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Variation in cross-sectional cortical thickness in femora of documented age at death from Schoten (Belgium)

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Summary

Aim. To examine variation in femoral neck and cross-sectional cortical thickness in relation to age at death.

Material. Documented skeletons from the Schoten Collection in the Royal Belgium Institute of Natural Sciences (RBINS), Brussels.

Methods. Assessment of trabeculae phases of femur neck, measurement of mid-shaft cross-sectional cortex on standard radiographs of the femur, and trace element analysis of ribs.

Results. Despite a general increase in trabecular phase the majority, even the very old, remained in Phase II; half of those aged over 70 scored Phase III or IV; Phases V and VI were not recorded in the final analysis. Differences in cross-sectional diameters of the cortex identified thinner anterior cortex and an increase in medio-lateral medulla width in a proportion of women aged over 65 years.

Conclusions. Femur neck trabeculae and cross-sectional cortex change are attributed to cumulative effects of habitual bone loading but can be exacerbated by chronic pathology. Trabecular degeneration of the femur neck is attenuated in older people of Schoten compared to the reference of Acsádi & Nemeskéri (1970). Cross-sectional cortical thinning of the femur mid-shaft identified only in a few old females can be attributed to chronic pathology.

Keywords: Bone ageing, cortex, femur, gait, radiography, Schoten, Spitalfields.

1. INTRODUCTION

The continuing need to study the correlates of age-related effects of bone remodeling and thinning has turned our attention to the small collection of known age individuals from the well documented skeletal sample derived from Schoten, a village in the outer suburbs of Antwerp, Belgium. It is already clear that not all populations show the same age-related bone changes in terms of incidence or degree (MASSET, 1973; STEVENSON *et al.*, 1989). These differences seem to be particularly apparent when skeletons of known age at death from past populations, such as Spitalfields, is examined (LEES *et al.*, 1993). The opportunity to compare Spitalfields with another partly contemporary sample that might highlight differences and similarities could help identify some of the underlying processes. Pearson and Lieberman (2004) showed that when bones function as beams they model to resist bending, twisting and compression. The cross-sectional geometry of long-bones should be a good indicator of the influential mechanical forces and a reasonable reflection of habitual activities (PEARSON & LIEBERMAN, 2004: 81, 168). Bone mineral density is less useful than measures of cross-sectional geometry, although they warn that cross-sectional properties do not necessarily provide reliable data on the orientations of loads to which bones are subjected. At least the changing orientation of load-bearing with long-term ageing could be documented.

The aim of this study was to compare the osteological status of those men and women of Schoten who were aged over 65 years at death, the 'survivors', with those who had died at younger ages. The resulting sub-sample of 27 individuals (14 females, 13 males) against 24 aged under 65 years (10 females and 14 males) while being much too small for such an analysis could hint at the potential for such studies. They can be considered much as are case studies in establishing pathological syndromes. The findings of a normal radiographic study of the femur are presented here.

2. MATERIAL

The Schoten Collection of 51 human skeletons comprises 27 adult males and 24 adult females who had died in 1931 (four in 1930) and who had been buried in the former cemetery at Schoten (ORBAN *et al.*, 2011). The last burial in the old cemetery took place on 24th June 1931, after which there were burials only in family plots. A new cemetery became operational from 29th June 1931. In 1952 the old cemetery was excavated (CHABOT & CAMP, 2000) and the remains were donated to Professor Twiesselmann, Anthropology and Prehistory Section of the Royal Belgium Institute of Natural Sciences (RBINS) under existing Belgian legislation. The context of the acquisition of the Collection by the RBINS and social background of the people of Schoten have been fully described by Rosine Orban, Jennifer Eldridge and Caroline Polet (ORBAN *et al.*, 2011).

During 1931 there had been 137 deaths in Schoten of which possibly 68 died in the first half of the year. Consequently, the 51 skeletons in the collection could represent 75% of all those who had died in the first half of the year. The number of deaths is compatible with a natural mortality in a cohort of about 5500 and explains the age distribution of the sample.

Year of birth, sex and place of birth, but not the names, of each individual are documented. Most of the adults, born between 1837 and 1912, are aged over 50 years. The age distribution for females is skewed, nearly half were in their eighties at the time of death; the ages of the males are more evenly distributed (average age: males 55; females 78). The age at death distribution reveals a lack of females between 61 and 67

Fig. 1 – Age at death distribution of females and males of Schoten in 1931-2.

