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TITOLO TESI

Diversity of the proximal femur in humans: morphological variations of the head-neck junction

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ABSTRACT

The proximal femur is a high-diversity region of the human skeleton, especially at the anterior junction between head and neck, where various bony morphologies have been recognized since mid nineteenth century. Classical literature on this topic is chaotic and contradictory, making almost impossible the comparison of data from different researches. Starting from an extensive bibliographic review, the first standardized method to score these traits has been created. This method allows representing both the anatomical diversity of the region already described in literature and a part of variability not considered before, giving few and univocal definitions and allowing to collect comparable data. The method has been applied to three identified and five archaeological European skeletal collections, with the aim of investigating the distribution of these features by sex, age and side, in different places and time periods. It has also been applied to 3D digital reconstructions of femurs from CT scan files of coxo-femoral joints from fresh cadavers. In addition to the osseous traits described in the standardized method, the presence and frequency of some features known as herniation pits have been scored both on bones and on CT scans.

The various osseous traits of the proximal femur are present at similar frequencies in skeletal samples from different countries and different historical periods, even if with clear local differentiation. Some of the features examined show significant trends related to their distribution by gender and age. Some hypotheses are proposed about the etiology of these morphologies and their possible implication with the acquisition of bipedalism in Humans. It is therefore highlighted the possible relation of some of these traits with the development of disorders of the hip joint. Moreover, it is not recommended the use of any of these features as a specific activity-related marker.

Keywords: hip joint, proximal femur, head-neck junction, Poirier’s facet, Allen’s fossa, femoroacetabular impingement, bipedalism.

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1. INTRODUCTION

1.1 Subject and aim of the study

At the very beginning of my doctorate I found myself in the need of using some skeletal features as markers of a specific activity. I was focused on some morphological variations of the human femur related, according to some authors (Molleson & Blondiaux, 1994; Pálfi and Dutour, 1996), with the horseback riding practice, in particular the so-called “Poirier’s facet”. However, trying to detect this variation on the proximal femur, I realized that it was more difficult than expected. In fact the front aspect of the proximal femur showed a great morphological variability in the head-neck junction region and there was a great confusion in the existing literature about the names, the descriptions and the distributions of these features. There was not a single standardized method to score the presence and quality of these morphologies or at least univocal definitions. Realizing the extent and complexity of the subject as well as the actual need of clarity, I made the anatomical variability of the proximal femur the subject of my doctorate research.

The first step of this research has been an extensive bibliographic review. The second step has been the creation, using an identified skeletal collection, of a standardized scoring method to score the presence and the morphology of the morphological variations of the proximal femur, published in Radi et al. (2013)(see *§Methods*). This method has been applied to three identified and five archaeological European skeletal collections (see *Materials*), with the aim of investigating the distribution of these features by sex, age and side, in different places and time periods. Understanding better these distributions is crucial for any interpretative consideration of these traits, taking into consideration that also anatomical and medical works have not yet succeeded in clarifying their etiology. The method has also been applied to 3D digital reconstructions of femurs from CT scan files of coxo-femoral joints from fresh cadavers, as a first try to find a match point between anthropological studies on dry bones and current medical studies on living patients (see *§ 1.3*) and it could represent a starting point for future *in vivo* investigations. Moreover, in addition to the osseous traits described in the standardized method, the presence and frequency of some features known as herniation pits (see *§ 1.3*) have been scored both on bones and on CT scans.

1.2 Morphological variations of the proximal femur in the academic literature

The first appearance of the morphological variations of the anterior femoral head-neck junction in literature has been in the second half of the 19^{th} century, when they were graphically represented for the first time in some anatomical plates (Henle, 1855; Cruveilhier et al., 1862). However, the first descriptions and definitions of these traits are reported in anatomical atlases only some years later, between the end of the 19^{th} century and the first three decades of the 20^{th} century (Allen & Shakespeare, 1882; Fick, 1904; Poirier & Charpy, 1911; Testut, 1911). In those years several authors made this portion of the proximal femur the subject of their studies (Bertaux, 1891; Charles, 1893; Evangeli-Tramond, 1894; Regnault, 1898; Frazer, 1906; Parsons, 1914; Walmsley, 1915; Pearson & Bell, 1919; Meyer, 1924, 1934; Odgers, 1931), and it is precisely in this period that originated most of the confusion existing in literature. The kind of material that has been used in these works was not uniform (dry bones, fresh bones from cadavers or both), affecting both the descriptions of the traits and the comparability and reliability of the data of their distributions.

The great morphological diversity characterizing this region, a real “hot spot” of variability, is reflected in the number of different names given to the several features existing: cervical fossa (Allen & Shakespeare, 1882), *empreinte* (Bertaux, 1891), *empreinte iliaque* (Regnault, 1898; Poirier & Charpy, 1911), *Halsgelenkhöcker* (*eminentia articularis colli femoris*) (Fick, 1904), capsular groove, anterior eminence, pubic imprint (Walmsley, 1915), alpha, beta and gamma facets (Pearson & Bell, 1919), anterior acetabular imprint (Meyer, 1924). Moreover, some authors also reported the possible presence of a bony ridge surrounding or delimiting someway these morphologies: *bourrelet osseux* (Poirier & Charpy, 1911), capsular ridge (Walmsley, 1915), cervical ridge

(Meyer, 1934). This area is so peculiar to induce Angel (1964) to name it "reaction area", term with whom it is generally known nowadays in medical studies. Various authors used the same term referring to different traits and different terms referring to the same trait. It is emblematic the case of the term "*eminentia articularis colli femoris*". Fick (1904), who originally coined this term, intended to refer by it to the *empreinte iliaque* of Poirier (1911). Some years later, however, the same term was improperly used by Odgers (1931) and Schofield (1959) to indicate another feature of the proximal femur. Of this last one Angel (1964) provided probably the best description: " …a bar of bone, which runs medially from the upper anterior part of the greater trochanter over to the head of the femur […] this is the last part of the neck to ossify, and […] is formed largely from a medial nodule extending from the epiphysis of the greater trochanter which joins the femur in later adolescence, at 14 through 18 years…". The same bar of bone is also known under different names: *Verstärkungsleiste* (Sudeck, 1899), *torus cervicalis* (Meyer, 1934), cervical eminence (Kostick, 1963).

The descriptions of these features are also the most varied: smooth, rough, raised, depressed, in continuity with the articular surface of the head, distinct from the head, covered by cartilage, cribriform, finger-like, ulcer-like, moth-eaten, etc. Angel (1964) and Finnegan (1978) were the only ones to describe the morphological variations of the proximal femur more univocally though without the creation of a standardized scoring method and disregarding part of the existing variability.

Despite the problems related to the definition and scoring of these traits, until present terms such as Poirier's facet, Allen's fossa, iliac imprint and plaque have been widely used (Schofield, 1959; Kostick, 1963; Angel, 1964; Trinkaus, 1975; Finnegan, 1978; Capasso et al., 1999; Donlon, 2000; Scheuer et al., 2000; Belcastro 2006; Nayak et al., 2007; White et al., 2012; Vyas et al., 2013), often citing different and contrasting studies as reference.

There is also no general consensus about the etiological interpretation of these features, with more or less contradictory hypotheses: pressure of the acetabular rim with the hip in flexion and internal rotation (Regnault, 1898; Poirier & Charpy, 1911; both referring to the "*empreinte iliaque*"); bony contact with the acetabular rim with the hip in full extension (Walmsley, 1915; referring to the “pubic imprint”); contact with the vertical limb of the ilio-femoral ligament in the position of complete extension (Walmsley, 1915; referring to the “anterior eminence”); pressure of the supero-lateral part of the anterior capsule in full extension (Walmsley, 1915; referring to the “capsular groove”); new bone formation by the irritated periosteum (cervical ridge and the raised facets) and bone resorption (fossa of Allen and the deeper and longer incisions) both caused by pressure of the acetabular rim with extremity flexed (Meyer, 1924,1934); pressure of the circular fibres (*zona orbicularis*) of the hip-joint capsule (Odgers, 1931; referring to “*empreinte of Poirier”* or “*cervical fossa of Allen”*); pressure and friction from the ilio-psoas muscle (Angel, 1964; referring to “Poirier’s facet”); result of dynamic factors: primarily the interaction of muscles (iliopsoas) and ligaments (*zona orbicularis*) with gravity and leverage in extreme extension and secondarily the arrangement of ligament fibers into the capsule (crossing of the *zona* and the iliofemoral ligament) (Angel, 1964; referring to the “reaction area”); the degree of habitual flexion and abduction during normal locomotion, the pressure exerted by the *m. iliopsoas* or the pressure of the *m. rectus femoris tendons* (Trinkaus, 1975; referring to “Poirier’s facet”).

Nevertheless some of them have been used as functional markers related to specific activities such as squatting (Charles, 1893), the habit of lying upon the side when sleeping (Meyer, 1924, 1934), running or even walking downhill (Angel, 1964), sitting cross-legged and horseback riding (Molleson & Blondiaux, 1994; Pálfi & Dutour, 1996; Larsen, 1999).

1.3 Herniation pits, femoroacetabular impingement and the renaissance of the reaction area in current medical studies

In 2009 Villotte and Knüsel for firsts recognized the importance of current medical studies about herniation pits and femoroacetabular impingement in order to improve our comprehension of the variations of the reaction area of the femoral neck. In 1982 Pitt and coauthors described the “herniation pits” of the femoral neck. At that time, round to oval areas of radiolucency surrounded by a thin zone of sclerosis were often noticed in radiographies of the anterior superior quadrant of adult femoral necks, immediately lateral to the head-neck junction. They identified these areas of radiolucency as subcortical cavities formed by herniation of soft tissue through pre-existing defects of the bone. They related these cortical defects to the possible cribriform appearance of the reaction area of Angel (1964), due to abrasive action of the overlying hip capsule during hyperextension of the hip. According to the anatomic study with magnetic resonance by Daenen et al. (1997), the progressive invagination of the soft tissues into the reaction area when conical perforations are present could be due to movements of the iliopsoas muscle with respect to the hip capsule, with repeated flexion and extension of the hip such as in runners. Ganz et al. (2003) proposed that herniation pits are associated with femoroacetabular impingement (FAI) and not just occasional findings, as they where generally considered until then. The study by Leunig et al. (2005) confirmed this statement: according to the authors the presence of these juxta-articular fibrocystic changes at the femoral head-neck junction could represent a radiographic indicator of FAI, being present in 33% of FAI patients and only in 5% of healthy individuals. Excluding few exceptions (Kim et al., 2011), today there is general consensus about the correlation between FAI and herniation pits (Kassarjian et al., 2005; Pfirrmann et al., 2006; Panzer et al., 2008, 2010, 2012; Ji et al., 2013; Guo et al 2013). The femoroacetabular impingement consists in the repeated abutment between the femoral neck and the acetabulum (Tannast et al., 2007a; Leunig et al., 2009; Banerjee & McLean, 2011; Lequesne & Bellaiche, 2012). There are two type of impingement: cam-type and pincer-type. In the cam-type the impingement is generated by an aspherical morphology of the head-neck junction that push against the acetabular rim (minor possible causes are femoral retrotorsion and *coxa vara*). In the pincer-type excessive acetabular over-coverage (due to *coxa profunda*, *protrusio acetabuli*, acetabular retroversion or prominent posterior wall) leads to early linear contact between femoral head-neck junction and acetabular rim (Figure 1). The two types of impingements are generally considered to occur usually together as a mixed entity, even if some authors disagree (Cobb et al., 2010). With few exceptions (Hartofilakidis et al., 2011; Rubin et al., 2013), FAI is generally recognized as one of the major causes of the osteoarthritis of the hip (Ganz et al., 2003, 2008; Wagner et al., 2003; Beck et al., 2005; Tannast et al., 2007a; Doherty et al., 2008; Leunig et al., 2009; Banerjee & McLean, 2011; Lequesne & Bellaiche, 2012; Agricola et al., 2013a).

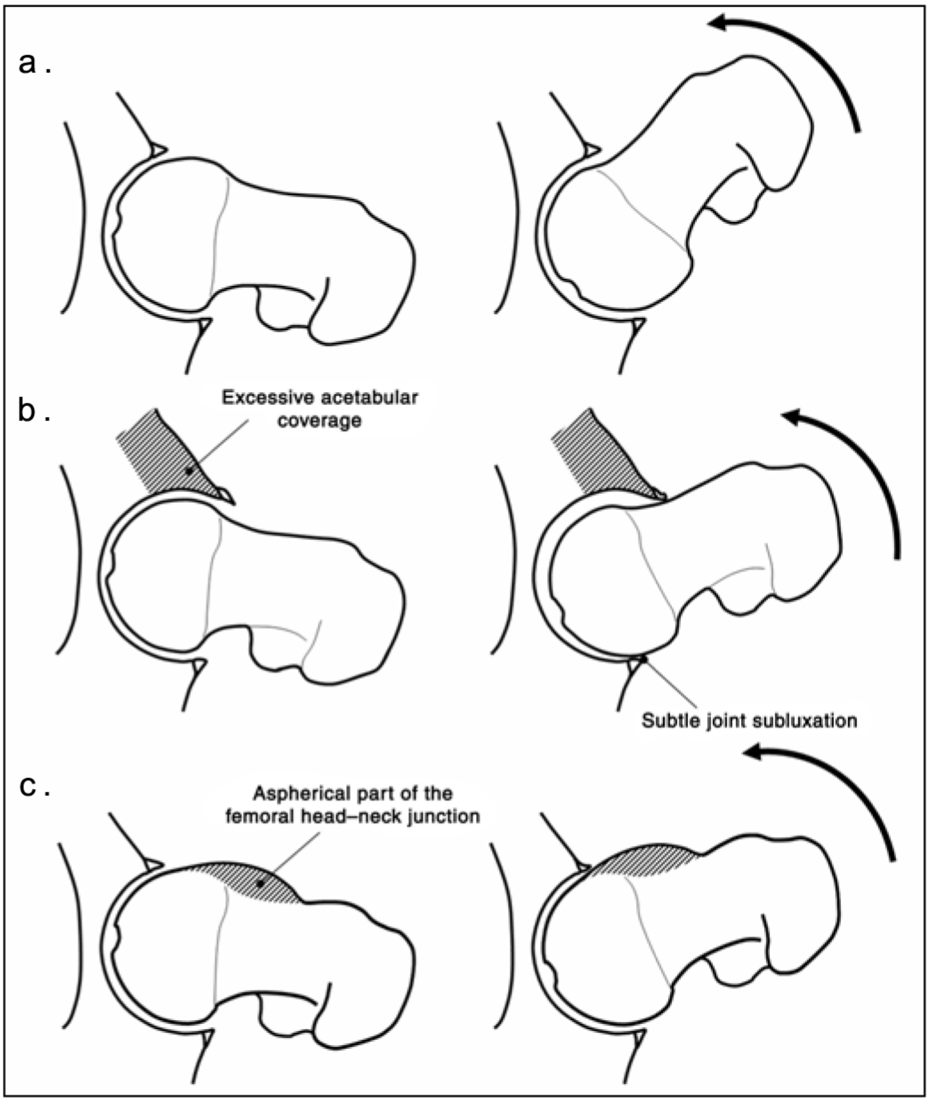


Figure 1. Normal configuration of hip with sufficient joint clearance allows unrestricted range of motion (a). In pincer impingement, excessive acetabular overcoverage leads to early linear contact between femoral head-neck junction and acetabular rim, resulting in labrum degeneration and significant cartilage damage. Posteroinferior portion of joint is damaged (contrecoup) due to subtle subluxations (b). In cam impingement, aspherical portion of femoral head-neck junction is jammed into acetabulum (c). *Figure and caption are taken from Tannast et al. (2007a).*

2. MATERIALS

The material used in the present study is composed by samples belonging to three identified skeletal collection (with known age, sex, profession, and cause of death), to five archaeological skeletal collections and to a CT scan files sample from contemporary cadavers.

2.1 Identified skeletal collections

Two of the three identified collections are housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy and were assembled by Prof. F. Frassetto and Prof. E. Graffi Benassi during the first half of the 20th century. One comes from the Certosa cemetery in Bologna and it is made up of 296 adolescent and adult skeletons of both sexes; the other one comes from a cemetery in Sassari (Italy) and its made up of 606 adolescent and adult skeletons of both sexes (Rastelli, 2005; Facchini et al., 2006; Belcastro & Mariotti, 2012).

The third identified collection, housed in the Department of Anthropology at Coimbra University (Portugal), comes from the Conchada cemetery in Coimbra and was primarily assembled by Professor E. Tamagnini between 1915 and 1942. It consists of 505 human skeletons, both from adults and subadults (Rocha, 1995).

The three identified collections are composed of individuals died between the end of the 19th century and the first half of the 20th century.

2.2 Archeological skeletal collections

The five archeological collections used in this study are housed in the Department of Archeological Sciences of the University of Bradford (UK) and curated by the Biological Anthropology Research Centre (BARC). The collections encompass a large period of time, from late prehistory to Mid-19th century.

The *Wetwang Slack* collection (on loan to the BARC from the Hull and East Riding Museum) comes from the site of Wetwang Slack, East Yorkshire (UK), one of the largest Iron Age cemeteries excavated in Britain. It is composed by circa 450 skeletons, both subadults and adults (Dent, 1984; Jay et al., 2008).

The *Baldock* collection comes from the Roman site of the California Cemetery (also known as the Upper Walls Common Cemetery) in Baldock, Hertfordshire (UK), occupied between 200 and 550 AD. It is composed by 139 individuals (Knüsel et al., 1996).

The *Raunds Furnells* collection comes from the late Anglo-Saxon site of Raunds Furnells Church cemetery, East Northamptonshire (UK). It is composed by 357 skeletons both males and females from the ages of neonates to old adults and dates from late 9th to mid-10th century (Boddington et al., 1996).

The *Hereford Cathedral* Medieval collection (on loan to the BARC from Hereford Cathedral) comes from the Hereford Cathedral Close, Hereford, Herefordshire (UK). It is composed by circa 1200 skeletons both males and females covering a large age range (Stone & Appleton-Fox, 1996).

The *St. Peter's Collegiate Church* collection comes from Wolverhampton City Centre, West Midlands (UK). It is made up of 152 individuals dating to the mid-19th century (Adams & Colls, 2007).

2.3 CT scans

The sample is composed by 225 CT scan files of coxo-femoral joint taken on fresh cadavers of the Laboratory of Biological Anthropology, Department of Forensic Medicine, Faculty of Health Sciences, University of Copenhagen (DK). See *Methods §3.2*.

2.4 Sample groups

The sample groups used in this study are shown in Table 1.

TABLE 1: Samples size.

Collection	Place	Adults	Subadults
Identified	Bologna	225 (M=124, F=101)	no
	Sassari	463 (M=262, F=201)	no
	Coimbra	424 (M=231, F=193)	44 (M=17, F=27)
Archaeological	Wetwang slack	189 (M=93, F=96)	32
	Baldock	54 (M=28, F=26)	no
	Rounds Furnells	139 (M=86, F=53)	55
	Hereford Cathedral	311 (M=164, F=147)	121
	St. Peter's Collegiate Church	49 (M=27, F=22)	19
CT scans	Copenhagen	169 (M=106, F=63)	no

Individuals showing clear pathological conditions or bad state of preservation were excluded. In the case of CT scans, files with a quality too low to obtain usable 3D reconstructions were also excluded.

For what concern the identified collections and the CT scans sample, sex and age were all known and in the case of the CT scans height and weight were also known. For the archeological collections sex and age were already estimated from BARC staff; however in some uncertain cases it has been necessary to make a new valuation of sex or age or both, following the most common methods collected in White et al. (2011). Age has been estimated in age groups following Buikstra & Ubelaker (1994) (Subadults: infant 0-2 years; child 3-11 years; adolescent 12-19 years; Adults: young adult, YA: 20-34 years; mature adult, MA: 35-49 years; old adult, OA: ≥ 50 years).

3. METHODS

3.1 Scoring method

The method for the scoring of the osseous variations of the anterior aspect of the head-neck junction is published in Radi et al. (2013), see *Appendix.*
It has been created using the sample from the Certosa cemetery in Bologna and it allows recording the presence of three main traits: Poirier's facet, Plaque and Cribra. Plaque can be present in three alternative *Forms* (A, B, C) and can be surrounded by an *Edge*.

3.2 CT scans of cadavers and 3D reconstruction

CT scans have been performed as part of the routine investigation of the Forensic Institute of the University of Copenhagen (Poulsen & Simonsen, 2007) during the period 2010-2013. The bodies were scanned within 3 days from the time of death and they showed no or very few signs of decomposition.

A Siemens Somatom Sensation 4 Multislice spiral scanner was used with the following settings:

kV = 120;
mAs = 112 (average value, Care Dose has been used);
Slice thickness = 1 mm;
Slice increment = 1 mm;
Kernel = B60s (sharp), B30s (medium-smooth);
Pixel size = variable, based on field of view.

The 3D reconstruction of the femurs from CT scans has been made using *Mimics Materialise® (version 15.01)* software (Figure 2).

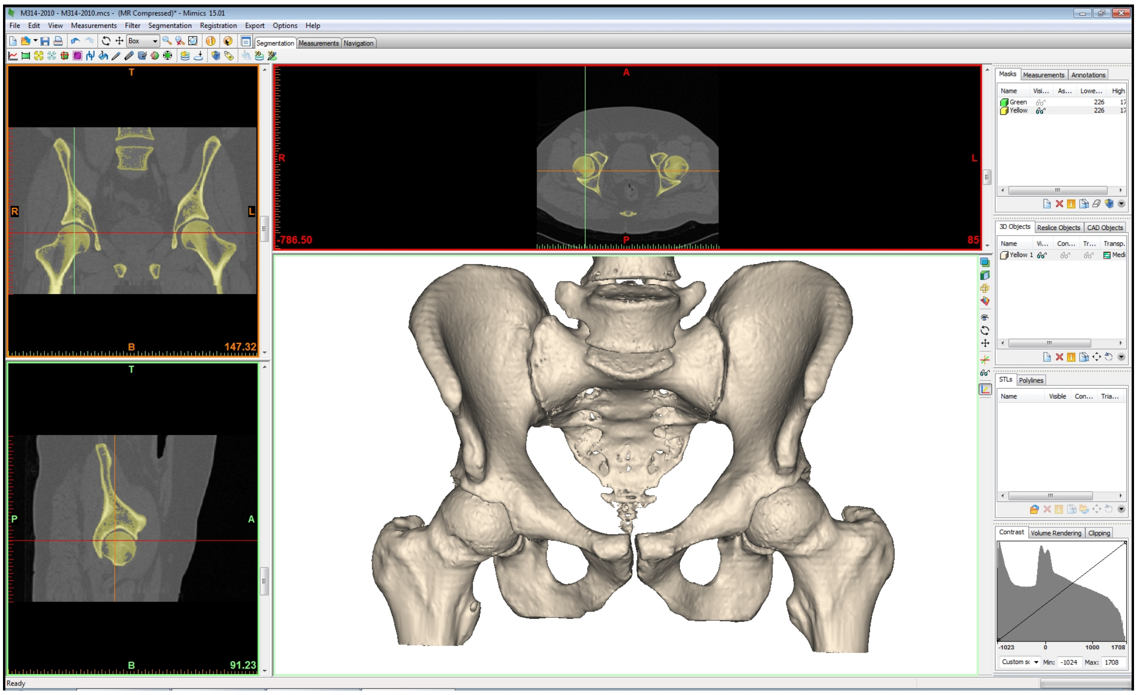


Figure 2. A screenshot showing the potential of Mimics Materialise® software in reconstructing 3D images of bones from MDCT files.

3.3 Recognition and classification of cystic appearing lesions

Cystic appearing lesions observed in the CT scans have been classified in five different categories following Panzer et al. (2010) (Figure 3).

The osseous lesions have been characterized according to the following criteria:

- Localization (head, neck)
- Existence and degree of marginating sclerosis (complete, partial, none)
- Demarcation (clear, not clear) in all three reconstruction planes
- Shape (round/oval, long, wedge-shaped)
- Cortical breaks

Lesions localized on the femoral neck:

- ✓ *Herniation pits*: round-to-oval shape, completely surrounding sclerosis and clear demarcation;

- ✓ *Focal osteoporosis*: change shape in different reconstruction planes, none or partial surrounding sclerosis and predominantly missing demarcation;
- ✓ *Non-specific trabecular restructuring*: partially changing shape in different planes, partial sclerotic margin and only partially clear demarcation;
- ✓ *Degenerative lesions*: located within new bone formation, round or oval-to-long shape, surrounding sclerotic margin and only partially clear demarcation.

Lesions localized on the femoral head:

- ✓ *Subchondral cysts*: round-to-oval shape, surrounding sclerotic margin and clear demarcation.

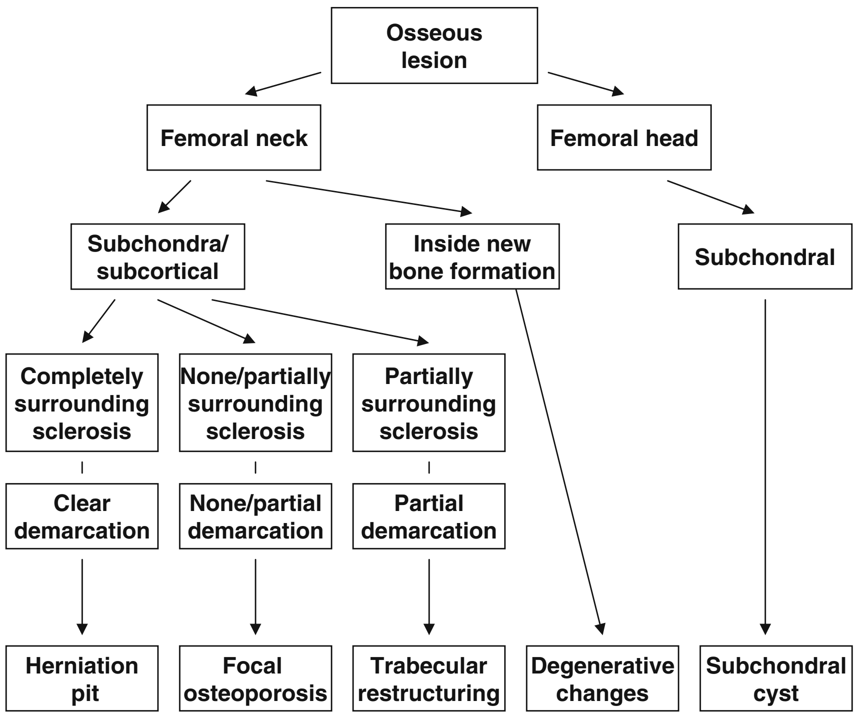


Figure 3. Diagram illustrating steps of categorization of osseous lesions in MSCT scans. Subchondral cysts were defined by their localization at the femoral head. Degenerative lesions were differentiated by their location within new bone formation. HPs were characterized by their completely surrounding sclerosis and clear demarcation, while focal osteoporosis was characterized by none or partial surrounding sclerosis and predominantly missing demarcation. *Figure and caption are taken from Panzer et al. (2010).*

3.4 Statistical analyses

Data were processed using the open source statistical package software R version 3.0.2 (R Core Team, 2013).
Statistical significance was inferred when the p-value was less than 0.05.
Absolute and percent frequencies were calculated for each side, sex, and age class (age groups where defined following Buikstra & Ubelaker, 1994).

