12
P32ADR	-0.70	0.60	30.18	29.67	27.41	-2.26
P33AK	0.90	1.00	31.84	34.89	31.26	-3.63
P38AAJ	0.50	1.50	31.43	32.84	26.29	-6.55
P39AR	2.00	3.20	32.99	28.11	14.91	-13.20
P40AS	0.40	0.40	31.32	32.82	31.39	-1.43
P41ALS	-0.70	0.50	77.56	29.79	27.57	-0.08

TOBMC: Bone mineral content in the global hip region; TOBMD: Bone mineral density in the global region of the hip. BMD measurements in (g/cm2). Normal medical condition ($t - score \geq -1$).

Table 4. Densitometry data of the global region of the hip joints of Patients in normal medical condition of decacification.

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Patient	t (z – s)	M_{loss}(g/year)	W_{adh} (cm²/N)	R_{adh} (N/cm²)	σ_t (Pa)
P2BM	3.834	-2.203	-4.46E-13	-2.24E+12	1.86E+05
P3CM	3.687	-0.374	-6.52E-14	-1.53E+13	1.64E+05
P4CR	4.793	-0.540	-8.95E-14	-1.12E+13	1.76E+05
P5CG	2.005	1.950	5.80E-13	1.73E+12	1.76E+05
P6DLO	6.475	0.751	1.34E-13	7.48E+12	1.76E+05
P7DLSM	5.158	0.067	1.40E-14	7.15E+13	1.76E+05
P8DLM	5.326	-0.655	-1.17E-13	-8.52E+12	1.76E+05
P9DD	4.934	0.128	2.75E-14	3.64E+13	1.76E+05
P12FC	2.887	-2.327	-4.40E-13	-2.27E+12	1.65E+05
P13FA	4.914	0.150	2.60E-14	3.84E+13	1.72E+05
P15GS	10.092	-1.454	-2.17E-13	-4.60E+12	1.91E+05
P16LRA	10.372	-2.997	-4.99E-13	-2.00E+12	1.75E+05
P17MM	9.452	-0.352	-6.11E-14	-1.64E+13	1.72E+05
P20SS	6.668	-1.167	-1.34E-13	-7.44E+12	1.86E+05
P21VL	8.318	-3.242	-7.69E-13	-1.30E+12	1.60E+05
P24AY	1.806	0.230	3.55E-14	2.82E+13	1.85E+05
P25AMY	5.090	-2.312	-3.08E-13	-3.24E+12	1.72E+05
P27AH	9.859	-0.082	-2.08E-14	-4.81E+13	1.60E+05
P28AO	10.680	-1.529	-2.66E-13	-3.76E+12	1.77E+05
P29AL	6.234	0.180	2.88E-14	3.47E+13	1.86E+05
P32ADR	2.639	-0.858	-1.53E-13	-6.52E+12	1.72E+05
P33AK	7.606	-0.477	-9.81E-14	-1.02E+13	1.58E+05
P38AAJ	5.326	-1.230	-2.07E-13	-4.83E+12	1.72E+05
P39AR	10.142	-1.301	-3.09E-13	-3.23E+12	1.64E+05
P40AS	5.380	-0.265	-5.10E-14	-1.96E+13	1.64E+05
P41ALS	9.726	-0.228	-3.80E-14	-2.63E+13	1.76E+05

Table 5. Data on loss of mass, rate of wear (Wadh), resistance to adhesive wear (Radh) and friction effort (σt) in the global region of the hip joints normal condition.

Patient	t-score	z-score	AG (cm^2)	TOBMC (g)	TOBMC_0 (g)	T OBMC$_{loss}$ (g)
P1BE	-1.30	0.20	29.95	25.31	24.57	-0.75
P10EA	-1.50	-0.20	31.95	25.06	25.86	0.80
P11FI	-1.50	-0.60	25.90	21.03	23.19	2.16
P14GA	-1.50	-1.40	31.91	27.94	33.88	5.94
P18PC	-2.20	-0.50	30.11	24.21	26.09	1.88
P19PC	-1.30	-0.30	29.19	27.01	28.23	1.22
P22ZR	-2.40	-0.70	29.08	19.77	22.31	2.54
P23AL	-1.40	-0.60	29.45	25.38	27.73	2.35
P26AC	-2.20	-0.60	28.61	21.30	23.45	2.15
P30AH	-1.50	0.40	29.34	20.78	19.05	-1.73
P31AH	-2.30	-0.40	28.51	18.29	19.97	1.68
P36AJ	-1.90	-1.60	28.93	19.32	25.76	6.43
P37AJ	-2.40	-2.10	28.41	17.84	26.13	8.29
P34AK	-2.70	-1.42	28.09	16.37	22.25	5.87
P35AK	-3.10	-1.47	27.68	16.48	22.45	5.97

Table 6: Densitometry data from the global hip joint region of Patients with osteopenia and osteoporumsis (last two).