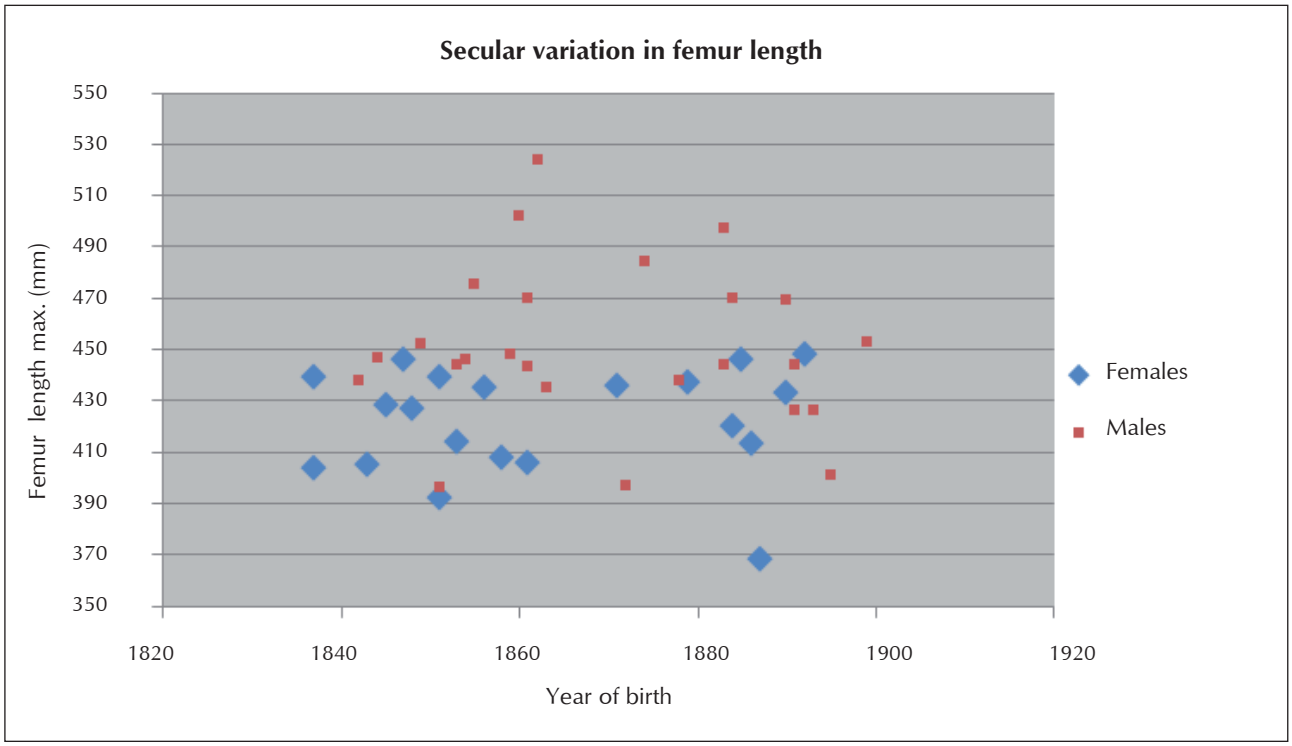


Fig. 2 – Secular variation in femur length (in mm) of Schoten females and males. Data from RBINS archive.

inclusive and of males between 60 and 67 inclusive (Fig. 1); it seems to reflect a dearth of births in the 1860s (Fig. 2). The archive, which is housed in the RBINS, includes a data sheet recording each skeleton and all major anthropological measurements for each bone (ORBAN *et al.*, 2002). Each bone has a unique number that is written on the bone, together with the tomb number and collection number. Storage is by anatomical part, all skulls together, all femora together etc., in large wooden drawers, with fitted glass topped lids (ORBAN *et al.*, 2011).

The environment of Schoten in the 100 years between 1830 and 1931 passed from a purely agricultural to a mixed agricultural and industrial economy; since 1950 it has become a comfortable suburb of Antwerp. The population also increased from about 1400 in 1830 to over 13000 in 1931 and by 1937 had reached more than 15000. In 1906 when the population was 4256 in 823 households, 1646 people were recorded as illiterate (ORBAN *et al.*, 2011: 28).

Jennifer Eldridge in her thesis presented a major overview of the quality of life and changing environmental conditions of the inhabitants of Schoten over the hundred years encompassed by the sample (ELDRIDGE, 2006-2007). Dates of birth, death and residency of 40 of the 51 individuals in the skeletal sample were verified (ELDRIDGE, 2006-2007; ORBAN *et al.*, 2011). Further, environmental aspects of economy, climate, pollution, nutrition and disease through the years of the XIXth and XXth centuries were documented. Only a few occupations were identified in the registers, and very often these were non-specific as to precise activity[1]. Women,

1 Task related activity markers: repeated and restricted performance of movements initiated while the individual was still growing can result in strongly developed entheses of muscle attachments and modification of the bone morphology; enthesopathies and localized osteoarthroses, sequels to accidental trauma, can occasionally be tentatively associated with specific occupations. The Docker (758) described by Orban *et al.* (2011) would be such a case. The pronounced unciform processes of the cervical vertebrae stabilizing the neck in response to carrying loads on the head and neck as a youngster; the severe arthroses of the vertebrae would be subsequent to accidents that impacted the neck.

described as "sans occupation", can be interpreted as undertaking the generalized range of activities of a housewife.

3. METHODS

The skulls were surveyed for notable anomalies, pathologies and completeness of dentition that might have a bearing on the radiographic geometry of the femur mid-shaft cortex. The ribs of all individuals were examined, and where appropriate one was selected for trace element analyses. No sample was taken if only two or three fragments survived (tombs 684, 688, 736, 746, 747) or where all ribs were intact (726). Non-metric traits of the pelvis were scored, including scars attributed to parturition. The size of the sciatic notch, presence or absence of a sacral facet and relative lengths of the cranial and caudal limbs of the sacro-iliac articulation were noted on left and right sides of both females and males; also the presence of a sulcus, pits of Houghton and the size of an inguinal tubercle (HOUGHTON, 1974).

3.1. Radiography

The left femora were selected for radiography to record the cortical thickness in standardized anterior-posterior, femoral head and neck horizontal, and medio-lateral, head and neck vertical, views. Radiographs of the femur head and proximal shaft were made directly (without Potter Bucky) on clinical film by Prof. Stéphane Louryan and the team of radiographers at the Erasmus Hospital of Brussels in two sessions: April and December 2003. The femur of one female, a girl of 15, was not available for radiography.

Preservation and superficial damage to the left femur was noted for the bearing this might have on reading the radiographic image. In general, the skeletons are well preserved and very complete. The bones have been treated with a varnish, probably several times. Precise identification of the coating has not been possible and it is quite resistant to removal. In the past most conservators made up their own formulae, probably based on resin and alcohol.

The radiographs were viewed on an illuminated box; peripheral light was shielded with black paper; a digital caliper was used to make the measurements. Radiographs of the anterior-posterior (a-p) view were marked just distal to the mid-point of the shaft, calculated from the total length of the dry bone. The dimensions of the medio-lateral diameter of the shaft, medial, and lateral cortical thickness and medulla were

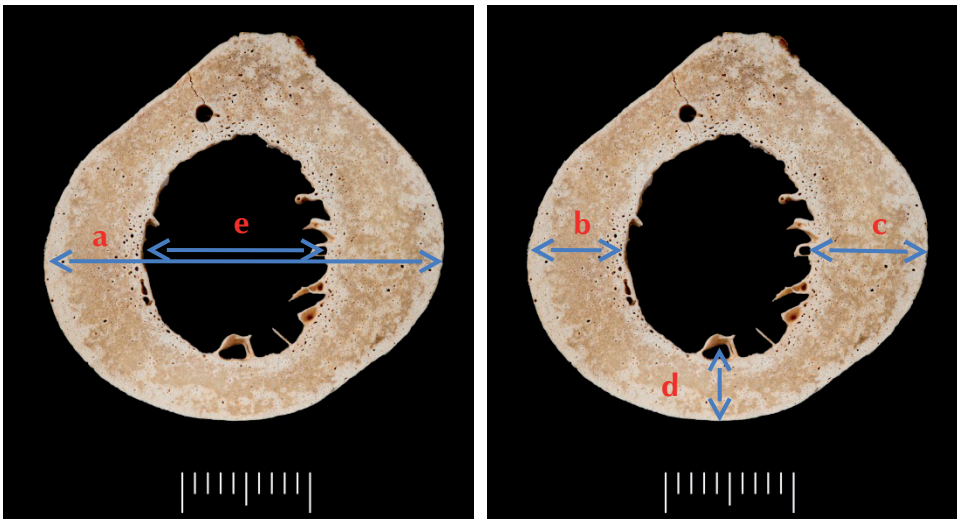


Fig. 3 – Measures of femur mid-shaft on radiographs (anterior-posterior view): a = maximum medio-lateral width, b = lateral cortex, c = medial cortex, e = medulla medio-lateral width; (lateral view): d = anterior cortex.

taken immediately proximal to this mark. On the lateral view radiograph the mid-point of the shaft was estimated by matching the radiograph with the a-p view. The dimension of the anterior cortex at the mid-shaft point was taken (Fig. 3). All measurements were made by one operator (Freddy Vandemeulebroecke). Measurements were repeated on five radiographs and on radiographs taken at different exposures.

