Patterns of Femoral Bone Remodeling: Comparison of the Tongariki Native Easter Islanders with European Population

Andrea G. Drusini*[,1], Annunziata Carrieri[1] and Anna Chiara Frigo[2]

[1]*Department of Medical-Diagnostic Sciences and Special Therapies, University of Padova, Via Giustiniani 2- 35128 Padova, Italy*

[2]*Dipartimento di Medicina Ambientale e Sanità Pubblica – Sede di Igiene, Università di Padova, Via Loredan 18, 35131 Padova, Italy*

Abstract: The relationship between sex, age and histomorphometry in femoral cortical bone was examined in a 19th century skeletal population from the XIX-XX Century Northern Italy, and compared with the femoral sections belonging to the Tongariki Easter Islanders (XVII-XVIII Century A.D.). Femoral cross sections were examined using an image analysis system. Several histological variables were calculated to assess differences between sexes and among age groups. The results indicate significant differences between the two populations in osteon remodeling. OPD (Osteon Population Density) increased especially in the female sample in both populations, but In the Easter Island female sample OA (Osteon Area) was lower than in the European female population. In the Easter Island female sample, %Or (percent Osteon refilling) decreased after 49 years of age. The phenomenon was also evident in both sexes of European population, although the involution process was not so marked as age advanced.

Keywords: Easter Island, osteon remodeling, *moai* building, stress.

INTRODUCTION

Rapa Nui is a hilly, high volcanic island of 64 square miles, settled by Polynesians derived from Asia and spoke an eastern Polynesian dialect related to Hawaiian and Marquesan. The giant statues of Easter Island – the *moai* – range from 2 to almost 10 m in height, and weight can reach the 82 tons. Archaeological evidence confirms intense building activity - especially *moai* building - on the island for 500 years. Hundreds of statues were moved from the quarry, some of them as far as 10 km (6 ¼ miles). Since 180 people could pull a 10 tons statue, as an experiment demonstrated, specialists in ancient technology calculate that 1500 people could certainly have moved a 82 tons statue. Anthropological studies revealed that humeral and femoral robusticity indices of Easter islanders were very similar in males and females; it can be supposed that also women were submitted to intense physical stresses [1]. Easter Island (Rapa Nui) is currently the focal point of research in an intensively studied archaeological area that extends from the plains at the foot of the southwest slopes of the Poike Peninsula. Close to three hundred ceremonial or burial structures are known and recognized as ahu (ceremonial centre) on the whole island: of these, a smaller number are large, complex, raised, rectangular platforms, sloping ramps and associated 'plazas', most of which supporting multi-ton monolithic statues of volcanic tuff. The 'moai', symbols of the prestige and status of the local groups, raised to worship deified ancestors, are the most conspicuous features of the archaeological landscape. The analysis of radiocarbon-dated structures indicates that the ahu and the statues represent a chronological progression of a single developing society [2].

During the period 1991-2001, the Italian Archaeological Mission directed by Giuseppe Orefici carried out some excavations in different sites of the island, and a huge quantity of skeletal remains belonging to pre-contact Easter islanders was recovered from the Ahu Tongariki ceremonial centre in an area of some 5000 square meters [1, 3]. All the bones were studied according to the standard physical anthropological methods, including sex and age determination, osteometrics, morphological variations, and palaeopathology. Moreover, histological sections were prepared from samples taken from femoral midshaft.

Bone possesses the unique property of providing a living, dynamic and durable record of past events encoded in its microstructure [4-7]. Quantitative histological studies of ancient bone can provide information relating to age at death and levels of physical activity [8-31]. Studies as far back as 1892 by Wolff have shown that bone is negatively influenced by reduction of its load-carrying role. Bone loss and reduction of functional-mechanical integrity of the tissue during life is mainly due to a decreased mechanical usage of skeleton. Mechanical stress is an important factor in the maintenance of normal cortical bone remodeling. Studies as well as bone density and histomorphometric analyses has been conducted *in vivo* to detect long-term bone loss resulting from long-term disuse, but few information was obtained from historical and archaeological skeletal material. As Burr *et al*. [26] have demonstrated, the data suggest that a more active lifestyle is associated with greater osteon population density (OPD). The aim of this study was a quantitative estimation of variation in bone microstructures in two populations, differing not only in geographic position, but also in

*Address correspondence to this author at the Department of Medical-Diagnostic Sciences and Special Therapies, University of Padova, Via Giustiniani 2- 35128 Padova, Italy; Tel: 049-8276302; Fax: 049-8276300; E-mail: andrea.drusini@unipd.it

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social-economic and adaptive background. Histomorphometric analysis of femoral cortical bone, based on image analysis techniques, has recently become an important investigative method in the study of the histological variables of bone remodeling. The aim of this study was a quantitative estimation of variation in bone microstructures in two populations, differing not only in geographic position, but also in social-economic and adaptive background.