Patient	t (z – s)	M$_{loss}$ (g/year)	W$_{adh}$ (cm^2/N)	R$_{adh}$ (N/cm^2)	σ_t (Pa)
P10EA	3.006	0.266	5.96E-14	1.68E+13	1.72E+05
P11FI	8.067	0.268	6.63E-14	1.51E+13	1.64E+05
P14GA	14.834	0.401	7.58E-14	1.32E+13	1.75E+05
P18PC	8.389	0.224	5.42E-14	1.85E+13	1.66E+05
P19PC	4.587	0.265	5.05E-14	1.98E+13	1.72E+05
P22ZR	11.414	0.223	6.64E-14	1.51E+13	1.64E+05
P23AL	9.667	0.243	4.75E-14	2.10E+13	1.74E+05
P26AC	7.677	0.280	7.39E-14	1.35E+13	1.65E+05
P30AH	3.845	-0.449	-1.40E-13	-7.12E+12	1.59E+05
P31AH	3.845	0.436	1.51E-13	6.64E+12	1.59E+05
P36AJ	9.775	0.658	1.73E-13	5.77E+12	1.72E+05
P37AJ	9.775	0.848	2.38E-13	4.21E+12	1.72E+05
P34AK	7.035	0.835	1.88E-13	5.33E+12	1.90E+05
P35AK	7.035	0.849	1.87E-13	5.36E+12	1.90E+05

Table 7. Adhesive wear data in female patients with osteopenia and osteoporumsis (last two).

Patients with a certain medical condition can maintain their state of pathology; Figure 4 indicates that time is an influential factor in the effect of the disease and the change of pathology as the bone tissue wears away, and it increases as time goes by due to the joint action of decicification and sliding of the elements of hip joints [22].

The effect of the adhesive wear phenomenon in hip joints has been quantified by the rate of wear measuring the amount of mass lost [12], [13]. However, wear resistance is an indicator of the physical integrity of the overall joint region. The resistance to adhesive wear due to sliding as a function of the time of the disease for all the patients is shown in Figure 5. The equation model that expresses a relationship with a coefficient of determination is R2 = 0.0127, indicating that the variables are not strongly correlated.

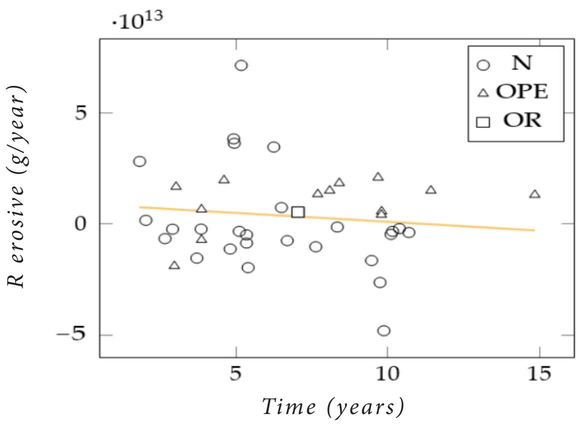

Figure 5. Resistance to adhesive wear by sliding (f (x) = −8 × 1011x + 9 × 1012; R2 = 0.0127) in patients analyzed. N: Normal medical condition, OPE: Osteopenia, OR: Osteoporumsis.

From the linear regression mathematical models determined for the rate of adhesive wear and for the resistance to adhesive wear of the femoral neck surface of each patient, which are shown in Figures 4 and 5, it can be said that the coefficient of determination is the proportion of the total variance of the variables explained by the regression. Likewise, in the case of this type of wear, the determination coefficient reflects the goodness of fit of the models to the variables that have been explained (Figure 4 and Figure 5).

On the other hand, Figure 6 shows the distribution of the resistance to adhesive wear in all the patients with a mean of 3.79385E + 12 (N/cm2), a coefficient of asymmetry of 0.710122 (between 1 and 1) indicating a distribution moderately inclined to the right and a kurtosis of 2.54094 (< 3) indicating a platykurtic distribution, that is, with a lower and broader peak with shorter ends than a symmetric distribution [23].