Structural changes in the spongiosa of the femoral epiphysis were estimated from each a-p radiograph according to the Phases I-VI described by Acsádi and Nemeskéri (1970) and table 1.

The procedure was repeated five times and found to have little consistency.

Both left and right femora were examined for macroscopic variants (e.g. coxa valgus, coxa vara), pathology (Paget's disease, rickets, osteoarthrosis, osteosarcoma) and non-metric traits.

The development of postural traits - ligament attachment in the femoral head, Poirier's facet, trochanteric spicule in the greater trochanter, and linea aspera - were recorded. (These are the traits that are prevalent in horseriders and osteo-arthrosis of both compartments of the distal condyle was noted (Sager in BROTHWELL, 1981; BLONDIAUX, 1994; MOLLESON 2007).

4. RESULTS

Two skulls (743 and 765) had cut marks incurred either for autopsy or during preparation; two, a male and a female (721 and 724) had bone resorption, but are very old. One male (735) aged 57 had severe cranial erosions perhaps due to a malignant tumor, possibly an epithelioma originating in the sinuses. The disease is not particularly rare, more frequent in carpenters because of the sawdust and if not treated it produces this sort of damage (Louryan, personal communication), though 735 seems to have had a trade (ELDRIDGE, 2006-2007: 47). No case of Paget's disease, which affects cortical thickness, was identified, rather surprising given the average age of the sample. In modern clinical practice this disease is often only recognized in older adults incidental to other investigations.

4.1. Trace elements

Ribs of 28 men and women were analysed for 23 elements by ICPAES after preparatory cleaning and drying. In general heavy metal levels were low, below 5 ppm for cadmium, less than 30 ppm for lead; only three individuals had copper levels over 50 ppm; four, all born locally (three of whom died young) had elevated (>0.5 ppm) antimony, including 760 the blacksmith and the doubtful female 765.

Phase I	Thick trabeculae extend into the medulla below the lesser trochanter. No areas of rarefaction
Phase II	Position of trabeculae in medulla not easily discerned. Rarefaction near epiphysis of head occurs both medially and proximally. Greater trochanter epiphyseal line not clear even in youngest (This part does not appear to progress in quite the same way as the Acsádi and Nemeskéri sample)
Phase III	Cavities, seen radiographically as areas of rarefaction or low density don't appear in the head, but in the mid neck and greater trochanter
Phase IV	Head lacks trabeculae but rarefactions not clear. A space c.5 mm below the head is clear. Trabeculae across the neck or space in the middle
Phase V	Rarefactions below the epiphysis of the head and in the greater trochanter, mid neck and possible in the head below the fovea
Phase VI	Rarefaction in the greater trochanter is clear. No trabeculae in the middle of the neck. Rarefaction in the middle of the neck. Rarefaction in the head not apparent

Tab. 1 – Trabecular Phases of the femoral neck described by Acsádi and Nemeskéri (1970).

Elevated cadmium (>10 ppm) found in four men and one woman, all born locally (within 20 km) was not associated with lead but rather with zinc and included the sailor, 745, and factory worker, 749. Cadmium could have been a contaminant of zinc. It is associated with smoke inhalation and it accumulates in the kidneys and liver causing hypertension, heart enlargement and early death (DUFFUS, 1980: 73-6). Three of the four men with elevated cadmium had died young (aged 38 -53).

High lead (>30 ppm) was found in three women, all over 80, and three men, all over 65 including 751 a cultivator, but not the plumber 756 (12.1 ppm). Titanium is associated with lead, a man (711) and a woman (733) having slightly elevated levels (6.27 and 3.11 ppm). Lead an environmental pollutant used in insecticides and paints accumulates in the liver and kidneys and generally in the system including bones, from where it is released in old age bone turnover. It causes anaemia and nerve damage (DUFFUS, 1980: 74). Lead seems to have been acquired from lifetime exposure rather than endemically since there are few cases of metopic suture. Of the five metopic individuals, two, a female (733) aged 83 and a male aged 38 (749) had high lead and cadmium. At Poundbury Camp Romano-British cemetery frequency of metopic suture in the cranium is higher where lead and cadmium levels are elevated (MOLLESON *et al.*, 1993). While bone density is increased by heavy metal uptake and bone turnover is reduced, no long term re-modelling of bone was detected in this small sample.

4.2. Femora

Many of the bones were very light to handle and apparently osteoporotic. The femoral head was detached in 720, a 92-year-old female. A high femoral neck angle, coxa valga, was noted in a female, 684, and coxa vara, in four individuals, both left and right femora having a low femoral neck angle (711, 729, 743 males, 724 female); slight rickets was suspected in 752 a female; the knee of an 88 year old female, 734, had been destroyed by degenerative disease and she must have used a crutch latterly and ultimately been bedridden.

Clear-cut associations did not emerge when the 'rider's' traits were assessed and horse riding may not have been an important means of locomotion, in contrast to the Master weavers of Spitalfields (MOLLESON *et al.*, 1993). Traits were often developed to different degrees in left and right femora. In males strong trochanteric spicules were found, a deep fovea and usually (except 2/6) well developed Poirier's facets. A deep fovea, Poirier's facets and trochanteric spicules in the male 746 suggest he might have ridden a horse; a linea aspera moderately developed and the condyles not deformed. In females there was no clear association; 720 had a strong Poirier's facet and strong linea aspera of the right but not the left femur. A strongly developed linea aspera was not usually associated with degenerative changes to the condyles of the knee but was noted in several females (684, 733, 738, and 740) and one male (764).

The diversity of the degree of degenerative changes to the condyles of the knee, either none or severe suggests that the occurrence of osteo-arthrosis was a sequel to repetitive trauma. The left and right knees of one female, 684, had severe arthrosis and eburnation of both medial and lateral femoral condyles; both condyles of the right but not the left knee of 722 (male). The medial condyle of both knees was more severely affected in five individuals (females 738, 740, and 764 male) the right only in 710 (female). The lateral condyle was the more severely affected in another three (733, 753 females and 741 male); the right but not the left of 730 (male). The asymmetry was reversed in 738 (female) the medial condyle being more severely affected on the left knee.

