Biological diversity of children who died during the perinatal period and funerary treatments in the Classic Kerma period

The examples of the necropolis 8B-51 (Classic Kerma, Sudan) and the cemeteries of Blandy-les-Tours (XIth-XIIth centuries, France) and Provins (XIIIth-XVIIIth centuries, France)

Despite high infant mortality rates in past populations, children have often been neglected in bioarchaeological studies. Under-represented in archaeological record, they were considered unimportant for the understanding of ancient societies. Over the past decade, however, there has been a growing scientific interest the archaeology of early childhood, with both new feminist (Halcrow and Tayles, 2011) and archaeothanatological (Duday et al., 1990) approaches. The relevance of studying children was therefore revealed on two scales. At the individual level, the analyses aim to offer an approach to the short life trajectory of the subject in order to understand her/his place in the community from which s/he comes. At group level, the child is now recognised as a potential proxy for the environment in which s/he has developed (Halcrow and Tayles, 2011; Han et al., 2017; Lewis, 2017b; a).

This long-term scientific marginalization is particularly true for those who die during the perinatal period. It has led to a double observation, the first being the lack of metrical and non-metrical reference data, as well as the lack of dedicated study methods. Biological analyses of newborns continue to focus primarily on estimating age-at-death. They are based on the publication of new reference works on the osteology of immature subjects, including Scheuer and Black (2000) and its second edition (Cunningham et al., 2016), as well as on the reliability of age estimation methods, which are defined more precisely due to rapid longitudinal growth during the perinatal period (Corron, 2016). However, these methods remain highly dependent on the reference populations from which they were developed, while their applicability in a sample other than the one used for its construction remains questionable (Sellier et al., 1997; Guihard-Costa, 1998; Tillier, 2005). These growth standards are also based on the assumption of low inter-individual variability in developmental trajectories, which does not take into account the effects of the multiple factors responsible for the diversity of this age group (Guihard-Costa et al., 2000). The lack of data on osteological variability thus represents a substantial limitation for both the adjustment of age estimation methods for application to multiple and variable groups and for the further development of individual and population biological analyses. Despite the rise of obstetrical sciences, small-scale skeletal variability of individuals around birth remains poorly documented. Therefore, unlike adult biological analysis, neonatal studies rarely include comparisons of individual or population variability as a major component.

Distinguishing between the remains of a stillborn and a liveborn infant thus remains very difficult. Age estimation based on diaphyseal length is not a sufficiently sensitive indicator due to variations in full-term stature (Bruzek et al., 1997). Methods reflecting both the health
status of the deceased individual in this age group and the state of vitality at birth are rare. However, stillbirth, as well as post-natal survival time in the event of a live birth are particularly sensitive criteria in relation to the status of the child as an individual in his or her own right in current as well as past societies. The identification of estimators of morbidity, mortality and vitality remains at the forefront of bioarchaeological research because the resulting differences in funerary treatment based on these factors may differ substantially.

It is in this context that the interest to investigate the subject of metric and non-metric biological diversity of the perinatal period has emerged. This doctoral research explored three research themes.

- The first theme aimed to characterise the intra-individual, inter-individual, and population variability related to age-at-death.
- The second theme aimed to identify characteristics that can be used to estimate the state of morbidity and of vitality at the birth of the individual. The purpose of these analyses was to provide answers to a current question, namely whether it was possible to estimate, on the basis of a macroscopic examination of bone remains, whether the individual has undergone postpartum survival or whether his or her health status could contravene it.
- From an application perspective, the results of these biological analyses were cross-referenced with archaeological contextual data from one of the sites studied, necropolis 8B-51 on the island of Saï (Sudan) in order to assess the funerary treatments and social status of the immature dead in one of the greatest civilizations of ancient Africa, the Kingdom of Kerma.

**MATERIAL AND METHODS**

This research concentrated on individuals who died between 22 and 48 amenorrhea weeks from two samples, one archaeological and the other composed of 3D scans of a hospital sample.

The first sample consists of 116 fetal and neonatal skeletons and is one of the largest archaeological samples of this age group found to date. It includes individuals from the 8B-51 Classic Kerma cemetery from the Nile island of Saï (1750 BC), and from two medieval and early modern French cemeteries from the Paris Basin (Blandy-les-Tours and Provins) dating from the tenth through eighteenth centuries. The three collections were excavated using the detailed recording of the remains and their burial context through the application of archaeothanatological techniques (Duday et al., 1990).