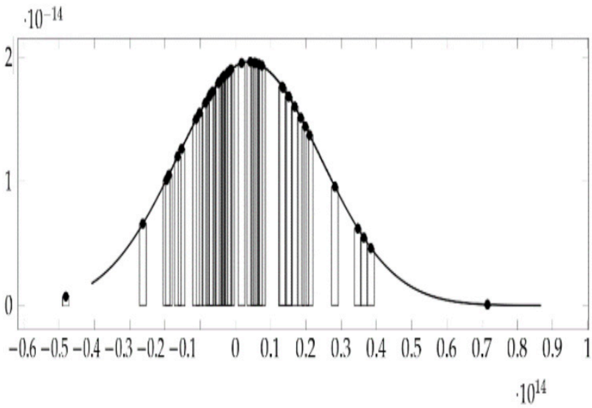

Figure 6. Probability distribution for resistance to adhesive wear by sliding in all patients.

CONCLUSIONS

The loss of bone mass and the mechanical behavior of the coxofemoral joints of female patients affected by diseases with bone decalcification, in pathological conditions of normal, osteopenia and osteoporumsis, were evaluated using medical imaging and tribological methods.

The results of bone densitometry of the left coxofemoral joints corresponding to 41 female patients were used. The women are from 25 to 80 years of age. Therefore, bone mineral content (BMC), bone mineral density (BMD), t-score and z-score were obtained and used to determine the rate and resistance to erosive wear and adhesive wear in joints. hip women.

The wear of the neck area of the left femur of the patients was analyzed and a rate that characterizes erosion due to decalcification was determined at 1.14818g/year and has an asymmetric distribution with moderate concentration on the extreme left.

In the case of the analysis of the adhesive wear due to sliding, a wear rate with an average value of −5.38614 × 10−14 cm2/N resulted, showing a direct relationship that shows the increase in wear as the time of the disease passes. patients and presents a mathematical model with a correlation coefficient equal to 0.6639 with p − value = 0.009612(< 0.05), using time based on the patient's z-score as a reference.

The coefficient of determination obtained both for the rates and resistances to erosive wear and for the rates and resistances to adhesive wear of the patients are the proportion of the total variance of the variable explained by the regression, in this case either the rate or resistance. erosive wear or adhesive wear of patients. Similarly, the coefficient reflects the goodness of fit of the models to the tribological variables.

The data from the bone densitometry analysis is very important, since it avoids a physical wear test and is a parameter for calculating and evaluating the damage caused by erosion and adhesion of the hip joints.

The determined adhesive wear rate quantifies the transfer of bone mass from the surface of the femoral portion as it slides into contact with the acetabulum in the hip joint of patients who have acquired osteopenia or either osteoporumsis, or who are in normal condition with the presence of decalcification of their bones when they walk or exert movement, this rate being higher in this last pathological condition.

From the tribological studies carried out, it can be said that the wear in the global region of the hips where the head of the femur makes contact is greater than in the surfaces that are not in contact, such as the neck of the femur; therefore, rate of adhesive wear is greater than rate of erosion in hip joints.

Decalcification gradually removes material from the surface of the hip joint, causing cracks and causing osteopenia up to osteoporumsis in many patients. The wear an indicator of the existence of these diseases due to decalcification and depends on several factors, such as age, alcoholism, overweight, menopause among other causes.

Finally, from the statistical analysis, an asymmetric distribution of resistance results was obtained, showing concentration at the left end of the curve for erosive wear and an asymmetric distribution with concentration at the right end for resistance to erosive wear.

REFERENCES

1. Ammann, P. y R. Rizzoli (mar. de 2003). «**Bone strength and its determinants**». En: Osteoporumsis International 14, págs. 13-18. doi: 10.1007/s00198-002-1345-4

2. González, Luis Alonso, Gloria María Vásquez y José Fernando Molina (mar. de 2009). «**Epi- demiología de la osteoporumsis».** En: Revista Colombiana de Reumatología 16, págs. 61-75. doi: 10.1016/s0121-8123(09)70119-7.

3. Athanasiou, K. A. y col. (ago. de 2000). «**Fundamentals of biomechanics in tissue engineering of bone».** En: Tissue Engineering 6.4, págs. 361-381. issn: 1076-3279. doi: 10. 1089 / 107632700418083.

4. Gulsen, Akdogan, Goncu Merve y Parlak Meltem (ene. de 2018). «**Biotribology of Cartilage Wear in Knee and Hip Joints Review of Recent Developments**». *En: IOP Conference Series: Materials Science and Engineering 295, pág. 012040. doi: 10.1088/1757- 899x/ 295/1/012040.*

5. Cereatti, A. y col. (feb. de 2010). *«Is the human acetabulofemoral joint spherical?» En: The Journal of Bone and Joint Surgery. British volume 92-B, págs. 311-314. doi:* 10.1302/ 0301-620x.92b2.22625.

