

A method for the study of activity related skeletal morphologies

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Abstract: *Our knowledge of the social and economic development of past societies and the people within them can be increased through an understanding of specialized activities. If an activity was time-consuming or arduous, especially when begun at an early age and the bones still growing, the bone morphology can be modified and techniques of production used in the past are recorded. The predisposing requirements for bone morphology to be distinctively modified are a restricted series of movements that are energetic and carried out for long periods probably on a daily basis and from a young age. Interpretation of an activity depends on the objective reconstruction of the biomechanical anatomy of the signs imprinted on the bones leading to a probability based on a differential diagnosis of the possibilities, in much the same way that a clinician evaluates a patient's signs and symptoms. The significant morphology is that which differs from the normal range for the population being studied.*

Key words: bone morphology; craft technology; differential diagnosis; load bearing; repetitive activity; task related

The need to know

The morphology of the human bones from Pre-Ceramic Neolithic levels at Nemrik, Iraq, indicates that running was of such major importance that the leg bones developed characteristic forms in relation to the stresses persistently imposed on them (Molleson 2006b). It is suggested that the method of hunting was to run down prey and catch the animals by grappling with them or by launching bolas stones at them. Stones, usually in groups of three, slung in a woven net or bolas have been widely used in the past for entangling animals. How likely this suggestion is can to some extent be checked by reference to independent sources of evidence for lifestyle of the Nemrik Neolithic populations.

The detailed analysis of the teeth by Krystyna Szlachetko and Małgorzata Zadurska (2006) is the basis for further interpretation. In some jaws the shape of the coronoid process of the mandible and the extreme crushing-type occlusal wear of the teeth indicates a powerful puncture-crushing component to mastication that is associated more with task related than nutritional purposes. Bone chewing, large seed crushing, or fraying of reeds for making cord, could all be involved to a greater or lesser degree depending on the individual, season or other needs. Barley grains are among the hardest of the cereal grains and unless boiled in a broth (difficult to do before the advent of pottery) demand hard chewing to crush and moisten them before swallowing. Barley has an affinity for chromium and this element would be worth looking for in the human remains (Molleson 1995). Barium has been found at very high levels

in the teeth from all levels at Nemrik indicating that plant foods were a significant part of the diet (Szostek et al. 2006). Low strontium-zinc ratios indicate a higher animal intake in the lowest burials (clusters *aa* and *nn*) from the site. In general animal protein indicated by zinc-calcium ratios was low, higher in older than younger individuals although this may be a cumulative effect. Agriculture as a subsistence economy seems to have been adopted during the late phase c. 9500–9000 BP and grinding stones, rubbers, mortars and pestles are part of the lithic assemblage. Thus, there is the possibility that hunting, as indicated by the lithics and bone morphology, might have had more of a social than nutritional function, as it does in so many societies. This however does not account for the very large number of animal bones, especially wild antelope, recovered from the site.

Although my contention that the form of the human bones from Nemrik demonstrates that hunting could have been achieved by running down the prey cannot be fully verified, the findings from Nemrik illustrate how our knowledge of the social and economic development of past societies and the people within them can be increased through an understanding of activity related bone changes. We need to know when crafts and techniques arose and who the specialists were. Who were the craftsmen, were they men, women, children or slaves? When did caste systems emerge? Only the human bones themselves can give the answers, at least before the emergence of writing.

The human remains that become available to historical anthropologists are largely reduced to bone fragments. Fortunately bone is remarkably pliable and responds to stresses and pressures exerted on it by muscular activity or weight loading. The growing skeleton is particularly responsive. Pressure imposed on bone can easily distort the form and robusticity. The muscles involved in repetitive movements carried out over a restricted range can be greatly developed and their enlarged insertions distinctively imprinted on the supporting bones. Thus a cluster or **syndrome** of morphological **signs** that are related to a specific activity can be established from changes to the usual shape of the bone in known performers and by reference to those muscles activated during the performance of specific actions. This information is surprisingly hard to assemble. Even where the activities are still being practiced in the traditional manner access to the skeleton is obviously denied. Interpretation of morphologies usually depends on the objective reconstruction of the biomechanical anatomy of the signs on the bones, signs of which the individual practitioner might not be aware.

Probably no two people carry out a given task in exactly the same way. In some their muscles will not develop despite the exertion, in others the muscle development might be quite disproportionate to the exertion involved; and conversely quite different tasks can require similar muscular exertion. Therefore we can never achieve certainty in interpreting bone morphology but a probability based on a **differential diagnosis** of the possibilities, in much the same way that a clinician evaluates a patient's signs and symptoms.

The clinical approach to assessing individual cases seems most appropriate to the needs of archaeological material at least initially. Once specialized skills had emerged the practitioners were usually relatively rare in the population and so have to be treated on an individual basis. This contrasts with the introduction of major behavioural changes that are taken up by whole sections of the population, such as hunting with spears or the bow and arrow, or a community of miners, which have been effectively documented by case control studies using comparative methods (Dutour 1986, 1993; Pálfi 1992; Bailly-Maître et al. 1996; Peterson 1997; Eshed et al. 2004; Weiss 2004). Great innovations like hunting with spears involving handed laterality are reflected in changes at the population level. The study of changes at the population level will not bring to notice individual specialists.

Nowadays probably only musicians and sportsmen in training impose such stresses on the young body that the bone morphology is actually modified. In the past the conditions of demanding and unrelenting exertion may have been more common and more evident, especially if the stresses were imposed while the bones were still growing. It is for these reasons that very occasionally we can recognise changes on excavated bones that can be attributed to specific postures and associated with particular tasks.

The predisposing requirements for bone morphology to be distinctively modified are a restricted series of movements that are energetic and carried out for long periods probably on a daily basis and from a young age often producing entheses of muscle insertions. There may or may not be associated patterns of trauma; healed fractures, enthesopathies and degenerative joint osteoarthropathies are of secondary consequence (Knusel et al. 1977, but see Merbs 1983; Mafart 1996). Some degenerative joint lesions, however, have been repeatedly associated with certain activities including osteoarthritis of the medial condyle of the left knee and myositis ossificans of the thigh muscles (rider's spur) in horse riders. Others, like vertebral crushing, are far too widespread to have much diagnostic value unless particular vertebrae are involved (e.g. T12 in the cereal grinders of Abu Hureyra, which risk is avoided when the quern is placed on a plinth as at Çatalhöyük). These assumptions underlie any attempt to infer cultural variation in the use of the body from physical anthropology, more specifically from the skeletal evidence provided by excavated material.

Establishing the syndrome

The methodological approach has been to recognize when morphologies displayed by the bones or teeth of an individual are outside the range normally displayed by the population being studied. An attempt is then made to reconstruct the physical activity that might have led to the changes with reference to the biomechanics of the muscles and ligaments noted. The problems that would have confronted the early Neolithic people in the preparation of their newly acquired technologies and the appropriate solutions that are used by present day people are considered. This approach differs from that of Peterson (1997) and others (e.g. Eshed et al. 2004) who analyse variation between groups. It is more akin to a clinical approach where

Table 1. Identification of the normal range of variation.

Normal range:	age	anomalies and variants
	sex	body weight and robustness
	ethnicity	
Pathology or abnormality:		deficiency and systemic disease
		genetic or congenital conditions
		healed trauma and degenerative change
Taphonomy:		erosion, gnawing, abrasion
		breakage and distortion
		fossilization, staining and diagenesis

the individual is examined and a differential diagnosis based on comparison with other possible normal and abnormal conditions. Since the same exertion can be demanded of different activities and a given activity can be executed in different ways association of a pattern of morphological changes with any particular task must be suggested with caution. Further one individual may have undertaken a number of strenuous tasks.

The identification of activity related morphology seen in individuals is approached in five stages: exclusion of the normal, pathological and taphonomically altered; description of the morphology; differential diagnosis; case control analysis; and evaluation using independent evidence. The first need is to establish what is normal for the population or sample and is summarized in **Table 1**. Individuals that are exceptions to the norm can then be identified.