As the research methods developed for adults cannot be directly applied to immature individuals, a study protocol dedicated to this age group had to be developed. Because of the high growth rate that characterises the perinatal period, age estimation was a key methodological focus of this research. After a bibliographical review of age estimation methods applied to immature individuals, Sellier’s (1993) revision of the formulae from Fazekas and Kosa (1978) published in Schmitt and Georges (2008) was adopted. These formulae provide
age estimates based on diaphyseal length, still the most widely applied skeletal growth indicator for this age group. The study protocol employed nearly 200 measurements, as well as 30 discrete anatomical variants (or “non-metric anatomical variations”, either bone or dental phenotypic variations that are not of pathological origin (Berry and Berry, 1967), and four maturation indicators (markers of the different stages of progression to the mature stage), both traditionally used and others newly proposed as a result of this research, in analyses. Repeatability and reproducibility were tested for each measurement.

Several metrical and non-metrical analyses were performed on the archaeological sample, including:

- **Analysis of anthropometric indices**: Some 29 anthropometric indices (relative proportions between two or three dimensions, e.g. diaphyseal robustness) were calculated in order to statistically analyse morphological variability by population and for age-at-death determinations. They constitute an "additional tool for comparison" (Garcin, 2009, p.127) by excluding to a certain extent differences in scale between individuals (Métairie, 2014).

- **Analysis of fluctuating and directional asymmetries**: the adaptation of existing statistical protocols made it possible to assess the extent and statistical significance of right-left asymmetry. Previous research has suggested that directional asymmetry (preferential expression of a characteristic on one side rather than the other) could be a signal for preferential lateralisalisation, the origin of which is still a debated issue (Van Dongen et al., 2010). Fluctuating asymmetry (random expression of a characteristic on one side or the other) is usually perceived as reflecting disturbances in developmental stability (Van Dongen and Gangestad, 2011). Their analysis could make it possible to assess the in utero impact of early environmental stress. To our knowledge, this research was the first to assess the asymmetry of a large number of variables (n=106) in this age group from an archaeological context.

- Macroscopic and Micro-CT analysis of an original discrete dental character, namely a perforation in the enamel of tooth germs of maxillary incisors discovered in the Moustier 2 Neandertal neonate and in two of the individuals in the Sudanese sample. The identification of this feature and the discussion of its aetiology raise the question of the origin of discrete characters

- An initial approach to the variability of muscle insertions (entheses) in subjects who died around birth, with a focus on the enthesis of M. biceps brachii in the proximal diaphysis of the radius.

- A bioarchaeological study of the Sudanese necropolis 8B-51 in order to study the social status of the newborn through their differential funerary treatments in comparison with the treatment dedicated to older children and adults in the Classic Kerma period.

The second sample is virtual and consists of 364 pre- and post-mortem medical 3D CT-scans acquired at the Hôpital de la Timone (Marseille, France). Most of the examinations were performed during pregnancy following a suspected disease or developmental disorder, with
40% of subjects dying in utero or ex utero before 48 amenorrhea weeks. The collection included individual and medical information rarely available in biological anthropology (age-at death, sex, presence of pathological conditions, etc.). Non-metrical observations were made on isosurfaces (three-dimensional representations of scan data) with the software Avizo Fire 8.1©.

Several non-metrical analyses were performed on both archaeological and virtual samples, including:

- Discrete anatomical variant analyses and evaluation of the reliability of various age-dependent indicators. While discrete characters are frequently studied in adults in biodistance studies of the biological relatedness between individuals and populations, they are not systematically studied in immature individuals

- Frequencies and documentation of morphological variability of supernumerary cervical ribs, which are present in only in 1% of adults, are very frequently observed in the Sudanese collection and in the virtual sample. This characteristic had not been documented previously in an archaeological context for individuals who died during the perinatal period. Although there is no archaeological series of immature subjects documenting a high frequency of cervical ribs, the results of the excavations of necropolis 8B-51 on the Island of Saï made it possible to provide previously unpublished data on their occurrence in an archaeological sample. The elements had been recorded in situ for each of the 64 immature individuals from the sample. For the Marseille series, the elements were also recorded for each individual on the left and right sides. Frequencies in this modern sample were analysed within the context of medical history, including first and foremost information on cause of death, in order to investigate their association with poor health status.