6. Caeiro Rey, J. R. y col. (ago. de 2005). «Factores determinantes de la resistencia ósea». En: Revista Espyearla de Enfermedades Metabólicas Óseas 14, págs. 67-74. doi: 10.1016/ S1132-8460(05)72686-6.

7. Haba, Yvonne y col. (2012). «Relationship Between Mechanical Properties and Bone Mi- neral Density of Human Femoral Bone Retrieved from Patients with Osteoarthritis». En: The Open Orthopaedics Journal 6. url: https : / / dx. doi. org / 10. 2174 % 5C % 2F1874325001206010458.

8. Gant, A.J., M.G. Gee y B. Roebuck (ene. de 2005). «Rotating wheel abrasion of WC/Co hardmetals». En: Wear 258, págs. 178-188. doi: 10.1016/j.wear.2004.09.028. (Visitado 06-01-2021).

9. Gulsen, Akdogan, Goncu Merve y Parlak Meltem (ene. de 2018). «**Biotribology of Cartilage Wear in Knee and Hip Joints Review of Recent Developments**». *En: IOP Conference Series: Materials Science and Engineering 295, pág. 012040. doi:* 10.1088/1757- 899x/ 295/1/012040.

10. **Test Method for Conducting Erosion Tests by Solid Particle Impingement Using Gas Jets»** (2018). En: ASTM. doi: 10.1520/g0076-18.

11. **Test Method for Ranking Resistance of Materials to Sliding Wear Using Block-on-Ring Wear Test»** (2017). En: ASTM. doi: 10.1520/g0077-17.

12. **Test Method for Wear Testing with a Pin-on-Disk Apparatus**» *(2017). En: ASTM. doi: 10.1520/g0099.*

13. Edith Miranda, V. y col. (ene. de 2013). «**Densitometría ósea». En: Revista Médica Clínica** Las Condes 24, págs. 169-173. doi: 10.1016/S0716-8640(13)70142-1.

14. Sheu, Angela y Terry Diamond (s.f.). «**Diagnostic tests: Bone mineral density**: Testing for osteoporumsis». En: Australian Prescriber 39, págs. 35-39. doi: 10.18773/austprescr. 2016.020.

15. Menezes, Pradeep L y col. (2013). **Tribology for Scientists and Engineers**. New York, Ny Springer New York.

16. Straffelini, Giovanni (2015). **Friction and Wear**. Springer International Publishing. doi: 10. 1007/978-3-319-05894-8.

17. Liu, J. y col. (abr. de 2019). «**State of the art in osteoporumsis risk assessment and treatment»**. En: Journal of Endocrinological Investigation 42, págs. 1149-1164. doi: 10.1007/s40618- 019-01041-6.

18. Looker, A. C. y col. (ago. de 1998). «Updated Data on Proximal Femur Bone Mineral Levels of US Adults». En: Osteoporumsis International 8, págs. 468-490. doi: 10.1007 / s001980050093.

19. Majumdar, S. y col. (dic. de 1994). «**Analysis of trabecular bone structure in the distal radius using high-resolution MRI**». En: European Radiology 4. doi: 10.1007/bf00226822. (Visitado 05-05-2021).

20. Osterhoff, Georg y col. (jun. de 2016). «**Bone mechanical properties and changes with osteo- porosis**». *En: Injury 47, S11-S20. doi: 10.1016/s0020-1383(16)47003-8.*

21. Oungoulian, Sevan R. y col. (jul. de 2015). «**Wear and damage of articular cartilage with fric- tion against orthopedic implant materials**». *En: Journal of Biomechanics 48, págs. 1957-1964. doi: 10.1016/j.jbiomech.2015.04.008.*

22. Ring, David y Jesse B. Jupiter (dic. de 2004). «**Treatment of osteoporumtic distal radius fractures**». *En:* Osteoporumsis International 16, S80-S84. doi: 10.1007/s00198-004-1808-x.

23. Mendenhall, William., Wackerly, **Dennos D. y Scheaffer, Richard L. (1994). Estadística** Matemática con Aplicaciones. México, 2da. ed., Grupo Editorial.

24. Layton, Robin, Todd Stewart y Neil Messenger (2020). **Understanding Movement and its Influence on Tribology of the Human Hip**. url: https://etheses.whiterose.ac.uk/26885/ 1/Layton_Thesis_2020.pdf.