A description of the morphological signs displayed forms the basis for the syndrome that characterizes the changes observed. Following clinical diagnostic practice several morphological signs will usually constitute the syndrome although not all will be developed equally or at all. An interpretation of the changes and reconstruction of the possible ways in which they might have come about leads, by a process of elimination, to a differential diagnosis of the most probable reason for the condition of the bones. Ideally this should be by reference to evidence based on known cases (Kennedy 1989; Blondiaux 1994). Where there are several individuals showing similar changes they can then be subjected to measurement and analysis by comparison with an equivalent normal sample—a case control study. Finally the concluding interpretation can be assessed in the light of the faunal, floral, lithic and environmental evidence (**Table 2**).

Table 2. Steps towards the identification of task related activity.

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1. The syndrome is defined from the description of the pattern of signs observed on the teeth or bones that differ from the normal.
 2. A differential diagnosis is arrived at following comparison of the observed signs with those seen in other possible conditions.
 3. Case controlled measurement and analysis of the identified cases contrasted with a generalized sample.
 4. Independent environmental or comparative evidence used to evaluate the diagnosis.
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Range of skeletal change

Ken Kennedy documented an impressive range of activities that have been associated with unusual bone morphology (Kennedy 1989 and references). A large number of pathological conditions associated with particular occupations have also been documented (Mafart 1996). This overview tries to synthesize the range of activities reflected in dental modification, bone form and resulting from muscular exertion. Details of some examples are presented in the **Appendix**.

1. Task related dental wear. The reasons for dental modification can sometimes be established by reference to living practitioners who use their teeth as a third hand. Individuals develop their own ways of performing specific tasks but often a pattern develops that is characteristic of the task.
2. Pressure deformation. Passive pressure on a bone can deform its shape in a surprisingly short space of time especially in the young. Cranial deformation, sitting positions and load bearing can all result in characteristic changes to bone form and articular surfaces of the joints.

3. Biomechanical responses. Labour intensive activities such as running, load bearing, cereal grinding, horse riding, and acrobatics can be cautiously deduced by reconstructing the mechanical forces that must have induced the exceptional muscle and ligament imprints observed on some bones.

1. Task related dental wear

Evidence for task related dental wear is seen in many sites from the Neolithic and beyond. By 'task related' I exclude food mastication, tobacco chewing, pipe smoking, beer drinking, labrets and tooth evulsion, but include any activity that involves using the teeth as a third hand: cord and basket makers, spinners, scribes, miners, boat builders (Molleson 2006a; Tuominen & Tuominen 1991; Heyerdahl 1971), Volga bargemen and Inuit ladies who have to chew their husband's boots (Molleson 2004; Hansen et al. 1991). Jaw morphology can be modified by habitual activity, even normal mastication, involving jaw muscles and, conversely, underdevelopment of the masticatory muscles leading to dental crowding can be a significant problem of oral hygiene in some modern populations (Inoue 1993; Lucas 2006). Abrasions on the dental crowns can often be matched by examining the teeth of living practitioners. Cord makers, basket makers, spinners, and bark strippers have all been recognized, notably at Abu Hureyra, Mallaha, Çatalhöyük (Molleson 2006a; Bocquentin et al. 2005; Molleson et al. 1996; Ravy et al. 1996; Schultz 1977; Hoffman 1989). Using scanning electron microscope studies Michel Billard (1996) demonstrated important differences between task-related dental wear and tooth pick abrasion.

There are now sufficient examples of task induced dental wear in the literature that an attempt to identify the resulting patterns seems worthwhile. The use of the mouth and teeth as a 'third hand' is doubtless more widespread than has been appreciated up to now and there must be many examples as yet unrecognized. The range of signs includes changes to bone form, accelerated tooth abrasion, tooth fracture and ante-mortem loss of the teeth, tooth-to-tooth attrition, enamel chipping, and possibly calculus deposits, hypercementosis, and periodontitis. The recognition of task-related dental modification must in each case rest on the fact that the features seen are beyond the normal range for the age of the individual compared to the rest of the group. Ideally, comparison should be made with reference to cases of documented history, which is sometimes possible with task related dental wear.

In the pre-pottery Neolithic levels at Abu Hureyra, Syria, dental abrasion is characteristically severe but there are cases where the abrasion and ante-mortem tooth loss is extreme for the age of the individual. Morphological characteristics of the jawbones indicate that extraordinary forces had been applied over a period of time sufficient to modify the usual shape of the bone. In a number of cases it has been possible to interpret the morphological changes as being consistent with certain task related activities that involve the use of the teeth as tools. Cord makers identified by dental wear and enlargement of the head of the mandible; basket makers identified by grooved teeth, broad ramus, and enlargement of anterior border of the ascending ramus and a possible spinner, identified by sharp edged grooves on the anterior teeth. Distinctive jaws were identified by case study and defined by metric and statistical quantification of groups (see **Appendix 1** for details of cases from Abu Hureyra, from Molleson 2006a).

An initial study of the mandibles from Abu Hureyra identified a number with enormously enlarged condyles and extreme bevelled tooth wear. It was evident that these jaws had been



Figure 1a. Egyptian scribes prepared the reed used for writing hieroglyphs by chewing.



Figure 1b. Molar teeth of scribe Horemknesi have uneven wear on the left side, presumably from chewing the writing reed. 21st Dynasty, Thebes (Bristol Museum H7386).

subject to stresses that were not purely to do with normal crushing chewing movements but due to abnormal forces imposed by task related activity. In a population with minimal dental disease teeth had been lost prematurely through the excessive crushing and pulling forces used. Tooth abrasion is extreme and asymmetric; even the palatal roots of the upper chewing teeth can be exposed and abraded. Sometimes anterior teeth, sometimes lateral teeth have been lost, reflecting the differing practices of individuals. The best comparison is with casts of dentitions of inhabitants of Danger Cave who chewed quids of *Scirpus* reeds and retted the reeds by pulling them between the teeth (Jennings 1957). The frayed reeds were then twisted together to make cord for binding rush mats. Although the ancient Egyptians had notoriously bad teeth, the healthy teeth of Horemknesi, an Egyptian scribe, have exceptional abrasion that has resulted in mesio-distal depressions along the molar teeth presumably from the scribe's habit of retting by chewing the reed brush he used to write hieroglyphs (**Figure 1**).

Other jaws from Abu Hureyra had untypical abrasion of the anterior teeth and unusual morphology. In addition to wide grooves along the occlusal surfaces of upper and lower anterior teeth several traits of the mandibular body, the breadth of the ramus, and the shape of the coronoid process distinguish this group as having protruded the jaw while using the teeth

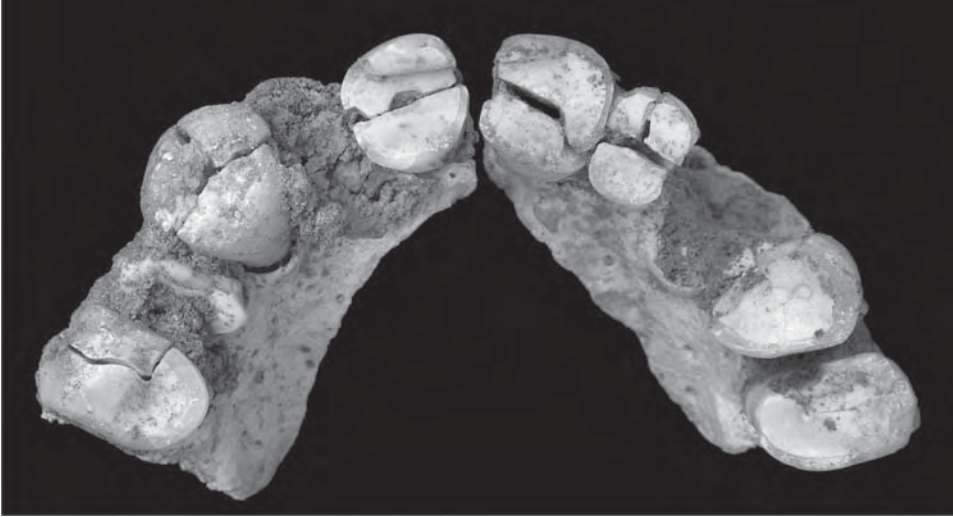


Figure 2. Sharp edged grooves on the front teeth of probable spinner from Abu Hureyra Neolithic Period (Tr.A 73.853).

to grip something. The front of the mandible is lifted to compensate for the anterior wear, which impedes occlusion, and the jaw has a tendency to rock when placed on a flat surface (Houghton 1977). It seems that reeds were held in the mouth to manipulate them in the process of weaving sieves and baskets, a worldwide practice (see Larsen 1985).