MATERIALS AND METHODS

Histological and histomorphometric analysis of femoral diaphyseal fragments (excluding the *linea aspera*, see Fig. **1**) from twenty precontact native Easter Islanders (9 males and 11 females) were compared with those of 151 Europeans from the 19th century (81 males and 70 females) of known age, sex, occupation and cause of death. Thin undecalcified histological sections of approximately 90 microns embedded in ethylmethacrylate were obtained using a Leitz 1600 rotating microtome. The sections were examined under low power with 10× ocular and 10× widefield ocular lenses using a standard laboratory microscope with a grid of 0.64 mm^2 on the eyepiece. The following twelve histomorphometric variables were studied [7, 14, 26, 30, 32-34] (Tables **1** and **2**):

- *Intact Osteon Density* (IO) - number of secondary intact osteons (n_o) per mm^2; secondary intact osteon is one where Haversian canal did not undergo remodeling at least for 90%;
- *Fragmentary Osteon Density* (FR) - number of fragmentary osteons (n_f) per mm^2; fragmentary osteon is one where Haversian canal underwent remodeling at least for 10%;
- *Osteon Area* (OA) - area average of secondary osteon surfaces (A_o), Haversian canals included;
- *Osteon Perimeter* (P_o) - perimeter average of secondary osteon surfaces (p_o), Haversian canals included;
- *Haversian Canal Area* (HcA) - area average of Haversian canal surfaces (A_{Hc});
- *Haversian Canal Perimeter* (P_{Hc}) - perimeter average of Haversian canals (p_{Hc});
- *Mean Osteonal Cross Sectional Area* (A_h) - area average of secondary osteon surfaces (p_o), Haversian canals excluded

$$A_h = OA - HcA$$

- *Mean Cross Sectional Diameter* (D_h) - diameter average of secondary osteon

$$D_h = \sqrt{\frac{4A_h}{\pi}}$$

- *Osteon Population Density* (OPD) - total number of intact secondary osteon (n_o) per mm^2 and total number of osteon fragments (n_f) per mm^2

$$OPD = IO + FR$$

- *Accumulated Osteon Creation* (AOC) - total number of intact secondary osteons (n_o) per mm^2, total number of osteon fragments (n_f) per mm^2 and missing osteons (old osteons completely replaced by new ones and so not visible), for a specific OPD

$$AOC = IO + FR + Missing_{osteons}$$

Missing osteons were calculated following the methods proposed by Frost [32], Stout and Paine [34] and Abbott *et al.* [5].

- *Net Osteonal Remodeling* (nOR) - total quantification of bone remodeling

$$nOR = AOC \times A_h$$

nOR is a very important index independent of both chronological age and real compact bone age.

- *Percent Osteonal Refilling* (%Or) - total quantification of bone refilling

$$\%Or = \frac{A_h}{OR}$$

The formula expresses the osteblast replacement modality due to the osteoclasts.

The two-tailed *t* test was utilized in order to evaluate the significant differences among the variables within the age classes and between the two populations (Tables **3**, **4** and **5**). The sexual dimorphism index after Hall [35] was also used to quantify the differences between sexes (Table **6**).