The following analyses and tests have been performed:

- Pearson's chi-squared, to test differences in sex and age distribution of the features in each sample and to test differences between samples.
- Mc Nemar's chi-squared, to test side differences in presence/absence of the features.
- Wilcoxon signed-rank, to test side differences in the distribution of the different form of the features.
- Kendall's tau rank correlation coefficient to test the correlation:

  1) between the various features and age (in years) in the identified collections and in Copenhagen sample;

  2) between the various features and height, weight and body mass index [BMI= weight/(height/100)^2] in the Copenhagen sample.
- Multiple Correspondence Analysis (MCA), to visualize differences between the various samples considering the presence and distribution of more traits at the same time.

4. RESULTS

4.1 Identified skeletal collections

4.1.1 Bologna

The results from Bologna sample are already published in Radi et al. (2013). In brief, the main results are:

- The creation of a reliable standardized scoring method for describing the morphological variability of the anterior femoral head-neck junction, with low intra- and inter-observer errors.
- The assessment of the frequency and distribution of the various features. Poirier’s facet displays very low frequencies (3%). Plaque is present in 87% of the subjects, in 83% of which is bilateral. Edge is present in circa 50% of the subjects, in 82% of which is bilateral. Cribra is present in 46% of the subjects, with higher frequencies in females, and is bilateral in 60%.
- The assessment of differences between sides. No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for all the features considered, either in males or in females. The only exception is represented by the occurrence of plaque forms in males, with form B more frequent on the left side and form C more frequent on the right side (form B: L 44%, R 37%; form C: L 29%, R 42%; P-value = 0.018).
- The assessment of differences between sexes. There is no significant difference for Poirier’s facet, plaque and form. Edge shows higher frequencies in males, with significant p-values on the left side. Cribra shows significantly higher frequencies in females.
- The assessment of differences between age classes and of the correlation with age. No significant differences between age classes emerged for Poirier’s facet, plaque and form. There are in general significant differences for edge and cribra, with the frequencies of edge

increasing with age, and the frequencies of cribra diminishing with age. Kendall's tau correlation test has been used to test the correlation of these features with age: tau values, even if rather low, are always positive for edge and negative for cribra and in many cases there are significant p-values.

4.1.2 Sassari

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature analyzed are shown in Table 2. Poirier's facet displays very low frequencies (2%), thus making it pointless to perform any further statistical analysis; therefore, it will not be shown in the next tables. Plaque is present in 93% of the subjects, 88% of which have it bilaterally. Edge is present in 60% of the subjects, bilateral in 56%. Cribra is present in 47% of the subjects, with higher frequencies in females, and is bilateral in 66%.

TABLE 2: Absolute and percent frequencies (presence/absence only) of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	453	6	1	75	2	0	25	0	0	0	8	2
	M	258	4	2	67	2	1	33	0	0	0	6	2
	F	195	2	1	100	0	0	0	0	0	0	2	1
Plaque	All	446	367	82	88	23	5	6	25	6	6	415	93
	M	250	216	86	90	14	6	6	10	4	4	240	96
	F	196	151	77	86	9	5	5	15	8	9	175	89
Edge	All	446	151	34	56	53	12	20	64	14	24	268	60
	M	250	89	36	59	29	12	19	34	14	22	152	61
	F	196	62	32	53	24	12	21	30	15	26	116	59
Cribra	All	448	140	31	66	40	9	19	31	7	15	211	47
	M	253	74	29	70	19	8	18	13	5	12	106	42
	F	195	66	34	63	21	11	20	18	9	17	105	54

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for all the features considered, either in males or in females.

Differences between sexes

There are significant differences between sexes in plaque presence, both left and right, being more frequent in males (Table 3).

TABLE 3: Gender differences in plaque presence/absence.

				0		1		
Feature	Side	Sex	N	n	%	n	%	p-value
Plaque	L	F	199	36	18	163	82	0.003
		M	256	21	8	235	92	
	R	F	198	32	16	166	84	0.047
		M	253	24	10	229	91	

There are highly significant differences in form distribution, both left and right: form A shows low frequencies in both sexes and is slightly more frequent in males, form B is more frequent in females and form C is more frequent in males (Table 4).

TABLE 4: Gender differences in the distribution of plaque forms

				0		A		B		C		
Feature	Side	Sex	N	n	%	n	%	n	%	n	%	p-value
Form	L	F	199	36	18	3	2	120	60	40	20	3.34E-07
		M	256	21	8	14	6	117	46	104	41	
	R	F	198	32	16	5	3	115	58	46	23	1.66E-08
		M	253	24	10	10	4	90	36	129	51	

No significant difference between sides has been found for edge, both in presence/absence and distribution.

Cribra shows significant differences in distribution both left and right (but not in presence/absence of the feature) with cribra 2 more frequent in females (Table 5).

TABLE 5: Gender differences in the presence/absence and distribution of cribra.

				0		1		2			Presence		
Feature	Side	Sex	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	F	198	110	56	25	13	63	32	0.042	88	44	0.109
		M	257	163	63	39	15	55	21		94	37	
	R	F	198	112	57	21	11	65	33	0.011	86	43	0.078
		M	258	168	65	37	14	53	21		90	35	

Differences between age classes and correlation with age

No significant differences emerged for plaque in both sides.

Results for form, edge and cribra are shown in Table 6 (form), Table 7 (edge) and Table 8 (cribra).

There are significant differences in left overall sample (males + females) and in males for form distribution, with form B more frequent in old adults and form C more frequent in mature adults.

TABLE 6: Differences between age classes in the plaque forms distribution.

					0		A		B		C		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	n	%	p-value
Form	L	All	YA	153	19	12	5	3	80	52	49	32	
			MA	131	20	15	3	2	55	42	53	40	0.034
			OA	171	18	11	9	5	102	60	42	25	
		M	YA	74	8	11	4	5	28	38	34	46	
			MA	75	7	9	1	1	30	40	37	49	0.033
			OA	107	6	6	9	8	59	55	33	31	
		F	YA	79	11	14	1	1	52	66	15	19	
			MA	56	13	23	2	4	25	45	16	29	0.103
			OA	64	12	19	0	0	43	67	9	14	
	R	All	YA	151	17	11	6	4	71	47	57	38	
			MA	131	13	10	3	2	56	43	59	45	0.546
			OA	169	26	15	6	4	78	46	59	35	
		M	YA	72	7	10	3	4	22	31	40	56	
			MA	76	4	5	2	3	27	36	43	57	0.474
			OA	105	13	12	5	5	41	39	46	44	
		F	YA	79	10	13	3	4	49	62	17	22	
			MA	55	9	16	1	2	29	53	16	29	0.708
			OA	64	13	20	1	2	37	58	13	20	

There are significant differences between age classes for the edge in the overall sample and in males, both in presence/absence and distribution: the frequency of edge is quite equally distributed between mature and old adults while it is evidently minor in young adults.

TABLE 7: Differences between age classes in the plaque edge presence/absence and distribution.

					0		1		2			Presence		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	p-value	n	%	p-value
Edge	L	All	YA	153	105	69	40	26	8	5		48	31	
			MA	131	60	46	53	40	18	14	1.785E-04	71	54	5.13E-05
			OA	171	81	47	75	44	15	9		90	53	
		M	YA	74	55	74	14	19	5	7		19	26	
			MA	75	32	43	31	41	12	16	2.205E-04	43	57	7.64E-05
			OA	107	49	46	49	46	9	8		58	54	
		F	YA	79	50	63	26	33	3	4		29	37	
			MA	56	28	50	22	39	6	11	0.321	28	50	0.182
			OA	64	32	50	26	41	6	9		32	50	
	R	All	YA	151	99	66	49	32	3	2		52	34	
			MA	131	58	44	59	45	14	11	3.612E-04	73	56	3.16E-04
			OA	169	79	47	72	43	18	11		90	53	
		M	YA	72	52	72	17	24	3	4		20	28	
			MA	76	34	45	34	45	8	11	0.001	42	55	1.48E-04
			OA	105	44	42	47	45	14	13		61	58	
		F	YA	79	47	59	32	41	0	0		32	41	
			MA	55	24	44	25	45	6	11	0.044	31	56	0.189
			OA	64	35	55	25	39	4	6		29	45	

Cribra presence tends to diminish with age, showing significant p-values in the overall sample and in males both left and right. There are significant differences in the distribution of cribra in all the sub-samples (overall, males, females) both left and right: cribra 1 is more frequent in young adults; cribra 2 is more frequent in young adults in males and in mature adults in females.

TABLE 8: Differences between age classes in the presence/absence and distribution of cribra.

					0		1		2			Presence		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	All	YA	155	68	44	32	21	55	35		87	56	
			MA	131	80	61	12	9	39	30	4.62E-07	51	39	2.27E-07
			OA	169	125	74	20	12	24	14		44	26	
		M	YA	76	27	36	17	22	32	42		49	64	
			MA	76	52	68	9	12	15	20	1.31E-08	24	32	3.85E-09
			OA	105	84	80	13	12	8	8		21	20	
		F	YA	79	41	52	15	19	23	29		38	48	
			MA	55	28	51	3	5	24	44	0.046	27	49	0.249
			OA	64	41	64	7	11	16	25		23	36	
	R	All	YA	157	74	47	36	23	47	30		83	53	
			MA	132	76	58	13	10	43	33	1.45E-08	56	42	5.72E-08
			OA	167	130	78	9	5	28	17		37	22	
		M	YA	78	30	38	22	28	26	33		48	62	
			MA	77	51	66	10	13	16	21	1.28E-08	26	34	1.02E-09
			OA	103	87	84	5	5	11	11		16	16	
		F	YA	79	44	56	14	18	21	27		35	44	
			MA	55	25	45	3	5	27	49	0.005	30	55	0.057
			OA	64	43	67	4	6	17	27		21	33	

Kendall's tau correlation test has been used to test the correlation between the various features and age (in years). Edge is positively correlated with age and cribra is negatively correlated with age, as shown in Table 9. These correlations show significant p-values in overall samples and in males, but not in females. The other features do not seem to be correlated with age.

TABLE 9: Kendall's tau test: correlation of edge and cribra with age (in years).

Feature	Side	Sex	N	tau	p-value
Edge	L	All	455	0.121	0.001
		M	256	0.123	0.014
		F	199	0.103	0.072
	R	All	451	0.128	0.001
		M	253	0.182	2.95E-04
		F	198	0.053	0.361
Cribra	L	All	455	-0.219	3.64E-09
		M	257	-0.301	1.24E-09
		F	198	-0.104	0.066
	R	All	456	-0.200	8.29E-08
		M	258	-0.303	9.73E-10
		F	198	-0.060	0.295

4.1.3 Coimbra

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 10. Poirier's facet displays very low frequencies, thus making it pointless to perform any further statistical analysis and it will not be shown in the next tables. Plaque is present in 92% of the subjects, 93% of which have it bilaterally. Edge is present in 49% of the subjects, bilateral in 52%. Cribra is present in 26% of the subjects, with higher frequencies in females, and is bilateral in 47%.

Table 10: Absolute and percent frequencies (presence/absence only) of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	414	3	1	30	3	1	30	4	1	40	10	2
	M	225	3	1	33	2	1	22	4	2	44	9	4
	F	189	0	0	0	1	1	100	0	0	0	1	1
Plaque	All	413	351	85	93	15	4	4	13	3	3	379	92
	M	224	203	91	94	8	4	4	4	2	2	215	96
	F	189	148	78	90	7	4	4	9	5	5	164	87
Edge	All	413	104	25	52	46	11	23	51	12	25	201	49
	M	224	57	25	50	30	13	26	27	12	24	114	51
	F	189	47	25	54	16	8	18	24	13	28	87	46
Cribra	All	403	48	12	47	23	6	22	32	8	31	103	26
	M	217	19	9	43	12	6	27	13	6	30	44	20
	F	186	29	16	49	11	6	19	19	10	32	59	32

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for all the features considered, either in males or in females.

Differences between sexes

There are significant differences between sexes in plaque presence, both left and right, being more frequent in males (Table 11).

TABLE 11: Gender differences in presence/absence of the plaque.

				0		1		
Feature	Side	Sex	N	n	%	n	%	p-value
Plaque	L	F	191	34	18	157	82	1.86E-04
		M	227	13	6	214	94	
	R	F	191	32	17	159	83	0.005
		M	228	17	8	211	93	

There are highly significant differences in form distribution, both left and right: form A shows low frequencies in both sexes and is more frequent in males; form B is more frequent in left males but it is equally distributed on the right side; form C is equally distributed on both sides (Table 12).

TABLE 12: Gender differences in the distribution of the plaque forms.

				0		A		B		C		
Feature	Side	Sex	N	n	%	n	%	n	%	n	%	p-value
Form	L	F	191	34	18	3	2	105	55	49	26	1.29E-04
		M	227	13	6	15	7	142	63	57	25	
	R	F	191	32	17	2	1	106	56	51	27	4.37E-04
		M	228	17	8	17	8	122	54	72	32	

There are no significant differences in edge distribution between sexes.
Cribra is more frequent in females and this difference is significant on the right side (Table 13).

TABLE 13: Gender differences in the presence/absence and distribution of cribra.

				0		1		2			Presence		
Feature	Side	Sex	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	F	188	148	79	22	12	18	10	0.149	40	21	0.072
		M	221	190	86	16	7	15	7		31	14	
	R	F	189	141	75	24	13	24	13	0.026	48	25	0.010
		M	223	190	85	17	8	16	7		33	15	

Differences between age classes and correlation with age

No significant differences emerged for plaque in both sides, excepting in left males where is less frequent in young adults than in mature and old adults (Table 14).

TABLE 14: Differences between age classes in the presence of plaque.

					0		1		
Feature	Side	Sex	Age	N	n	%	n	%	p-value
Plaque	L	All	YA	124	17	14	107	86	
			MA	114	14	12	100	88	0.391
			OA	180	16	9	164	91	
		M	YA	73	9	12	64	88	
			MA	66	2	3	64	97	0.013
			OA	88	2	2	86	98	
		F	YA	51	8	16	43	84	
			MA	48	12	25	36	75	0.321
			OA	92	14	15	78	85	
	R	All	YA	121	14	12	107	88	
			MA	115	16	14	99	86	0.652
			OA	183	19	10	164	90	
		M	YA	71	7	10	64	90	
			MA	67	7	10	60	90	0.159
			OA	90	3	3	87	97	
		F	YA	50	7	14	43	86	
			MA	48	9	19	39	81	0.810
			OA	93	16	17	77	83	

Results for form, edge and cribra are shown in Table 15 (form), Table 16 (edge) and Table 17 (cribra).

There are significant differences in form distribution of left males: form A is almost absent in young adults, form B is more frequent in old adults, which show lower frequencies of form C.

TABLE 15: Differences between age classes in the distribution of the plaque forms.

					0		A		B		C		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	n	%	p-value
Form	L	All	YA	124	17	14	1	1	65	52	41	33	
			MA	114	14	12	7	6	68	60	25	22	0.054
			OA	180	16	9	10	6	114	63	40	22	
		M	YA	73	9	12	1	1	39	53	24	33	
			MA	66	2	3	7	11	38	58	19	29	0.002
			OA	88	2	2	7	8	65	74	14	16	
		F	YA	51	8	16	0	0	26	51	17	33	
			MA	48	12	25	0	0	30	62	6	12	0.107
			OA	92	14	15	3	3	49	53	26	28	
	R	All	YA	121	14	12	7	6	58	48	42	35	
			MA	115	16	14	6	5	64	56	29	25	0.516
			OA	183	19	10	6	3	106	58	52	28	
		M	YA	71	7	10	7	10	31	44	26	37	
			MA	67	7	10	6	9	31	46	23	34	0.065
			OA	90	3	3	4	4	60	67	23	26	
		F	YA	50	7	14	0	0	27	54	16	32	
			MA	48	9	19	0	0	33	69	6	12	0.149
			OA	93	16	17	2	2	46	49	29	31	

The frequencies of the edge tend to get higher with age both in males and females: there are significant differences between age classes in the overall sample and in males both in presence/absence and distribution, but not in females.

TABLE 16: Differences between age classes in the presence/absence and distribution of the plaque edge.

Feature	Side	Sex	Age	N	0		1		2		p-value	Presence		p-value
					n	%	n	%	n	%		n	%	
Edge	L	All	YA	124	96	77	27	22	1	1		28	23	
			MA	114	75	66	37	32	2	2	6.924E-05	39	34	8.66E-05
			OA	180	96	53	70	39	14	8		84	47	
		M	YA	73	60	82	12	16	1	1		13	18	
			MA	66	39	59	25	38	2	3	2.751E-05	27	41	1.08E-05
			OA	88	40	45	38	43	10	11		48	55	
		F	YA	51	36	71	15	29	0	0		15	29	
			MA	48	36	75	12	25	0	0	0.171	12	25	0.197
			OA	92	56	61	32	35	4	4		36	39	
	R	All	YA	121	92	76	27	22	2	2		29	24	
			MA	115	68	59	44	38	3	3	6.345E-04	47	41	0.001
			OA	183	100	55	66	36	17	9		83	45	
		M	YA	71	55	77	16	23	0	0		16	23	
			MA	67	40	60	24	36	3	4	0.003	27	40	0.004
			OA	90	47	52	33	37	10	11		43	48	
		F	YA	50	37	74	11	22	2	4		13	26	
			MA	48	28	58	20	42	0	0	0.073	20	42	0.116
			OA	93	53	57	33	35	7	8		40	43	

There are significant differences in the distribution of cribra in all the sub-samples (overall, males, females), both left and right: both cribra 1 and 2 are more frequent in young adults and tend to diminish with age.

TABLE 17: Differences between age classes in the presence/absence and distribution of cribra.

Feature	Side	Sex	Age	N	0		1		2		p-value	Presence		p-value
					n	%	n	%	n	%		n	%	
Cribra	L	All	YA	119	82	69	18	15	19	16		37	31	
			MA	113	98	87	9	8	6	5	1.108E-04	15	13	1.39E-05
			OA	177	158	89	11	6	8	5		19	11	
		M	YA	69	51	74	8	12	10	14		18	26	
			MA	65	57	88	6	9	2	3	0.003	8	12	0.001
			OA	87	82	94	2	2	3	3		5	6	
		F	YA	50	31	62	10	20	9	18		19	38	
			MA	48	41	85	3	6	4	8	0.017	7	15	0.003
			OA	90	76	84	9	10	5	6		14	16	
	R	All	YA	119	75	63	22	18	22	18		44	37	
			MA	112	97	87	7	6	8	7	1.924E-06	15	13	1.23E-07
			OA	181	159	88	12	7	10	6		22	12	
		M	YA	69	49	71	10	14	10	14		20	29	
			MA	65	58	89	4	6	3	5	0.002	7	11	2.70E-04
			OA	89	83	93	3	3	3	3		6	7	
		F	YA	50	26	52	12	24	12	24		24	48	
			MA	47	39	83	3	6	5	11	0.001	8	17	1.04E-04
			OA	92	76	83	9	10	7	8		16	17	

Kendall's tau correlation test has been used to test the correlation between the various features and age (in years). Table 18 shows the results for edge and cribra. Edge is positively correlated with age and cribra is negatively correlated with age, with significant p-values in all the sub-samples, excepting for edge in left females. The other features do not seem to be correlated with age.

TABLE 18: Kendall's tau test: correlation of edge and cribra with age (in years).

Feature	Side	Sex	N	tau	p-value
Edge	L	All	418	0.171	1.62E-05
		M	227	0.258	1.55E-06
		F	191	0.091	0.127
	R	All	419	0.166	2.61E-05
		M	228	0.205	1.29E-04
		F	191	0.125	0.034
Cribra	L	All	409	-0.197	7.74E-07
		M	221	-0.202	2.16E-04
		F	188	-0.213	2.99E-04
	R	All	412	-0.216	5.04E-08
		M	223	-0.212	9.54E-05
		F	189	-0.250	1.89E-05

4.2 Archaeological skeletal collections

4.2.1 Wetwang Slack

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 19. Poirier's facet displays very low frequencies (2%), thus making it pointless to perform any further statistical analysis and it will not be shown in the next tables. Plaque is present in 92% of the subjects, 93% of which have it bilaterally. Edge is present in only 12% of the subjects (edge 2 is basically absent in this sample), bilateral in 38%. Cribra is present in 45% of the subjects, with higher frequencies in males, and is bilateral in 66%.

TABLE 19: Absolute and percent frequencies (presence/absence only) of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	117	1	1	50	0	0	0	1	1	50	2	2
	M	61	1	2	50	0	0	0	1	2	50	2	3
	F	56	0	0	0	0	0	0	0	0	0	0	0
Plaque	All	134	114	85	93	3	2	2	6	4	5	123	92
	M	65	53	82	90	1	2	2	5	8	8	59	91
	F	69	61	88	95	2	3	3	1	1	2	64	93
Edge	All	133	6	5	38	4	3	25	6	5	38	16	12
	M	65	3	5	43	1	2	14	3	5	43	7	11
	F	68	3	4	33	3	4	33	3	4	33	9	13
Cribra	All	125	37	30	66	16	13	29	3	2	5	56	45
	M	65	23	35	66	10	15	29	2	3	6	35	54
	F	60	14	23	67	6	10	29	1	2	5	21	35

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for plaque and edge, either in males or in females. Wilcoxon signed-rank test (Table 20) shows significant p-values in the overall sample and in males for form, with form B more frequent on the left side and form C more frequent on the right side.

TABLE 20: Wilcoxon signed-rank test: side differences in the distribution of plaque forms.

				0		A		B		C		
Feature	Sex	Side	N	n	%	n	%	n	%	n	%	p-value
Form	All	L	134	17	13	8	6	87	65	22	16	0.007
		R	134	14	10	8	6	75	56	37	28	
	M	L	65	11	17	6	9	36	55	12	19	0.019
		R	65	7	11	6	9	34	52	18	28	
	F	L	69	6	9	2	3	51	74	10	15	0.156
		R	69	7	10	2	3	41	59	19	28	

There are significant side differences both in the presence/absence (Table 21) and distribution (Table 22) for cribra in the overall sample and in males, with cribra (both cribra 1 and cribra 2) more frequent on the right side.

TABLE 21: Mc Nemar's chi squared test: side differences in the presence/absence of cribra.

				0		1		
Feature	Sex	Side	N	n	%	n	%	p-value
Cribra	All	L	125	72	58	53	42	0.006
		R	125	85	68	40	32	
	M	L	65	32	49	33	51	0.043
		R	65	40	62	25	39	
	F	L	60	40	67	20	33	0.131
		R	60	45	75	15	25	

TABLE 22: Wilcoxon signed-rank test: side differences in the distribution of cribra.

				0		1		2		
Feature	Sex	Side	N	n	%	n	%	n	%	p-value
Cribra	All	L	125	72	58	13	10	40	32	0.014
		R	125	85	68	7	6	33	26	
	M	L	65	32	49	8	12	25	39	0.065
		R	65	40	62	5	8	20	31	
	F	L	60	40	67	5	8	15	25	0.141
		R	60	45	75	2	3	13	22	

Differences between sexes

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sexes for all the features considered, either in males or in females.

Differences between age classes

No significant differences emerged for plaque in both sides, excepting in right overall sample, where is less frequent in young adults than in mature and old adults (Table 23).

TABLE 23: Differences between age classes in the presence of the plaque.

Feature	Side	Sex	Age	N	0		1		p-value
					n	%	n	%	
Plaque	L	All	YA	79	14	18	65	82	
			MA	64	6	9	58	91	0.343
			OA	17	2	12	15	88	
		M	YA	32	7	22	25	78	
			MA	43	6	14	37	86	0.426
			OA	6	2	33	4	67	
		F	YA	47	7	15	40	85	
			MA	21	0	0	21	100	0.073
			OA	11	0	0	11	100	
	R	All	YA	82	14	17	68	83	
			MA	65	2	3	63	97	0.019
			OA	16	1	6	15	94	
		M	YA	31	6	19	25	81	
			MA	42	2	5	40	95	0.102
			OA	4	0	0	4	100	
		F	YA	51	8	16	43	84	
			MA	23	0	0	23	100	0.121
			OA	12	1	8	11	92	

No significant difference emerged for edge. Results for form and cribra are shown in Table 24 (form) and Table 25 (cribra).

There are significant differences in form distribution in the overall right sample and in left females: form B is less frequent in young adults, which show higher frequencies of form C.

TABLE 24: Differences between age classes in the distribution of the plaque forms.

Feature	Side	Sex	Age	N	0		A		B		C		p-value
					n	%	n	%	n	%	n	%	
Form	L	All	YA	79	14	18	2	3	48	61	15	19	
			MA	64	6	9	5	8	45	70	8	12	0.476
			OA	17	2	12	1	6	12	71	2	12	
		M	YA	32	7	22	2	6	18	56	5	16	
			MA	43	6	14	4	9	25	58	8	19	0.766
			OA	6	2	33	0	0	4	67	0	0	
		F	YA	47	7	15	0	0	30	64	10	21	
			MA	21	0	0	1	5	20	95	0	0	0.024
			OA	11	0	0	1	9	8	73	2	18	
	R	All	YA	82	14	17	4	5	38	46	26	32	
			MA	65	2	3	5	8	44	68	14	22	0.048
			OA	16	1	6	1	6	11	69	3	19	
		M	YA	31	6	19	3	10	14	45	8	26	
			MA	42	2	5	4	10	27	64	9	21	0.390
			OA	4	0	0	1	25	2	50	1	25	
		F	YA	51	8	16	1	2	24	47	18	35	
			MA	23	0	0	1	4	17	74	5	22	0.180
			OA	12	1	8	0	0	9	75	2	17	

There are significant differences in the presence of cribra in the overall sample, both left and right and in left males, with cribra that tends to diminish with age.