Statistical analysis of the jaw dimensions of the basket makers revealed them to be morphologically distinct from the rest of the Abu Hureyra mandibles. Not all of the mandibles that showed evidence of task related dental wear were sufficiently complete for measurement but a striking pattern did emerge that distinguished the basket makers especially from the bulk of the Neolithic sample from Abu Hureyra. All have a robust body of constant height, the mylohyoid line is parallel to the alveolar border, the ascending ramus is broad and has a strongly convex anterior border, and the coronoid process has a broad, double upper edge where the temporalis muscle is attached. This feature is also seen on jaws from Neolithic Nemrik, Iraq and Mallaha, Israel (Szlachetko & Zadurska 2006; Bocquentin et al. 2005). There are additional features especially in the gonial region that suggest that basket making at Abu Hureyra was a family based craft (Molleson 2006a).

Sharp edged grooves have been noted on teeth from Neolithic levels at Abu Hureyra (**Figure 2**). These compare best with abrasion of teeth caused by running threads over the front teeth described by Ravy et al. (1996). In spinning the fine thread may be habitually drawn across one or more teeth eventually cutting a sharp-sided facet especially if the thread has been created from plant fibre.

2. Passive pressure remodelling

2i. Pressure modification of bones

Passive pressure applied to the cranial bones of a newborn child can achieve permanent deformation in a matter of days. Manual manipulation, cradling boards or straps have all been widely used in the past (Dingwall 1931; Kiszely 1978; Molleson & Campbell 1995). Caps with a tight head-band were worn until recently by young girls to ensure an aesthetically pleasing round, symmetrical head-form (Billard & Simon 1995). Similarly the carrying of loads in a basket slung from a head-



Figure 3a. The straps of a cassie are taken over the arms, which are pinioned to the sides.



Figure 3b. Shoulder joint of Norseman. The scapula is impacted below the neck of the humerus (Orkney 69/67A).

band or tumpline can result in a shallow depression from side to side across the frontal or parietal bones of the cranial vault. This is often easier to feel than to see and can be palpated on the living.

Pronounced uncinate processes on the cervical vertebrae giving head support seem to be developed in those who carry loads on the head; inferior articular processes of the thoracic vertebrae are buttressed against the adjacent superior articular processes in those who carry heavy loads on the back or slung from the shoulders (Sofaer 2000); lower back loading that puts pressure on the sacro-iliac joints extends the sacral-iliac articulations (Kennedy 1989).

A deep radial fossa on the distal end of the humerus could result from the habit of carrying loads in a bag slung over the shoulder and held in place with the hand. The arm is tightly flexed at the elbow so that the head of the radius impacts above the distal epiphysis of the humerus.

The ultimate in this type of deformation has been found in a medieval boatman who, it is suggested, had to pull heavy boats overland by bearing on a strap placed across his chest and over his upper arms, which were thus pinioned to his sides. Boats until recently were often dragged overland between rivers and hauled upstream in this way (**Figure 3**). The bones of both upper arm bones atrophied and became hollowed out where the head of the scapula had impinged on the humerus shaft (see **Appendix 2i** from Molleson 2004).

(In rickets even body weight loading of the under-mineralized bones results in characteristic deformities e.g. angulation of the sacrum and bowing of the femora and tibiae, while obesity can result in changes to weight transfer resulting in knock knees and enlargement of the medial condyles of the tibiae and asymmetry of the cortical thickness of the femora).

2ii. Pressure modification of articular surfaces

a. Positions of rest. The pattern of torsion and squatting facets observed on hip and leg bones has been used to suggest a variety of sitting positions that might have been taken up by people in the Neolithic and more recent times (Molleson 2007a; see **Appendix 2ii**).

Despite the discovery of a seated figurine by James Mellaart in the 1960s (Mellaart 1962; 1967) it is almost certain that the Neolithic people of Çatalhöyük, central Turkey, did not normally use chairs but squatted or sat directly on the ground when at rest or to undertake



Figure 3c. A Norseman from Orkney has extreme modifications to his teeth, shoulders, wrists and knees (69.67A Medieval Period).

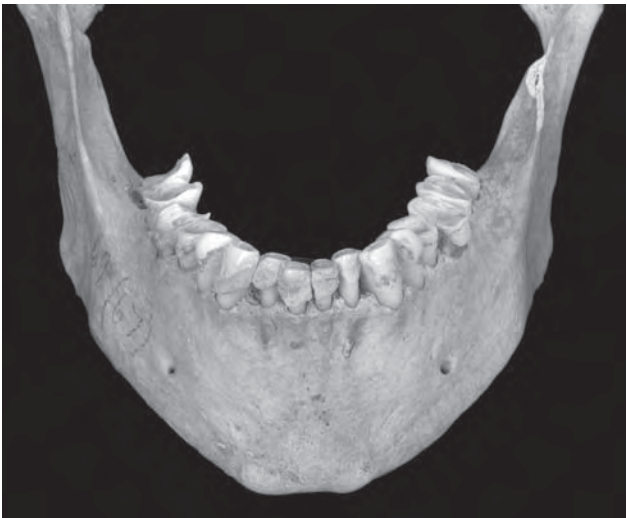


Figure 3d. The unevenly worn teeth of the Norse bargeman who grinded his teeth from the exertion needed to haul the boat (Orkney 69/67A).

various stationary tasks. In the hocker squatting position a squatting facet persists where the talus pressed against the front of the tibia (Huard & Montagné 1951); and the patella has a notch where it pressed against the end of the femur (Buchet 1989; Boule 2001). Squatting in human evolutionary terms is the natural position of rest and is adopted by most infants when they start to move about. Squatting with the heels together flat on the ground is a position that many adults these days who are used to sitting on chairs find physically impossible or at best difficult to maintain for any length of time but one which is comfortable for those who have the appropriate bone morphology—and who comprise most of the world's population.

Whilst positions will have varied according to the activity, there will have been a general tendency by an individual to revert to a preferred position. Some individuals will tend to an active position, balanced on their toes from which they can get up quickly, others with a more passive temperament or lifestyle would take up a more static position. Since these habits are established and may even be enforced in childhood and are held for long periods of time each day, putting continued pressure on the limb bones over a restricted area, the shape of the affected bones and articular surfaces will be modified.

It may be possible to infer preferred (or imposed) positions of rest from the morphological features of the leg bones, including long bone torsion, cross sectional shape, squatting facets, kneeling articulation and general asymmetry. Eight positions have been very tentatively identified and the expected bone changes predicted (Molleson 2007a, 2007b). Even though it will be impossible to test these predictions without reference skeletons from individuals of known habit we can at least postulate where the biomechanical forces will be and see if the expected patterns occur. The contrary effects of resting in the squatting or hocker position on the one hand and sitting cross-legged in the sartorial position on the other hand, are well known to orthopediatrics, and we should be able to identify them in skeletal material and thus infer preferred sitting positions (see **Appendix 2ii** from Molleson 2007a).