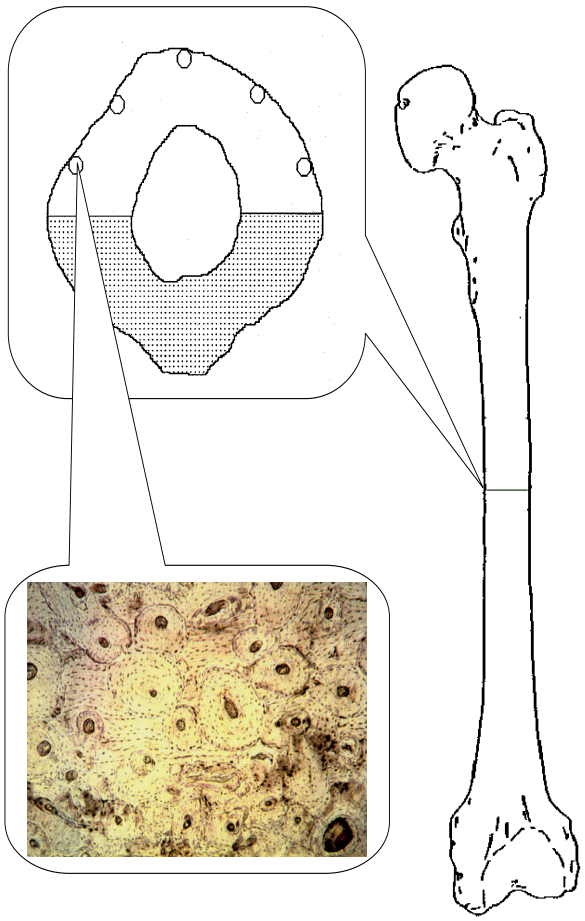

Fig. (1). Location of transverse section along the femural diaphysis.

RESULTS

Table 1. Summary of the 12 Variables Considered Per Age Class and Sex in the European Population

		20-29 Years		30-39 Years		40-49 Years		50-x Years	
		MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
IO	**M**	4.960	1.380	7.050	0.700	7.540	1.170	7.480	1.310
	F	4.830	0.920	4.420	1.460	7.080	0.700	7.980	0.530
FR	**M**	1.480	1.050	2.790	0.720	2.800	0.890	3.230	1.050
	F	1.120	0.310	1.090	0.680	3.220	0.610	3.840	0.250
OA	**M**	0.092	0.014	0.081	0.011	0.087	0.012	0.077	0.017
	F	0.091	0.022	0.070	0.006	0.080	0.013	0.077	0.007
P_O	**M**	1.140	0.080	1.070	0.080	1.120	0.080	1.030	0.110
	F	1.140	0.080	1.010	0.040	1.090	0.090	1.070	0.080
HcA	**M**	0.006	0.002	0.006	0.002	0.010	0.003	0.009	0.004
	F	0.006	0.002	0.004	0.001	0.006	0.002	0.007	0.002
P_{Hc}	**M**	0.310	0.030	0.320	0.040	0.380	0.070	0.360	0.080
	F	0.310	0.040	0.240	0.030	0.310	0.060	0.330	0.040
A_h	**M**	0.085	0.013	0.076	0.010	0.077	0.010	0.068	0.013
	F	0.085	0.021	0.066	0.005	0.074	0.011	0.070	0.006
D_h	**M**	0.329	0.024	0.310	0.021	0.313	0.021	0.293	0.027
	F	0.327	0.039	0.290	0.011	0.306	0.023	0.298	0.014
OPD	**M**	6.440	2.140	9.840	0.880	10.340	1.470	10.720	1.940
	F	5.940	1.090	5.490	2.000	10.300	1.000	11.820	0.540
AOC	**M**	8.010	3.950	15.380	5.500	16.320	3.840	15.120	5.200
	F	7.370	3.620	6.670	1.660	15.790	4.500	20.870	5.070
nOR	**M**	0.682	0.323	1.199	0.1552	1.262	0.356	1.039	0.437
	F	0.689	0.612	0.440	0.109	1.190	0.458	1.479	0.448
%Or	**M**	93.190	1.310	92.490	1.560	89.100	2.990	88.580	2.960
	F	93.260	1.420	94.480	1.370	92.630	1.820	90.530	2.240

Table 2. Summary of the 12 Variables Considered Per Age Class and Sex in Easter Islanders

		30-39 Years		40-49 Years		50-x Years	
		MEAN	SD	MEAN	SD	MEAN	SD
IO	**M**	-	-	7.160	1.230	9.000	0.740
	F	5.430	0.550	7.700	0.870	10.500	0.850
FR	**M**	-	-	2.940	0.260	4.050	0.750
	F	2.730	0.310	3.050	0.180	3.970	1.090
OA	**M**	-	-	0.075	0.007	0.075	0.005
	F	0.069	0.014	0.068	0.012	0.990	0.080

(Table 2). Contd…..