TABLE 25: Differences between age classes in the presence/absence and distribution of cribra.

					0		1		2			Presence		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	All	YA	79	41	52	8	10	30	38		38	48	
			MA	62	37	60	5	8	20	32	0.163	25	40	0.042
			OA	15	13	87	0	0	2	13		2	13	
		M	YA	34	14	41	4	12	16	47		20	59	
			MA	43	23	53	4	9	16	37	0.127	20	47	0.028
			OA	6	6	100	0	0	0	0		0	0	
		F	YA	45	27	60	4	9	14	31		18	40	
			MA	19	14	74	1	5	4	21	0.706	5	26	0.413
			OA	9	7	78	0	0	2	22		2	22	
	R	All	YA	78	49	63	5	6	24	31		29	37	
			MA	63	50	79	3	5	10	16	0.120	13	21	0.038
			OA	15	13	87	1	7	1	7		2	13	
		M	YA	31	17	55	2	6	12	39		14	45	
			MA	40	29	72	3	8	8	20	0.262	11	28	0.102
			OA	4	4	100	0	0	0	0		0	0	
		F	YA	47	32	68	3	6	12	26		15	32	
			MA	23	21	91	0	0	2	9	0.212	2	9	0.089
			OA	11	9	82	1	9	1	9		2	18	

4.2.2 Baldock

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 26. Poirier’s facet displays frequencies higher than expected, reaching 17% of individuals. Plaque is present in 92% of the subjects, 88% of which have it bilaterally. Edge is present in 24% of the subjects, never bilaterally. Cribra is present in 21% of the subjects, and it is bilateral in 83%. However the very low sample size could lead to over or under estimation of the frequencies and make it pointless performing further analyses.

TABLE 26: Absolute and percent frequencies of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	30	3	10	60	2	7	40	0	0	0	5	17
	M	17	3	18	75	1	6	25	0	0	0	4	24
	F	13	0	0	0	1	8	100	0	0	0	1	8
Plaque	All	37	30	81	88	2	5	6	2	5	6	34	92
	M	20	15	75	88	1	5	6	1	5	6	17	85
	F	17	15	88	88	1	6	6	1	6	6	17	100
Edge	All	37	0	0	0	3	8	33	6	16	67	9	24
	M	20	0	0	0	2	10	40	3	15	60	5	25
	F	17	0	0	0	1	6	25	3	18	75	4	24
Cribra	All	29	5	17	83	0	0	0	1	3	17	6	21
	M	16	1	6	50	0	0	0	1	6	50	2	13
	F	13	4	31	100	0	0	0	0	0	0	4	31

4.2.3 Raunds Furnells

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 27. Poirier's facet displays frequencies higher than expected, reaching 12% of individuals. Plaque is present in 97% of the subjects, 84% of which have it bilaterally. Edge is present in 43% of the subjects, in 47% of which bilaterally. Cribra is present in 38% of the subjects, and it is bilateral in 50%. However the low sample size could lead to over or under estimation of the frequencies.

TABLE 27: Absolute and percent frequencies of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	90	5	6	45	4	4	36	2	2	18	11	12
	M	58	5	9	45	4	7	36	2	3	18	11	19
	F	32	0	0	0	0	0	0	0	0	0	0	0
Plaque	All	104	85	82	84	7	7	7	9	9	9	101	97
	M	65	53	82	83	5	8	8	6	9	9	64	98
	F	39	32	82	86	2	5	5	3	8	8	37	95
Edge	All	101	20	20	47	8	8	19	15	15	35	43	43
	M	62	12	19	46	3	5	12	11	18	42	26	42
	F	39	8	21	47	5	13	29	4	10	24	17	44
Cribra	All	91	18	20	51	6	7	17	11	12	31	35	38
	M	55	8	15	53	2	4	13	5	9	33	15	27
	F	36	10	28	50	4	11	20	6	17	30	20	56

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for all the features, excluding edge.

Wilcoxon signed-rank test (Table 28) shows significant p-values in males with both edge 1 and 2 more frequent on the right side.

TABLE 28: Wilcoxon signed-rank test: side differences in the distribution of the plaque edge.

				0		1		2		
Feature	Sex	Side	N	n	%	n	%	n	%	p-value
Edge	All	L	101	73	72	26	26	2	2	0.096
		R	101	66	65	31	31	4	4	
	M	L	62	47	76	13	21	2	3	0.040
		R	62	39	63	20	32	3	5	
	F	L	39	26	67	13	33	0	0	0.984
		R	39	27	69	11	28	1	3	

Differences between sexes

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sexes for plaque, form and edge. There are significant differences on the left side for Poirier's facet, being present only in males (Table 29).

TABLE 29: Gender differences in the presence of Poirier's facet.

				0		1		
Feature	Side	Sex	N	n	%	n	%	p-value
Poirier's facet	L	F	39	39	100	0	0	0.032
		M	69	59	86	10	15	
	R	F	43	43	100	0	0	0.091
		M	73	66	90	7	10	

Cribra shows significant differences between sexes both in the presence and in the distribution, being more frequent in females (Table 30).

TABLE 30: Gender differences in the presence/absence and distribution of cribra.

				0		1		2			Presence		
Feature	Side	Sex	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	F	44	27	61	5	11	12	27	0.063	17	39	0.034
		M	65	53	82	3	5	9	14		12	19	
	R	F	45	24	53	6	13	15	33	0.006	21	47	0.004
		M	71	57	80	6	9	8	11		14	20	

Differences between age classes

No significant difference has been found between age classes.

4.2.4 Hereford Cathedral

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 31. Poirier's facet displays very low frequencies (6% of the subjects), thus making it pointless to perform any further statistical analysis and it will not be shown in the next tables. Anyway it has to be noted that it is present basically only in males. Plaque is present in 92% of the subjects, 85% of which have it bilaterally. Edge is present in only 52% of the subjects, bilateral in 43%. Cribra is present in 35% of the subjects and is bilateral in 61%.

TABLE 31: Absolute and percent frequencies of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	167	5	3	50	2	1	20	3	2	30	10	6
	M	92	5	5	56	2	2	22	2	2	22	9	10
	F	75	0	0	0	0	0	0	1	1	100	1	1
Plaque	All	185	145	78	85	10	5	6	15	8	9	170	92
	M	98	81	83	88	4	4	4	7	7	8	92	94
	F	87	64	74	82	6	7	8	8	9	10	78	90
Edge	All	184	41	22	43	22	12	23	33	18	34	96	52
	M	98	29	30	56	10	10	19	13	13	25	52	53
	F	86	12	14	27	12	14	27	20	23	45	44	51
Cribra	All	175	38	22	61	13	7	21	11	6	18	62	35
	M	92	17	18	55	5	5	16	9	10	29	31	34
	F	83	21	25	68	8	10	26	2	2	6	31	37

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for all the features considered, either in males or in females.

Differences between sexes

No significant difference was found between sides for plaque and form. There are significant differences between sexes in edge, both left and right, being more frequent in males, especially edge 2 (Table 32).

TABLE 32: Gender differences in the presence/absence and distribution of plaque edge.

				0		1		2			Presence		
Feature	Side	Sex	N	n	%	n	%	n	%	p-value	n	%	p-value
Edge	L	F	117	82	70	33	28	2	2	0.038	35	30	0.128
		M	130	78	60	41	32	11	9		52	40	
	R	F	115	76	66	39	34	0	0	0.017	39	34	0.524
		M	132	81	61	42	32	9	7		51	39	

There are significant differences only in presence/absence on the left side for cribra, which is more frequent in females (Table 33).

TABLE 33: Gender differences in the presence/absence and distribution of cribra.

				0		1		2			Presence		
Feature	Side	Sex	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	F	113	73	65	8	7	32	28	0.078	40	35	0.035
		M	122	95	78	6	5	21	17		27	22	
	R	F	111	82	74	5	5	24	22	0.398	29	26	0.962
		M	124	93	75	10	8	21	17		31	25	

Differences between age classes

There are significant differences between age classes for all the features considered.

Plaque displays significant p-values on the right side in the overall sample and in females (Tables 34).

TABLE 34: Differences between age classes in the presence of plaque.

					0		1		
Feature	Side	Sex	Age	N	n	%	n	%	p-value
Plaque	L	All	YA	103	17	17	86	83	
			MA	63	11	17	52	83	0.967
			OA	82	13	16	69	84	
		M	YA	57	7	12	50	88	
			MA	32	6	19	26	81	0.709
			OA	41	6	15	35	85	
		F	YA	46	10	22	36	78	
			MA	31	5	16	26	84	0.784
			OA	41	7	17	34	83	
	R	All	YA	108	14	13	94	87	
			MA	61	15	25	46	75	0.047
			OA	78	8	10	70	90	
		M	YA	59	7	12	52	88	
			MA	32	6	19	26	81	0.625
			OA	41	5	12	36	88	
		F	YA	49	7	14	42	86	
			MA	29	9	31	20	69	0.039
			OA	37	3	8	34	92	

There are significant differences in form distribution only in right overall sample: form A is almost absent in young adults, form A and B are more frequent in old adults, which show lower frequencies of form C (Table 35).

TABLE 35: Differences between age classes in the distribution of plaque forms.

					0		A		B		C		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	n	%	p-value
Form	L	All	YA	103	17	17	4	4	57	55	25	24	
			MA	63	11	17	3	5	30	48	19	30	0.473
			OA	82	13	16	6	7	50	61	13	16	
		M	YA	57	7	12	2	4	34	60	14	25	
			MA	32	6	19	2	6	14	44	10	31	0.054
			OA	41	6	15	5	12	28	68	2	5	
		F	YA	46	10	22	2	4	23	50	11	24	
			MA	31	5	16	1	3	16	52	9	29	0.990
			OA	41	7	17	1	2	22	54	11	27	
	R	All	YA	108	14	13	1	1	60	56	33	31	
			MA	61	15	25	0	0	27	44	19	31	0.033
			OA	78	8	10	3	4	51	65	16	21	
		M	YA	59	7	12	0	0	32	54	20	34	
			MA	32	6	19	0	0	16	50	10	31	0.332
			OA	41	5	12	1	2	28	68	7	17	
		F	YA	49	7	14	1	2	28	57	13	27	
			MA	29	9	31	0	0	11	38	9	31	0.144
			OA	37	3	8	2	5	23	62	9	24	

The frequencies of the edge tend to get higher with age both in males and females: anyway there are significant differences between age classes only in presence/absence in right females (Table 36).

TABLE 36: Differences between age classes in the presence/absence and distribution of the plaque edge.

					0		1		2			Presence		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	p-value	n	%	p-value
Edge	L	All	YA	103	69	67	30	29	4	4		34	33	
			MA	63	41	65	18	29	4	6	0.906	22	35	0.758
			OA	81	50	62	26	32	5	6		31	38	
		M	YA	57	34	60	21	37	2	4		23	40	
			MA	32	19	59	9	28	4	12	0.424	13	41	0.988
			OA	41	25	61	11	27	5	12		16	39	
		F	YA	46	35	76	9	20	2	4		11	24	
			MA	31	22	71	9	29	0	0	0.191	9	29	0.387
			OA	40	25	62	15	38	0	0		15	38	
	R	All	YA	108	72	67	35	32	1	1		36	33	
			MA	61	43	70	16	26	2	3	0.059	18	30	0.087
			OA	78	42	54	30	38	6	8		36	46	
		M	YA	59	38	64	20	34	1	2		21	36	
			MA	32	20	62	10	31	2	6	0.171	12	38	0.695
			OA	41	23	56	12	29	6	15		18	44	
		F	YA	49	34	69	15	31	0	0		15	31	
			MA	29	23	79	6	21	0	0	-	6	21	0.048
			OA	37	19	51	18	49	0	0		18	49	

There are generally significant differences in the presence and distribution of cribra in all the sub-samples (excluding left females), with cribra more frequent in young adults (both *cribra 1* and *2*) (Table 37).

TABLE 37: Differences between age classes in the presence/absence and distribution of cribra.

					0		1		2			Presence		
Feature	Side	Sex	Age	N	n	%	n	%	n	%	p-value	n	%	p-value
Cribra	L	All	YA	103	61	59	10	10	32	31		42	41	
			MA	58	51	88	2	3	5	9	0.002	7	12	3.47E-04
			OA	74	56	76	2	3	16	22		18	24	
		M	YA	56	33	59	6	11	17	30		23	41	
			MA	30	29	97	0	0	1	3	1.58E-04	1	3	1.86E-05
			OA	36	33	92	0	0	3	8		3	8	
		F	YA	47	28	60	4	9	15	32		19	40	
			MA	28	22	79	2	7	4	14	0.397	6	21	0.203
			OA	38	23	61	2	5	13	34		15	39	
	R	All	YA	107	64	60	12	11	31	29		43	40	
			MA	55	48	87	2	4	5	9	1.17E-04	7	13	1.51E-05
			OA	73	63	86	1	1	9	12		10	14	
		M	YA	57	33	58	9	16	15	26		24	42	
			MA	29	26	90	0	0	3	10	0.001	3	10	2.66E-04
			OA	38	34	89	1	3	3	8		4	11	
		F	YA	50	31	62	3	6	16	32		19	38	
			MA	26	22	85	2	8	2	8	0.054	4	15	0.036
			OA	35	29	83	0	0	6	17		6	17	

4.2.5 St. Peter's Collegiate Church

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 38. Poirier's facet is present in 8% of individuals, all males. Plaque is present in 93% of the subjects, 88% of which have it bilaterally. Edge is present in 59% of the subjects, in 38% of which is bilateral. Cribra is present in 50% of the subjects, and it is bilateral in 46%. However the very low sample size could lead to over or under estimation of the frequencies and make it pointless performing further analyses.

TABLE 38: Absolute and percent frequencies of each feature in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	25	0	0	0	1	4	50	1	4	50	2	8
	M	15	0	0	0	1	7	50	1	7	50	2	13
	F	10	0	0	0	0	0	0	0	0	0	0	0
Plaque	All	28	23	82	88	3	11	12	0	0	0	26	93
	M	15	11	73	79	3	20	21	0	0	0	14	93
	F	13	12	92	100	0	0	0	0	0	0	12	92
Edge	All	27	6	22	38	2	7	13	8	30	50	16	59
	M	15	3	20	38	1	7	13	4	27	50	8	53
	F	12	3	25	38	1	8	13	4	33	50	8	67
Cribra	All	26	6	23	46	3	12	23	4	15	31	13	50
	M	15	3	20	50	1	7	17	2	13	33	6	40
	F	11	3	27	43	2	18	29	2	18	29	7	64

4.3 Subadults

Due to the very low samples size, it has only been possible to score the frequencies of the features, without any further statistical analysis. The collections of Bologna, Sassari and Baldock did not have (or had very few) subadults and have been excluded. In the archaeological collections attribution of sex to subadults has not been possible.

Poirier's facet (that can be scored only after the fusion of the capital physis) and plaque edge were never found in subadults, not even in late adolescents.

In Coimbra sample (Table 39) plaque is present in 20% of the subadults, in 88% of which bilaterally. All the individuals with plaque are adolescents between 16 and 19 years old. Cribra is present in 91% of subadults, almost always bilateral (97%).

TABLE 39: Absolute and percent frequencies of plaque and cribra in individuals with both sides observable in Coimbra subadults.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Plaque	All	41	7	17	88	1	2	13	0	0	0	8	20
	M	16	4	25	100	0	0	0	0	0	0	4	25
	F	25	3	12	75	1	4	25	0	0	0	4	16
Cribra	All	43	38	88	97	0	0	0	1	2	3	39	91
	M	16	14	88	100	0	0	0	0	0	0	14	88
	F	27	24	89	96	0	0	0	1	4	4	25	93

The plaques scored are all of form B, excluding one form C in left females (Table 40).

TABLE 40: Frequencies distribution of plaque forms in Coimbra subadults.

				0		A		B		C	
Feature	Side	Sex	N	n	%	n	%	n	%	n	%
Form	L	All	41	33	81	0	0	7	17	1	2
		M	16	12	75	0	0	4	25	0	0
		F	25	21	84	0	0	3	12	1	4
	R	All	41	34	83	0	0	7	17	0	0
		M	16	12	75	0	0	4	25	0	0
		F	25	22	88	0	0	3	12	0	0

Cribra is in more than 80% of type 2 (Table 41). Cribra 1 is present only in females, all adolescents. Between 17 and 19 years of age, cribra is absent or type 1.

TABLE 41: Frequencies distribution of cribra in Coimbra subadults.

				0		1		2		Presence	
Feature	Side	Sex	N	n	%	n	%	n	%	n	%
Cribra	L	All	43	5	12	3	7	35	81	38	88
		M	16	2	13	0	0	14	88	14	88
		F	27	3	11	3	11	21	78	24	89
	R	All	43	4	9	4	9	35	81	39	91
		M	16	2	13	0	0	14	88	14	88
		F	27	2	7	4	15	21	78	25	93

In Wetwang Slack collection (N=32) only 2 plaques have been found on the left side, both adolescents. Cribra is present in 92% of the subadults, in circa 80% of which is of type 2.

In Rounds Furnells collection (N=55) no plaque has been found, and cribra is present in 98% of individuals, in circa 90% of which is of type 2.

In Hereford Cathedral collection (N=121) plaque is present in 11% of individuals, all adolescents. Form B is prevalent. Cribra is present in 100% of individuals (98% bilaterally), 87% of which is of type2.

In St. Peter Collegiate Church collection (N=19) no plaque has been found, and cribra (all of type 2) is present in 100% of individuals. No adolescent was present.

4.4 CT scans

The first result gained has been an effective 3D reconstruction of the proximal femur so that has been possible to detect and score all the features of the reaction area (Figures 4-6), excepting cribra. In fact, the porous nature of this feature made very difficult and arbitrary its 3D reconstruction.

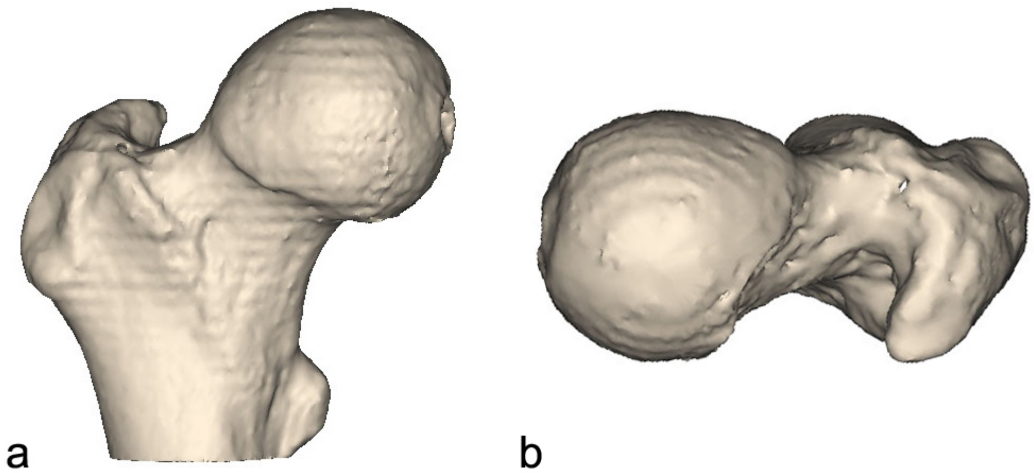


Figure 4. 3D reconstruction of Poirier's facet in antero-posterior (a) and craneo-caudal (b) view.

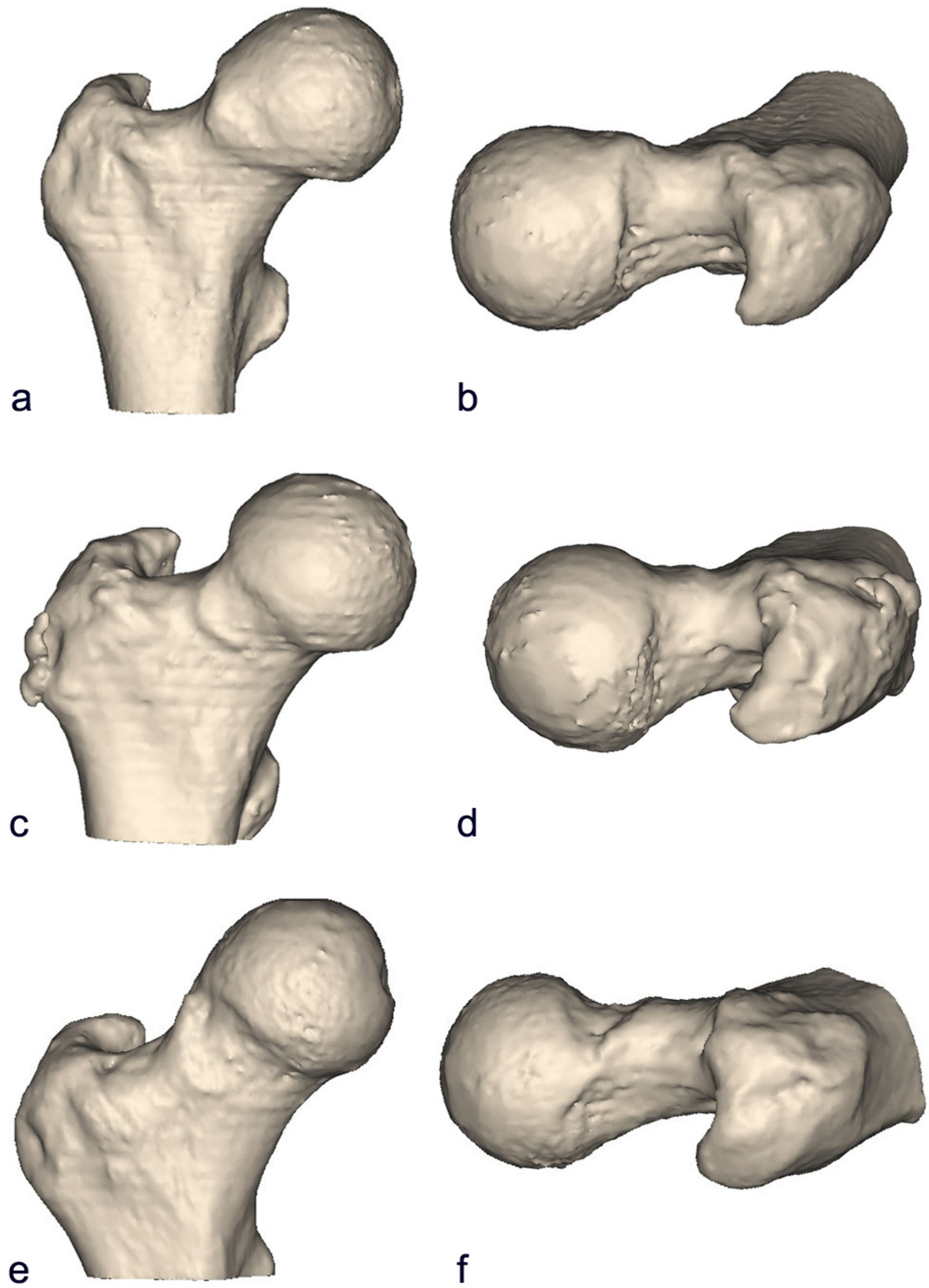


Figure 5. 3D reconstruction of plaque forms: form A in antero-posterior (a) and craneo-caudal (b) view; form B in antero-posterior (c) and craneo-caudal (d) view; form C in antero-posterior (e) and craneo-caudal (f) view.

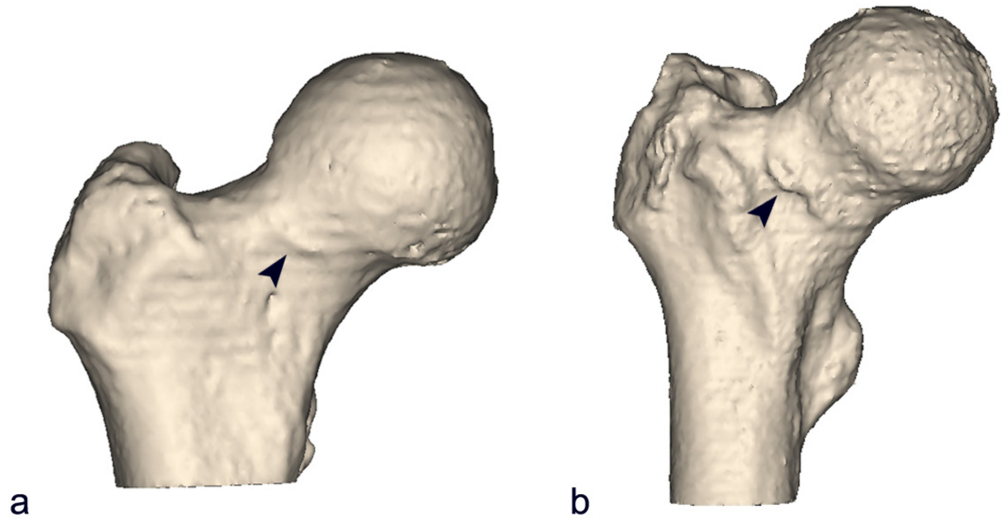


Figure 6. 3D reconstruction of plaque edge in antero-posterior view: edge of degree 1 (a); edge of degree 2 (b).

Frequencies distribution

Absolute and percent frequencies (presence/absence only) of each feature are shown in Table 42. Poirier's facet is present in 6% of individuals, more frequent in males. Plaque is present in 90% of the subjects, 89% of which have it bilaterally. Edge is present in 17% of the subjects, in 25% of which is bilateral.

TABLE 42: Absolute and percent frequencies of Poirier's facet, plaque and cribra in individuals with both sides observable.

			Bilateral			Left only			Right only			Tot	
Feature	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Poirier's facet	All	169	5	3	50	1	1	10	4	2	40	10	6
	M	106	4	4	50	0	0	0	4	4	50	8	8
	F	63	1	2	50	1	2	50	0	0	0	2	3
Plaque	All	167	133	80	89	5	3	3	12	7	8	150	90
	M	104	86	83	92	5	5	5	2	2	2	93	89
	F	63	47	75	82	0	0	0	10	16	18	57	90
Edge	All	167	7	4	25	8	5	29	13	8	46	28	17
	M	104	3	3	17	7	7	39	8	8	44	18	17
	F	63	4	6	40	1	2	10	5	8	50	10	16

Differences between sides

No significant difference in presence/absence and distribution (considering the different degrees or morphologies) was found between sides for Poirier’s facet and edge. There are significant differences in females for plaque as shown by the Mc Nemar's chi-squared test in Table 43, with plaque more frequent on the right side.