4.3. Age related changes

The phases of age changes in the spongiosa of the proximal epiphysis of the femur established by Acsádi & Nemeskéri (1970) inferred from the anterior-posterior radiographs revealed very little change with increasing age in the males. Phase 1 was observed in five individuals, all aged less than 45 years (5/8); most, even the very old, remained in Phase II; Phase III was seen in three, aged 47, 70 and 89, the oldest of the males. Phases V and VI were not recorded in the final analysis. Among the females

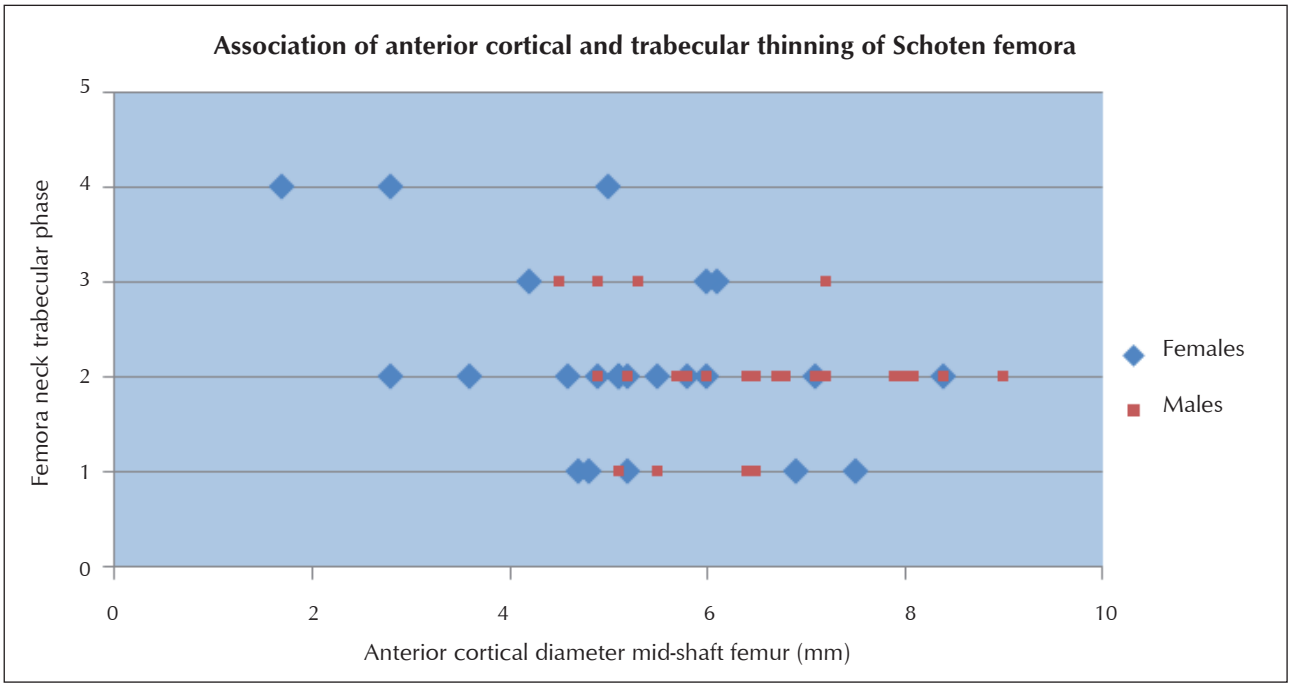


Fig. 4 – Association of anterior cortical and trabebular thinning of Schoten femora.

three out of four aged under 45 were in Phase 1, while two others, one aged 60 and another aged 88 also showed Phase 1. Phase II was seen first in a 30-year-old and last in a 94 year old - the oldest female in the sample. Phase III was seen in three individuals all aged over 70 years (3/14); Phase IV in three (3/11) females, 734 the cripple, 736 and 753 had arthritic knees; all were aged over 78 years (Fig. 4).

Cross-sectional cortical thickness measured on the radiographs at the mid-point of the femoral shaft was analyzed in females and males (Tab. 2). Excepting the anterior cortex, distributions were normal with slight negative skewing in the lateral cortex of males and positive skewing in both females and males of the medial cortex. The anterior cortex thickness was the most variable of the dimensions. The averages of all dimensions in females were less than in males, who generally had larger and thicker bones (Tab. 2).

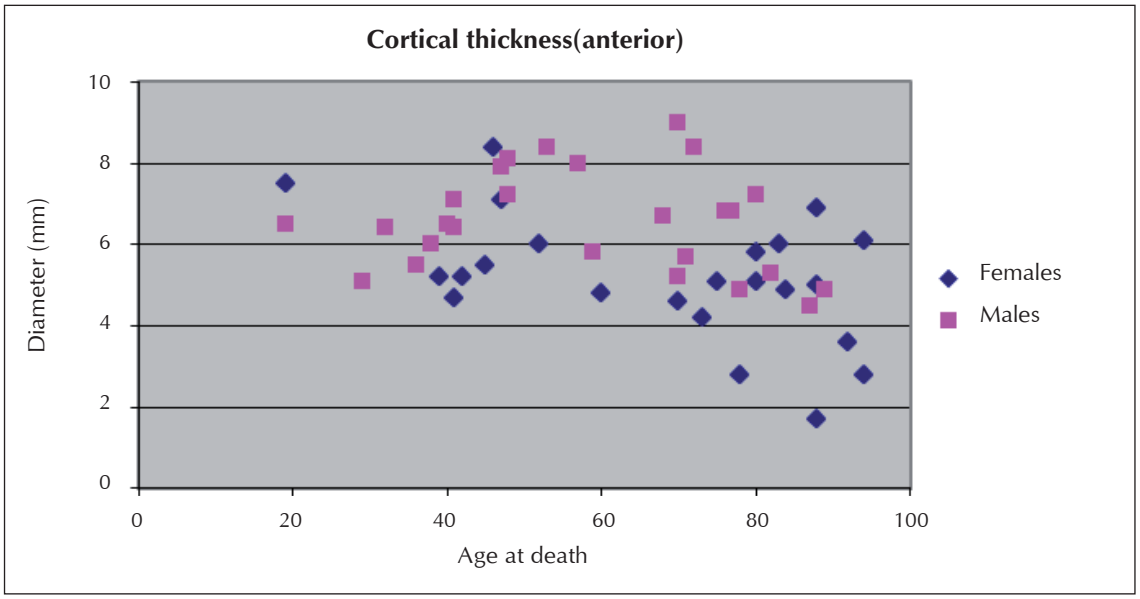
4.3.1. Anterior cortex

A few females (720, 724, 734 and 736) all aged over 70, could be identified as having thinner than normal anterior cortical bone (Fig. 5a). The