All statistical tests were made on the free software Past3 or R3.4.

MAJOR RESULTS

I. General biological diversity

I.1. Intra-individual (right-left) variability

Symmetry is, in biology and for some organs, a never-achieved mathematical ideal because of the actual conditions under which organisms develop (Palmer and Strobeck, 1986; Palmer, 1994, 1996; Storm, 2010). The organismal phenotype is a constant compromise between its ability to maintain optimal development - homeostasis - on the one hand, and the physiological constraints it undergoes on the other hand (Palmer and Strobeck, 1986, 2003; Palmer, 1996; Storm, 2010). Under sub-optimal conditions, the stability of development, which is genetically programmed, is confronted with multiple disruptive factors, both endogenous and
exogenous. These include physiological stresses, environmental and cultural stresses, developmental pathologies and abnormalities, as well as genetic predispositions (Palmer and Strobeck, 1986; Palmer, 1996; Storm, 2010).

These disturbances, whose action seems to be antagonistic to development stability, are at the origin of part of the phenotypic variability. They are assumed to manifest as random deviations, called fluctuating asymmetries, for example in dental or bone tissues (Albert and Greene, 1999). This phenomenon has been widely studied in organismal biology and, in particular, in animal models, paving the way for the question of its interest in biological anthropology and in particular their identification in dental tissues (Perzigian, 1977; Saunders and Mayhall, 1982; Kieser et al., 1986). Fluctuating asymmetries, used as a "fitness proxy", a signal of individual "genetic quality" (Van Dongen et al., 2009), have since been considered an effective tool for studying the developmental constraints applied to past populations (Van Valen, 1962; Palmer and Strobeck, 1986; Storm, 2010; Van Dongen et al., 2010; Ten Broek et al., 2017). The purpose of these studies is to assess the degree of developmental instability of a population based on the extent of fluctuating asymmetry found amongst its members. These are then studied to find correlations between this instability and exposure to stress in particularly adverse environmental conditions (Livshits et al., 1988; Klingenberg, 2015).

Another type of asymmetry, directional asymmetry, appears to be related to lateralisation of the neurological system, responsible for preferential lateralisation (i.e. handedness) in humans, which results in differential use on the left and right sides of the body (Van Dongen et al., 2010). The question of the ontogenetic origin of this preferential lateralisation and its identification from the fetal stage was raised very early in the scientific literature (Schultz, 1923), but remains open to discussion. Directional asymmetry is believed to have a partial genetic origin (Palmer and Strobeck, 1986, 1992), but is not an indicator of developmental instability.

Two main reasons have led to investigation of both directional and fluctuating asymmetries. Although conventional protocols have been applied to archaeological series of adults, there have been no previous bioarchaeological studies that assessed the extent of these asymmetries in a sample of individuals who died during the perinatal period. Previous studies have mainly focused on analysing asymmetries of a small number of variables such as maximum diaphyseal long bone lengths (Van Dongen et al., 2009, 2010; Bots et al., 2011, 2015). The methodological question of the applicability of study protocols to a sample of this type (small in size, large in fragility and potentially altered by taphonomy) therefore remained an open question to which to apply the protocol developed as part of this research. Analyses on the metric database collected as part of this research afforded the opportunity to explore the presence of asymmetries on a greater number of variables and not limited to maximum long bone lengths.

(i) Question 1 addresses the question of the presence or absence of asymmetries (directional and fluctuating) in the archaeological samples of individuals who died during the perinatal period by way of a large number of variables using classical statistical protocols for the study of archaeological series.

(ii) Question 2: by acknowledging the link between fluctuating asymmetries and developmental disruptions, the objective of the second question was to examine the
presence of population differences between the Kerma and medieval samples, reflective of heterogeneous health conditions and environmental pressures experienced by the members of the two samples.