TABLE 43: Mc Nemar's chi squared test: side differences in the presence of plaque.

				0		1		
Feature	Sex	Side	N	n	%	n	%	p-value
Plaque	All	L	167	29	17	138	83	0.146
		R	167	22	13	145	87	
	M	L	104	13	13	91	88	0.45
		R	104	16	15	88	85	
	F	L	63	16	25	47	75	0.004
		R	63	6	10	57	91	

There are significant differences in the overall sample and in females for form as shown by the Wilcoxon signed-rank test in Table 44, with form C more frequent on the right side.

TABLE 44: Wilcoxon signed rank test: side differences in the distribution of plaque forms.

				0		A		B		C		
Feature	Sex	Side	N	n	%	n	%	n	%	n	%	p-value
Form	All	L	167	29	17	22	13	101	61	15	9	0.005
		R	167	22	13	21	13	95	57	29	17	
	M	L	104	13	13	17	16	63	61	11	11	0.685
		R	104	16	15	16	15	53	51	19	18	
	F	L	63	16	25	5	8	38	60	4	6	0.001
		R	63	6	10	5	8	42	67	10	16	

Differences between sexes

No significant difference was found between sexes for all the features considered, both left and right.

Differences between age classes and correlation with age

No significant difference was found between age classes, both left and right and no significant correlation with age was found using a Kendall's tau correlation test for all the features examined.

Correlation with Height, Weight and BMI

Correlation with height, weight and BMI has been investigated for all the features trough a Kendall's tau test and significant results are shown in Table 45. The most evident result concerns form A, positively correlated with height, weight and BMI.

TABLE 45: Significant correlation of various features with height, weight and BMI.

Correlation with Height

Feature	Sex	Side	tau	p-value
Poirier's facet	All	All	0.111	0.017
Plaque	M	R	-0.17	0.041
Form A	All	All	0.103	0.029
Form B	All	All	-0.109	0.019
	M	L	-0.224	0.008
	F	L	0.289	0.010
	All	R	-0.174	0.008
	M	R	-0.217	0.009
	F	R	0.232	0.039
Form C	F	L	-0.261	0.021

Correlation with Weight

Feature	Sex	Side	tau	p-value
Poirier's facet	F	L	-0.24	0.033
Plaque	F	R	0.286	0.010
Form A	All	All	0.116	0.013
Form C	F	L	-0.27	0.015

Correlation with BMI

Feature	Sex	Side	tau	p-value
Poirier's facet	F	L	-0.25	0.024
Plaque	All	All	0.095	0.040
	F	R	0.281	0.011
Form A	All	All	0.092	0.047

4.5 Differences between samples from different collections

Differences between all the samples (paired) have been assessed using Pearson's chi-squared test. Because of the general absence of lateralization in all the samples, these analyses have been performed merging sides (thus considering each femur as a single individual). No significant difference emerged between the various archaeological samples from U.K., according to the chi-squared test results and to the MCA analysis (Figure 7), and they have been grouped together in the following analyses (labeled as "BARC").

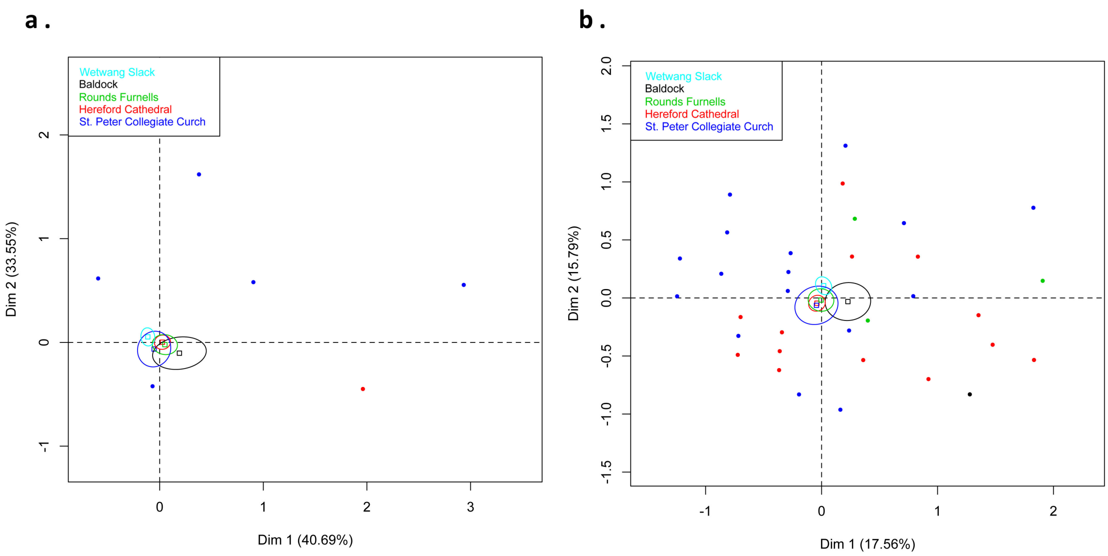


Figure 7. Plot of MCA between the British archaeological samples: (a) using the presence absence of the three main traits (Poirier's facet, plaque and cribra); (b) using the frequencies of all the traits.

Figures 8-10 show the frequency of the three main feature (Poirier's facet, Plaque and Cribra respectively) of the anterior proximal femur in the various samples. Poirier's facet is generally present at low frequencies and it is more frequent in Copenhagen and BARC samples, especially in males.

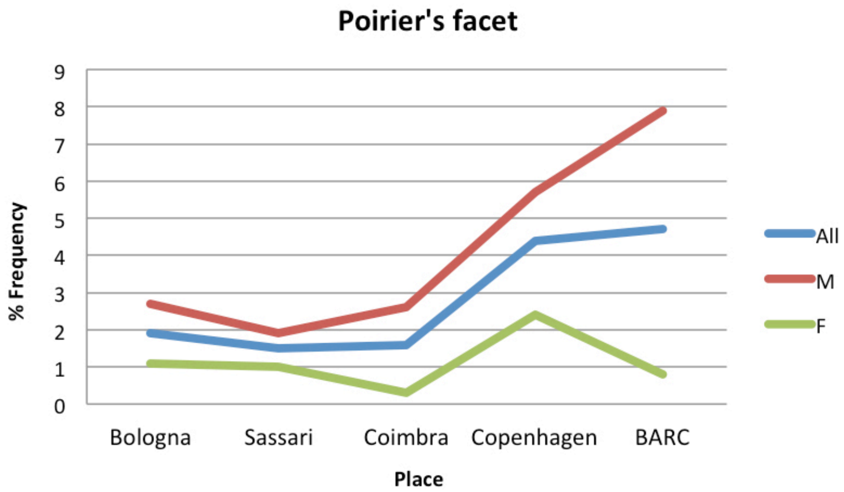


Figure 8. Percent frequency of Poirier's facet in the samples.

Plaque is present at high frequencies in all the samples and it is more frequent in Sassari and Coimbra, especially in males.

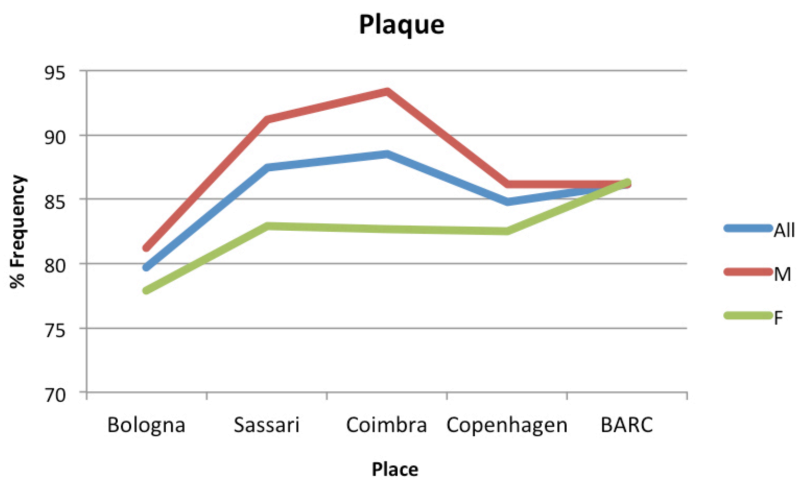


Figure 9. Percent frequency of plaque in the samples.

Cribra (not available for Copenhagen) is present with variable frequencies, ranging from circa 15% in Coimbra males to circa 45% in Bologna females and is always more frequent in females.

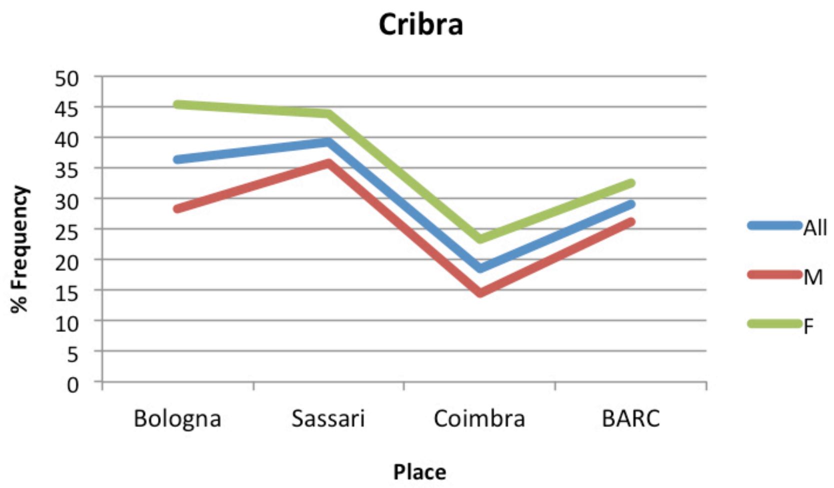


Figure 10. Percent frequency of cribra in the samples.

The frequencies of the three forms of plaque (Figure 11) have similar distribution in the samples, with form A lower than 15%, form B generally between 40% and 50% and form C generally between 20% and 40%. Thus the general trend is represented by form B > form C > form A, with the exception of Bologna sample (and Sassari males) presenting more forms C than forms B.

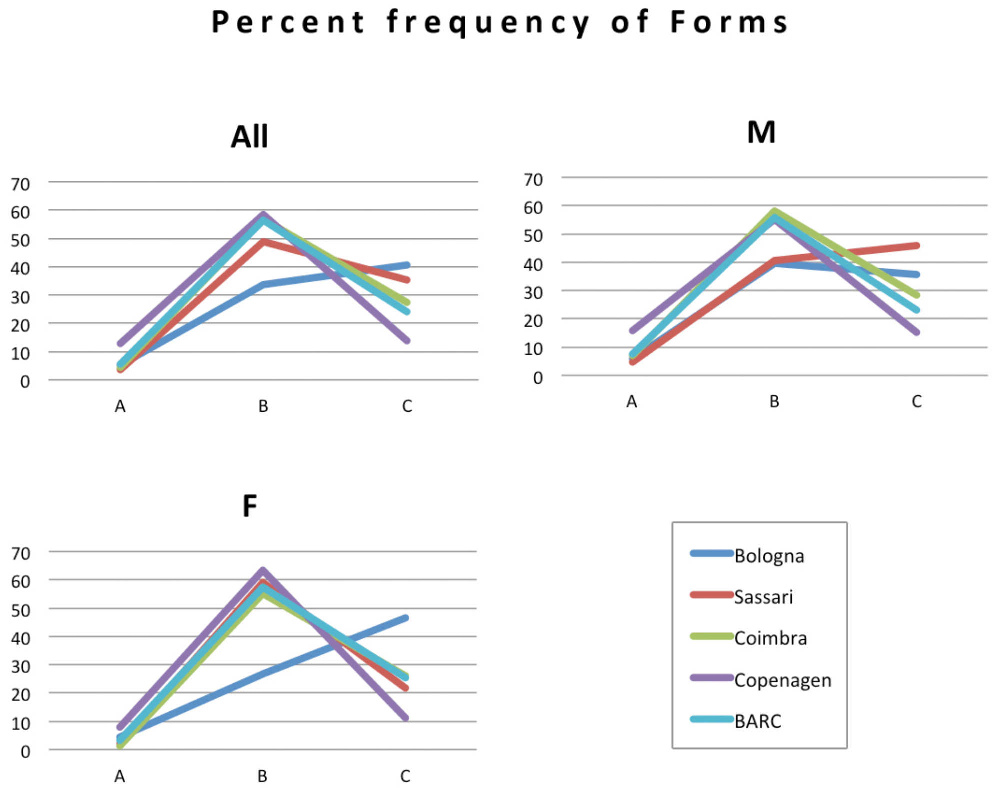


Figure 11. Percent frequency of the plaque forms in the samples.

The frequencies of the plaque edge (Figure 12) are similar in the various samples, with edge 1 generally present between 20% (excluding Copenhagen) and 40% and edge 2 under 15%.

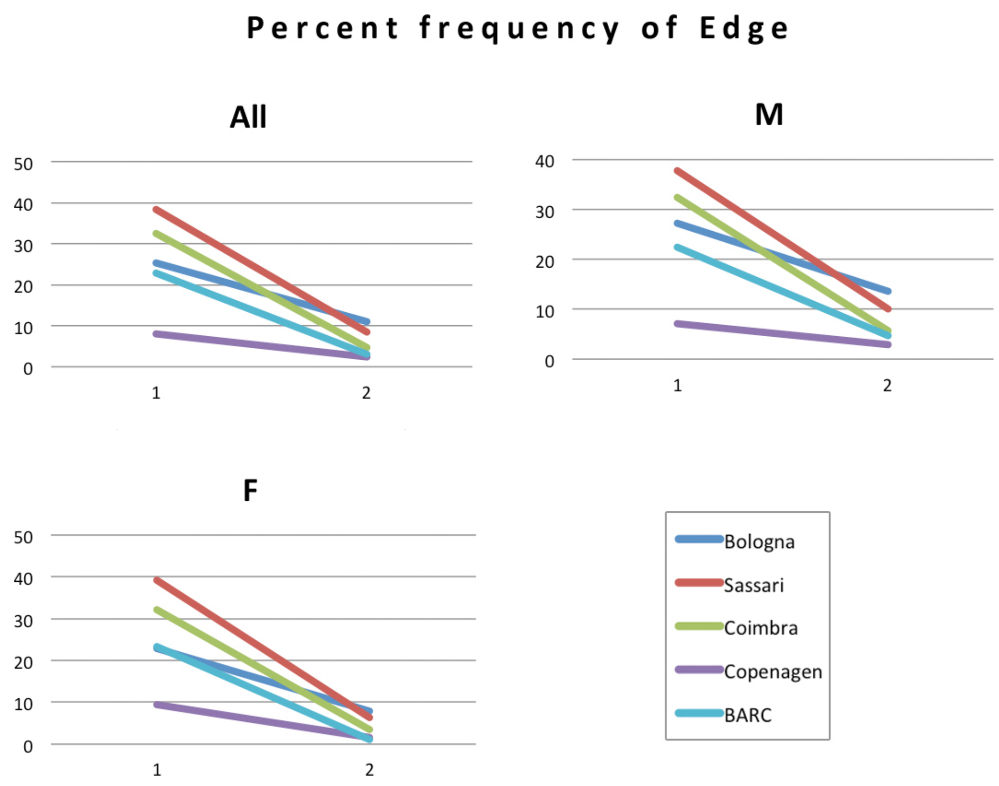


Figure 12. Percent frequency of the two degree of plaque edge in the samples.

Figure 13 shows the frequencies of the two forms of cribra in the various samples. Excluding Coimbra sample and Bologna males, cribra 2 (20-30%) is generally more frequent than cribra 1 (7-15%).

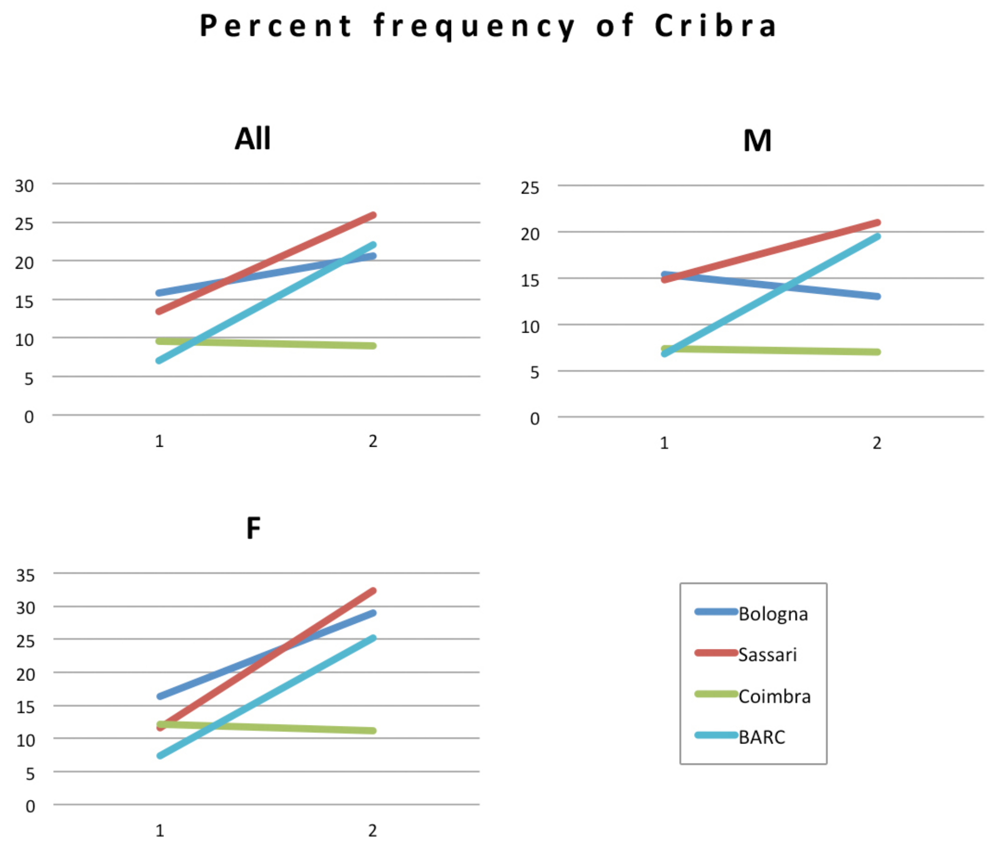


Figure 13. Percent frequency of the two forms of cribra in the samples.

Even if the various samples present generally similar frequency distributions, the differences between them are often statistically significant. Tables 46-50 show the resulting p-values of paired Pearson's chi-squared test for all the features and all the samples.

TABLE 46: Differences between samples in the presence of Poirier's facet (p-values resulting from paired Pearson's chi squared test).

All	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.758	0.793	0.077	0.019
Sassari	0	1	0.005	9.09E-05
Coimbra	0	0	0.006	1.88E-04
Copenhagen	0	0	0	0.933

Males	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.713	1	0.183	0.010
Sassari	0	0.594	0.014	9.69E-06
Coimbra	0	0	0.084	3.54E-04
Copenhagen	0	0	0	0.345

Females	Sassari	Coimbra	Copenhagen	BARC
Bologna	1	0.530	0.650	1
Sassari	0	0.391	0.471	1
Coimbra	0	0	0.080	0.548
Copenhagen	0	0	0	0.300

TABLE 47: Differences between samples in the presence of plaque (p-values resulting from paired Pearson's chi squared test).

All	Sassari	Coimbra	Copenhagen	BARC
Bologna	3.30E-04	4.69E-05	0.087	0.002
Sassari	0	0.569	0.247	0.425
Coimbra	0	0	0.102	0.146
Copenhagen	0	0	0	0.563

Males	Sassari	Coimbra	Copenhagen	BARC
Bologna	1.98E-04	2.27E-06	0.200	0.085
Sassari	0	0.238	0.063	0.012
Coimbra	0	0	0.004	2.25E-04
Copenhagen	0	0	0	1

Females	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.191	0.211	0.395	0.010
Sassari	0	1	1	0.175
Coimbra	0	0	1	0.161
Copenhagen	0	0	0	0.348

TABLE 48: Differences between samples in the distribution of plaque forms (p-values resulting from paired Pearson's chi squared test).

All	Sassari	Coimbra	Copenhagen	BARC
Bologna	1.42E-06	8.30E-13	1.65E-18	7.74E-15
Sassari	0	0.002	4.61E-17	2.48E-07
Coimbra	0	0	4.41E-10	0.149
Copenhagen	0	0	0	2.93E-07

Males	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.001	2.12E-07	1.54E-07	6.58E-05
Sassari	0	2.81E-08	2.75E-15	1.07E-14
Coimbra	0	0	1.44E-06	0.001
Copenhagen	0	0	0	0.001

Females	Sassari	Coimbra	Copenhagen	BARC
Bologna	2.16E-12	1.41E-09	4.99E-12	1.73E-11
Sassari	0	0.427	0.001	0.195
Coimbra	0	0	1.69E-05	0.115
Copenhagen	0	0	0	0.001

TABLE 49: Differences between samples in the presence/absence and distribution of plaque edge (p-values resulting from paired Pearson's chi squared test).

	Presence/Absence				Frequency of the degrees			
All	Sassari	Coimbra	Copenhagen	BARC	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.001	0.862	7.90E-16	8.44E-05	2.39E-05	3.02E-05	3.16E-15	3.07E-10
Sassari	0	4.59E-05	8.50E-32	2.78E-23	0	3.06E-05	5.26E-31	1.42E-23
Coimbra	0	0	2.82E-19	1.01E-07	0	0	9.04E-19	5.03E-07
Copenhagen	0	0	0	2.64E-09	0	0	0	5.10E-09
Males	Sassari	Coimbra	Copenhagen	BARC	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.105	0.561	5.55E-13	2.00E-04	0.019	0.002	2.17E-12	4.02E-06
Sassari	0	0.004	3.04E-21	7.98E-13	0	0.004	1.45E-20	3.02E-12
Coimbra	0	0	2.06E-13	1.40E-04	0	0	5.59E-13	4.57E-04
Copenhagen	0	0	0	3.98E-07	0	0	0	1.08E-06
Females	Sassari	Coimbra	Copenhagen	BARC	Sassari	Coimbra	Copenhagen	BARC
Bologna	0.001	0.298	9.92E-05	0.114	0.001	0.011	2.28E-04	6.64E-06
Sassari	0	0.006	6.52E-12	1.08E-11	0	0.009	2.75E-11	1.02E-12
Coimbra	0	0	3.16E-07	2.64E-04	0	0	1.09E-06	2.20E-04
Copenhagen	0	0	0	0.002	0	0	0	0.002

TABLE 50: Differences between samples in the presence/absence and distribution of cribra (p-values resulting from paired Pearson's chi squared test).

	Presence/Absence			Frequency of the forms		
All	Sassari	Coimbra	BARC	Sassari	Coimbra	BARC
Bologna	0.358	1.35E-11	0.008	0.094	2.12E-11	1.05E-06
Sassari	0	4.40E-21	1.48E-06	0	7.87E-23	1.01E-07
Coimbra	0	0	9.38E-08	0	0	3.74E-14
Males	Sassari	Coimbra	BARC	Sassari	Coimbra	BARC
Bologna	0.070	3.53E-05	0.613	0.043	1.17E-04	2.29E-04
Sassari	0	9.89E-14	7.02E-04	0	2.47E-13	2.40E-05
Coimbra	0	0	4.80E-06	0	0	6.40E-08
Females	Sassari	Coimbra	BARC	Sassari	Coimbra	BARC
Bologna	0.831	1.56E-07	0.002	0.264	4.70E-08	2.99E-04
Sassari	0	2.36E-09	4.45E-04	0	5.49E-12	0.001
Coimbra	0	0	0.003	0	0	1.98E-07

The differences between collections could be better visualized performing and plotting a multiple correspondence analysis (MCA). Figure 14 shows how the greater part of the diversity is due to the frequency distribution of form and edge (Dim 1) and the remaining to that of cribra (Dim 2).

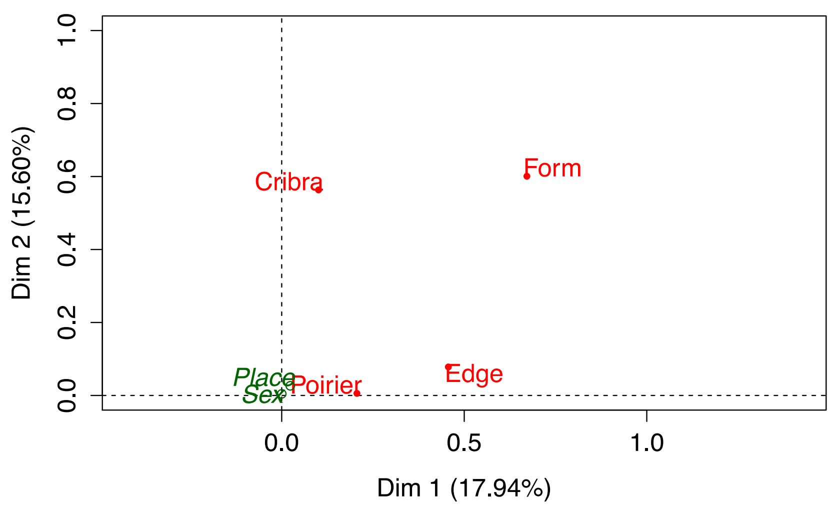


Figure 14. Plot of MCA of all the samples using all the variables: greater part of the diversity is due to the frequency distribution of form and edge (Dim 1) and the remaining to that of cribra (Dim 2).

Using the presence/absence of the three main traits (Poirier's facet, plaque and cribra) the resulting plot (Figure 15) shows that only the confidence ellipse of Coimbra sample is well distinct from the others, which partially overlap.