In the sartorial or cross-legged position lateral rotation of the femur is combined with abduction and flexion exceeding 90 degrees. The range of rotation depends on the angle of anteversion of the femoral neck, which is usually quite wide in the child. In the hocker position the wide angle of anteversion is maintained or even increased when children become accustomed to sitting with their heels pressed against each other and their hips flexed. This posture causes medial rotation of the femur and accentuates the angle of anteversion as a result of the great plasticity of the young skeleton (Kapandji 1987:12). Paediatricians encourage children to sit cross-legged or even adopt the lotus position to correct the rotation of the thighs, to avoid problems in later life. The Chinese have a very low incidence of hip osteoarthritis which has been related to a protective effect of squatting (Hoaglund et al. 1973).

Males at Neolithic Çatalhöyük were more likely to develop a notch on the patella (6 of 8) than were females (1 of 5). They also had large lateral or central squatting facets at the anterior distal articulation of the tibia or on the talus. If these traits are determined by posture, males at rest were most likely to squat either on their toes or with their heels flat on the ground. Females display a wider range of positions including squatting (Molleson 2007a). Their leg bones often have an asymmetrical development of features. The (comfortable) position taken up by an individual may relate to convention or to task. Body size may play a part but no trait was found to be strongly associated with stature.

The pattern of squatting facets, restricted in the men, varied in the women, must reflect the differences in habitual resting positions at Çatalhöyük. Men at rest took up a preferred position, sitting on their haunches, feet together flat on the ground. This squatting position

is one of the most ergonomically efficient; it is static and can be maintained for a long time. We can infer that men at rest at Çatalhöyük were at rest not doing very much except perhaps with their hands. In contrast the variety of squatting prints on the bones of women from Çatalhöyük must reflect less uniformity in their sitting positions through individual preference or the most convenient postures to accommodate the range of activities undertaken by the women (and girls). There is no indication at Çatalhöyük that girls were expected to sit in a given position as they are in some parts of the world today (where there may be specific words to describe particular positions; Huard & Montagné 1951).

Squatting facets aren't solely indicative of positions of rest. Evidence from the prevalence of strongly developed squatting facets at the ankle and knees of the majority skeletons from the site of a Medieval lead-silver mine at Brandes, France, demonstrated that the miners had worked in cramped kneeling positions (Bailly-Maitre et al. 1996). This observation was substantiated by the evidence from entheses for strongly developed muscles of the arm, hand and thigh; and was further substantiated by the analytical evidence for high levels of lead in the bones.

b. Restricted repetitive movement. The saddle quern when used to grind cereal grains is both labour intensive and, without adjustments, risky. At Abu Hureyra saddle querns were found in the houses placed directly on the ground (Moore et al. 2000). The operator would have had to kneel before the quern with her toes curled under—on to the upper surface of the foot. To grind the cereal she would drive the rubber over the grains pushing off from her toes, pivoting from her hips and knees. The range of movement is constrained by the need to be positioned close to the quern and puts pressure on the hip, knee and toe joints. The bending moments imposed between the hip and knee result in bowing and buttressing of the femur. The articular surface of the head of the first metatarsal is extended on to the upper surface of the bone; it is diagnostic of the kneeling position (Ubelaker 1979). The plantar surface of the head of the second metatarsal can become flattened through being pressed on the ground (Wood Jones 1944). Sometimes the grinder overshoot the saddle-quern resulting in injury to toes and back—specifically the 12th thoracic vertebra. The consequences are seen in crushing of the vertebra and traumatic osteoarthritis of the articular surface of the first metatarso-phalangeal joint (Molleson 1994). Not surprisingly a way was found to avoid the painful accidents and evidence for these lesions has not been seen in sites where the saddle quern has been placed on a plinth, as at Çatalhöyük (Mellaart 1962).

2iii. Mobility of the joints

Repeated uneven pressure on different parts of an articular surface may result in a division of the joint surface. The double occipital condyle which is observed in many of the workers from Spitalfields who were weavers seems to be associated with the repeated turning of the head from left to right and right to left to follow the shuttle (see **Appendix 2iii** for details). The Neolithic (c. 3000 BC) sample from Isbister, Orkney, is the only other documented sample in which a high incidence (30 of 83 condyles) of the anomaly has been recorded (Chesterman 1983:100). Here weaving is improbable. They are not associated with signs of head loading.

It is possible that double condyles of the talo-calcaneus joint, also seen at Isbister, relate to mobility of the ankle in those who walk over uneven terrains and would be less prevalent in those who wear fitted shoes rather than sandals. The stability of the calcaneus is a function of the surface of the subtentaculum tali (Kapandji 1987:170). A persistent separate acromion process of the scapula, one of the last epiphyses to unite, is associated with strain on the shoulder joint in such activities as climbing rigging by young sailors (Stirland 2000).

3. Biomechanics and musculoskeletal stress markers

Muscle attachments on bones are formed by the extension of the bone into the tendinous tissue of the muscle. They are reconstructed throughout life. In the young the bony ridges or entheses are less conspicuous and may even be represented by a depression or groove (Hamilton 1976:33; Lovejoy et al. 1976, 2002). With activity the entheses can become markedly rugose in response to the strength of the muscle action. Traumatic strain can result in tearing of the area of muscle attachment. Methods for scoring muscle impressions on bone have been developed (Hawkey & Merbs 1995; Robb 1998; Weiss 2004). Overall it seems best not to divide scoring of muscle impressions into too many stages unless the sex and age of the individual can be ascertained, since these two factors influence the degree of development of the impressions (see discussion in Mafart 1996; Lagier 1991). The effects of mechanical loading on different bones are discussed in detail by Pearson and Lieberman (2004). Their studies of the effects of exercise on the skeleton in different age groups showed that mechanical loading stimulates periosteal growth mostly prior to skeletal maturity. This is a major reason for concentrating on specialist activities that were initiated in the young. When bones function as beams the resulting form develops to resist bending, twisting and compression and the cross-sectional area often reflects this.

3i. Hunting

Human beings have caught, trapped and chased animal prey for millions of years. The various hunting strategies become deeply integrated into the social structure of society in ways that are characteristic of the method (Merbs 1983; Dutour 1986; Legge in Moore 2000). The morphological consequences of trapping at Abu Hureyra can be contrasted with running down animals at Nemrik (Molleson 2006b).

The human bones from Nemrik are characterised by a number of features not often seen at other sites of the same general period and by the absence of a number of features that are observed elsewhere. To judge from the development of the hypotrochanteric fossa on the femora of young and old, we see what must have been the enormous development of the attachment area of the gluteus maximus muscles on the femora. The gluteal tuberosity where the gluteus maximus inserts on the femur is often long and deep. Gluteus maximus is important in running and jumping more so than in walking. It is a major extensor of the thigh especially when the thigh is flexed as in rising from a forward flexed position and in climbing and running when the thigh is thrust backwards. It would develop as a powerful muscle in those who had to run down an animal, whether it was to be taken live or killed. Further, there is a general lack of any marked development of supinator crest on the ulna. This suggests that hunting with spears or arrows was not important. In fact there is a lack of spear straighteners or arrowheads in the lithic assemblages at Nemrik, but there are bolas stones. These can be used to ensnare animals alive. The increase in bolas stones implies a sudden increase in hunting activities or in catching live animals for domestication (Mazurowski 1997:163). The fauna at Nemrik comprises some sheep, cattle and pig but mainly antelope, all of which have been herded from time to time. Horse, deer, wild cattle, boar, beaver, badger, buffalo, jackel and panther are also present.

The Nemrik tibia is invariably strongly platycnemic and, where it could be observed, the proximal articulation with the fibula, which is a relatively robust bone, is well developed indicating that the fibula was a weight bearing bone, adapted to locomotion over uneven terrain. Tibias from Abu Hureyra are also platycnemic and it is possible that the side-to-side flattening of the shinbone can



Figure 4a. Pounding develops the arm and chest muscles (from Richards 1939).