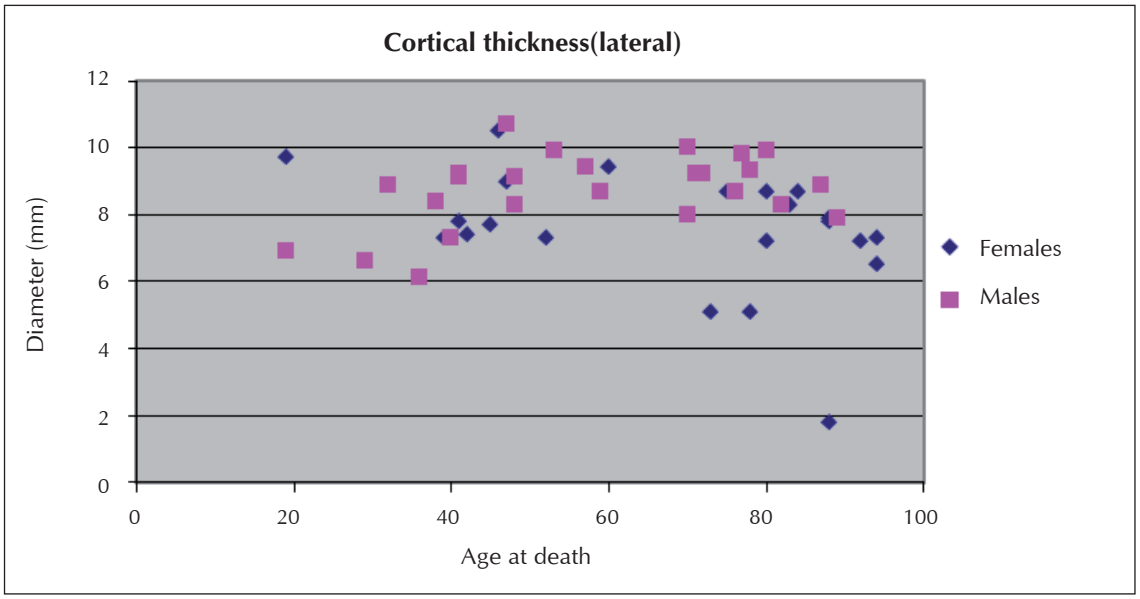
	Females				*Males*					
Mid-shaft	*Range*	*Average*	*St.Dv*	*No.**	*Range*	*Average*	*St.Dv.*	*No.*	*P*	
Anterior	2.8-8.4	5.33	1.38	22	4.5-9	6.55	1.24	26	0.002	sig
Lateral	5.1-10.5	7.75	1.36	22	6.1-10.7	8.63	1.16	26	0.019	sig
Medial	5-10.2	7.63	1.33	22	5.9-12.5	8.28	1.74	26	0.159	not sig
Medulla	9.3-17.3	12.8	1.98	22	11.2-16.8	13.53	1.42	26	0.145	not sig
Total width	*21.4-30.2*	*26.31*	*2.4*	*22*	*23-35.4*	*28.29*	*2.54*	*26*	*0.008*	*sig*

Tab. 2 – Mid-shaft cross-sectional diameters of the femur in females and males from Schoten.
*The outlier 734 has been removed.

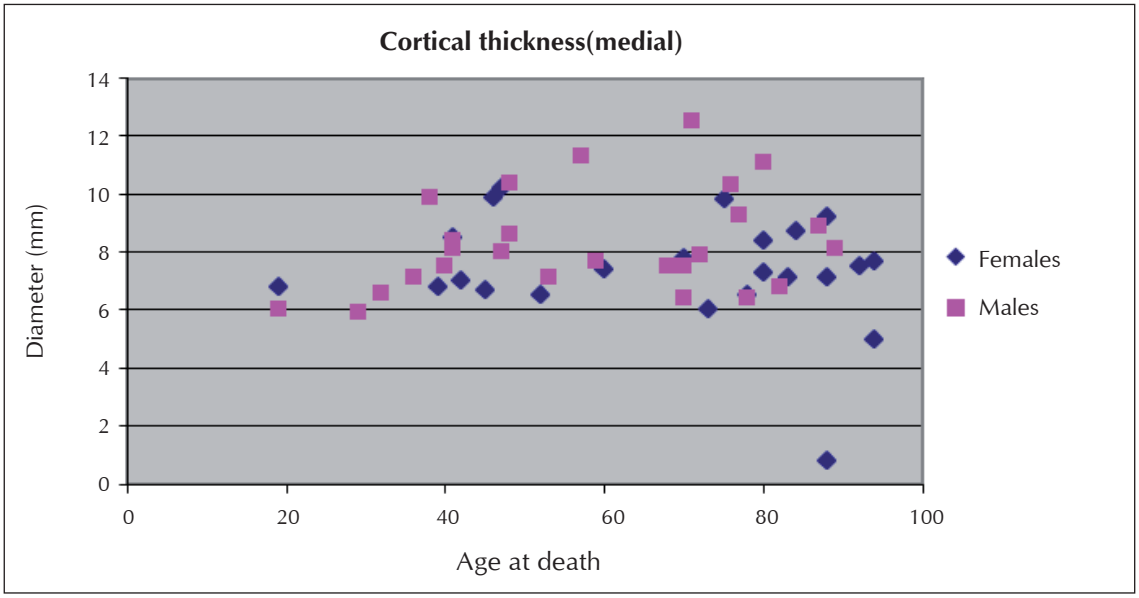
a


Cortical thickness(anterior)
Diameter (mm)
0
2
4
6
8
10
0
20
40
60
80
100
Age at death
Females
Males