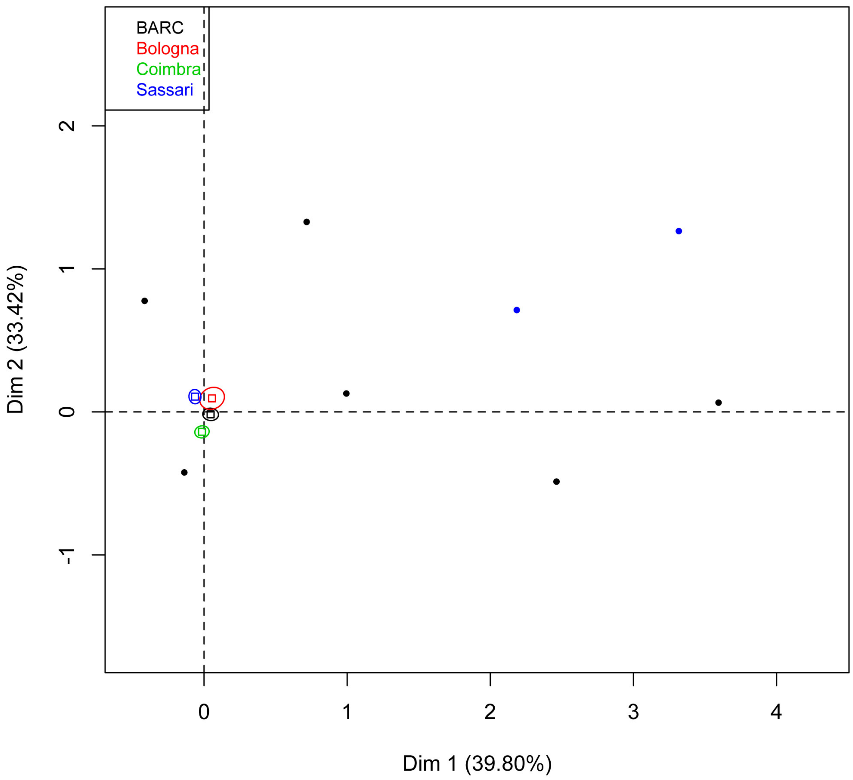


Figure 15. Plot of MCA using the presence absence of the three main traits (Poirier's facet, plaque and cribra). Only the Coimbra sample (green ellipse) is well distinct from the others.

Using only form and edge as variables (Figure 16) the resulting plot shows four distinct confidence ellipses corresponding to BARC, Bologna, Coimbra and Sassari samples, with the ellipse of Copenhagen overlapping all the others.

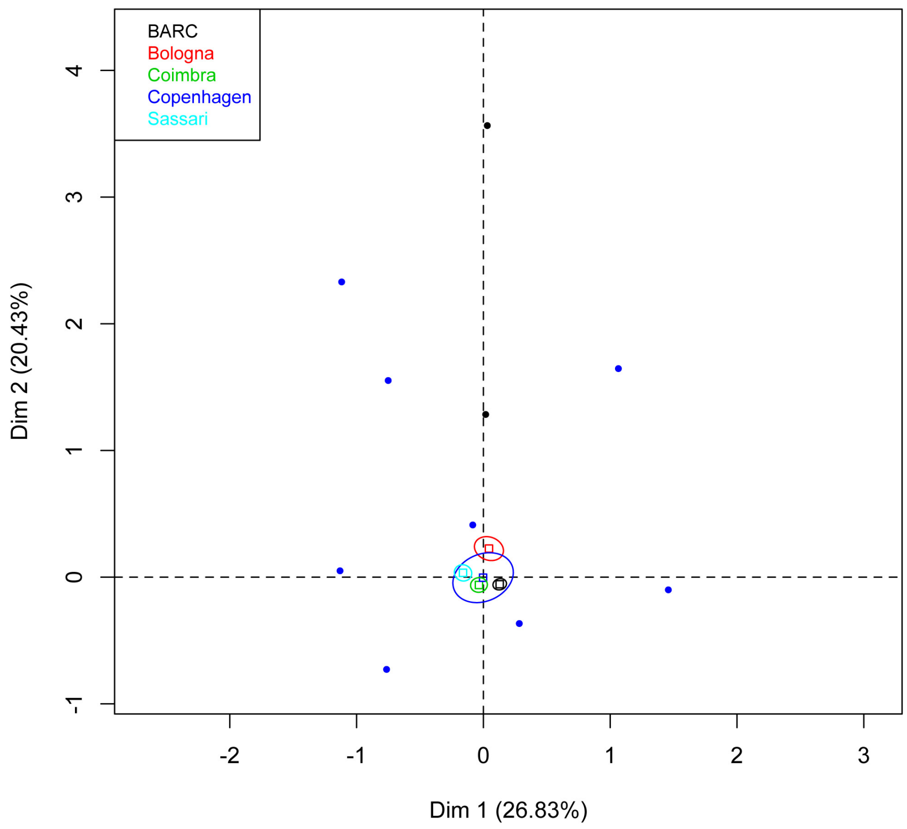


Figure 16. Plot of MCA using only plaque form and edge as variables. BARC, Bologna, Coimbra and Sassari samples are well distinct, with the ellipse of Copenhagen overlapping all the others.

Using all the variables together (Figure 17) the resulting plot shows four well distinct confidence ellipses corresponding to BARC, Bologna, Coimbra and Sassari samples.

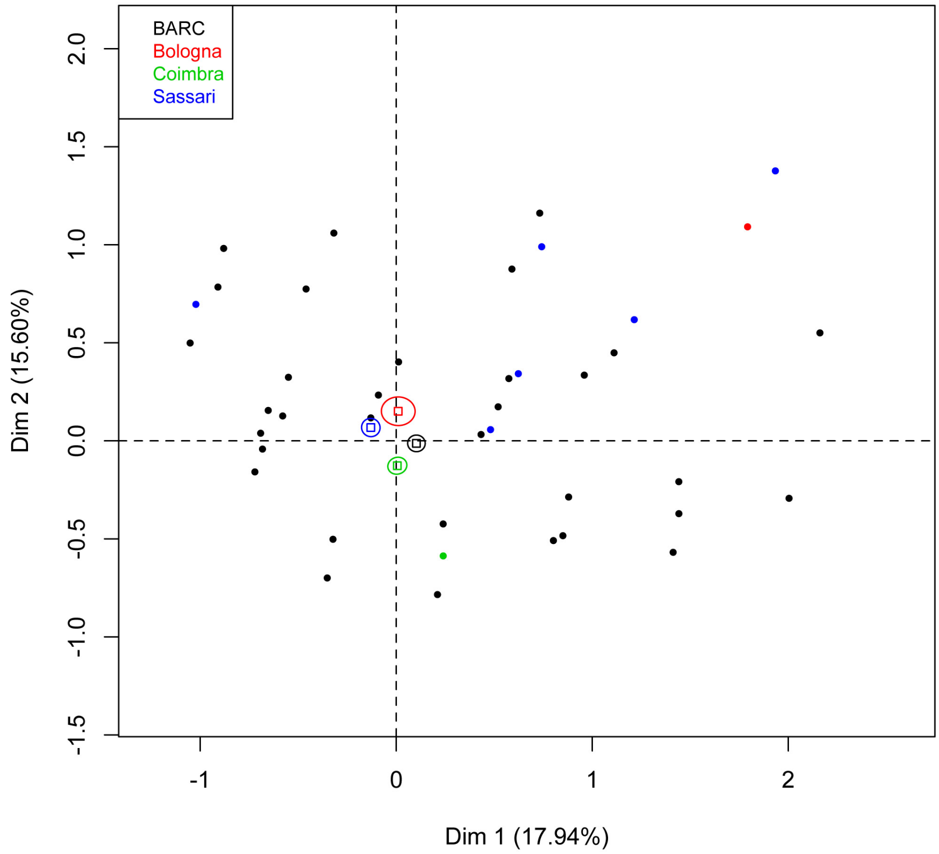


Figure 17. Plot of MCA using all the traits together. All the samples are well distinct.

4.6 Herniation pits

Applying the scoring method to the various collections, a new trait emerged with a certain frequency on the reaction area: a single round and deep hole on the cortical bones basically always overlapping the plaque. This hole is very likely the entity that Pitt and coauthors (1982) described as herniation pit (Figure 18).

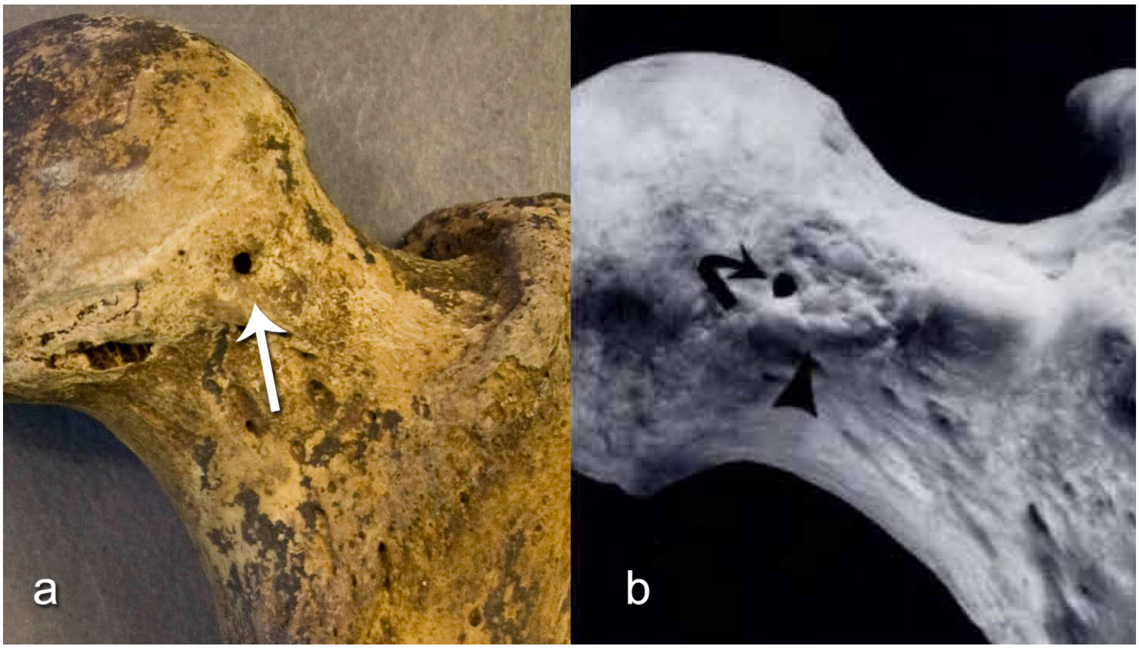


Figure 18. Herniation pits with cortical perforation. (a) herniation pit in a 60-year-old males from Sassari sample; (b) picture of an herniation pit taken from Pitt et al. (1982).

Pitt and all the following studies analyzed this feature on living patients using radiography, CT scan and magnetic resonance (together with histological analysis), but never on dry bones (excluding Daenen et al., 1997). Even if herniation pits showing cortical breaks are just a part of the total herniation pits that could be present, the presence of this trait in the various collections have been scored and results are presented in the following paragraphs. Furthermore, the frequency of herniation pits has been investigated more deeply on the CT scan sample from Copenhagen. Following Panzer et al. (2010) in fact, the radiological appearance of the reaction area is often characterized by a multitude of different cystic appearing lesions with or without cortical breaks, not only the herniation pits. The various lesions observed in this sample have been divided in five categories (see *Methods § 3.3*) and results are presented in *§ 4.6.3*.

4.6.1 Identified skeletal collections

Frequencies distribution

Table 51 shows absolute and percent frequencies of herniation pits in individuals with both sides observable. In Sassari sample herniation pits are present in 15% of the subjects, in 26% of which bilaterally. In Coimbra sample this feature is present in 10% of the subjects, bilaterally in 19%. In both samples herniation pits are more frequent in males.

TABLE 51: Absolute and percent frequencies of herniation pits in Sassari and Coimbra samples.

			Bilateral			Left only			Right only			Tot	
Collection	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Sassari	All	446	17	4	26	17	4	26	31	7	48	65	15
	M	251	16	6	33	9	4	19	23	9	48	48	19
	F	195	1	1	6	8	4	47	8	4	47	17	9
Coimbra	All	413	8	2	19	12	3	29	22	5	52	42	10
	M	224	4	2	15	10	4	38	12	5	46	26	12
	F	189	4	2	25	2	1	13	10	5	63	16	8

Differences between sides

Mc Nemar's chi-squared test (Table 52) shows that there are significant differences between sides in Sassari males and in Coimbra females: in both cases herniation pits are more frequent on the right side.

TABLE 52: Mc Nemar's chi squared test: side differences in the presence of herniation pits in Sassari and Coimbra samples.

				0		1		
Collection	Sex	Side	N	n	%	n	%	p-value
Sassari	All	L	446	412	92	34	8	0.061
		R	446	398	89	48	11	
	M	L	251	226	90	25	10	0.022
		R	251	212	85	39	16	
	F	L	195	186	95	9	5	1
		R	195	186	95	9	5	
Coimbra	All	L	413	393	95	20	5	0.123
		R	413	383	93	30	7	
	M	L	224	210	94	14	6	0.831
		R	224	208	93	16	7	
	F	L	189	183	97	6	3	0.043
		R	189	175	93	14	7	

Differences between sexes

There are significant differences between sexes in Sassari right sample, with herniation pits more frequent in males (Table 53). No significant difference has been found in Coimbra sample.

TABLE 53: Gender differences in the presence of herniation pits in Sassari sample.

				0		1		
Collection	Side	Sex	N	n	%	n	%	p-value
Sassari	L	F	198	189	96	9	5	0.055
		M	256	231	90	25	10	
	R	F	198	188	95	10	5	0.001
		M	254	214	84	40	16	

Differences between age classes and correlation with age

No significant difference between age classes and no correlation with age has been found in both samples.

4.6.2 Archaeological skeletal collections

Frequencies distribution

Table 54 shows absolute and percent frequencies of herniation pits in individuals with both sides observable. In all the samples herniation pits are included between 14% and 16%.

TABLE 54: Absolute and percent frequencies of herniation pits in the archaeological samples.

			Bilateral			Left only			Right only			Tot	
Collection	Sex	N	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N	%/Tot	n	%/N
Wetwang Slack	All	135	6	4	30	8	6	40	6	4	30	20	15
	M	66	4	6	33	4	6	33	4	6	33	12	18
	F	69	2	3	25	4	6	50	2	3	25	8	12
Baldock	All	38	1	3	17	1	3	17	4	11	67	6	16
	M	21	0	0	0	1	5	25	3	14	75	4	19
	F	17	1	6	50	0	0	0	1	6	50	2	12
Rounds Furnells	All	104	2	2	12	9	9	53	6	6	35	17	16
	M	65	1	2	11	3	5	33	5	8	56	9	14
	F	39	1	3	13	6	15	75	1	3	13	8	21
Hereford Cathedral	All	185	5	3	18	15	8	54	8	4	29	28	15
	M	98	2	2	15	6	6	46	5	5	38	13	13
	F	87	3	3	20	9	10	60	3	3	20	15	17
St. Peter's Collegiate Church	All	28	0	0	0	2	7	50	2	7	50	4	14
	M	15	0	0	0	1	7	33	2	13	67	3	20
	F	13	0	0	0	1	8	100	0	0	0	1	8

Other analyses

No differences have been found in all the archaeological samples between sides, sexes and age classes.

4.6.3 CT scans

In few cases more type of lesions or more lesions of the same type have been found on the same femur. Table 55 shows the presence and the kind of cystic appearing lesions. Cystic appearing lesions are present in 35% of the subjects; half of them have herniation pits.

TABLE 55: Frequency of the various type of cystic lesion in the CT scan sample.

	Presence of lesions					Kind of lesion											
		Total		Bilateral			Subchondral cyst		Herniation pit		Focal osteoporosis		Trabecular reconstructing		Degenerative change	
Sex	N	n	%	n	%	N	n	%	n	%	n	%	n	%	n	%
All	180	63	35	17	27	63	25	40	32	51	4	6	9	14	5	8
M	113	40	35	10	25	40	18	45	16	40	3	8	7	18	4	10
F	67	23	34	7	30	23	7	30	16	70	1	4	2	9	1	4

Herniation pits are present in 18% of the subjects, in 16% of which bilaterally (Table 56). In 30% of the individuals with herniation pits these present cortical breaks (5% of all the individuals). Cortical breaks are more frequent in females.

TABLE 56: Herniation pits distribution in the CT scan sample.

	Presence			Bilateral			Intact cortex		Cortical break	
Sex	N	n	%	N	n	%	n	%	n	%
All	180	32	18	32	5	16	22	69	10	31
M	113	16	14	16	2	13	13	81	3	19
F	67	16	24	16	3	19	9	56	7	44

5. DISCUSSION

5.1 Summary of the main results

The most important result of this work has been the creation of the first standardized method for scoring the anatomical variations of the anterior aspect of the proximal femur (Radi et al., 2013). This method, thanks to its reliability and easy applicability, allows collecting comparable data about presence and distribution of many osseous traits. These traits have been investigated in various samples from different countries and time periods, achieving important indications about their distribution in human populations. The terminological issue in the existing literature made it is very difficult to make comparisons with older studies. For instance, Parsons (1914), Pearson & Bell (1919), Meyer (1924), Odgers (1931) and Schofield (1959) found the "empreinte" to be more frequent in males, but they considered under this terms different formations (including Allen's fossa). Nevertheless, it has been possible to find some interesting correspondence with part of these studies.

Poirier's facet shows very low frequencies: it exceeds 6% of individuals only in the three archaeological samples (Baldock, Rounds Furnells and St. Peter's Collegiate Church), but in these cases the sample size is very small and there is very likely an overestimation of this feature. This is in accordance with Meyer (1924) that believed it (under the term "eminentia articularis colli femoris") to be "present in somewhat less than 10 per cent of the cases". In the subadults samples Poirier's facet it is not detectable, as the femoral head physis is generally not yet completely fused. Moreover, Poirier's facet resulted always more frequent in males (in some cases it is present <u>only</u> in males). These results are in contrast with Angel (1964), who found Poirier's facet in most of his femurs (71%). The reason of this very high frequency could be that he likely considered even very slight lateral prominence of the head surface ("Since this is a <u>slight</u> outward bulging of the femoral head toward the greater trochanter, sometimes it is blended with the plaque morphologically."). I noted such small smooth prominences diffusely in all the samples, in the <u>superior</u> or antero-superior (cf. Schofield, 1959) aspect of the femoral head (Figure 19), usually in spatial continuity (but morphologically well distinct from it) with some kind of plaque.

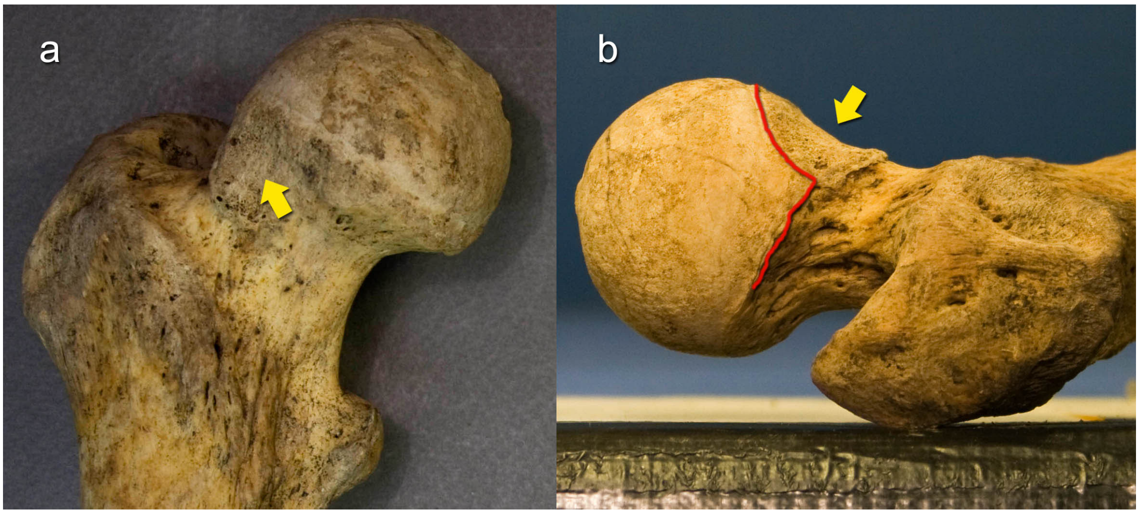


Figure 19. Slight lateral extension of the femoral head articular surface (red line) in a 47-year-old male form the Sassari sample. Note that the extension is in spatial continuity with a plaque (yellow arrow).

Being these formations very small, I considered them as normal slight variation of the head shape, and scored only the plaque (when present). I considered as Poirier's facet only noticeable lateral and smooth expansions of the head surface (Figure 20), usually found on the anterior aspect of the head-neck junction. Kostick (1963) found Poirier's facet in 50-70% of the femurs, but he clearly included also the plaque under this term.

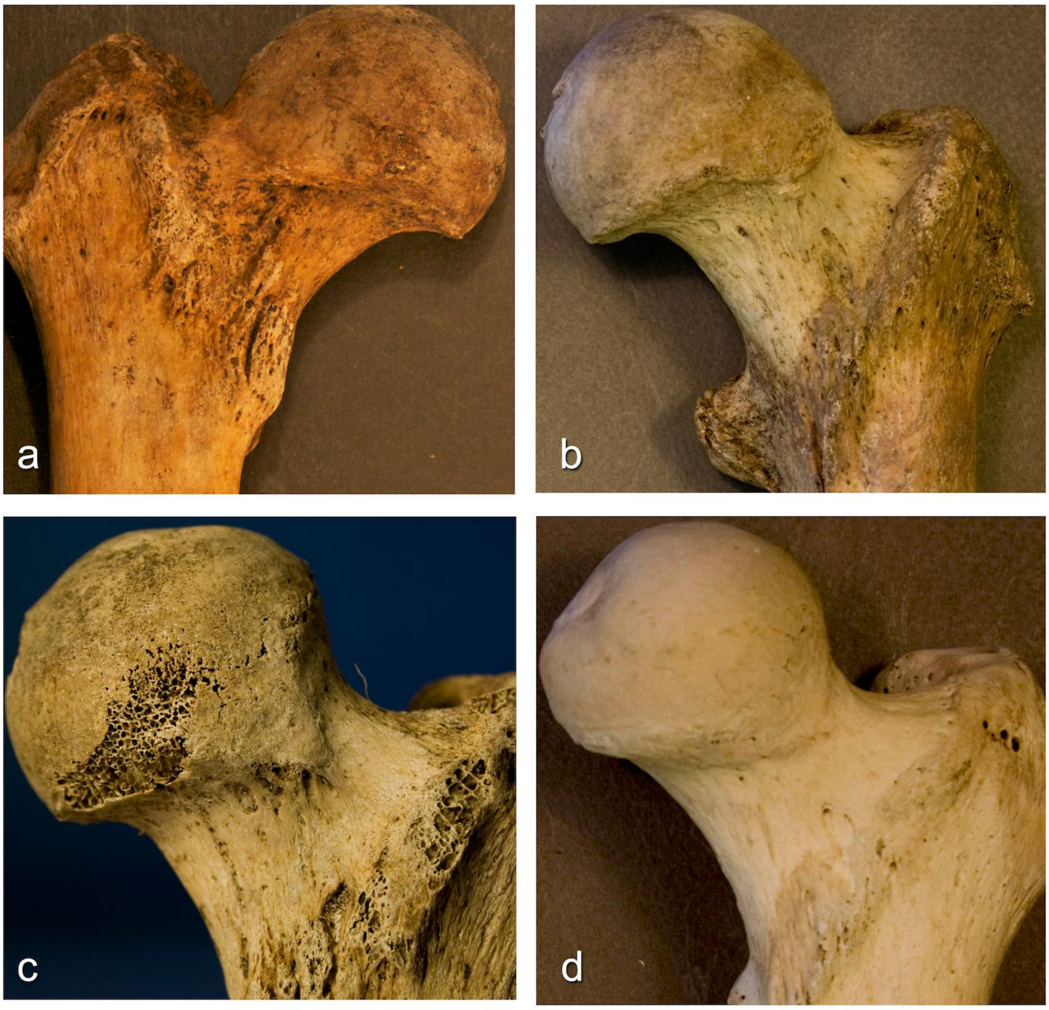


Figure 20. Various appearances of Poirier's facet. (a) 54-year-old male from Coimbra sample; (b) 40-year-old male from Sassari sample; (c) 45-year-old male from Bologna sample; (d) 66-year-old male from Bologna sample.

Plaque is generally present in over 90% of the individuals and almost always bilaterally. In some cases it resulted more frequent in males with statistical significance (Sassari and Coimbra). The frequency of raised plaques (form A and B) is comparable with that of Meyer (1934), who found "raised facets" in 65%-67% of his sample and with that of Angel (1964), who found plaque to occur in 2/3 to 3/4 of modern American femoral necks (he didn't counted form C, considering it as Allen's fossa). No particular trend seems to be present, excepting that form A is more frequent in males in all the samples and form C is constantly less frequent in old adult males (significant p-values in Sassari and Coimbra only). The edge (specially of degree 2) is generally more frequent in males, in two cases (Bologna and Hereford Cathedral) with statistical significance. It is positively correlated with age and it tends to be more frequent in old adults (most of degree 2 are in old adults) and less frequent in young adults (degree 2 often absent in young adults). Edge 2 is generally less frequent than edge 1. The increase of the edge with age, already noted for the Bologna sample (Radi et al., 2013), was observed in the past by Walmsley (1915) and Meyer (1924). In Copenhagen sample there are no difference between age classes, but this could be related to a possible underestimation of the presence of the edge due to the method of 3D reconstruction and to the impossibility of observing the bones directly. In subadults the plaque is really rare and it is present only in late adolescents, according to Walmsley (1915). When present, it is usually barely visible. Most of the plaques are of form B type, with very few forms C and no form A. No edge is present.

Concerning cribra, it is important to note that, compared to the previous descriptions of this feature in literature, there is a fundamental difference. As highlighted in Radi et al. (2013), we consider the presence of two kind of "fossa": one is represented by form C of plaque, that is a depressed notch in the anterior or antero-superior portion of the head-neck junction, without cortical erosion; the other one is the fossa (commonly known as Allen's fossa) that sometimes accompanies cribra 2 and is usually antero-inferior. It is an important distinction because often the two type of groove are considered as the same unit, but are two different and distinct traits, that can be present on the same bone (even blended sometimes) but not necessarily do. The cribra (specially cribra 2) is more frequent in females, almost always with statistical significance and is negatively correlated with age (it is constantly higher in young adults, both cribra 1 and 2), in accordance with the findings of Kostick (1963) on "cervical imprint" and of Angel (1964) on "Allen’s fossa". Cribra 2 is generally more frequent than cribra 1. Cribra is present in almost hundred percent of subadults, mostly of type 2 (cribra 1 is present almost only in adolescents). Anyway, cribra in subadults seems to be a distinct feature respect to the one in adults, involving developmental mechanisms. In fact it tends to disappear in the late adolescence (cribra 1 or no cribra at all) and have a different appearance. The exposed trabeculae of subadults have sharp margins, while trabeculae in adults have usually rounded and remodeled margins (Figure 21).