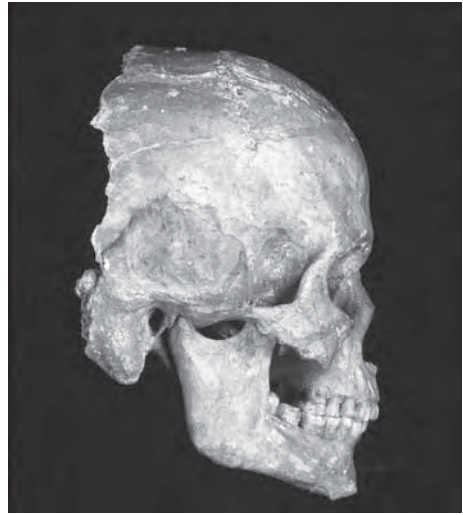


Figure 4b. Skull of C18 was buried with a large pounder. (Al-'Ubad, Iraq).



Figure 4c. The sternum and clavicle of C18 have large attachment areas for the pectoralis major muscles (2nd Dynasty, Al-'Ubad, Iraq).



Figure 4d. The anterior teeth of C18 are very worn, from clenching the teeth while pounding (2nd Dynasty, Al-'Ubad, Iraq).

result from rotational stresses imposed in running over uneven terrain, especially where shoes are not worn. The side-to-side flattening of the tibia would allow large flexor muscles of the ankle that attach between the tibia and fibula, to be accommodated (Lovejoy et al. 1976).

3ii. Load bearing

The Porters of Ur (see **Appendix** from Molleson & Hodgson 2000). Study of the extraordinary development of certain muscle imprints on some of the bones from burials in the Royal Cemetery at Ur, Iraq, has enabled us to suggest a probable occupation for some of the individuals. It was noted that several of the skeletons had extremely marked muscle attachment areas and it was suggested that these might offer clues as to the activities of the individuals during their lifetime. The muscles, which had been used so extensively, were noted and the activities, which might have led to such a change assessed. These activities were then compared with those, which were known to have taken place historically from the archaeological record so that some could be eliminated. We could then look more closely at the activities, which fitted both the changes in the skeleton and the time at which the individual had lived. Pathologies, joint osteoarthritis or enthesopathies, were not of primary consideration, since morphological modifications that develop in response to stresses imposed on the bones during growth are considered to be more reliable indicators of habitual activity.

A surprising number of the people appear to have laboured hard at very specific tasks that could be tantamount to employment or even slavery. The attendant PG1648d is one of a group of individuals whose occupation was probably similar to that of the porters shown on the Peace side of the Standard of Ur (Woolley 1934). If he used a head restraint as illustrated this would have encouraged an upright posture and effected the transfer of weight down the ventral aspect of the spine. Consequently, the sacrum is unusually straight and depressions (Schmorl's nodes) where the weight carried had caused the intervertebral discs to protrude into the bone are on the ventral sides of the centra of the lumbar vertebrae. The clavicles have large areas for attachment of the subclavius muscles and coraco-costo-clavicular and trapezius ligaments, which must have been particularly powerful, although the bones themselves are not especially robust, but blade-like. Despite, or perhaps because of, the headband there must still have been considerable muscular tension stabilizing the sterno-clavicular joint.

3iii. Muscular exertion

a. Pounding (see also **Appendix** from Molleson & Hodgson 2003). The woman C18 from Al-'Ubaid, Iraq, buried with a large pounder shows major expansion of the sternum and clavicles related to massive development of the pectoralis muscles (**Figure 4**). It is significant that it is the bones of the arms and chest that are distinctive in pounding not the legs and feet (they are not constrained). The sternum is also expanded in the cripple from Jericho. It is the muscles used whatever the activity that can result in bone modification not the activity *per se*, which can be carried out in different ways.

b. Rotary quern. There is potentially a differential development of insertion areas for the teres major and t. minor muscles on left and right humeri and scapulae in populations where cultural mores demand that the wheel of the rotary quern is always turned in the direction of the sun (D. Lorimer pers. comm.). The teres spur on the lateral edge of the scapula was noted by Hrdlička (1942). The teres muscles together with the deltoid, back and leg muscles are also important in rowing a boat. In rowing the strongest muscles of the thigh, the quadriceps

and gluteus maximus, power the initial drive when the boat is moving at its slowest; the back and arm muscles are more effective in the second half of the stroke. Marked asymmetry of the shoulder muscles can develop in oarsmen who habitually row on one side of the boat.

3iv. Ligamental strain

Horse riding (see **Appendix** from Molleson & Blondiaux 1994). In a rare documentation from cavalry records Joel Blondiaux established a number of traits, mostly on the femora, that characterize habitual horse-riders (Blondiaux 1994). These include hypertrophied ligament attachment areas around the fovea of the femur, the hypotrochanteric spur in the greater trochanter, as well as a pronounced linear aspera which supports attachment of the muscles that a rider uses to grip the back of the horse. These same traits were observed in femora from Bronze Age Kish, Iraq, thus confirming the pictorial evidence that equids were being ridden at this time. See Molleson and Blondiaux (1994) for discussion of the significance of the evidence for riding in Early Dynastic times. Subsequent work on bones from 19th century Spitalfields, London, has noted that degenerative joint changes occur on the medial condyle of the left knee: riders mount a horse from the left side.

At The Royal Cemetery of Ur, one of the burials has been identified as a chariot or cart driver from the evidence for pronounced attachment areas on the knees for the cruciate ligaments—a response to twisting and turning movements centred on the knees and extreme development of the calf or ‘bouncing’ muscles of the lower leg (Molleson & Hodgson 1993). He would have needed these muscles to balance on the back of the cart or chariot, as depicted on the war side of the Standard of Ur.

Evolution of social behaviour

Studies that demonstrate methods of hunting, load-bearing, food preparation and craft activities have established the value of bone morphology as a pointer to the role of the individual in past societies.

During the Neolithic the development of technology seems to have been driven by the needs of food production. Some consequences of the methods of production used are recorded in the physique and demography of the populations. At Abu Hureyra, the advent of agriculture during the Neolithic about 10,000 years ago, introduced large cereal grains into the regular human diet. The need to process these seeds to prepare the ‘daily bread’ imposed long periods of energetic movement of a restricted range on the operator, who would have started to perform these tasks from a very young age. The effects of stresses imposed on the joints and bones of the skeleton can be recognised in the distinctively altered morphology of the bones and in the patterns of activity related trauma. The new cereal grains had to be de-husked by pounding, then ground on a saddle quern. Sieves and baskets to sort and to contain the grain had to be woven from prepared fibres. Subsequently pottery was manufactured to cook the food. Ropes or cords had to be made for catching, leading and tethering animals and for binding mats and baskets. All are needed and their manufacturers often had defined roles sometimes at the domestic level, sometimes as specialist craftsmen.

Evidence for some of these task related morphologies is found predominantly on female skeletons. The use of the saddle quern is labour intensive, as much as five hours a day to grind a bushel (36 litres) of grain. By demonstrating that the first metatarsal is dimorphic between

the sexes it was possible to show that the majority of the toe bones that show the articular changes associated with kneeling are from females. Therefore, it can be inferred that most of the grain preparation at Abu Hureyra was carried out by women and girls. From the number and distribution of querns it is probable that each household prepared its own grain products. Thus there was a division of labour at the domestic level, with the females undertaking most of the grinding. From an early age daughters would become involved in the cycle of preparation, becoming identified with the female roles of the household, eventually to be buried within the dwelling which had been their domain in life (Molleson 1994; Wright 2000). Thus we can probably take the origins of gender-based roles back to the beginnings of plant production, all because the regular processing of plant products is obligatory; whereas there is circumstantial evidence from femur size that both sexes followed the hunt at Nemrik.