		30-39 Years		40-49 Years		50-x Years	
		MEAN	SD	MEAN	SD	MEAN	SD
P_O	M	-	-	1.000	0.060	1.010	0.020
	F	0.980	0.100	0.990	0.080	1.000	0.100
HcA	M	-	-	0.009	0.003	0.009	0.002
	F	0.008	0.002	0.008	0.002	0.015	0.008
P_{Hc}	M	-	-	0.390	0.060	0.370	0.030
	F	0.360	0.040	0.370	0.060	0.440	0.090
A_h	M	-	-	0.066	0.005	0.067	0.004
	F	0.061	0.012	0.059	0.010	0.055	0.007
D_h	M	-	-	0.289	0.011	0.291	0.010
	F	0.278	0.028	0.274	0.023	0.264	0.016
OPD	M	-	-	10.100	1.300	13.005	0.310
	F	8.150	0.660	10.750	0.910	14.470	1.940
AOC	M	-	-	13.540	4.610	26.800	7.690
	F	8.850	0.910	12.950	1.420	24.820	8.470
nOR	M	-	-	0.904	0.364	1.815	0.634
	F	0.544	0.143	0.775	0.182	1.372	0.479
%Or	M	-	-	88.230	2.600	88.430	1.990
	F	88.470	1.690	87.930	1.600	80.400	6.500

Table 3.

---------- AGE=30-39 ----------

The TTEST Procedure

Statistics

Variable Wilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t| Pr
IO	I	15	6.3333	1.296	0.3346	3.8	8	
IO	P	4	5.425	0.6305	0.3152	4.8	6.25	
IO	Diff	(1-2)	0.9083	1.2055	0.6784		0.1982	0.1768
FR	I	15	2.34	0.9898	0.2556	0.4	4	
FR	P	4	2.725	0.3594	0.1797	2.4	3.2	
FR	Diff	(1-2)	-0.385	0.9108	0.5126		0.4628	0.4225
OA	I	15	0.078	0.0112	0.0029	0.062	0.1	
OA	P	4	0.0693	0.016	0.008	0.05	0.089	
OA	Diff	(1-2)	0.0087	0.0122	0.0069		0.2188	0.4521
po	I	15	1.054	0.0761	0.0197	0.95	1.22	
po	P	4	0.9775	0.1109	0.0554	0.85	1.12	
po	Diff	(1-2)	0.0765	0.0833	0.0469		0.1212	0.2920
HcA	I	15	0.0055	0.0019	0.0005	0.003	0.009	
HcA	P	4	0.0083	0.0026	0.0013	0.006	0.011	

(Table 3). Contd…..

Variable Wilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t| Pr
HcA	Diff	(1-2)	-0.003	0.0021	0.0012		0.0319	0.0608
phc	I	15	0.2967	0.0551	0.0142	0.21	0.39	
phc	P	4	0.3575	0.0499	0.025	0.31	0.41	
phc	Diff	(1-2)	-0.061	0.0542	0.0305		0.0625	0.0796
Ah	I	15	0.0726	0.01	0.0026	0.057	0.091	
Ah	P	4	0.061	0.0139	0.0069	0.044	0.078	
Ah	Diff	(1-2)	0.0116	0.0108	0.0061		0.0723	0.2696
Dh	I	15	0.3035	0.0209	0.0054	0.27	0.34	
Dh	P	4	0.2778	0.0323	0.0161	0.237	0.316	
Dh	Diff	(1-2)	0.0257	0.0233	0.0131		0.0664	0.2933
OPD	I	15	8.6733	2.0436	0.5277	4.2	11.4	
OPD	P	4	8.15	0.7627	0.3813	7.2	9.05	
OPD	Diff	(1-2)	0.5233	1.882	1.0591		0.6275	0.3951
AOC	I	15	12.477	6.3719	1.6452	4.24	27.6	
AOC	P	4	8.855	1.0514	0.5257	7.52	9.97	
AOC	Diff	(1-2)	3.6223	5.7993	3.2634		0.2825	0.2501
nOR	I	15	0.9457	0.5991	0.1547	0.291	2.512	
nOR	P	4	0.5443	0.1642	0.0821	0.411	0.78	
nOR	Diff	(1-2)	0.4014	0.548	0.3084		0.2104	0.2501
%Or	I	15	93.157	1.8289	0.4722	90.35	95.78	
%Or	P	4	88.473	1.9481	0.9741	86.34	91.04	
%Or	Diff	(1-2)	4.6842	1.8505	1.0413		0.0003	0.0059

Table 4.