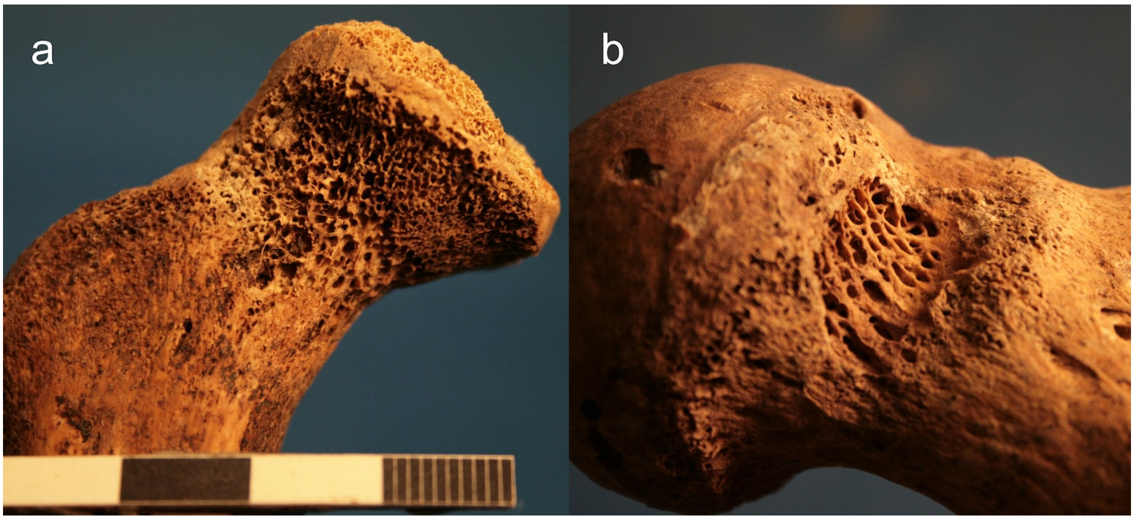


Figure 21. Different appearance of cribra in subadults and adults: (a) Trabeculae with sharp margins in a child from Bologna sample; (b) trabeculae with remodeled appearance in an adult female from Hereford Cathedral sample.

Lateralization is basically absent for all the features. Anyway, even if rarely reaching statistical significance, some constant trends have been noted for form and edge across all the samples. Form B is usually more frequent on the left side (specially in males) and form C is basically always more frequent on the right side (significant p-values in Bologna, Wetwang Slack and Copenhagen). Edge is more frequent on the right side, but only in one sample with statistical significance (Rounds).

Even if the various traits present similar frequencies in samples from different collections, significant differences emerged between them, with a clear differentiation for place of provenience. This is in accordance with the study of Donlon (2000), who used differences in the frequency of intracranial variations of the skeleton (including some of the traits described in the present work) to calculate distance between populations. Moreover, given the relation of some of the traits with age and sex, it has been verified that these differences were not due to differences in the structure of the samples, being sexes and age classes generally equally distributed. The interpretation of this differentiation for place of provenience remains obscure.

For what concerns the correlation of the features with body dimension (height, weight and BMI), no clear indication emerged from Copenhagen sample and further analysis could be performed on skeletal samples using other measurements (such as head diameters, neck diameters, lengths and angles).

Herniation pits and other cystic appearing lesions: in the skeletal collections cortical perforations like the herniation pits described by Pitt et al. (1982) have been found between 10% and 16% of the individuals, more frequent in males. In the CT scan sample cystic appearing lesions have been observed in 35% of the subjects, rarely bilaterally. Of these, from a more in depth analysis, herniation pits represent circa 50%. Herniation pits with cortical break are present in circa 5% of the subjects.

5.2 Theories on the etiology of the various features and other considerations

Poirier's facet

Poirier's facet, as intended in this study (according to Radi et al., 2013), is very rare and with different appearances. It is probably due to variations in the development of the head of the femur and in the closure of the physeal line. These variations could be originated by chance or possibly mechanically driven. Its origin could be considered in an evolutionary context as related to bipedal locomotion (see next paragraph).

Plaque and edge

As seen in the introduction, in the classic literature multiple hypotheses have been proposed to explain the etiology of the features of the head-neck junction. Despite the existing confusion and disagreement, these hypotheses could be gathered in two main (and opposite) groups:

- Linear contact with the acetabular rim in flexion and internal rotation of the hip proposed by Evangeli-Tramond (1894), Regnault (1898), Poirier & Charpy (1911), Pearson & Bell (1919) and Meyer (1924,1934).

- Pressure of the capsular fibers, more or less influenced by additional muscular strain (in particular *m. iliopsoas* and *m. rectus femoris*) in full extension of the hip proposed by Walmsley (1915), Odgers (1931), Kate (1963) and Angel (1964).

These hypotheses have been often used to explain the etiology of all the feature of the junction (Poirier's facet, plaque and cribra). For example, Angel (1964), proponent of the capsular-muscular pressure hypothesis, considered plaque to be an age change of Allen's fossa (i.e. cribra 2 with depressed fossa): open erosion fossae of young subjects would be gradually covered by bony scar tissue until the formation of a plaque in advanced age. This seems to be hardly plausible: plaque and cribra often coexist on the same bone and occupy two distinct zones (plaque antero-superior, cribra antero-inferior). Moreover, in the present work the presence of plaque in adults (even considering only the raised plaques) doesn't seem to be correlated with age. On the contrary, the appearance of the plaque changes, with rougher and remodeled surfaces, more prominent edges, like other osteo-productive features at entheses and joints (cf. Rogers & Waldron, 1995; Robb, 1998; Jurmain, 1999; Ortner, 2003; Weiss, 2003, 2004, 2007; Mariotti et al., 2004, 2007; Buikstra & Beck, 2006; Cardoso & Henderson, 2010; Villotte et al., 2010; Niinimäki, 2011; Milella et al., 2012).

In the last decade, with the exponential increase of publication on femoroacetabular impingement (FAI), the hypothesis of linear contact with the acetabular rim as major causing factor of these features is once again popular. As pointed out by Villotte & Knüsel (2009) and highlighted in Radi et al. (2013), the femoral component of the cam-FAI (usually known under the term "bump") it is likely to generally correspond to the anatomical variations of the head-neck junction (in particular Poirier's facet and raised plaques). This is evident looking at images presented in most of the studies on FAI (Figure 22).

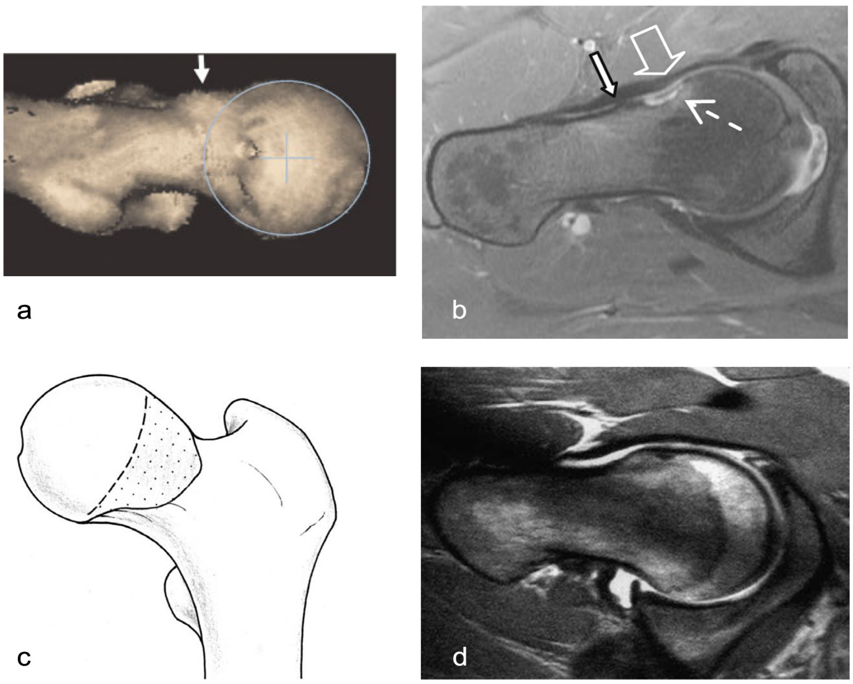
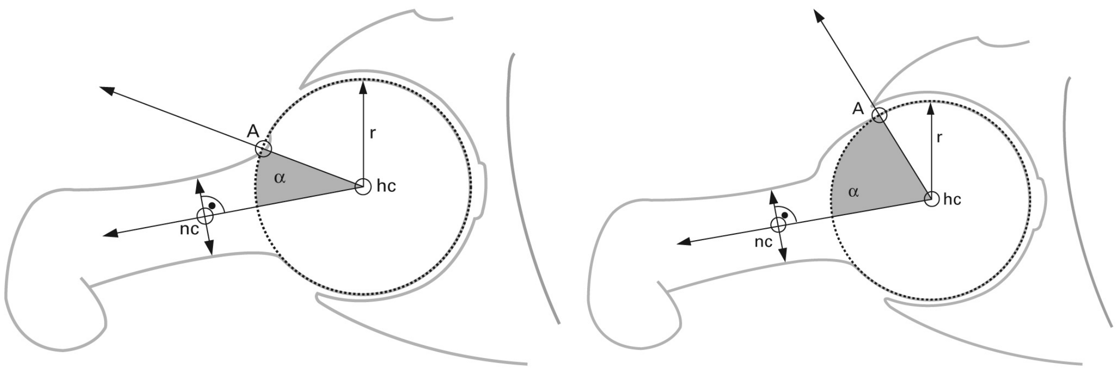


Figure 22. Figures taken from various medical papers showing typical cam deformities: (a) image from Tannast et al. (2007b); (b) image from Petchprapa et al. (2012); (c) image from Siebenrock et al. 2004; (d) image from Ganz et al. (2003).

Furthermore, today the most used, even if largely criticized (Nouh et al., 2008; Lohan et al., 2009; Audenaert et al., 2011), parameter to diagnose the entity of cam FAI is the alpha angle. This angular measurement, originally developed on MRI by Notzli and coworkers in 2002, measures the level of asphericity of the femoral head. The angle is defined by two lines: the first line between the center of the femoral head and the anterior point where the distance of the center of the femoral head exceeds the radius of the surface of the femoral head and the second line between the center of the femoral head and the center of the femoral neck at its narrowest point (Figure 23).



a . **b .**

Figure 23. Diagrams showing the construction of α angle. Point A is the anterior point where the distance from the centre of the head (hc) exceeds the radius (r) of the subchondral surface of the femoral head. α is then measured as the angle between A-hc and hc-nc, nc being the centre of the neck at the narrowest point. (a) hip in a normal subject and (b) a typical deformation. *Figure and caption taken from Notzli et al. (2002).*

It is generally considered as a symptom of cam FAI when it exceeds 50°(Notzli et al., 2002), even if many studies questioned this threshold, elevating it of various degrees (cf. Audenaert et al., 2011; Agricola et al., 2013b). It is quite evident how elevated values of this angle usually correspond to a lateral extension of the head (Poirier's facet) or to the presence of raised plaques (Figure 24).

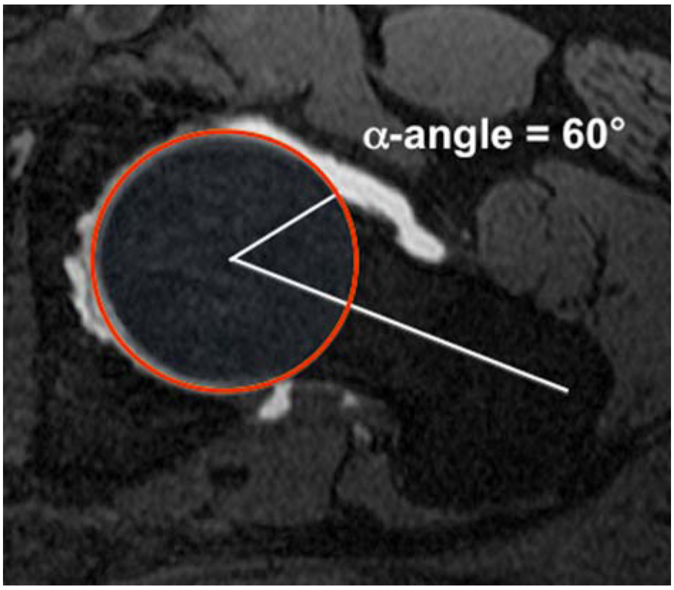


Figure 24. An elevated value of the α angle corresponding to a plaque formation on the neck of the femur. *Figure taken from Lohan et al. (2009).*

Tannast et al. (2007a) noted a "notch sign" accompanied by cortical thickening, formation that it is comparable to the form C of plaque (or maybe to the fossa appearance of cribra) in hip with pincer type FAI. Moreover, cam impingement is generally found more frequently in young and athletic men, whereas pincer impingement is more common in middle-aged and unathletic women (Ganz et al., 2003; Nakahara et al., 2011). I found Poirier's facet and form A of plaque generally more frequent in males. Distribution of form B is more or less equivalent in the two sexes, but in the present study under form B are included also plaque lying on the neck plane and not just the raised ones. Form C doesn't display gender differences (but cribra are generally more frequent in females).

Now the question is: which came first, the chicken or the egg? That is: is it the impingement that generates these formations at the head-neck junction or are these formations (originated by other factors) that generate the impingement? The current literature is not completely exhaustive in this regard. According to Banerjee et al. (2011), FAI is essentially a dynamic problem: even patients with normal hip morphology can suffer from impingement due to extreme range of movement in their hip joint. So it could be possible that impingement due to an over-normal range of motion is a sufficient stimulus to trigger a bony reaction such as a plaque formation. Some authors suspect sports with repetitive flexion-internal rotation and impingement-type movements to be a causative factor (Hogervorst et al., 2011). Siebenrock et al. (2011) suggest that the cam-type morphology is in part a developmental deformity, and that its expression in young adulthood may be triggered by environmental factors such as high-level sports activity during childhood and around the time of closure of the capital growth plate. According to Pollard et al. (2010) the deformity is determined at conception or there is a genetic predisposition to abnormal development or subclinical hip disease before skeletal maturity. They suggest that the primary cam deformity gradually worsens over time, with a "bump" growing as a consequence of reactive bony deposition. Ng & Ellis (2011a) consider cam-type deformity a common morphological variant in Caucasians that may represent a physeal adaptation to increased load-bearing activity (and not impingement traumas) during adolescence. They suggest that, being the proximal femur undergone many adaptations in terrestrial life to accommodate different locomotory modalities, human bipedalism could be the biomechanical environment to produce this new structural formation.

I also believe that bipedal locomotory pattern plays a substantial role in the etiology of most of the morphologies of the head-neck junction, especially for plaque formations, being present in the majority of the subjects. Trinkaus (1975) already postulated that an increase in the total articular surface will proportionately reduce the compressive stress on the articular cartilage and that, under conditions of habitually high joint reaction forces such as in bipedal locomotion, an enlargement of the articular surfaces would be adaptive. Moreover, Odgers (1931) and Angel (1964) didn't find any surface marking on ape proximal femurs. In this context, Poirier's facet and plaque could represent "two sides of the same coin", that is two visually different (but sometimes "blended") reaction to the same environment (upright posture and gait). The main difference between the two features is that Poirier's facet is smooth and covered by hyaline cartilage (Odgers, 1931; Meyer, 1934; Angel, 1964) and plaque is rough and supposed to be covered by fibrocartilage (Odgers, 1931; Angel, 1964). Meyer (1934) describe transitional forms similar to form A of plaque: "A transition form of eminentia articularis colli femoris with a more or less markedly irregular and uneven surface, which, though covered wholly or partly by cartilage in the fresh state, is not formed by a prolongation of the compacta of the head". In the present study rare bony transitional form have been noted (Figure 25).

Figure 25. Morphology someway transitional from Poirier's facet to plaque. The compacta of the head seems to extend over the plaque (arrow).

Angel (1964) claims that Poirier's facet e plaque may be morphologically blended even if they could be distinguished by their different cartilage coverage (hyaline or fibrocartilage). Siebenrock et al. (2004) examined a group of patients with cam-type FAI and noted a cartilage extension (at the same location of the cam-deformity) characterized by redness, surface roughening and ulcerations caused by the repetitive impingement trauma, in contrast with the cartilage of the spherical central portion of the head, typically white and smooth. In that regard, it is possible that some form A of plaque, being on the same plane of the femoral head surface, represent a secondarily degenerated version of Poirier's facet due to impingement (for that extensions enough laterally protruded to abrupt against the acetabular rim). Other studies on FAI and herniation pits show a cartilage extension in continuity with the head surface (Figure 26).

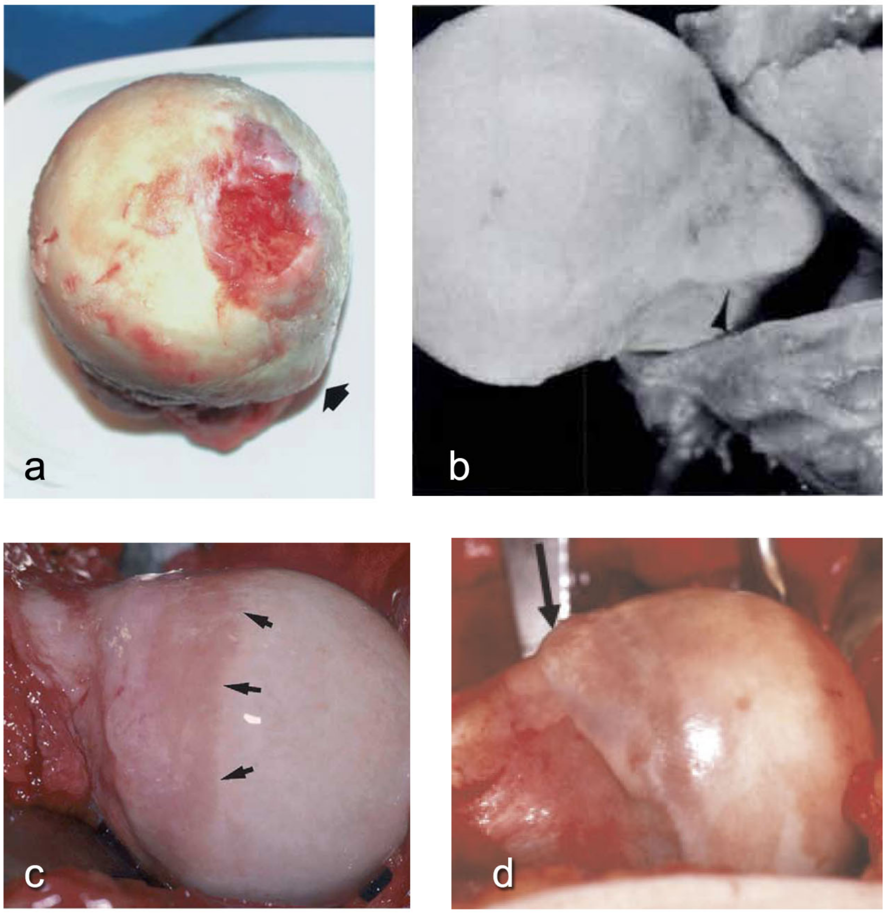


Figure 26. Extensions of the cartilage of the head have been reported in many studies. (a) Image taken from Jäger et al. (2004); (b) image taken from Pitt et al. (1982); (c) image taken from Wagner et al. (2003); (d) image taken from Tannast et al. (2007b).

In order to clarify the nature of the cartilage extension and its relation with the osseous variations new histological analysis are needed accompanied by an accurate description of the underlying bony formation. Finally, it is possible that the presence and magnitude of the "torus cervicalis" may have some influence on the genesis of this formations as noted by Meyer (1934) ("Its absence or presence does not absolutely condition the occurrence of a capitular articular prolongation, or a cervical fossa, facet or ridge, except in so far as it helps to bring this region of the femoral neck nearer to the level of the adjacent articular surface of the head and thus makes contact with the ligamentous acetabular lip easier"), but unfortunately it was not considered in the present work.

Bone is a dynamic tissue that undergoes continuous remodeling throughout life (phenotypic plasticity). Although metabolic or biochemical factors might have an effect on the process (Canalis et al., 1988; Raisz, 1999), bone remodeling is thought to be a predominantly mechanically regulated phenomenon (Carter et al., 1996; Martin, 2000; Frost, 2001; Burr et al., 2002; Ruff et al., 2006; Robling et al., 2006). Regardless of the specific morphology (i.e. if Poirier's facet or plaque) and the type of cartilage that covers it, the main mechanical stimulus to cause the extension of the articular surface is most probably the bipedal gait. This mechanical stimulus it is very likely multifactorial. It is currently believed that bone formation is increased by dynamic, but not static strain and that both loading frequency and strain rate are important determinants of bone adaptation (Robling et al., 2006). As reported by Ng & Ellis (2011a), some studies have demonstrated the ability of the physis to respond to mild to moderate increases in pressure and to directionally self-adjust. The slope of the femoral head physis changes throughout childhood and adolescence with closure first occurring peripherally at the supero-lateral margin. Thus, dynamic loading (related to body mass and to the magnitude of muscular forces acting across the hip joint) during walking and running could generate extension of the physis during its development, generating Poirier's facet like shape of the head of the femur, with common slight protrusions (as described by Angel, 1964) and rare extensive protrusions (as described by Radi et al., 2013). Once the development of the head is completed and the physis is closed, the strain could no more be managed by rearrangements in the head shape and the part of the neck immediately lateral to the head and lying on the direction of the strain should be forced to take-charge of this load, with a cartilage extension through the neck. As stated above, many factors should be taken into account to explain the morphologies of the neck, and the two classic theories are not necessarily mutually exclusive. Capsular pressure (that originate in walking and running) on the cartilage extension onto the neck, enhanced by muscular strain (likely as described by Angel, 1964), could trigger new bone formation and generate plaques in the late adolescence-early adulthood. The strain generated by the pressure of the capsule probably increase during growth together with muscular strength till it reaches a plateau in adult age. Another factor involved in the plaque formation could be an occasional impingement of the junction with the acetabulum due to exaggerated range of motion in very active subadults. After twenty years of age, once developed a plaque-like formation, the impingement could gradually increase, stimulating a positive feedback reaction in the neck. Also in relation with the level of activity, the morphologies may undergo remodeling process (growing in dimensions, developing or increasing edges) as a periosteal reaction to a more or less marked impingement. Advancing with age, it could be hypostasized some bone resorption due to the decrease in the frequency and intensity of physical activity and this would explain the greater frequency of form C in old adults. Anyway, the effect of disuse is generally more apparent at the periosteal surfaces of long bones (where normal appositional bone formation is suppressed) in young, growing individuals. In mature ones, bone loss (involving accelerated bone resorption and turnover) occur mainly at the endosteal surface of long bones (Robling et al., 2006). Thus form C could represents more likely a fatigue damage caused by impingement repetitive traumas.

It should also be taken into account that the different appearance of the plaque could be related to individual variability in reacting to the stimuli as well as in the dimensions of proximal femur (diameters and lengths of the neck, diameters of the head, anteversion and neck-shaft angles) and of the overlying soft tissues.

In this adaptive context it should be considered if this morphological changes (Poirier's facet and plaque) occur only at the presence of a direct mechanical stimulus or are developmental changes genetically (or epigenetically) acquired. It could be maybe tested looking for their presence on people paralyzed from birth or before late adolescence (in this study no marking on the bone has been noted before late adolescence).

Cribra

The etiology of cribra is even more complex and surely multifactorial. In the adults, age and sex are important variables. This could be a clue of the influence of hormonal factors. It is also probable a mechanical component similar to what proposed for plaque. The different reaction of the bone could be due to differences in cortical thickness, greater for the plaque that usually develops over the *torus cervicalis* than for the cribra developing more inferiorly, as postulate in 1931 by Odgers. As noted in Radi et al. (2013), plaque and cribra could be found in spatial continuity and sometimes they seems to be surrounded by a common edge formation (as also observed by Meyer, 1924). Anyway, in the case of cribra an edge formation is present only when they lie on surface depressed respect to the neck surface and it has generally the appearance of a lipping directed toward the medial direction, as a sort of healing process that try to recover the fossa (Figure 27).

Figure 27. Edge of the cribra fossa with the appearance of a lipping directed medially in an adult male from Hereford Cathedral sample.

This morphology was observed by Angel (1964), according to which it represents a clue of his theory of plaque being an age change of Allen's fossa. But, as already noted, plaque and cribra often coexist on the same bone and occupy two distinct zones and this type of lipping margin is usually noted in older subjects, who already developed plaque formations.

In subadults cribra are present in most of the subjects in samples coming from different places and historical period. It is thus improbable their pathological etiology, as supposed by Miquel-Feucht (1999) and Djuric (2008, 2010). According to Ortner (2003), they are more likely an expression of the normal development process of the epiphysis ["...to the uninitiated observer, even some of the normal changes in skeletal tissue associated with growth can be confused with pathological change. An example of this is the very porous external appearance of the metaphysis in the growing bone. This normal porosity is the result of the reduction of the metaphyseal diameter to form the diaphysis as the bone grows in length. The osteoclasts that remove the metaphyseal cortex cut through and expose vascular (haversian) canals in the bone, creating the porous appearance seen in the metaphyseal surface of infants' and children's long bones...As the flared ends grow, what was formerly part of the metaphysis must be converted to the narrower diaphysis, so that growth in length is accompanied by the removal of bone on the external surface of the metaphysis in the region not involved in active growth (the cutback zone)"]. Moreover, the study from Williams et al. (2004) shows how growth rate is associated with rapid periosteal bone deposition e how this provokes decreased mineralization and increased cortical porosity. Even if cribra of subadults seems to gradually disappear during the transition to adulthood (and thus to be a different formation in respect to cribra of the adults), it is also possible that these cribra remain present in a variable percentage of adults and then undergo a various degree of remodeling to form cribra 1 and 2 in adults. In this context, cribra 2 on the same plane of the neck and cribra 1 could represent two successive stages of the same healing process to reform the cortex once the development of the bone is complete. It is possible that the more extreme appearance of cribra 2, with a deep fossa, represent a secondary modification of pre-existing cribra 2 due to mechanical loading: the fossa could be due to capsular pressure or impingement impacts, the remodeled appearance of the trabeculae to dynamic load-bearing compressive forces (Figure 28).