The tendency of girls to undertake the more sedentary tasks would have resulted in a lower energy output. This together with the change in diet towards a (somewhat) higher carbohydrate intake must have predisposed them to lay down fat reserves. The dimensions of the head of the femur is a good indicator of body weight in human beings since so much of the body weight is taken on these joints with each step taken. At Çatalhöyük (Level 6) the diameter of the head of the femur is almost the same in males and females indicating that body weight at the end of growth was similar in the two sexes; yet the girls were shorter than the boys. Thus girls must have been relatively heavier than the boys (Molleson et al. 2005).

At Abu Hureyra there is physical evidence for craft specialisation at a very early date. There are differences both in different parts of and during the Neolithic at this site. Basket makers and other specialists who worked fibres in the mouth were concentrated in trench A, the seed grinders in trenches B and E. Although these trenches are not fully contemporary with one another, the evidence for division of roles, specialisation and craft production so early in the Neolithic is important for our understanding of the development of the structure of society. The dental evidence for weaving and basket making is rare, presumably because the skills for these crafts were confined to a few people. Although not everyone would necessarily have used her or his teeth to manoeuvre the fibre there does seem to be conformity in the method of production over a wide, if not global, area. When the mouth is used to work the fibre mandibles have an enlarged development of the ascending ramus and coronoid process. These features are already present in the mandible of a five or six year old.

The presence of the juvenile (Tr.B 73.2127) aged about five or six years at Abu Hureyra displaying many of the morphological features of the basket maker jaw raises the question as to whether the traits are familial or acquired. If acquired, the traits must be the consequence of forces imposed on the developing jaw from a very young age and five years would not be too soon for a child to become involved in the family craft. The distinctive jaw morphology, if familial, links this group of basket makers from Abu Hureyra to similar mandibles from Wadi Halfa, Nubia (Greene & Armelagos 1972), Jebel Sahaba (Anderson 1968) and Ishango (Twisselmann 1958) and their presence in northern Syria at this time even raises the possibility of a tribe of specialist craftsmen. Once economic factors became relevant, craft specialisation might have been family based or restricted to a defined group, even caste.

The increasing complexity of society sees the emergence, alongside the trade systems of local agriculturalists, of controlled labour in increasingly urbanised societies with agrarian economies, religious and military institutions dominating the control of labour forces. While many of these issues are best examined demographically, the extraordinary development of certain muscle imprints on the bones from Bronze Age Ur, Iraq, has enabled us to suggest

a probable occupation for some. It implies that their activities were followed intensively, from childhood and for long periods and with little alternative exercise, a concentration that is seen today only among sportsmen and musicians but in the past would also have included slaves and client or bonded workers. This role specialization can be taken as reflecting the level of economic activity and urbanization of the communities at Ur. To help us here we have the unique evidence from pictorial representations of people performing tasks that can be directly related to the skeletons that we have to study. The 'Standard of Ur' shows the nation at Peace and at War and we have examples from both among the surviving bones in the collection.

Woolley noticed the continuity of activity from 5,500 years ago to the present day in the role of the porter, carrying large loads on his back, taking some of the strain from a headband, and still to be seen in the streets of Middle Eastern cities (Woolley 1934). Porterage was by many methods—the backpack with or without a headband; loads could be carried on the head or slung over the shoulder; and two porters might carry a load on a pole between their shoulders. Like the female, G48 AH, from Ur, carrying loads on the head is still the preferred method for women in many parts of the world. Men were occasionally depicted carrying loads on their heads e.g. at Khafaje (Early Dynastic III) on a wall plaque but of a decorative subject that must have occurred also at Ur (Lloyd 1984:115). That such depictions are not more frequent is likely to be for reasons of art composition—the inevitably taller figure distorts the symbolism of the pictorial narrative or must be represented as a very short person. Otherwise it would be tempting to assume that differentiation of an elite well fed and tall class from a labouring inadequately nourished and undersized class had been established 5000 years ago. Estimates of sexual dimorphism from bone dimensions would be a more reliable way of looking at such social differences (Molleson 1996). Physically many of the skeletons reflect the importance of human effort in everyday life. There is evidence of social organization and a stratification of society from the skeletal remains. Some of the skeletons do not appear to have undertaken much physical activity at all including unsurprisingly Meskalam Dug and Puabi, whose graves were richly furnished—evidence that should not be overlooked.

Sometimes even socially imposed rituals can be demonstrated. Daphne Lorimer identified the spur of the *teres minor* muscle on the scapula of several individuals from the medieval and earlier periods of Scotland. The attachment of this weak muscle could become hypertrophied where the left arm is required to turn in a clockwise direction, as would be the case in cultures that expect a rotary quern always to be operated in the direction of the sun's orbit. The equivalent movement with the right hand uses the stronger, larger *t. major* muscle (Hrdlička 1942; Lorimer pers. comm.).

Conclusions

Excavated human bones occasionally show modifications that can be interpreted as resulting from constrained activities carried out over long periods from a young age. The significant morphology is that which differs from the normal range for the population being studied.

Where possible the postulated interpretation of the skeletal morphology should be checked against independent evidence from other sources, cultural and environmental including fauna and plant remains. This can point to the direction of further research.

Many of the suppositions put forward in this paper need to be tested. Of course other interpretations of the bone morphologies observed are possible, that is the hazard of this type of

work. Perhaps all we can achieve is the identification of some remarkably energetic labourers who commenced their work at a very young age whilst the growing bones could respond to the pressures put upon them.

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Appendix 1

Task related dental wear (from Molleson 2006a). The strong crushing forces used in some task related activities involving the teeth can result in a modified mandibular form. These changes include enlargement of the head of the mandible. The human jaw joint has a structure inappropriate for stress bearing and the jaw closing muscles combine to ensure that all the muscle force exerted is effective at the teeth (Moore 1981:154). During incisal biting the mandible acts as a lever and condylar reaction forces are maximal. During powerful unilateral chewing the mandible is clearly functioning as a lever, the mandible head acting as a fulcrum, although when a food bolus is gently clamped during bilateral chewing neither head is acting as a fulcrum (Aiello & Dean 1990:100). It is evident that larger than normal condyles must be the result of abnormal forces exerted at the joint; such as the unilateral chewing required of cord makers who chew reeds first on one side then on the other in order to ret the fibres for cord making. Grinding chewing which follows the angle of the cusp surfaces can exert a force up to 750 Newtons (about body weight) with the second molars, but only 450 with the canines (Alexander 1992:136). Opinion seems to vary as to whether the greater force is on the side of chewing or on the counter-balanced side. Moore (1981:156) clearly indicates that the greater force (63:15) is on the counter-balanced side. And this is supported by the fact that those with a fracture of the condylar neck of the jaw find it easier to chew on the injured side (Dean & Pegington 1996:106).

Structurally the mandible has thickened bone between the oblique line and the mylohyoid line due to the tension stresses set up when teeth are clenched. The direction in which the teeth are thrust may explain the thickened bone on the inner side of the sockets and the lower border of the body (Hamilton 1976:80). Thus a deep residual sulcus in the anterior margin of the ascending ramus is formed between the temporalis attachment on the external side and a bony bar on the inner side. Where the medial pterygoid muscles, which attach to the inner side of the gonial region, aid in chewing first on one side and then on the other the inner angles of the jaw may be turned inwards.