---------- AGE=40-49 ----------

The TTEST Procedure

Statistics

Variable PrWilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t|
IO	I	14	7.2429	0.9573	0.2559	5.8	9.4	
IO	P	9	7.4	1.1856	0.3952	5.45	8.75	
IO	Diff	(1-2)	-0.157	1.0502	0.4487		0.7296	0.8747
FR	I	14	3.0714	0.779	0.2082	1.2	4.6	
FR	P	9	2.9889	0.2472	0.0824	2.6	3.4	
FR	Diff	(1-2)	0.0825	0.6316	0.2699		0.7627	0.6350
OA	I	14	0.0824	0.0131	0.0035	0.064	0.102	
OA	P	9	0.0716	0.0106	0.0035	0.055	0.085	
OA	Diff	(1-2)	0.0109	0.0122	0.0052		0.0494	0.0584
po	I	14	1.0993	0.0911	0.0243	0.97	1.22	
po	P	9	0.9956	0.0767	0.0256	0.89	1.11	
po	Diff	(1-2)	0.1037	0.0859	0.0367		0.0101	0.0195
HcA	I	14	0.0074	0.0032	0.0009	0.003	0.014	

(Table 4). Contd…..

Variable PrWilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t|
HcA	P	9	0.0088	0.0024	0.0008	0.006	0.013	
HcA	Diff	(1-2)	-0.001	0.003	0.0013		0.2750	0.1609
phc	I	14	0.3386	0.0749	0.02	0.22	0.48	
phc	P	9	0.3789	0.0609	0.0203	0.29	0.45	
phc	Diff	(1-2)	-0.04	0.0699	0.0299		0.1915	0.1734
Ah	I	14	0.0752	0.0112	0.003	0.059	0.092	
Ah	P	9	0.0629	0.0089	0.003	0.049	0.075	
Ah	Diff	(1-2)	0.0123	0.0104	0.0044		0.0112	0.0231
Dh	I	14	0.3085	0.023	0.0061	0.275	0.342	
Dh	P	9	0.2827	0.02	0.0067	0.251	0.309	
Dh	Diff	(1-2)	0.0258	0.0219	0.0094		0.0118	0.0232
OPD	I	14	10.314	1.234	0.3298	8.6	13.2	
OPD	P	9	10.389	1.2631	0.421	8.35	12.05	
OPD	Diff	(1-2)	-0.075	1.2452	0.532		0.8898	0.8499
AOC	I	14	15.979	4.4456	1.1881	10.79	24.56	
AOC	P	9	13.28	3.7887	1.2629	9.44	21.94	
AOC	Diff	(1-2)	2.6993	4.2075	1.7976		0.1481	0.1755
nOR	I	14	1.2157	0.4418	0.1181	0.694	1.956	
nOR	P	9	0.6882	0.2602	0.0867	0.158	1.079	
nOR	Diff	(1-2)	0.5275	0.3829	0.1636		0.0041	0.0022
%Or	I	14	91.373	2.9714	0.7941	83.72	95.31	
%Or	P	9	88.093	2.3516	0.7839	84.34	91.88	
%Or	Diff	(1-2)	3.2795	2.7518	1.1757		0.0110	0.0074

Table 5.

---------- AGE=50+ ----------

The TTEST Procedure

Statistics

Variable PrWilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t|
IO	I	21	7.6952	1.1066	0.2415	5.6	9.8	
IO	P	7	9.6429	1.1728	0.4433	7.9	11.7	
IO	Diff	(1-2)	-1.948	1.1222	0.4898		0.0005	0.0016
FR	I	21	3.4952	0.8846	0.193	0.6	4.6	
FR	P	7	4.0143	0.9856	0.3725	2.8	5.5	
FR	Diff	(1-2)	-0.519	0.9089	0.3967		0.2022	0.2742
OA	I	21	0.0772	0.0138	0.003	0.06	0.11	
OA	P	7	0.0727	0.0115	0.0044	0.057	0.09	
OA	Diff	(1-2)	0.0045	0.0133	0.0058		0.4478	0.4096
po	I	21	1.0476	0.1007	0.022	0.91	1.27	
po	P	7	1.01	0.0714	0.027	0.91	1.14	
po	Diff	(1-2)	0.0376	0.0948	0.0414		0.3715	0.3125

(Table 5). Contd…..