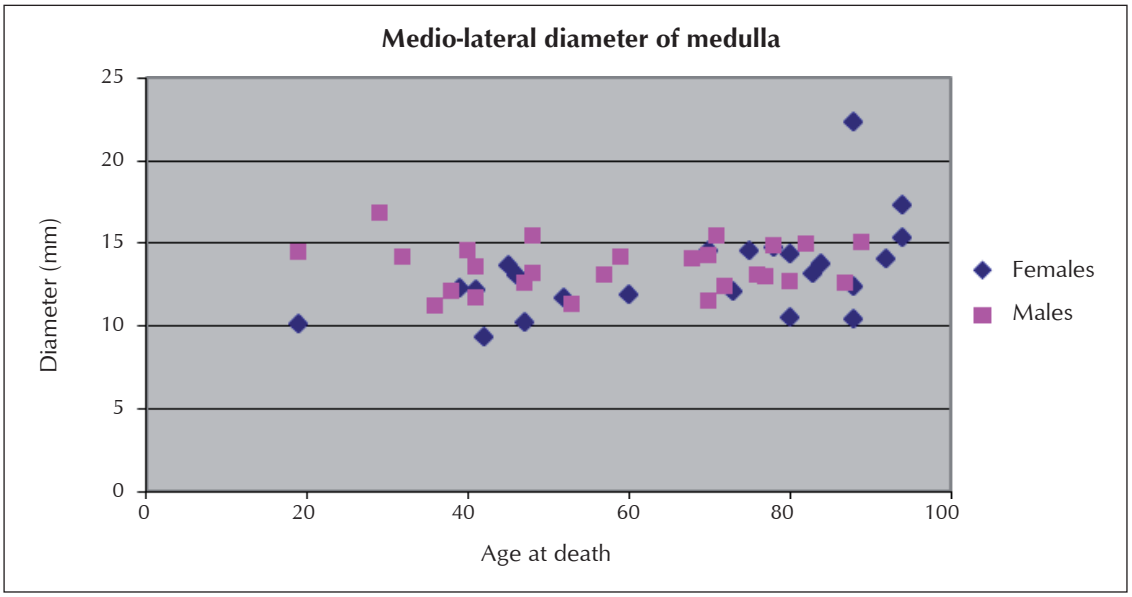
b


Cortical thickness(lateral)
Diameter (mm)
0
2
4
6
8
10
12
0
20
40
60
80
100
Age at death
Females
Males

c


Cortical thickness(medial)
Diameter (mm)
0
2
4
6
8
10
12
14
0
20
40
60
80
100
Age at death
Females
Males

d



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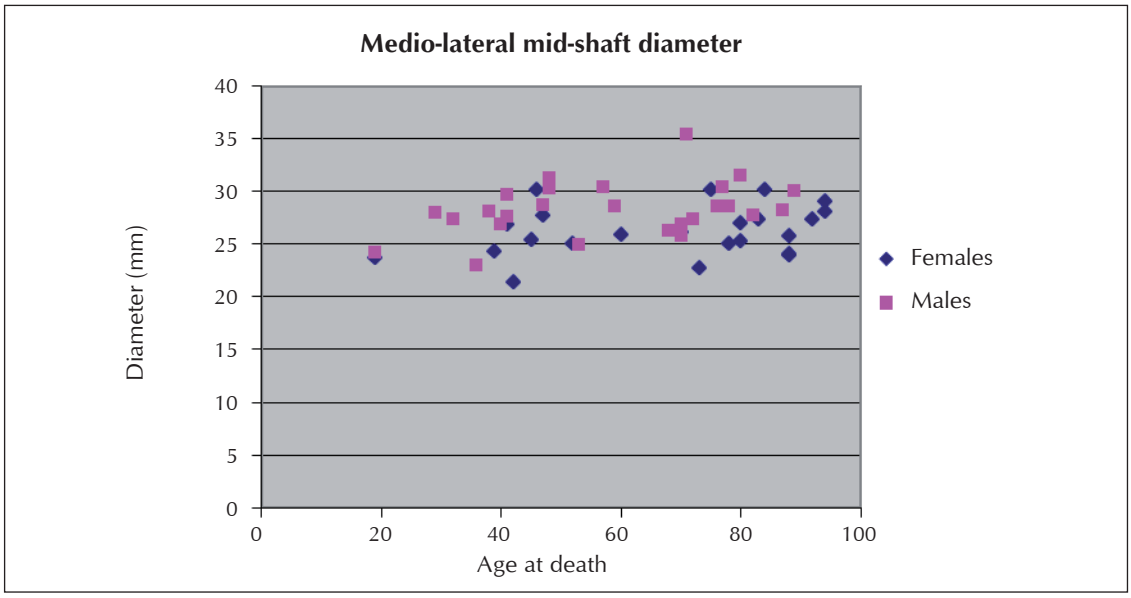

Fig. 5 – Variation in femur mid-shaft diameters according to the age at death of Schoten femora.

head of the right femur of 720 was detached; 724 had a low femoral neck angle (coxa vara), 734 the cripple. The questionable female 765 stands out as having thicker anterior cortical bone than any of the other females. Males generally have a thicker anterior cortex. Those (721, 741, 748) with thin anterior cortical bone were all over 80 years, the latter two both had severe osteoarthrosis of the knee, 721 may have had leprosy.

4.3.2. Lateral cortex

There was some evidence for thinning of the lateral cortex in four (4/13) women over 70 years (Fig. 5b). Of the four (684, 734, 736, 752) osteoarthrosis of the knee was present in 684, 734 the cripple. The questionable female 765 had the thickest lateral cortex of any of the females. Males on average have a wider cortex than do females. None of the men had a thinner than normal lateral cortex.

4.3.3. Medial cortex

Among the females only two or three (684, 724, 734) had a notably thin medial cortex (Fig. 5c). They were all over 70, 684 had severe osteoarthrosis of the knees, 724 coxa vara;

and 734 osteoporosis. No late age thinning was observed in the males. A male, 729, with coxa vara had the thickest medial cortex and presumably had a rolling gait. He also had the widest medio-lateral mid-shaft dimension.

4.3.4. Medulla width

A few (3/14) females aged over 70 have wider than normal medulla width (Fig. 5d). Osteoarthrosis was evident in the right knee of 710, 724 had coxa vara and leprosy; and 734 disuse osteoporosis. Any tendency of the medulla dimension to increase with age was not significant in the males (Tab. 3).

4.3.5. Total mid-shaft medio-lateral diameter

There was an increase in total shaft medio-lateral width with increasing age in males and to a lesser extent in females; in neither case was the increase significant (Fig. 4).

Inspection of the scatter plots for age related cortical thickness revealed that females aged over 65 years, when the outliers are included, had thinner cortical bones than those aged less (Fig. 5c). There was apparently no evidence for a progressive thinning during adulthood although the sample sizes were too small to test this observation. Age related trends in cortical dimensions in sub samples of females and males aged less than 65 years and those aged over 65 years were assessed (Tab. 3). For this analysis the pathological outlier 734 was retained.