The jaw of the basket maker has enlarged attachment areas for those muscles that act to close the jaws. The main chewing muscles are the masseters, the temporalis and the medial pterygoids. Where the protruded mandible is required to exert maximum crushing, the anterior part of the temporalis muscle is developed around the anterior border of the mandible and on the coronoid process, which develops a forward expansion and a double edge along the upper edge. This development is most often seen where the mandible is pulled forward

in order to carry out a task, including chewing leather, basket making, spinning thread. The ascending ramus is broad with large attachment areas for the masseter muscle on the lateral aspect. Together with the medial pterygoid muscle, which is attached to the inner side, the masseter produces bite. The greatest force is exerted when the teeth are in contact. The forces exerted by the basket makers must have been prolonged, as is to be expected in performing a task. The lower and upper (or superior) lateral pterygoids arise from the lateral pterygoid plate and from the greater wing of the sphenoid and insert on the neck of the mandible below the condyle. The lower lateral pterygoid draws the condyle forward in opening and in protracting the mandible; the upper lateral pterygoid closes the mandible. The lateral pterygoids do not appear to be modified in task related activity, presumably because they are not under any extra strain in pulling the mandible forward or back, the normal action. The action of the lateral pterygoids tends to pull the condyles together, with the resultant forces concentrated at the mandibular symphysis (Aiello & Dean 1990:81). Where the activity is concentrated on the anterior teeth, the chin and symphysis of the mandible seem to be raised relative to the body of the bone, the jaw is not stable when placed on a flat surface but 'rocks' (Houghton 1977). 'Rocker' jaws are seen in young individuals where the protruding action is applied but where the anterior attrition is still minimal.

Appendix 2

2i. Passive pressure remodelling

Norse Age Boatman (from Molleson 2004). The remains of a Norse Age skeleton, 69/67A, from Newark Bay, Orkney, comprise the skull and post-cranial skeleton of an old adult male. At 1.749m he was above average height for an Orcadian male of the time. His teeth are extremely worn especially on the back molars. In the lower jaw the second and third molars are more worn than the first. On both humeri there is a marked depression on the inner (medial) side below the humeral neck where the head of the scapula impacted against the shaft. The bone is extremely thin or missing altogether. This seems to be a constriction atrophy that can only have been made by pressure forcing the two bones together. Both arms are affected. The constant pressure of the edge of the glenoid of the scapula on the humerus shaft has led to a depression and loss of bone in the area below the humeral neck of both arms. Until very recently, the carrying of loads in a basket suspended from the back with the holding straps taken across the chest and over, rather than under, the arms was widespread in Europe, the Near East and North Africa.

Whether the degenerative changes to the man's shoulders resulted merely from carrying a cassie wasn't at all clear without the evidence of the dental attrition. The wear on the teeth is concentrated on the back molars, a reversal of the normal wear pattern. From this we can conclude that the teeth were subjected to something other than simple chewing, and that stress was exerted on individual molars. Tooth to tooth contact from clenching the teeth to fix the jaw during forced exertion would lead to attrition of the back teeth. This implies that some great force was required to achieve his task. Attrition can become extreme from clenching the teeth during sustained exertion, for example when using a hand screwdriver. The wear is angled because the clenching has a crushing action and there may be over-closure of the jaws causing wear on the cheek side of the lower molar teeth.

A possible explanation for the changes observed is that the man had hauled a boat with the hauling rope tied across the shoulders to add the weight of the body rather than just the strength of the arms. Formerly tens of thousands of burlaki were employed in dragging laden boats up the Volga River and its tributaries. The work of the burlaki or barge haulers was notoriously hard. Illustrated by Ilya Repin in the nineteenth century the haulers were linked to the boat by means of a strap that passed over the arms, which were pinioned to the sides of the body. It would take many continuous hours of intense hauling for the atrophy of the bone seen in the upper arm bones of 69/67A to develop.

2ii. Modification of articular surfaces

Positions of rest and squatting (from Molleson 2007a). Thomson (1889) was one of the first to describe the changes associated with squatting. Charles (1893) amplified the earlier work adding the effects of the sartorial position—sitting cross-legged. The extreme flexion of the knee is rendered easy by a greatly increased articular area of the upper surface of the internal condyle of the femur, which is received upon the internal condylar surface of the tibia and has a very oblique plane.

In the cross-legged (sartorial) sitting position lateral rotation of the femur is combined with abduction and flexion exceeding 90 degrees. The range of rotation depends on the angle of anteversion of the femoral neck, which is usually quite wide in the child. This leads to medial rotation of the femur. With time remodelling of the femoral neck leads to a more retroverted position (Kapandji 1987:12). During abduction the femoral neck impacts onto the rim of the acetabulum. In extreme flexion the antero-superior aspect of the neck comes into contact with the rim of the acetabulum and in some the neck at this point bears an impression just above the edge of the articular cartilage (Kapandji 1987:24). The sartorius muscle produces lateral rotation of the femur at the hip and flexion and medial rotation at the knee and can be seen as marked imprints on the hip and tibia.

In the squatting or hocker position, the legs are flexed upon the thighs and the thighs on the trunk; the heels are generally some distance apart (about the width of the buttocks or ischial callosities) and the toes turned outwards. In this posture the knee joint is in a state of extreme flexion associated with a certain degree of rotation of the femur. A backward curve of the external articular surface of the tibia is associated with extreme flexion of the knee. The ankle joints are also in a state of extreme flexion. Squatting facets present on the anterior surface of the distal tibia and upper surface of the talus are associated with the extreme flexion of the ankle. These facets are present in the foetus (Boulle 2001).

The heels and backs of the tibias support the weight of the trunk in the hocker squatting posture. From the talus the weight is transmitted to the inferior calcaneo-navicular ligament. Therefore the tibialis postici muscles will have more work to bring about support giving rise to an increase in antero-posterior diameter—platycnemia of the tibia. Aitken (1905) doubted the direct role of the tibialis posticus in creating a platycnemic (flattened side to side) tibia. Lovejoy et al. (1976) recognized that side-to-side flattening of the tibia would allow large flexor muscles of the ankle that attach between the tibia and fibula, to be accommodated.

Charles (1893) also noted differences in the hip. In squatting the head of the femur rests against the ischial portion of the acetabulum. The femoral head has a large articular area and the anterior-superior border forms a marked convexity—Poirier's facet. Allen's fossa, an im-

print on the anterior inferior medial part of the neck of the femur may also be present. These features, however, are not specific to squatting (Kostick 1963). Lamont (1910) described facets of the inner surface of the patella as being influenced by squatting.

2iii. Joint mobility

Double occipital condyle. The dominant role of the double occipital condyle and large mastoid process in the 19th century sample from Spitalfields was revealed by statistical analysis. It can be argued that the two traits are linked; they are each both developmental and functional traits.

At birth the occipital bone consists of four units, the basilar, two condylar and the squamous. The basilar unit includes the anterior parts of the condyles, the condylar units the posterior parts of the condyles. By the age of six years the four elements are united and form a single bone (Hamilton 1976:72). The occipital condyles support the skull on the spine.

Changes in posture during growth are accompanied by small changes in growth and remodelling within the cranial base. These changes affect the degree of cranial base flexion and also the position of the foramen magnum (Aiello & Dean 1990:213). Rotation of the occiput in one direction is associated with linear displacement of 2–3mm in the opposite direction and lateral flexion (Kapandji 1974:182). It is possible that repeated movement of this joint at a critical time in growth served to delay synchondrosis of the two halves of the occipital condyle (just as the metopic suture will remain open when there is intracranial pressure in infancy).

Large mastoid processes provide mechanical advantage for the two muscles that stabilize and rotate the head from side to side (Kapandji 1974:218ff; Aiello & Dean 1990:230). These are the sterno-cleido-occipito-mastoid, which is inserted into the superior and anterior borders of the mastoid, and longissimus capitis, which is inserted into the posterior border of the mastoid process.

The significance of the double occipital condyle and the large mastoid process in the Spitalfields sample can be understood in terms of a functional response to habitual behaviour from an early age; in much the same way that the sutural ossicles respond to stress induced by artificial cranial deformation of skulls (Konigsberg et al. 1993).