Variable PrWilcoxon	Population Two-Sample Test	N	Mean	Std Dev	Std Err	Minimum	Maximum	Pr > |t|
HcA	I	21	0.0085	0.0035	0.0008	0.004	0.018	
HcA	P	7	0.0113	0.0067	0.0025	0.007	0.026	
HcA	Diff	(1-2)	-0.003	0.0044	0.0019		0.1567	0.1470
phc	I	21	0.349	0.0735	0.016	0.24	0.53	
phc	P	7	0.4043	0.0791	0.0299	0.33	0.57	
phc	Diff	(1-2)	-0.055	0.0749	0.0327		0.1029	0.0668
Ah	I	21	0.0689	0.011	0.0024	0.054	0.094	
Ah	P	7	0.0616	0.0089	0.0034	0.048	0.073	
Ah	Diff	(1-2)	0.0073	0.0106	0.0046		0.1238	0.1366
Dh	I	21	0.2952	0.0233	0.0051	0.263	0.346	
Dh	P	7	0.2793	0.02	0.0076	0.248	0.304	
Dh	Diff	(1-2)	0.0159	0.0226	0.0098		0.1182	0.1304
OPD	I	21	11.19	1.6431	0.3586	7.2	13.4	
OPD	P	7	13.657	1.587	0.5998	12.7	17.2	
OPD	Diff	(1-2)	-2.467	1.6304	0.7115		0.0018	0.0017
AOC	I	21	17.588	6.0257	1.3149	8.92	28.66	
AOC	P	7	25.954	8.7453	3.3054	15.04	38.59	
AOC	Diff	(1-2)	-8.367	6.7512	2.9465		0.0087	0.0196
nOR	I	21	1.2278	0.5043	0.11	0.582	2.154	
nOR	P	7	1.625	0.6625	0.2504	0.723	2.798	
nOR	Diff	(1-2)	-0.397	0.5449	0.2378		0.1068	0.2029
%Or	I	21	89.416	2.9108	0.6352	83.64	94.13	
%Or	P	7	84.991	6.4958	2.4552	71.24	90.54	
%Or	Diff	(1-2)	4.4243	4.0317	1.7596		0.0184	0.0496

Table 6. Summary of Sexual Dimorphism Index (After Hall [35]) for the 12 Variables Considered Per Age Class in the European Population and Easter Islanders

		20-29 Years		30-39 Years		40-49 Years		50-x Years	
		EUROPE	EASTER I.	EUROPE	EASTER I.	EUROPE	EASTER I.	EUROPE	EASTER I.
IO		2.621	-	37.305	-	6.101	-7.542	-6.684	-16.667
FR		24.324	-	60.932	-	-15.000	-3.741	-18.885	1.975
OA		1.087	-	13.580	-	8.046	9.333	-	-1220
P_O		-	-	5.607	-	2.679	99.901	-3.883	0.990
HcA		-	-	33.333	-	40.000	11.111	22.222	-66.667
P_{Hc}		-	-	25.000	-	18.421	5.128	8.333	-18.919
A_h		-	-	13.158	-	3.896	10.606	-2.941	17.910
D_h		0.608	-	6.452	-	2.236	5.190	-1.706	9.278
OPD		7.764	-	44.207	-	0.387	-6.436	-10.261	-11.265
AOC		7.990	-	56.632	-	3.248	4.357	-38.029	7.388
nOR		-1.026	-	99.963	-	5.705	14.270	-42.348	24.408
%Or		-0.075	-	-2.152	-	-3.962	0.340	-2.201	9.081

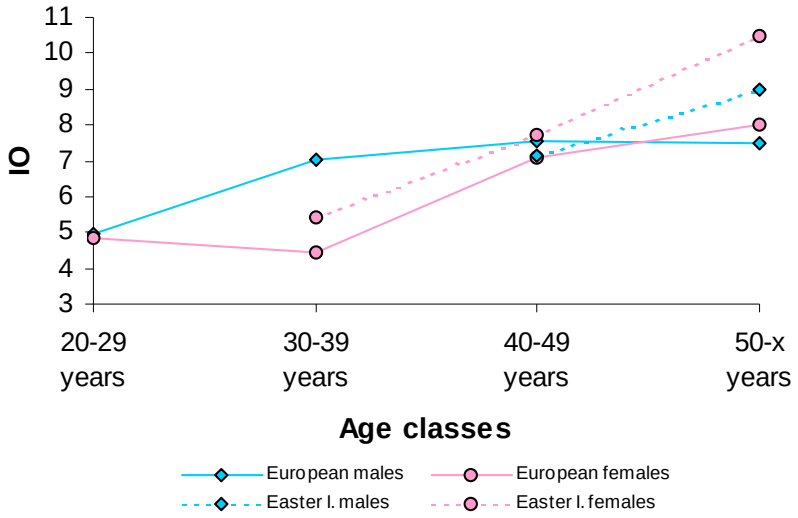

Fig. (2). Intact osteon density (IO) per age class.