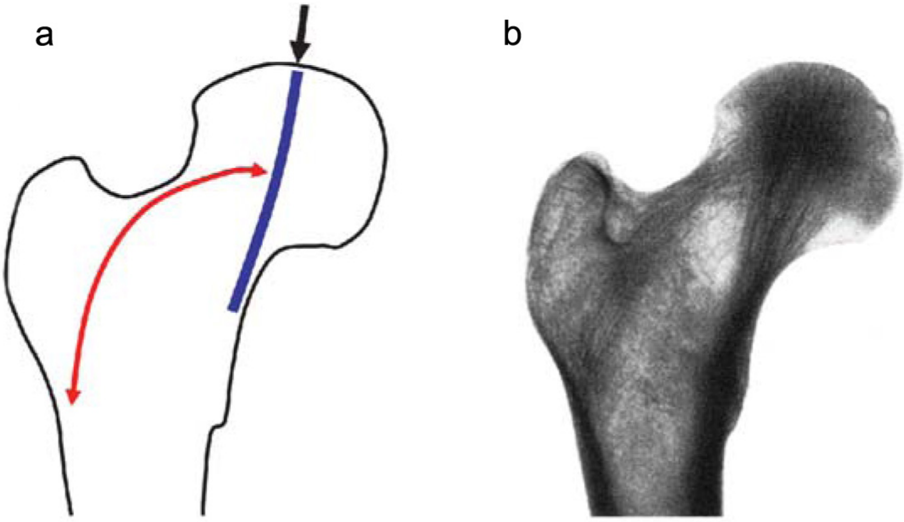


Figure 28. The customary forces on the femoral head from walking (arrows) cause stresses within the trabecular bone of the femoral neck (narrow section). In the normal hip, these stresses are mostly compressive in the inferior (bottom) region of the femoral neck and tensile in the superior (top) region. Trabecular struts are aligned with the principal stress directions and most densely spaced where the stresses are highest. The blue lines show primary compressive stress directions and the red bands depict tensile stresses. Figure and caption taken from Robling et al. (2006).

Herniation pits

The etiology of herniation pits is currently widely debated. From the analysis of the CT scan sample, herniation pits with cortical break are more frequent in females, who usually present more cribra. This could be in accordance with the hypotheses of Pit et al. (1982) and Daenen et al. (1997) about the etiology of these lesions as herniation of soft tissues through preexisting erosions or perforations of the reaction area surface (they explicitly refers to Allen's fossa/cribra). Unfortunately, it has not been possible to investigate the presence of cribra in the CT scan, but, on the other hand, on dry bones cortical perforations attributable to herniation pits have been found more frequently in males (in accordance with findings of Panzer et al., 2008; Laborie et al., 2011; Guo et al., 2013) and usually on plaque formations. Being plaque and cribra clearly spatially differentiated and being the (usually single) cortical break of herniation pit very different from cribra, the herniation of soft tissues through cribra it is unlikely. According to Leunig et al. (2005) and Panzer et al. (2010) these formations are more likely intra-osseous ganglia than synovial invaginations.

With the premise that:

- On dry bones it has been possible to observe only the herniation pits with cortical break and thus, without a radiological analysis, a substantial part of these lesions remains latent;
- Given the possible various nature of these lesions (as seen in the CT scan sample applying the method from Panzer et al., 2010), there could be different lesion-specific etiologies;
- Herniation pits on dry bones have been always seen in association with plaques;
- Many studies found strong association between these lesions and FAI (Ganz et al., 2003; Leunig et al., 2005; Pfirrmann et al., 2006), in particular the cam-type impingement (Panzer et al., 2008; Guo et al., 2013);
- Some studies documented the increase in size over time of these features in hyperactive subjects, such as ballerinas and joggers (Pitt et al., 1982; Crabbe et al., 1992);
- The frequency of these lesions seems to increase with age (Guo et al., 2013);

it is plausible that these cystic lesions represent a degenerative form of the head-neck junction due to a prolonged low impingement stress in mature subjects with less reactive bones or to an exaggerated level of activity in younger sportive subjects, leading *in extremis* to cortical erosion.

5.3 Additional annotations

To complete the description of the variability of the head-neck morphology, in two cases distinct osteophytic formations have been founded on the anterior aspect of the neck. They are comparable to the exostoses described by Fritz et al. (2010) that they suggested to be a reactive response of the femoral neck to linear contact with the acetabular rim (Figure 29).

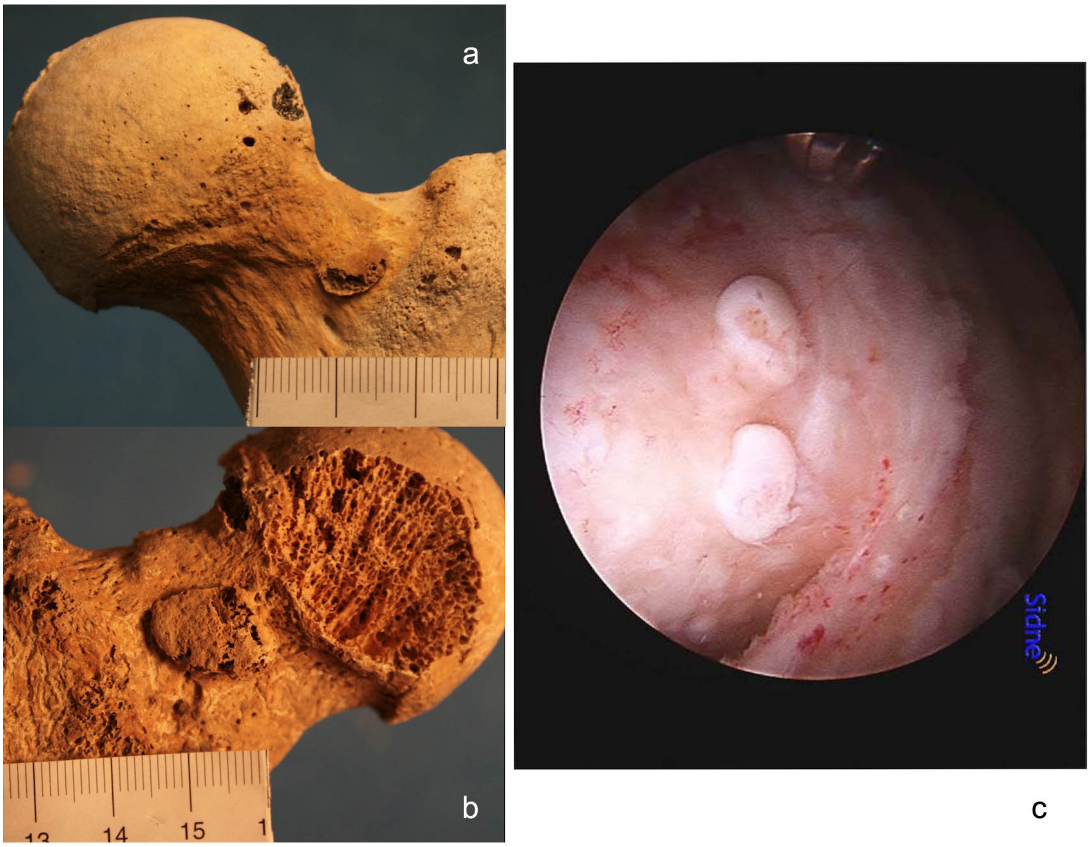


Figure 29. Exostoses on the neck of the femur of two adult females from Baldock sample (a) and from Wetwang slack sample (b); (c) exostoses described in Fritz et al. (2010).

As also noted by Ng & Ellis (2011b) and Rubin (2013), although it might predispose individuals to clinically symptomatic FAI and early degenerative joint disease, the development of cam morphology (that, as seen before, corresponds to Poirier's facet or plaque) is not necessarily a pathologic process in itself, but more likely represent a common set of variations. It is therefore not advisable to preventively surgically remove these formations ("bumpectomy") before the onset of symptoms, as it is commonly suggested today to prevent hip diseases (Lavigne et al., 2004; Pfirrmann et al., 2006; Leunig et al., 2009), also considering the absence of follow up studies over long time after surgery.

As seen in the introduction, some of the features of the junction are commonly used as functional markers related to specific activities. Villotte & Knüsel (2009), who relate the etiology of these features to FAI, considered possible to describe reliable occupational stress markers trough a multidisciplinary approach involving radiology, osteological macroscopic observation, dissections and FAI findings. As already noted in Radi et al. (2013), given the high and constant frequency of plaque in all the samples analyzed and considering the difficulty in even imagine a specific activity that could result in specific skeletal changes in the thigh (everybody walks), it is strongly not recommended the use of the features of the junction as skeletal markers of specific activity.

5.4 Future perspectives

In the scoring method used in this work and published in Radi et al. (2013) we tried to encompass as much morphological diversity of the proximal femur as possible. Anyway, given the high difficulty in forcing a continuous variability into qualitative categories, there is always a certain quote of diversity that remains latent. After the examination of more than 5000 femurs during this doctoral project, some future improvements to the method could be taken into account to enhance its sensitivity:

- To score the presence of "torus cervicalis" (Meyer, 1934) as described by Angel (1964), given its possible connection to the presence and morphology of Poirier's facet, plaque or cribra.
- To score the presence of slight lateral prominence of the head surface in the superior (and antero-superior) aspect of the head neck junction (the Poirier's facet probably intended by Angel) as a distinct formation. The term "superior Poirier's facet" could be suggested for this formation and the term "anterior Poirier's facet" for the Poirier's facet of this study (or in alternative, create two totally new terms to not generate further confusion in literature).
- To split form B of plaque in two sub-categories, one raised above the neck plane and one lying on the neck plane, in order to obtain a more accurate estimation of the frequency of raised forms, given their importance as cam-FAI indicators.
- To distinguish between cribra 2 with fossa (and score the presence/absence of its edge) and cribra 2 without it.
- To score the presence herniation pits.
- To score the presence of the "posterior femoral imprint" of Meyer (1924), (rarely noted during data collection of this study, but not scored), and more generally analyze also the variability of the posterior aspect of the femoral head neck junction.

- To score the presence of cribriform formations along the physeal line excluded in the present method (Figure 30).

Figure 30. Cribriform formation along the physeal line in a 56-year-old female from Coimbra sample.

In order to examine in depth the hypothesized connection of the morphology of the head-neck junction with the acquisition of bipedalism in humans, it would be very interesting to look for the presence of these (or similar) features in Apes and in fossil Hominidae.

Concerning herniation pits and more generally the cystic appearing lesions, it would be interesting to analyze them in the identified skeletal collections trough CT scan. For this purpose it would be absolutely necessary the presence of experienced radiologists. The main advantage of working on such material instead of living patients it is the availability of considerably more numerous samples comparing to medical studies: from samples like Sassari (circa 600 individuals) and Coimbra (circa 500 individuals) it could be possible to get a reliable estimation of the distribution of these lesions into human population.

Concerning femoroacetabular impingement issue, alpha angle (being the most used parameter to infer the presence of cam-type impingement) could be measured on the CT scan sample by an experienced radiologist, to confirm the correspondence between raised plaque and Poirier's facet and cam-FAI. 3D reconstruction is quite easy and fast and gives a general, all-inclusive view of the morphology of the joint (not just a single plane section). Recognizing the presence of a feature such as plaque or Poirier's facet is instantaneous compared to the several measurements usually taken by radiologist. It could therefore find a practical application in clinical diagnosis of impingement. It would also be very interesting to apply common radiological measurements to bones (as above, the main advantage in using bones is the big sample size) together with our method to go deeper into the causes of cam-type impingement morphology. Unfortunately, the only method existing to export these measurements on dry bones (Toogood et al., 2009; and some additional measurements in Unnanuntana et al., 2010) seems to be easily error-prone and has never been tested for error.

6. CONCLUSIONS

Important indications for both evolutionary and medical-anatomical interpretations emerged from the study of the various collections. The various osseous traits of the proximal femur are present at similar frequencies in skeletal samples from different countries and different historical periods, even if with clear local differentiation. Some of the feature examined show significant trends related to their distribution by gender and age.

Starting from the results obtained and from the most recent medical literature, some hypotheses are proposed about the etiology of these morphologies and their possible implication with the acquisition of bipedalism in Humans. It is therefore highlighted the possible relation of some of these traits with the development of disorders of the hip joint.

Finally, the use of any of these features as a specific activity-related marker is not recommended.

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9. APPENDIX

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"Variation of the Anterior Aspect of the Femoral Head-Neck Junction in a Modern Human Identified Skeletal Collection"

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Variation of the Anterior Aspect of the Femoral Head-Neck Junction in a Modern Human Identified Skeletal Collection

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ABSTRACT The effectiveness of the so-called skeletal markers of activity as functional indicators is widely debated. Among them, certain morphological features of the anterior aspect of the femoral head-neck junction (Poirier's facet, cervical fossa of Allen, etc.) have been considered in relation to some behaviors and specific activities (e.g., squatting, horseback riding, etc.). However, disagreement on terminology and descriptions, the absence of standardized scoring methods and poor knowledge of the variability and distribution of these features make it difficult to interpret their meaning. The aim of this study is to analyze the variability of the anterior aspect of the femoral neck through a new scoring method taking into account three main traits: Poirier's facet, plaque, and cribra (including the Allen's fossa). This method has been applied to a sample of 225 adult individuals of both sexes coming from an identified modern skeletal collection, achieving low intraobserver and interobserver error values. The results highlight some significant trends: plaque, almost always bilateral, appears to be a normal condition of the femur, being present in approximately 90% of the individuals. Cribra is more frequent in females and decreases with age. Poirier's facet shows a very low frequency. This method allows the representation of both the anatomical diversity of the region already described in literature and part of the variability never considered before. Our results suggest caution in considering these features as markers related to specific activities. Am J Phys Anthropol 152:261 272, 2013. © 2013 Wiley Periodicals, Inc.

The front aspect of the proximal femur shows great morphological variability in the head-neck junction region. The features of this area have long been interpreted as functional markers, also in relation to particular activities: squatting (Charles, 1893); the habit of lying on one's side when sleeping, with partial flexion and intrarotation of one or both thighs (Meyer, 1924, 1934); the degree of habitual flexion and abduction during normal locomotion (Trinkaus, 1975); full thigh extension as in running, or even walking downhill (Angel, 1964); and sitting cross-legged and horseback riding (Molleson and Blondiaux, 1994; Pálfi and Dutour, 1996; Larsen, 1999). However, the interpretation of these features remains obscure, with proposals of often contradictory functional hypotheses: pressure of the acetabular rim with the hip in flexion, capsular pull in both flexion and extension, or pressure exerted by the *m. iliopsoas* or by the *m. rectus femoris ten don* (Bertaux, 1891; Charles, 1893; Poirier and Charpy, 1911; Walmsley, 1915; Meyer, 1924; Odgers, 1931; Kostick, 1963; Angel, 1964; Trinkaus, 1975). More recently Villotte and Knüsel (2009) pointed out the usefulness of current medical studies on femoroacetabular impingement in achieving a better understanding of osseous non-metric traits of the femoral neck. This is a condition of repeated contact between the femoral head-neck junction and the acetabular rim: today, it is considered one of the major causes of osteoarthritis of the hip (Ito et al., 2001; Notzli et al., 2002; Ganz et al., 2003, 2008; Wagner et al., 2003; Beck et al., 2005; Beaule et al., 2007; Tannast et al., 2007; Leunig et al., 2009; Lequesne and Bellaiche, 2012).

Angel (1964) first referred to the anterior aspect of the femoral head-neck junction as the "reaction area of the femoral neck" ["…a raised scarlike bony plaque usually occurs or, rarely, a sizable hole in the cortical bone (cervical fossa of Allen). We are naming this the reaction area of the femoral neck"; Angel, 1964: 140]. Some surface markings in the reaction area were depicted in anatomical illustrations of the 19th century (Henle, 1855; Cruveilhier et al., 1862), without any mention of them

Additional Supporting Information may be found in the online version of this article.

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TABLE 1. Features examined, their definitions, and their scoring methods

Feature	Definition	Recording method
Poirier's facet	Lateral expansion of the anterior portion of the femoral head articular surface toward the anterior aspect of the femoral neck (Finnegan, 1978). The expansion surface is virtually smooth, on the same plane and in continuity with the articular surface of the head.	**0**. Absent. **1**. Present (Fig. 1C,D). **NR:** Not Recordable: either the femoral head physeal line is not completely fused, or more than 50% of the bone surface is damaged.
Plaque[a]	Imprint located on the anterior margin of the femoral neck close to the head. The plaque may be present in three shapes (form) and may be delimitated, even partly, by a distinct border (edge). In the case of presence, the form and edge should be scored as follows.	**0.** Absent. If the plaque area is completely covered by *cribra 2* (see below), score the plaque as Absent (Fig. 4B). **1.** Present. **NR:** Not Recordable: when more than 50% of the bone surface is damaged.
	Form	**A**. The plaque is on the same plane as the femoral head, but is perceptible as a distinct formation, due to its entirely rough surface, with respect to the head surface, which is smooth (Fig. 2A,B). **B**. The plaque lies on an intermediate plane between the femoral head surface and the neck surface (Fig. 2C,D). **C**. The plaque surface is entirely or in part lower than the femoral neck plane (Fig. 2E,F). **NR**. Not Recordable: the plaque is present, but the form cannot be assessed due to: (1) damaged surface; (2) extensive presence of cribra (see below).
	Edge	**0**. Absent. **1**. Bony rim protruding no more than 1 (Fig. 3A,B)[c]. **2**. Pronounced bony rim protruding more than 1 mm (Fig. 3C,D)[c]. **NR**. Not Recordable: when more than 50% of the edge is damaged.
Cribra	Cortical discontinuity in a circumscribed area on the anterior portion of the femoral neck, next to the head. Any porosity on the articular surface of the femoral head as well as on the physeal scar is not to be taken in account.	**0**. Absent. **1**. Clustered pores (diameter about 1mm or more) on the cortical surface (Fig. 4A). **2**. Cortical erosion with exposition of trabecules (Fig. 4B). The area of the erosion could be depressed (Fig. 6)[c]. **NR:** Not Recordable: when more than 50% of the bone surface is damaged.

[a] Note that in the present standard the term "plaque", taken from Finnegan (1978), does not refer to a new bone formation on the top of the existing surface.
[b] Sometimes true osteophytes may be present.
[c] This feature corresponds to the fossa of Allen as defined by Finnegan (1978).
N.B.: Poirier's facet, plaque and cribra can coexist on the same femur.

in the accompanying text. More and more detailed descriptions can be found in anatomical atlases between the end of the 19th century and the first three decades of the 20th century (Allen and Shakespeare, 1882; Fick, 1904; Poirier and Charpy, 1911; Testut, 1911), when the reaction area became the subject of numerous works (Bertaux, 1891; Charles, 1893; Evangeli-Tramond, 1894; Regnault, 1898; Frazer, 1906; Parsons, 1914; Walmsley, 1915; Pearson and Bell, 1919; Meyer, 1924, 1934; Odgers, 1931). However, the different features which may be present in this area are as yet far from being clearly described and classified, thus leading to a great deal of confusion in the existing literature (cf. Villotte and Knüsel, 2009). The difficulty inherent in making some order of the morphological variability characterizing this area is evident in the numerous terms used: cervical fossa (Allen and Shakespeare, 1882), *empreinte* (Bertaux, 1891), *empreinte iliaque* (Regnault, 1898; Poirier and Charpy, 1911), *Halsgelenkhöcker* (*eminentia articularis colli femoris*) (Fick, 1904), capsular groove, anterior eminence, pubic imprint (Walmsley, 1915), alpha, beta, and gamma facets (Pearson and Bell, 1919), and anterior acetabular imprint (Meyer, 1924). The descriptions reported by various authors also encompass a great deal of variability: rough, almost smooth, depressed, raised, in continuity with the articular surface of the head, distinct from the head, cribriform, etc. Some authors also described a bony ridge possibly surrounding or delimiting these morphologies: *bourrelet osseux* (Poirier and Charpy, 1911), capsular ridge (Walmsley, 1915), and cervical ridge (Meyer, 1934). Different terms were often used to refer to the same trait, or the same term was used to refer to different traits. Angel described the human femoral neck as "not cylindrical, as it is in apes,

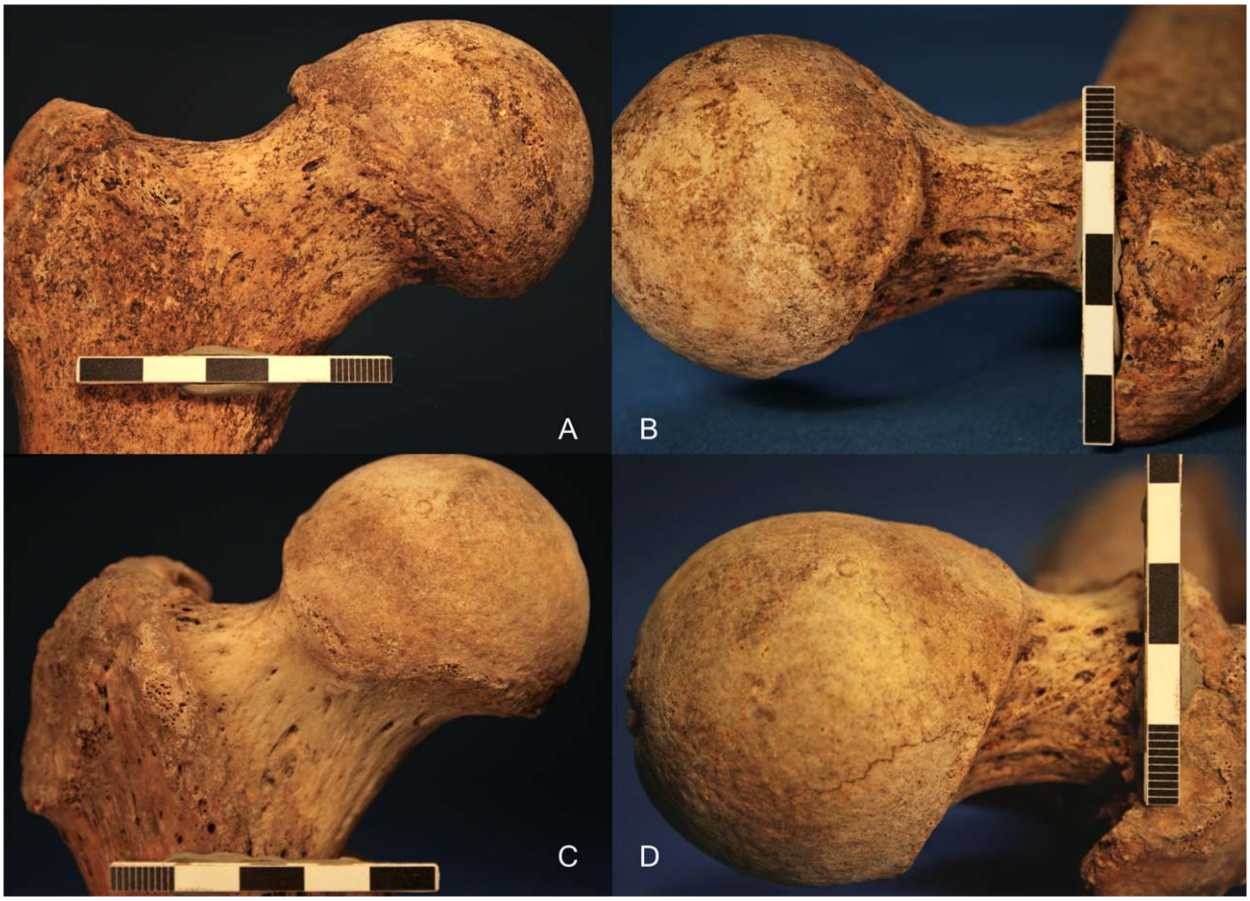

Fig. 1. **A**, **B**: Condition of absence of all the considered traits; Poirier's facet from anterior (**C**) and superior view (**D**). A,B: Spec imen Bologna 4 (male, age 74) and C and D: specimen Bologna 60 (male, age 66) from the Certosa cemetery collection housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

but has an oval cross section with a slightly angled protrusion in the antero-superior quadrant. This angle is formed by a low elevation or bar of bone, which runs medially from the upper anterior part of the greater trochanter over to the head of the femur [. . .] this is the last part of the neck to ossify, and [. . .] is formed largely from a medial nodule extending from the epiphysis of the greater trochanter, which joins the femur in later adolescence, at 14 through 18 years" (Angel, 1964: 130). Many authors before Angel described this bar of bone and called it by many names: *Verstärkungsleiste* (Sudeck, 1899), *eminentia articularis colli femoris* (Odgers, 1931; Schofield, 1959), *torus cervicalis* (Meyer, 1934), and cervical eminence (Kostick, 1963). The term "*eminentia articularis colli femoris,*" however, was used improperly to describe this epiphyseal formation, as it was created by Fick (1904) to designate the *empreinte iliaque* of Poirier, which created further confusion. Another origin of the existing chaos lies in the kinds of materials that have been used for these studies, being based on either dry or fresh bones or both.

In the second half of the 20th century, terms such as Poirier's facet, Allen's fossa, iliac imprint, and plaque became widely used (Schofield, 1959; Kostick, 1963; Angel, 1964; Trinkaus, 1975; Finnegan, 1978; Capasso et al., 1999; Donlon, 2000), but they remain ambiguous, making it difficult to compare the data of different researchers. In effect, Angel (1964) and Finnegan (1978) described the features of the reaction area quite unambiguously, but a great deal of variability remains outside of their classifications and there is no true scoring method. Starting from these works, we created a recording method based on the presence and morphology of three main traits: Poirier's facet, plaque (possibly surrounded by an edge), and cribra. This method makes it possible to represent both the anatomical diversity of the region already described in the literature and a previously disregarded portion of variability, while at the same time providing unambiguous definitions of the non-metric traits of the anterior aspect of the proximal femur. The variability and distribution of the observed features have been investigated in a modern identified skeletal collection from the Certosa cemetery in Bologna (Italy). The distribution by sex and age of these features, not adequately investigated until now, is crucial for any interpretative consideration.