Results of analyses showed very low directional asymmetry, this being most often limited to the width of upper limb bones and, with the exception of the radius, to the maximum length of the long bones. These results are consistent with those of the study by Van Dongen and collaborators (2010), which did not identify directional asymmetry for diaphyseal lengths. These results therefore support the hypothesis that there is no preferential lateralisation of the skeleton (potentially reflecting the fact that a person is left-handed or right-handed) in the perinatal period.

Twenty-eight variables were also identified as expressing significant fluctuating asymmetry. From a methodological point of view, these results indicate that the search for and identification of asymmetries in the skeleton is possible in practice. These results also indicated that it is possible to identify the variables most likely to express this type of asymmetry, which opens up perspectives for comparison with other archaeological series. From a biological point of view, several new elements can be highlighted when placed in the context of previous work. Results indicated that asymmetries of both types not only characterised the maximum diaphyseal lengths of long bones, but also were sometimes even more pronounced in the other dimensions. They showed that these asymmetries were particularly identifiable in the elements of the upper limb. Compared to the results of previous studies on certain maximum diaphyseal long bone lengths, the results of this study results showed highly marked (up to nearly 7%) fluctuating asymmetry of dimensions of the bone elements other than length, and in particular in those of the upper limb.

The second question addressed in this research focused on the interpretation of these random right-to-left deviations. Based on the generally accepted causal relationship between developmental disorders and the emergence of fluctuating asymmetries, the existence of a difference in the extent of asymmetry between the Kerma sample and the medieval sample was investigated. Only a few variables were found to be statistically significant, suggesting that there are no real differences in the level of fluctuating asymmetries between the two samples. Because these results do not support the existence of a difference in environmentally-mediated developmental disruption between the two populations, it is hypothesised that fluctuating asymmetries reflect the expected extent of intra-individual variability in these population samples.

I.2. Inter-individual and age-related variability

As expected in this age group, results from both metric and non-metric analyses revealed variability correlated with age-at-death. This is the case for many relative dimensions between bone segments of the upper limb and the pectoral girdle, as well as for the robusticity indices of the lower limb, which vary linearly with age. These dimensions reflect the morphological changes produced by longitudinal and transverse growth processes. For example, the relative
width of the proximal end of the clavicle varies with age-at-death, while the relative width of the distal end better reflects inter-individual variability.

The inclusion in the sample of very premature individuals enabled documentation of another aspect of this diversity related to age-at-death, also identifiable in terms of anthropometric indices. Two indices of relative proportions, the IH2 humero-femoral index and the IF5 inter-membral index are characterised by significant variability in very premature individuals, while the indices observed in newborns show a high degree of homogeneity. These morphological changes between the age classes of very premature individuals and those who died around full-term could reflect the existence of a variability depending mainly on individual factors in the early stages of pregnancy (fetal or parental genomes, maternal physiological characteristics, etc.), preceding the progressive acquisition of a "standard biometric model" around the full-term period.

### I.3. Inter-population variability

The results of this study showed the existence of inter-population variability early in the perinatal period in certain anthropometric proportions, particularly for robusticity indices and proximal and distal long bone diaphyseal diameters. Individuals from Kerma therefore seem to be "thinner" (more gracile) than medieval individuals, whose skeletal architecture is more robust. Variability between populations could be observed in the same way for some non-metric characteristics.

### I.3. Intra-population variability

Several arguments supported the hypothesis of greater biological relatedness among the members of the Kerma sample compared to those of the medieval sample. For several anthropometric indices, and in particular the relative dimensions of the proximal segments of the upper limbs, the extent of variability (represented by the ends of the boxplots) is greater in the medieval sample (Figure 1). Diversity was greater in the Kerma sample for only a single relative dimension, the distal tibial width index (IT5).

The results of the non-metric analyses also supported the hypothesis of greater biological variability in the medieval sample compared to that of the Kerma sample. If several discrete characters have higher frequencies in the Kerma sample, with the characters such as the perforation of the tooth germ and supernumerary cervical ribs can be considered as specific indicators of biological relatedness. With regard to the perforation of the tooth germ, even in the context of a mechanical disturbance of ameloblastic activities, the recurrence of the character at the same location in three different individuals is an argument in favour of a strong biological relatedness, especially since the processes of dental tissue development are identified as being highly canalised and thus closely related to genetic predisposition. The presence of numerous supernumerary cervical ribs also indicates significant biological relatedness of the
individuals in the Sudanese sample. If this high frequency reflects the presence of genetic developmental abnormalities, these may be due to reduced genetic diversity in this group.