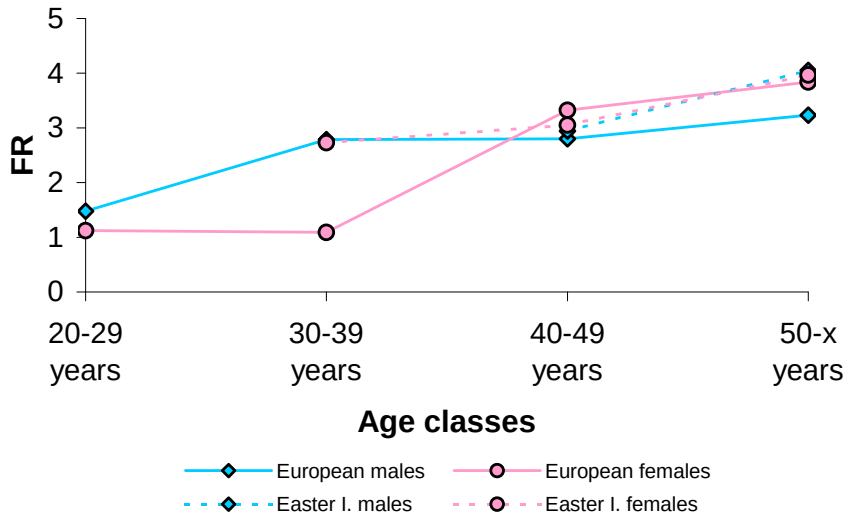

Fig. (3). Fragmentary osteon density (FR) per age class.

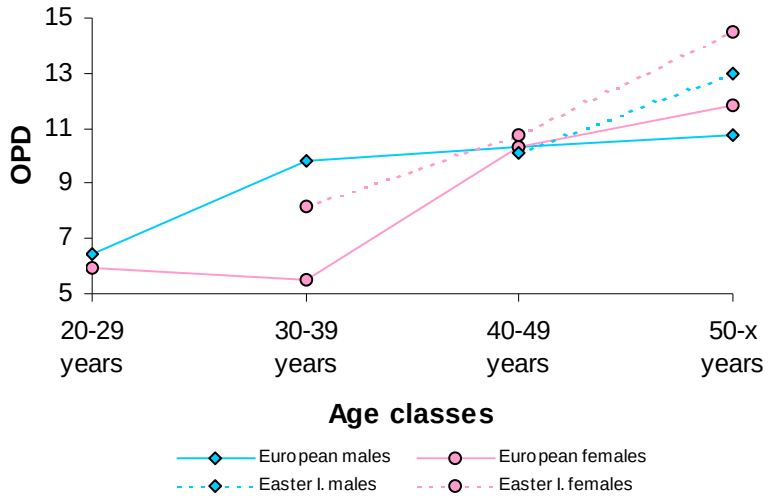

Fig. (4). Osteon population density (OPD) per age class.

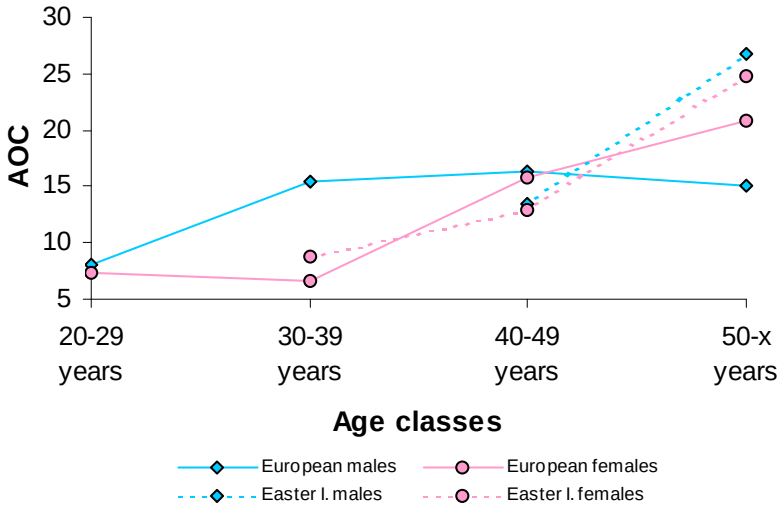

Fig. (5). Accumulated osteon creation (AOC) per age class.