Females aged 65 and over showed a loss of cortical bone in all dimensions, and an increase in medulla and total widths of the shaft. The thinning was significant in the anterior and lateral cortex, which with the considerable expansion of the medulla reflects loss of cortical bone.

Males over 65 compared to those aged under 65 showed much less difference in cortical bone dimensions than did the females. The anterior cortex showed the greatest loss but this was much less than in the females. Average lateral and medial cortex dimensions both increased slightly in the older age group, as did the total medio-lateral width of the femoral shaft. Medulla increase was minimal in the older males.

5. DISCUSSION

Although this is a minimum sample with which to examine age related trends, clear patterns appear to emerge. There is evidence in females

	Females < 65				*Females > 65*					
Mid-shaft	*Range*	*Average*	*St.Dv.*	*No.*	*Range*	*Average*	*St.Dv.*	*No.**	*P*	
Anterior	4.7-8.4	6.04	1.32	9	1.7-6.9	4.61	1.46	14	0.027	sig
Lateral	7.3-10.5	8.46	1.21	9	1.8-8.7	6.88	1.91	14	0.039	sig
Medial	6.5-10.2	7.76	1.43	9	0.8-9.8	7.06	2.2	14	0.409	not sig
Medulla	9.3-13.7	11.61	1.46	9	10.4-22.3	14.24	2.96	14	0.022	sig
Total width	*21.4-30.2*	*25.61*	*2.52*	*9*	*22.7-30.2*	*26.6*	*2.31*	*14*	*0.344*	*not sig*
	Males < 65				*Males > 65*					
Anterior	5.1-8.4	6.78	1.03	14	4.5-9	6.28	1.44	12	0.314	not sig
Lateral	6.1-10.7	8.47	1.31	14	6.7-10	8.83	0.97	12	0.44	not sig
Medial	5.9-11.3	8.04	1.6	14	6.4-12.5	8.56	1.93	12	0.46	not sig
Medulla	11.2-16.8	13.44	1.6	14	11.5-15.4	13.63	1.25	12	0.742	not sig
Total width	*23-31.2*	*27.77*	*2.41*	*14*	*25.8-35.4*	*28.9*	*2.65*	*12*	*0.266*	*not sig*

Tab. 3 – Age differences in mid-shaft cross-sectional diameters of the femur in females and males from Schoten. *The outlier 734, aged 88, is included.

for a cortical thinning in the older age group, which together with the apparent expansion of the medulla (p 0.022) reflects a loss of cortical bone (Tab. 3, Fig. 5). The endosteal surface is more vulnerable to osteoclastic bone resorption because it is more hypoxic (ARNETT *et al.*, 2003; PEARSON & LIEBERMAN, 2004). The systemic and local actions on bone cells of inorganic elements such as hydrogen ions, and oxygen molecules are of importance. Whether the thinning is a general phenomenon or due to bone thinning in a few susceptible individuals, evident in figure 5, is difficult to test. If the outlier 734 is removed obviously the mean differences are reduced. Males over 65, in contrast, only exhibit thinning of the anterior cortex. This, together with increases in the lateral and medial cortical dimensions suggests that gait in adulthood, the cumulative influence of regional weight loading on bone formation have an effect on cortical remodeling. The strain resulting from mechanical loading is a key regulator of remodeling in some parts of the skeleton. The long bones and the vertebral bodies appear to require modest but regular loading cycles in order to maintain their mass (EHRLICH & LANYON, 2002; ARNETT, 2013). The loss of anterior bone is interesting in this respect. Under normal circumstances in young adults, remodeling activity keeps overall bone morphology relatively constant (Fig. 5). Ageing, the menopause and many other pathophysiological states can alter the balance of the turnover process, such that resorption begins to outstrip formation, leading to net bone loss (PEARSON & LIEBERMAN, 2004: 69; ARNETT, 2013). Bone thinning specifically associated with the menopause years in the Schoten females could not be defined.

The possibility that occupation was influential was considered but without detailed information could not be followed up, although most married women presumably followed the variety of activities common to housewives of all ages and had had children. Association with other features of the femur in those who did have exceptionally thin or thick bones was examined. The anterior cortex was the most variable, quite possibly reflecting differences in gait or activity among the elderly. Since all dimensions of cortical thickness were not necessarily affected in each individual excepting the pathological 734, a genetic input specifically to the anterior cortex seems highly unlikely. Bone morphology, whether it is femoral neck angle, development of entheses or osteophytes, seemed to have little effect on cortical thickness that is consistent or predictable, whereas bone pathology can have a profound influence. Neither trace element values now any of the nonmetric traits showed other than random association with variation in cortical thickness in any of the sectors measured.

In examining the older groups markedly thin bones were only noted in a few individuals and these are aged at least 65 years. The existence of any onset of thinning cannot be tracked, because of the lack of individuals in their sixties. In fact most individuals in the older age groups, female or male, did not have bones that were notably thinner than their younger counterparts. Neither trace element values nor any of the nonmetric traits examined showed other than random association with cortical thickness in any of the sectors measured. Some of those that did have thinner bones were radiologically pathological or anomalous in some way but they could not be reliably predicted from the morphological, nor even available trace element data. As older men and women tend to develop a pronounced rolling lateral gait, throwing the weight from side to side as they walk, this may have protected the bone of the medial and lateral aspects of the shaft. Bones are not only able to withstand functional loads without either breaking or sustaining extensive damage because they have evolved the capacity to adapt their architecture in relation to changes in their habitual loading environment (EHRLICH & LANYON, 2002). It is evident in this sample that bone cells respond directly or indirectly to local strains engendered in their vicinity by the loads of normal functional activity. It is notable how restricted the loading strain can be, so that the anterior cortex is not stimulated and on the contrary suffers local disuse atrophy. Weight transfer from femur head through trabeculae and cortex on medial and lateral sides of the femoral neck transferred along the diaphysis would account for the persistence in older individuals of Phases II, III and IV of Acsádi and Nemeskéri (SHEA *et al.*, 2001: 153). The effect of habitual weight transfer mainly through the medial side of the femur is seen in 729 a robust male with coxa

vara - a low femoral neck angle. Aged 71 years he had the thickest medial cortex of any in the sample (Fig. 5). Pearson & Lieberman (2004: 84) suggested that "possibly bone cross-sectional properties mostly reflect shape adaptations to only the most vigorous forms of loading rather than typical habitual activities".