Figure 1. A: proximal width index of the humerus IH4, B: proximal width index of the ulna IU2, C: proximal width index of the radius IR3; D: distal width index of the radius IR4; E: proximal width index of the tibia IT4, yellow: Kerma individuals, red: Medieval individuals

A series of arguments has therefore made it possible to support the hypothesis of strong biological relatedness among individuals in the Island of Saï sample, a close biological relatedness that could be explained by several competing hypotheses. First, it is possible that the subjects come from a homogeneous group, potentially isolated from a more diverse population. This case can be encountered in the context of a system operating with several social classes, some of which may be endogamous. Bioarchaeological analyses of the cemeteries of the City of Kerma and the Island of Saï have shown the existence of a social hierarchy structured around an elite from the Early Kerma period (Gratien, 1985; Bonnet, 2000). This hierarchy is reflected in the form of funeral superstructures attributed to certain individuals (Testart, 2004). In this context, it is possible that the immature individuals of necropolis 8B-51 come from a potentially endogamous local elite, the practices of which could have promoted a decrease in genetic diversity, the appearance of developmental anomalies, and an increase in infant mortality. The second hypothesis potentially accounting for the close biological relatedness of those in the Kerma sample is that of an overall reduced diversity of the population itself. Several factors such as the insularity of the environment or relative isolation from the city of Kerma may have contributed to the reduction of the biological diversity of the group. Future genetic and genomic studies would be interesting to apply to document both the genetic diversity of the group and potential endogamy within this elite group.

The medieval sample appears to have a higher biological diversity than the Kerma sample, diversity mainly identifiable from anthropometric indices. Again, several hypotheses can be levelled to explain this higher variability, the first being related to the origin of the sample. From the 10th century onwards, the region of Provins became a commercial crossroads
on a European scale with significant population flows, a factor that could have strongly promoted local biological diversity. Another hypothesis explaining this greater diversity is related to the time interval covered by the two series, between the end of the 10th and the 18th centuries. It is indeed possible that the variability observed for some relative lengths may reflect secular biometrical variation. The biological study of a larger number of individuals would make it possible to address the latter hypothesis, while the existence of greater diversity could be revealed, again, by genetic and genomic analyses.

II. Vitality

II.1. Anthropometric indices, a possible indicator of the intrauterine period?

According to the results of anthropometric analyses carried out on the archaeological assemblage, some relative dimensions depart from the regression line around the theoretical full-term period. This is particularly the case for the humero-femoral index (IH2), which corresponds to the maximum length of the humerus in relation to the maximum length of the femur. After showing high variability in the sample among individuals aged 22 to about 33 amenorrheic weeks, the ratio between the two dimensions tends to stabilise until the end of pregnancy, before decreasing in the early stages of life ex utero (Figure 2).

![Humero-femoral index distribution IH2 based on estimated ages-at-death](image)

*Figure 2. Humero-femoral index distribution IH2 based on estimated ages-at-death, yellow: Island of Sai, green: Provins, blue: Blandy. Red ellipse: variability of the 5 subjects under 33 amenorrheic weeks of age, arrow: inflection point*

By discussing these results in the light of previous work, it can be hypothesised that this trend observed at the end of the period of theoretical full-term (greater growth of the femur compared to the humerus) could correspond to a modification in the growth trajectory of this relative dimension, produced by the transition from an in utero environment to an ex utero environment. Individual growth kinetics is, in fact, the subject of a conflict between paternal genetic pressure to ensure that the subject is born as tall as possible and a maternal phenotypic pressure to maintain dimensions compatible with childbirth. After birth, since the individual is
no longer subject to maternal regulatory pressure, he or she can then continue to develop according to his or her genetic heritage and living conditions (health status, nutritional intake, etc.). The greater growth of the femur relative to the humerus could therefore reflect the new growth dynamics of a skeleton no longer subject to the restrictive constraint of the maternal uterus. It could therefore be a signal of live birth.

II.2. Mechano-sensitivity of entheses, a way to identify live birth?