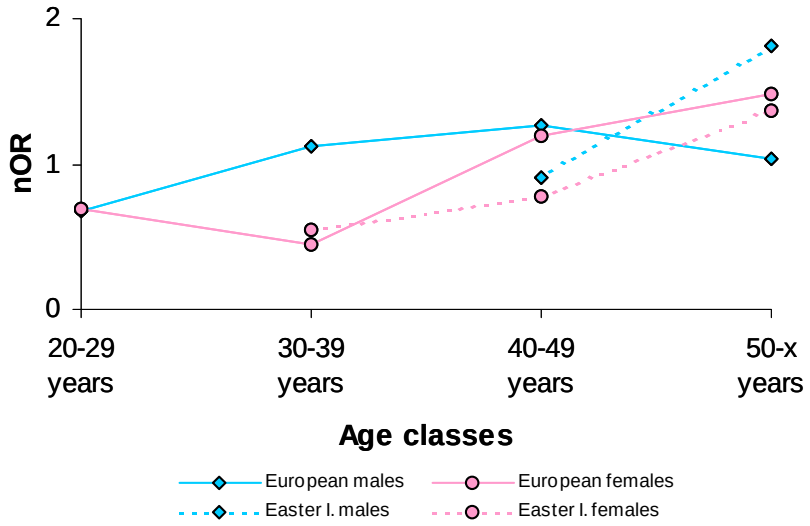

Fig. (6). Net osteonal remodeling (nOR) per age class.

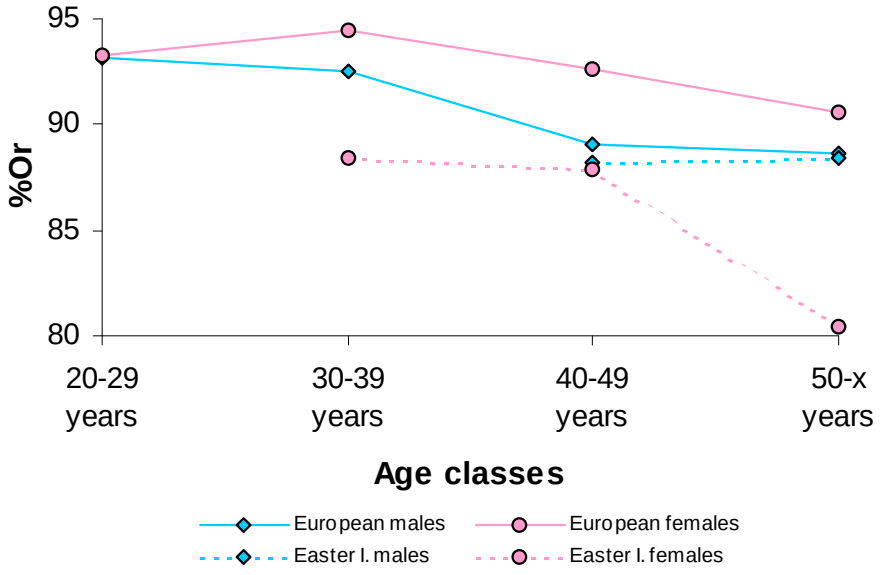

Fig. (7). Percent osteonal refilling (%Or) per age class.

DISCUSSION AND CONCLUSION

The histomorphometric analysis made on femoral diaphyseal sections from European and Easter Islanders populations showed the following results:

- OPD increased especially in the female sample in both populations. In European males, this variable significantly increased until 30 years of age to remain constant up to death. For European females, the phenomenon was initially slower but after 40 years of age it increased rapidly, surpassing the males values. High OPD values were also registered for Easter Islanders, in both sexes but particularly for females. Macroscopic studies revealed that Polynesians humeral and femoral robusticity indices were very similar in males and females; it can be supposed that also women were submitted to intense physical stresses. Archeological evidence confirms intense building activity - especially *moai* building - on the island for 500 years.
- In the Easter Island female sample, OA was lower than in the European female population.
- Sexual dimorphism index was high for the 30 to 39 years of age-group in the European population for most variables (see Figs. **2-7**).
- In the Easter Island female sample, %Or decreased after 49 years of age. The phenomenon was also evident in both sexes of European population, although the involution process was not so marked as age advanced.

The comparative study between modern and archeological populations allows the differences in inner bone remodeling to be revealed: in this way skeletal dynamics can be linked to cultural and environmental factors. Obviously, account must be taken of the methodological errors that can derive from the intrinsic nature of the archeological material, in particular the bone's degree of conservation.

This field of study is still in its infancy, but the future should provide more archeological and paleoenvironmental information - this is the trend of current data analysis. Bone histomorphometric investigation will then be on an even stronger footing as a tool for population studies.

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