The ageing phases of the femur established, as part of the Complex Method, by Acsádi & Nemeskéri (1970) were originally derived from the study of bones that had been cut in half. The method has been applied to radiographic images and did yield an age related trend on femora from Spitalfields aged sample (MOLLESON *et al.*, 1993: 168). The performance of the method, however, was important in showing that bone changes were not closely correlated with biological age. This observation was supported by other methods that used direct observation of the cranial and pelvic bones, and including amino acid racemization, suggesting that age related bone morphology reflects population ethology rather than any distortion in the use of radiographs. The Schoten femoral radiographs, when scored according to the criteria of Acsádi & Nemeskéri (1970) indicate a slow rate of ageing for the sample. This is consistent with the findings from the femoral cortex, where there isn't any evidence for cortical thinning before the seventh-eighth decades, and that only in a few individuals, mostly women. Given the difficulties of scoring the radiographs it is fortunate that the technique has been largely superseded by the use of DEXA radiography (LEES *et al.*, 1993; GILISSEN *et al.*, 2006; ORBAN *et al.*, 2011). The indications from the DEXA analysis of the London 18th century Spitalfields sample of known age individuals are that rates of bone loss were slower in this group when compared to a modern reference (LEES *et al.*, 1993). Bone density (DXA) results for Schoten indicated that densities in those aged over sixty five were similar to the reference NHANES (GILISSEN *et al.*, 2006; ORBAN *et al.*, 2011).

The overall impression is that the people of Schoten born in the nineteenth century, of which this is a sample, did not manifest cortical remodeling as early as do their modern counterparts. A similar, though less dramatic, observation was made for the XIXth century sample from Spitalfields (LEES *et al.*, 1993). The age at death of the Schoten sample indicates that they were 'survivors', having lived through the many famines and epidemics of the later 19th and 20th century. The pattern of cortical change suggests that the majority may have remained active throughout their lives. Thus they may have been less likely to become obese. Angel (1960) in a follow-up study of obese women found that they had a tendency to accelerate the ageing processes. Arnett (2003, 2007; ARNETT *et al.*, 2003) has demonstrated a relationship between metabolic acidity and activity of osteoclasts in the destruction of bone. This finding blames diets, which emphasize protein, cheese, wheat at the expense of fruit and vegetables. Other factors, however, must be involved to cause anterior cortical bone to be lost more than lateral and even for medial cortical bone to gain in thickness. Erickson (1976) compared age-related changes in cortical thickness in three skeletal samples of native North Americans. In all three groups bone loss in females was much greater than in males. She also found a difference between populations in the rate of bone loss with age. She concludes that environmental factors, nutrition and physical activity, rather than genetics are the major factor in the differences. A suggestion by Dewey, Armelagos and Bartley (1969) that early onset of bone loss in Nubian archaeological populations was through inadequate calcium intake and extended lactation seems unlikely in the light of more recent work (STEVENSON *et al.*, 1989).

Osteoporosis as a disease seems to have been rare in the past. Ortner and Putchar (1981) note that osteoporosis is associated with a range of diseases, coccidioidomycosis, Cushing's syndrome, disuse, Gaucher's disease, hyperparathyroidism, hypophosphatasia, extended lactation, rheumatoid arthritis, rickets, sickle cell anaemia, scurvy, vitamin D resistant rickets and, lastly, senility (ORTNER & PUTCHAR, 1981: 485). It is not necessarily a normal process.

The aged were survivors of privations and stresses experienced during fetal growth and childhood; experiences that have been held to be responsible for reduction of growth achievement of adulthood (MOLLESON, 1994, 2010). Femur lengths (used as a stable indi-

Females					*Males*					*Dimorphism*
Age (yrs)	*N*	*Average*	*St.Dv.*	*Range*	*Age (yrs)*	*N*	*Average*	*St.Dv.*	*Range*	*100F/M Ave.*
< 65	9	427.56	25.35	368-448	< 65	14	447.36	28.71	397-497	95.6
> 65	12	420.25	17.52	392-439	> 65	13	455.38	31.93	396-524	92.3

Tab. 4 – Comparison of dimorphism in maximum femur length (in mm) of female and male Schoten 'survivors' (> 65) and those who died young (< 65).

cator of stature) of the two groups of Schoten men and women aged more or less than 65 years at death were found not to differ significantly (Tab. 4). The severe famines of 1916-18, suffered when the older individuals were in utero, born under-weight, or growing up apparently did not leave a permanent legacy (Fig. 5). There are a number of caveats: the two cohorts are not equivalent since many outsiders had moved to Schoten to work in the factories or transport and this might be reflected in the somewhat greater stature of some of the older men. Among the under 65 years males ten were born locally, one 17 km and one 91 km away; among those over 65 years only one was born locally, one within 10 km, six within 40 km and five 50-70 km away. The four tallest men less than 65 years at death were born locally and the four tallest over 65 were all born 18 or more km distant from Schoten, suggesting that there is not much difference between the two age classes, whereas variation in dimorphism between the sexes is evident and might be a better indicator of environmental stress (MOLLESON, 1994). Likewise all seven women under 65 years at death, for whom there is evidence, were born locally or within 10 km of Schoten; while among the over 65 class nine were born locally, six within 40 km and one 145 km in Germany (ELDRIDGE, 2006-2007).

The difference in maximum femur length (not overall stature) in survivors and those who died young is not significant for either females or males although the women over 65 had shorter femora. Thus, dimorphism between the sexes paradoxically appears to be greater in the survivor class (Tab. 4, Fig. 5). Small women might have been better resistant to deprivation - survivors - in the famine years of the nineteenth and early twentieth century. Social factors could have been influential (HARVEY & BENNETT, 1985; MOLLESON, 1994).

6. CONCLUSIONS

Overall, cross-sectional cortical thickness of the femur mid-shaft is generally greater in males than in females. Thinner bones are only detected in a proportion of those aged 65 or more.

The people of Schoten, born in the 19th century before mechanized transport was generally available, remained active throughout their lives. Cross-sectional cortical thickness of the femur and persistence of trabeculae in the femoral neck reflect gait in habitual bone loading. There was no evidence for an age-related trend in bone thinning from about 30 years as is often cited for modern populations; nor for thinning associated with the menopause in females. Thin bones were recorded in a few individuals, rather than as a general trend, and there were some radiological indications that these individuals were pathological; and soft tissue conditions could not be included. Thus the rate of ageing appears to have been much slower for this late 19th to early 20th century sample than it is for modern samples.

That ageing can vary is clearly demonstrated when the Schoten results are viewed against modern data. We need to recognize that ageing varied in the past as it doubtless does today. So-called age-related trends that are based on bone degeneration in one sample will not necessarily be applicable to another.

It is worth noting that there can be uncertainties in identification of biological sex even in documented material.

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