MATERIALS AND METHODS

Sample

This study was performed on the identified skeletal collection (with known age, sex, profession, and cause of death) from the Certosa cemetery in Bologna (Italy), housed at the Museum of Anthropology of the University

Fig. 2. Plaque forms: form A from anterior (**A**) and superior view (**B**), form B from anterior (**C**) and superior view (**D**), and form C from anterior (**E**) and superior view (**F**). Plaque (P), head (H), and neck (N) planes are highlighted by lines. A, B: specimen Bolo gna 63 (male, age 69), C, D: specimen Bologna 166 (male, age 60), and E, F: specimen Bologna 104 (male, age 26) from the Certosa cemetery collection housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

of Bologna. Assembled by Prof. F. Frassetto and Prof. E. Graffi Benassi, it is made up of 296 adolescent and adult skeletons of both sexes who died during the first half of the 20th century (Rastelli, 2005; Facchini et al., 2006; Belcastro and Mariotti, 2012). The sample group used in this study consisted of 225 adult individuals (M 124, F 101), broken down into three age groups (young adults, YA: 20 34 years: 33 males and 33 females; mature adults, MA: 35 49 years: 22 males and 22 females; old adults, OA: $\geq$ 50 years: 69 males and 46 females; Buikstra and Ubelaker, 1994). Individuals showing clear pathological conditions or poor states of preservation were excluded from our sample group.

Recording method

The examined features, their definitions, and the proposed recording standards are shown in Table 1. All the features are shown in Figures 1 4. Figure 1A,B shows the very rare condition of absence of all the considered

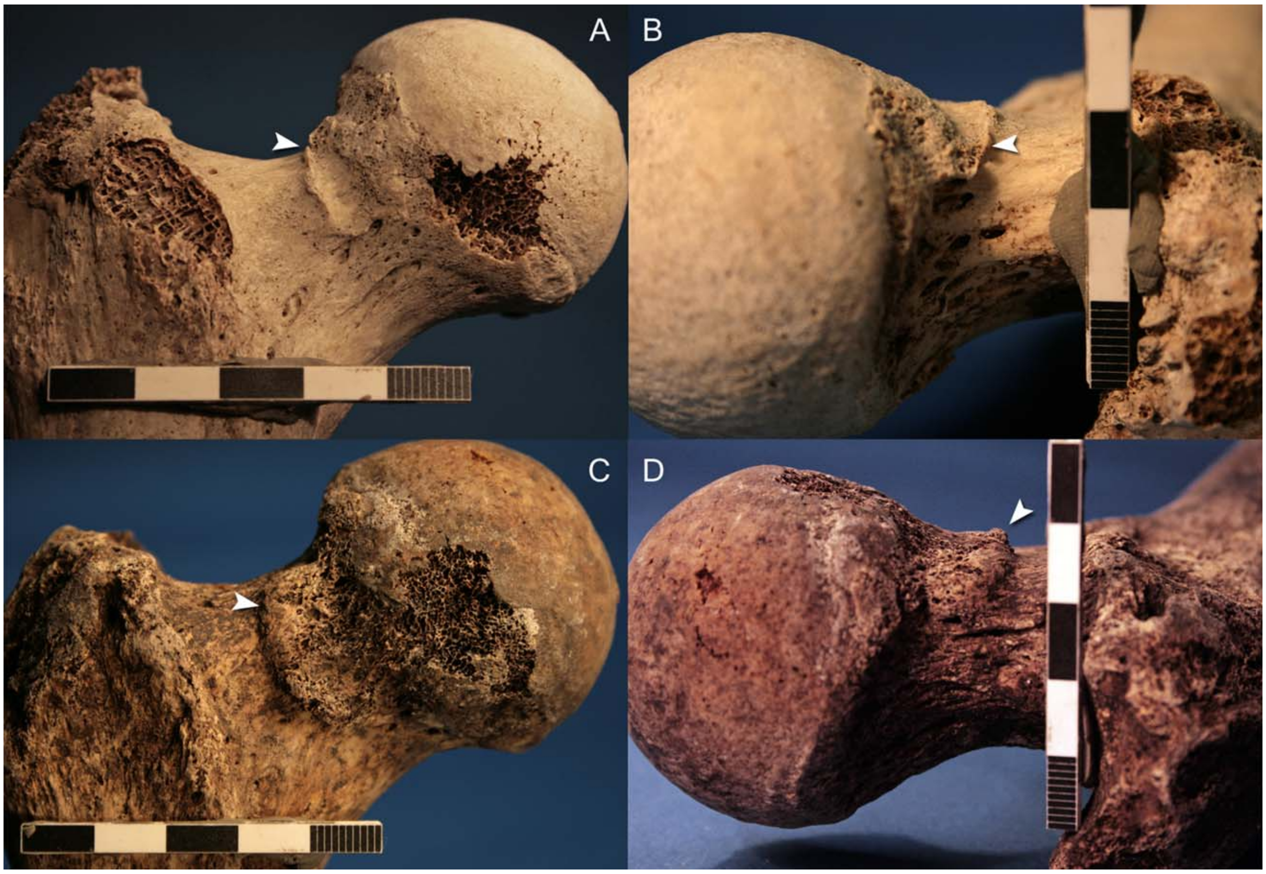

Fig. 3. Plaque edge: edge of degree 1 from anterior (**A**) and superior view (**B**), edge of degree 2 from anterior (**C**), and superior view (**D**). A, B: specimen Bologna 120 (female, age 56) and C, D: specimen Bologna 109 (female, age 59) from the Certosa cemetery collection housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Fig. 4. Cribra from anterior view: form 1 (**A**), form 2 (**B**). A: Specimen Bologna 17 (male, age 44) and B: specimen Bologna 148 (male, age 31) from the Certosa cemetery collection housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

traits. An example of a recording sheet is presented as Supporting Information (Recording Sheet SuppInfo.xlsx).

Three-dimensional models of Poirier's facet, plaque, and edge were obtained using a surface laser scanner with a resolution of 0.1 mm (the posterior aspect of the proximal femur was not scanned). Surface scans were performed using a 650 nm red line laser (optical output power 5mW) and a high-resolution camera (CCD monochrome camera with 1024 × 768 resolution, sensitivity of 0.5 l× at 1/15 s, gain 20 dB, 30 frame rate with focal

TABLE 2. Intraobserver and interobserver percent (%) error

		Intraobserver			
Features	Merged categories	Observer 1 (%)	Observer 2 (%)	Average (%)	Interobserver (%)
Poirier's facet		0.0	1.7	0.9	1.7
Plaque		0.0	3.4	1.7	6.7
Cribra		5.0	5.0	5.0	3.3
Plaque form		11.7	19.3	15.5	13.6
Plaque edge		13.3	25.0	19.2	27.6
Plaque form	A + B	11.7	19.3	15.5	13.6
	B + C	0.0	3.5	1.8	6.8
Plaque edge	0+1	3.3	1.8	2.6	8.6
	1+2	10.0	23.2	16.6	19.0

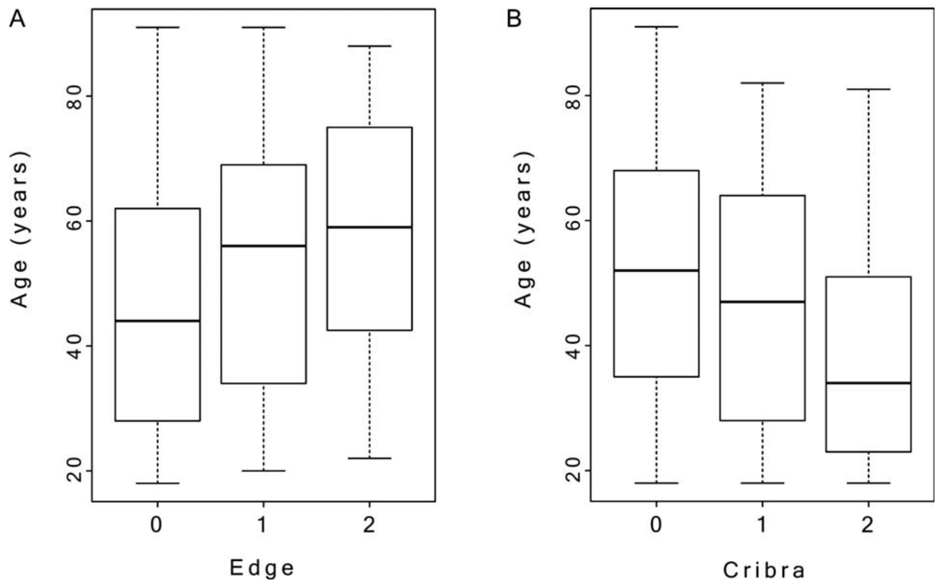

Fig. 5. Correlation between plaque edge and age (**A**) and between cribra and age (**B**).

length of the lens of 6 mm). 3D models provide a better visualization than "flat" photographs and can be more useful in recording the features. 3D models can be found as Supporting Information (Zero SuppInfo.pdf; Poirier's Facet SuppInfo.pdf; Form A SuppInfo.pdf; Form B SuppInfo.pdf; Form C SuppInfo.pdf; Edge 1 SuppInfo.pdf; Edge 2 SuppInfo.pdf).

Statistical analyses

To test the validity of our method, we calculated intraobserver and interobserver error for each feature. A sample group of 30 randomly selected adults (15 for each sex; 60 femurs) was used to perform the test. Two observers (NR and AR) collected the data in two independent scoring sessions each. Intraobserver and interobserver errors were calculated as the percentage of mismatching between the two sets of data (no. of cells with different content × 100/total no. of cells). For the interobserver error the results of the first scoring session of both observers were used. Cohen's kappa test was also performed. The judgment for the estimated kappa about the extent of agreement was given following Landis and Koch (1977): $k < 0$ "No agreement," $k < 0.2$ "Slight agreement," $0.21 < k < 0.4$ "Fair agreement," $0.41 < k < 0.6$ "Moderate agreement," $0.61 < k < 0.8$, "Substantial agreement," $0.81 < k < 1.0$, "Almost perfect agreement," k 1 "Perfect agreement."

Absolute and percent frequencies were calculated for each side, sex, and age class. Differences in sex and age distribution of the features were assessed by Pearson's chi-squared test. McNemar's chi-squared test was performed to test side differences in presence/absence of the features and Wilcoxon signed-rank test was used to test side differences in the distribution of the different form of the features. A Kendall's tau (τ) rank correlation coefficient and relative *P*-values were calculated to test the correlation between edge and age (in years) and between cribra and age (in years). Statistical significance was inferred when the *P*-value was 0.05. Data were processed using the open source statistical package software R (R Core Team, 2012).

RESULTS

Intraobserver and interobserver percent errors were calculated for each trait (Table 2). The percentage of error varies consistently among the features. Very low percent errors, well below 2%, were obtained for Poirier's facet, both intraobserver and interobserver. Plaque and cribra also gave satisfactory results, with values equal to or below 5%, except in the case of the

Fig. 6. Co occurrence of plaque form B (1) and cribra 2 (2). Usually cribra are located in the inferior portion of the affected area. Specimen 1577 from Hereford Cathedral, Herefordshire, UK, housed within the BARC collections of the University of Bradford, Bradford, West Yorkshire, UK. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 3. Cohen's kappa test for intraobserver and interob server agreement

	Feature	k	Judgment
Intra Obs. 1	Poirier's facet	1.00	Perfect agreement
	Plaque	1.00	Perfect agreement
	Cribra	0.90	Almost perfect agreement
	Plaque form	0.77	Substantial agreement
	Plaque edge	0.75	Substantial agreement
Intra Obs. 2	Poirier's facet	0.74	Substantial agreement
	Plaque	0.58	Moderate agreement
	Cribra	0.90	Almost perfect agreement
	Plaque form	0.65	Substantial agreement
	Plaque edge	0.54	Moderate agreement
Inter	Poirier's facet	0.85	Almost perfect agreement
	Plaque	0.25	Fair agreement
	Cribra	0.93	Almost perfect agreement
	Plaque form	0.71	Substantial agreement
	Plaque edge	0.49	Moderate agreement

interobserver value for plaque, which was 6.7%. The greatest errors concerned plaque form and edge. A substantial reduction in both intraobserver and interobserver errors for form may be achieved considering form B and C together. Edge error decreases when considering only the presence/absence of the feature, by merging degrees 1 and 2, while we obtained a dramatic reduction by merging degrees 0 + 1. The Cohen's kappa test results substantially confirm the percent error results (Table 3). However, due to the nature and the structure of the data it could lead to misleading results, as in the case of interobserver error for plaque (where an error of 4/60 gives a k of 0.25).

Absolute and percent frequencies (presence/absence only) of each feature analyzed are shown in Table 4. Poirier's facet displays very low frequencies (five cases), thus making it impossible to perform any further statistical analysis; therefore, it will not be shown in the next tables. Plaque is present in 87% of the subjects, and in 73% of cases is bilateral. Cribra is present in 46% of the samples, with higher frequencies in females, and is bilateral in 27%. No significant difference in frequency (presence/absence) and distribution (considering the different degrees or morphologies) was found between sides for all the features considered, either in males or in females. The only exception is represented by the occurrence of plaque forms in males, with form B more frequent on the left side and form C more frequent on the right side (form B: L 44%, R 37%; form C: L 29%, R 42%; *P*-value 0.018). Differences in frequency distribution among age classes were investigated for all the features considered. No significant differences emerged for plaque in both sides, in either males or females, or in the overall sample either, while considering both the forms and the presence/absence (see Supporting Information Table 1). As for edge and cribra, their results are shown in Tables 5 (edge) and 6 (cribra). In general, the frequencies of edge increase with age (Fig. 5A), displaying significant *P*-values on the right side in the overall sample. Cribra frequencies tend to diminish with age (Fig. 5B), showing significant p-values in the overall sample both left and right, and in right males' presence-absence. These trends are highlighted by the Kendall's tau correlation test (Table 7). Tau values, even if rather low, are always positive for edge and negative for cribra; in many cases there is a significant correlation. Differences between sexes for plaque form, plaque edge, and cribra and corresponding Chi square *P*-values are shown in Table 8. There is no significant difference in plaque form. Form A shows low frequencies in both sexes; form B is higher in males and form C is higher in females. Plaque edge shows higher frequencies in males, with significant p-values on the left side. Cribra shows significantly higher frequencies in females, mainly due to cribra 2. Finally, it is important to note that the three main features can coexist on the same bone, in particular plaque and cribra (Table 9 and Figs. 6 8).

DISCUSSION

Our recording method for the morphological variability of the reaction area of the femoral neck produces low overall intraobserver and interobserver errors. These errors are rather high for form and edge. However, it should be noted that the values of observer one, the most experienced observer, are consistently lower than those of observer two, not exceeding 14%. This demonstrates the importance of appropriate training, together with the use of a recording standard. We consider errors below 15% acceptable, in view of the fact that we are forcing a continuous variability into qualitative categories (Mariotti et al., 2007). It must be noted that both errors drop dramatically (intraobserver below four percent; interobserver below nine percent) with merging form B and C and edge 0 and 1. Merging different categories can be a useful way to detect where most of the error lies. In this case considering form B and C together, we notice a substantial reduction of the error. Confusion between these two forms is due to the presence of borderline cases, not very elevated or not very depressed with respect to the neck plane. Merging edge degrees 0 + 1 permits us to highlight the difficulty in detecting the faint presence of the feature, while there is substantial agreement in scoring the edge when it is more developed (degree 2). Thus, only in absence of adequate training, we suggest scoring both plaque and

TABLE 4. Absolute (n) and percentage (%) frequencies of each feature considering bilateral/unilateral (R only, L only) presence and presence on right and left femurs (N sample size)

			Bilateral		R only		L only		All		Right			Left		
Sex	Feature	*N*	*n*	%	*n*	%	*n*	%	*n*	%	*N*	*n*	%	*N*	*n*	%
All	Poirier's facet	192	3	2	2	1	0	0	5	3	207	5	2	206	3	1
	Plaque	183	133	73	16	9	11	6	160	87	203	167	82	199	153	77
	Cribra	186	51	27	20	11	15	8	86	46	204	76	37	194	69	36
Males	Poirier's facet	102	2	2	2	2	0	0	4	4	112	4	4	113	2	2
	Plaque	100	76	76	8	8	4	4	88	88	112	94	84	110	86	78
	Cribra	93	16	17	10	11	10	11	36	39	107	30	28	101	29	29
Females	Poirier's facet	90	1	1	0	0	0	0	1	1	95	1	1	93	1	1
	Plaque	83	57	69	8	10	7	8	72	87	91	73	80	89	67	75
	Cribra	93	35	38	10	11	5	5	50	54	97	46	47	93	40	43

TABLE 5. Differences in absolute (n) and percentage (%) frequencies of plaque edge among age classes and relative Chi square test P values

				0		1		2			Presence		
Side	Sex	Age	*N*	*n*	%	*n*	%	*n*	%	χ^2 *P* value	*n*	%	χ^2 *P* value
Right	All	YA	61	43	70	15	25	3	5	0.028	18	30	0.023
		MA	40	29	72	5	12	6	15		11	28	
		OA	106	56	53	34	32	16	15		50	47	
	Males	YA	29	19	66	8	28	2	7	0.169	10	34	0.091
		MA	18	13	72	2	11	3	17		5	28	
		OA	63	30	48	22	35	11	17		33	52	
	Females	YA	32	24	75	7	22	1	3	0.407	8	25	0.355
		MA	22	16	73	3	14	3	14		6	27	
		OA	43	26	60	12	28	5	12		17	40	
Left	All	YA	57	44	77	12	21	1	2	0.080	13	23	0.070
		MA	41	29	71	7	17	5	12		12	29	
		OA	102	61	60	28	27	13	13		41	40	
	Males	YA	24	18	75	6	25	0	0	0.225	6	25	0.216
		MA	20	11	55	6	30	3	15		9	45	
		OA	60	33	55	16	27	11	18		27	45	
	Females	YA	33	26	79	6	18	1	3	0.205	7	21	
		MA	21	18	86	1	5	2	10		3	14	0.213
		OA	42	28	67	12	29	2	5		14	33	

Fig. 7. Co occurrence of plaque form C (1) and cribra 2 (2). Specimen Bologna 21 (female, age 75) from the Certosa cemetery collection housed at the Museum of Anthropology of the University of Bologna, Bologna, Italy. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

Fig. 8. Co occurrence of plaque form C (1) and cribra 2 (2). Note that the two features are not clearly delimited, but cribra are located in the inferior portion of the area. Specimen 1610 from Hereford Cathedral, Herefordshire, UK, housed within the BARC collections of the University of Bradford, Bradford, West Yorkshire, UK. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

TABLE 7. Kendall's tau test: correlation with age (in years) of plaque edge and cribra

Feature	Side	Sex	*N*	τ	*P* value
Plaque edge	Right	All	207	0.132	0.017
		Males	110	0.143	0.060
		Females	97	0.114	0.166
	Left	All	200	0.167	0.003
		Males	104	0.175	0.025
		Females	96	0.125	0.135
Cribra	Right	All	204	−0.192	0.001
		Males	107	−0.241	2E 03
		Females	97	−0.153	0.057
	Left	All	194	−0.174	0.002
		Males	101	−0.150	0.061
		Females	93	−0.187	0.024

edge as presence/absence. In the case of edge, it is advisable to consider the feature as present only when clearly demarcated.

Poirier's facet is very rare and appears to be an occasional finding. Plaque seems to characterize the normal condition of the femur, being present in around 90% of the subjects and basically almost always bilaterally. This suggests caution in considering these features as a specific activity marker, such as for instance in the case of the so-called "horseback riding syndrome" (Molleson and Blondiaux, 1994; Pálfi and Dutour, 1996; Larsen, 1999) or squatting (Charles, 1893) and also might suggest a possible adaptive value in relation to the human locomotory pattern. Other physiological and developmental factors must also be considered. The side difference in the distribution of plaque form in males suggests that mechanical loading could play a role. The analysis of a wider sample, currently in progress, consisting of two identified skeletal collections (Sardinians, University of Bologna, Italy, approximately 600 individuals; Coimbra Identified Skeletal Collection, University of Coimbra, Portugal, ~500 individuals) with known occupation will allow testing of this hypothesis.

The rather high frequency of the raised forms of plaque (form A and B, present in around 40% of the subjects (see Supporting Information Table 2), is interesting in light of recent works on cam-type impingement (Ito et al., 2001; Notzli et al., 2002; Ganz et al., 2003; Beck et al., 2005; Cobb et al., 2010). This type of impingement is due to an altered contour of the femoral head-neck junction resulting from an increased anterior radius of the head. This condition, observed by the researchers on living patients, could very likely correspond to either Poirier's facet or the raised forms of plaque (A and B) as described here on dry bone (cf. also Siebenrock et al., 2004; Villotte and Knüsel, 2009; Fritz et al., 2010). A better understanding of these features, besides providing useful information on the possible functional meanings, could also make a substantial contribution to current medical research on femoroacetabular impingement.

The edge surrounding plaque increases with age, as already noted by Meyer (1924), especially in males. This trend is common for other osteo-productive features at

TABLE 6. Differences in absolute (n) and percentage (%) frequencies of cribra among age classes and relative Chi square test P values

				0		1		2			Presence		
Side	Sex	Age	*N*	*n*	%	*n*	%	*n*	%	$\chi^2_{P\ \text{value}}$	*n*	%	$\chi^2_{P\ \text{value}}$
Right	All	YA	62	32	52	11	18	19	31	0.048	30	48	0.047
		MA	40	24	60	8	20	8	20		16	40	
		OA	102	72	71	18	18	12	12		30	29	
	Males	YA	29	18	62	6	21	5	17	0.077	11	38	0.037
		MA	18	10	56	5	28	3	17		8	44	
		OA	60	49	82	9	15	2	3		11	18	
	Females	YA	33	14	42	5	15	14	42	0.344	19	58	0.283
		MA	22	14	64	3	14	5	23		8	36	
		OA	42	23	55	9	21	10	24		19	45	
Left	All	YA	57	28	49	10	18	19	33	0.042	29	51	0.016
		MA	40	28	70	3	8	9	22		12	30	
		OA	97	69	71	13	13	15	15		28	29	
	Males	YA	24	14	58	4	17	6	25	0.427	10	42	0.271
		MA	19	14	74	1	5	4	21		5	26	
		OA	58	44	76	7	12	7	12		14	24	
	Females	YA	33	14	42	6	18	13	39	0.286	19	58	0.107
		MA	21	14	67	2	10	5	24		7	33	
		OA	39	25	64	6	15	8	21		14	36	

TABLE 8. Differences between sexes for plaque form, plaque edge, and cribra and corresponding Chi square P values

				0		A		B		C			Presence		
Feature	Side	Sex	*N*	*n*	%	*n*	%	*n*	%	*n*	%	$\chi^2_{P\ value}$	*n*	%	$\chi^2_{P\ value}$
Plaque form	Right	F	91	18	20	4	4	23	25	46	51	0.227	73	80	0.491
		M	112	18	16	6	5	43	38	45	40		94	84	
	Left	F	89	22	25	4	4	25	28	38	43	0.197	67	75	0.629
		M	110	24	22	7	6	45	41	34	31		86	78	
				0		1		2					Presence		
Feature	Side	Sex	*N*	*n*	%	*n*	%	*n*	%			$\chi^2_{P\ value}$	*n*	%	$\chi^2_{P\ value}$
Plaque edge	Right	F	97	66	68	22	23	9	9			0.209	31	32	0.084
		M	110	62	56	32	29	16	15				48	44	
	Left	F	96	72	75	19	20	5	5			0.040	24	25	0.021
		M	104	62	60	28	27	14	13				42	40	
				0		1		2					Presence		
Feature	Side	Sex	*N*	*n*	%	*n*	%	*n*	%			$\chi^2_{P\ value}$	*n*	%	$\chi^2_{P\ value}$
Cribra	Right	F	97	51	53	17	18	29	30			0.001	46	47	0.004
		M	107	77	72	20	19	10	9				30	28	
	Left	F	93	53	57	14	15	26	28			0.100	40	43	0.038
		M	101	72	71	12	12	17	17				29	29	

TABLE 9. Co occurrence of plaque and cribra: absolute (n) and percentage (%) frequencies of each feature considering bilateral/unilateral (R only, L only) presence and presence on right and left side (N sample size, individuals with both side scored)

		Bilateral		L only		R only		Total		L		R	
	N	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
All	170	28	16.5	14	8.2	20	11.8	62	36.5	42	24.7	48	28.2
M	88	10	11.4	6	6.8	10	11.4	26	29.5	16	18.2	20	22.7
F	82	18	22.0	8	9.8	10	12.2	36	43.9	26	31.7	28	34.1

entheses and joints (cf. Rogers and Waldron, 1995; Robb, 1998; Jurmain, 1999; Ortner, 2003; Weiss, 2003, 2004, 2007; Mariotti et al., 2004, 2007; Buikstra and Beck, 2006; Cardoso and Henderson, 2010; Villotte et al., 2010; Niinimäki, 2011; Milella et al., 2012). Cribra is more frequent in females and decreases with age, confirming the findings of Angel (1964) on Allen's fossa. Other kinds of osteolytic lesions, namely at entheses, have been found more frequently in young subjects (Mann and Murphy, 1990; Mariotti et al., 2004; Milella et al., 2012).

CONCLUSIONS

In the framework of the debate about the methodological and interpretative problems related to the so-called skeletal markers of activity (cf. International Journal of Osteoarchaeology, Volume 8, Issue 5, 1998; Jurmain, 1999; Jurmain et al., 2012; Henderson et al., 2013), we focused on the reaction area of the femoral neck, first addressing the methodological issue. We developed a standardized scoring method for describing the morphological variability of this area, starting from an in-depth review of the anatomical literature produced so far. Intraobserver and interobserver errors suggest that our method is reliable and permits a clear recognition of Poirier's facet, plaque, and cribra, whose definitions were quite confused in the previous literature. As regards plaque form and edge, the results of error highlight the importance of the experience of the observer. Taking into account that these features show sex and age variation, we recommend adequate training before applying this standard instead of merging categories with consequent loss of information.

Our results on sex and age distribution of the features observed suggest caution in using them as specific activity-related markers. This method has been applied in the study of other identified skeletal collections (Sardinians, University of Bologna, Italy, ~600 individuals; Coimbra Identified Skeletal Collection, University of Coimbra, Portugal, ~500 individuals) as well as in various osteoarchaeological series, and data analysis is currently in progress. It will be interesting to see if these new data will validate the results that we obtained on the sample from the Certosa cemetery of Bologna.

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