The majority of the occupations identified in the named sample at Spitalfields were associated with the textile industry (Molleson et al. 1993). Many of the men (and some women) were journeymen weavers or Master Weavers who would have started weaving in childhood. They would have worked 12-hour days, six days a week (Molleson et al. 1993). Inevitably their head movements would have followed the shuttle as this was thrown repeatedly from right to left and from left to right. It seems just possible that this arduous and lengthy activity influenced the growth of the cranial base.

Appendix 3

3ii. Biomechanics I

Porters of Ur (see Molleson and Hodgson 2003). Attendant PG 1648d is the skeleton of a mature adult male. It includes parts of the cervical, thoracic, lumbar and sacral vertebrae; the clavicles; fragments of scapulae and pelvis. All long bones are represented and the bones of the hands and feet. Both patellae are present.



Figure 5. Attendant PG 1648d from Ur, Iraq. The bone morphology is consistent with the strain of carrying heavy loads on his back (from Molleson & Hodgson 2000).

The vertebral bodies of C6–C7 and T1 are large; the uncinate processes are not pronounced and the neural arches are rather gracile; C6 is slightly crushed. In the lower back T12–L5 are present and fairly complete. They show marked degenerative changes: degenerative changes

are present in the bodies and there are additional arthritic changes along the proximal ventral margins of T12–L4 indicative of disc damage. There are arthritic changes to the proximal joints of L3. The sacrum is very straight. These changes to the spine could be the result of carrying loads persistently from adolescence.

The clavicles are robust and have especially deep grooves for insertion of the subclavius muscles. The impression on the conoid tubercle and trapezoid line for the clavicular ligament and for the coraco-costo-clavicular ligament is also marked. If a heavy load is carried on the back, it tends to pull the scapula away from the clavicle. The trapezoid ligament stabilizes any strain on the acromio-clavicular joint and the costo-clavicular ligament similarly stabilizes the sterno-clavicular joint.

The humerus is robust, with well-developed deltoid impressions. The two ulnas, two radii, and the carpals have a slight lipping of the articular surface margins. The metacarpals of the right hand are complete. The head of the IInd metacarpal is deflected towards the palm. The bone is robust with particularly marked insertions for the 2nd palmar interosseus and the 1st dorsal interosseus muscles, so that there is a ridge between the two on the palmar surface. On the IIIrd metacarpal the 2nd and 3rd dorsal interosseus insertions are also marked. The head of MCI (the base of the thumb) is flattened and the proximal phalanx has a marginal tubercle for the adductor pollicis muscle. This combination of features suggests that the hand was used for gripping—with the fingers splayed—perhaps the straps holding the pack to relieve the weight on the back.

The femora are robust and each has a strong torsion of the head relative to the distal condyles, so that it is anterior to the knee. This form, in bearing a heavy load, would ensure that weight transfer was vertical from hip to knee if the knees were slightly bent. The insertions for the medial and lateral heads of the gastrocnemius muscle are pronounced on the femora implying well developed calf muscles used in flexing the knees when walking.

The pattern of ligament and muscle development observed on the bones of PG 1648d would be those of one who had to carry loads on his back. We have a pictorial representation of such a porter on the “Peace” side of the Standard of Ur where there is depicted a man carrying on his back a great bundle which, like a Stambul porter, he supports by a band across his forehead (Woolley 1934:273). It is therefore possible that PG1648d could have been one such porter.

3iii. Biomechanics II

Pounding (from Molleson & Hodgson 2003). Skeleton C18 comes from al-'Ubaid, about four miles from Ur, Iraq. Woolley noted in his field notebook that the bones of C18 were fairly well preserved; that there was a large spindle whorl of green stone (later identified as pottery), and behind the head a rough stone pounder almost a cube (BM Ms).

The relatively complete skeleton is probably that of a robust mature adult female. The skull is unusually well preserved and most of the teeth are present. The pattern of wear is strange; it is much heavier on the upper teeth, especially on the lingual side of the anteriors; the dentine is more worn than the enamel so that the surface of the tooth is scooped out, and an incisor and two molars are chipped. Strong development of the insertion areas for the masseter, temporalis, buccinator and anterior belly of the digastric muscles give the jaw a masculine appearance. These muscles are involved in closing and opening the jaws. The styloid is long and robust. The hyoid bone with greater horn and ossified hyoid cartilage are preserved. Muscles between the hyoid and styloid are involved in stabilising the jaw in a fixed position when the weight of the body is required to exercise force on an outside object.

Most of the vertebrae are present and reveal a spine with unusually large lower thoracic vertebrae and rather narrow lumbar; the first two vertebrae of the sacrum are cleft. The clavicles both have a remarkably broad area for the attachment of the clavicular part of pectoralis major muscle and the sternum is unusually wide, presumably to support a large sterno-costal part of this muscle. The muscle insertion areas on the humeri for this muscle are well developed. As a whole the pectoralis major takes an active part in the movements of adduction and medial rotation of the humerus, but the activity is only marked if resistance is to be overcome—as when using a pounder? On both ulnae the supinator crest is pronounced and extends to merge with the interosseus border. The supinator muscle rotates the radius, so that objects, which may be heavy, can be picked up with the forearm pronated; the more powerful supinators can lift an object against gravity.

The femora have strongly developed *linea aspera* for the adductor muscles; and there is a clear Allen's fossa on the superior border of the femoral neck. The tibia does not have a squatting facet. Both the first metatarsals have extended articular surfaces associated with kneeling.

So we have a picture of this strong woman, energetically and with teeth clenched, working away with the heavy pounder that was found in her grave.

3iv. Biomechanics III

Horse riding at Kish (from Molleson & Blondiaux 1994). Fifteen femora from Early Dynastic and later levels at Kish, Iraq were examined for traits that have been associated with habitual riding. No attempt was made to distinguish between the characteristics of horse and other equid riders.

Four of the femora from Kish have a strongly developed *linea aspera* indicative of strong adductor muscles. Two of these also have pronounced areas of insertion of all three gluteal muscles, but especially *gluteus minimus* and *g. medius* on the greater trochanter; and one has a distinct spicule in the trochanteric fossa. The trochanteric spicule is an enthesis at the insertion on the medial aspect of the greater trochanter of the *obturator internus*, a muscle important in the lateral rotation of the thigh, a position taken up with force during riding (Blondiaux 1994). The *obturator interna* and *gemelli* muscles are placed under strain when the thigh is flexed and rotated laterally as in sitting on the back of an equid.

The *adductor longus* muscle, which inserts in the mid-shaft region of the *linea aspera*, adducts the thigh at the hip, and ensures that the rider maintains his seat on the animal's back. Riders often sustain an injury to the *adductor longus* ('rider's strain'). Riding always throws great strain on the adductor muscles, at no time more than when a horse refuses a jump or stumbles, or throws the rider out of the saddle. The rider makes a reflex gripping action, the adductors are put under sudden additional load and the weakest of these is likely to give way. Three conditions follow: traumatic periostitis, chiefly at the attachment of the tendon of the *adductor longus* to the ischial ramus; tendon-muscle strain of the *adductor longus*; and rupture of the muscle-belly of *adductor longus*. These strains would be frequent among equestrians who had to ride, without stirrups, a mettlesome animal.

Two of the femora from Kish have well marked iliac impressions (Poirier's facets) on the anterior aspect of the femoral neck. Poirier's facet develops where the femur abuts against the rim of the acetabulum (iliac impression) as also in sitting cross-legged.

Whilst any one of these features might result from a variety of activities, the association of the three, trochanteric spicule, gluteal and adductor development, would seem to result from habitual

riding. Only one of the Kish femora, from a tall male, displays all three traits. It also has a marked development of the adductor tubercle for insertion of the tendon of the adductor magnus muscle, which may be important in medial rotation of the thigh. The area of attachment of the medial head of the gastrocnemius muscle on the popliteal surface is pronounced. This muscle flexes the knee.

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In these days of internet access no attempt has been made to provide a complete bibliography and what follows is frankly idiosyncratic and overloaded with my own publications simply because I can most easily quote at length from them.

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