Entheses are the “areas of insertion into the bone of ligaments, tendons and capsules” (Claudepierre and Voisin, 2005, p.34). Osteotendinous attachments make it possible to ensure motor functions (Benjamin and McGonagle, 2009; Thomopoulos et al., 2010). The morphology of these insertion regions changes from the fetal stage to the death of the individual according to a large number of factors acting continuously or punctually (Bertram and Swartz, 1991; Ruff et al., 2006). These regions are thus described as “a self-designing system where morphology is dictated by the influences of mechanical load” (Benjamin and McGonagle, 2009, p.520). The remodelling of these regions is a major focus of behavioural research in biological anthropology (e.g. Wood Jones, 1910; Dutour, 1986; Villotte, 2008). The fact that these "entheseal changes" (Jurmain and Villotte, 2010; Villotte and Knüsel, 2013) may reflect repeated muscle recruitment leads them to be used as "proxies" of individual mechanical environment (Ruff et al., 2006), or even to be considered as markers of habitual activities (e.g. Trinkaus et al., 1994; Ruff et al., 2006; Villotte, 2009). Although frequently included in the biological study of adults, observations of muscle insertions and cortical surfaces of children remain poorly addressed, resulting in a lack of data as well as methods for their study.

In order to address the issue of the variability of muscle insertion sites of individuals who died during the perinatal period, an exploratory study focusing on the region of the bicipital tuberosity of the radius was undertaken. This anatomical region is the focus of study because it presents significant morphological variability in the archaeological sample, and because its development is particularly the subject of debate in the scientific literature.

This study had two objectives:

(i) biological objective: document the macroscopic morphological variability of an enthesis under maturation as a function of estimated age-at-death and population factors in order to question the developmental origin of this diversity,

(ii) methodological objective: in the absence of enthesis analytical methods specific to this age group (and adapted to these very small areas), the aim to develop a protocol for their study.

The results revealed variations in the appearance of the cortical surface in the insertion region. While the morphology of some radii can be attributed to normal variation related to growth phenomena, some of them have a very particular osteolytic appearance affecting the bicipital region (Figure 3). This bilateral and symmetrical alteration is only found among the oldest individuals in the two medieval series.
Different hypotheses explaining the existence of this appearance were levelled, including a taphonomic hypothesis. The fact that the alterations are similar, bilateral and found in two collections dating from the Early Middle Ages to the Modern period seems to mitigate against a taphonomic origin for the observed appearances, even if in some cases slight erosion may have superimposed itself on the osteolytic lesion. The alteration could also reflect a normal process of diaphyseal growth, the appearance of which on the cortical surface for this age group is itself very poorly documented. However, the extent of the defect is not very compatible with what could be considered a normal process of osteoblastic and osteoclastic responses, and its absence in the Kerma sample is difficult to explain due to population or secular differences. The existence of a pathology (such as rickets) that would be responsible for hypo-mineralization was also ruled out due to the young age of the individuals.

Comparison with the results of in vivo studies carried out on animal models finally led to the possibility of a hyper-osteolysis due to immobilisation. These studies demonstrated the importance of mobility in the "normal" development of entheses, and in particular the appearance of localised osteolysis in cases of post-partum muscle immobilization. The immobility of the developing member would cause a lack of mineralization of the structures (Zelzer et al., 2014), and the immobilised entheses of individuals who underwent botox injections are characterised internally by a porous appearance and enlarged trabeculae, and externally by a locally deficient cortical bone (Figure 4).
The identification of the alteration in individuals whose estimated age is greater than 42 weeks of amenorrhea can be explained by the nature of osteolytic dynamics. As these are mainly canalised by genetic factors during pregnancy and at the very beginning of intrauterine life, the influence of mechanical factors would only become predominant (at least in the animal model) after about two weeks post-partum (Thomopoulos et al., 2007).

The cross-referencing of the results obtained from the archaeological sample with anthropological and historical information made it possible to posit a hypothesis explaining both the presence of immobilization hyper-osteolysis and the disparities between the Kerma and medieval samples. It seems that osteolytic damage could be due to the immobilization of the limbs of newborns by the practice of swaddling which was systematically used in the Middle Ages and in the Modern period, but never attested in Nilotic populations. This forced holding of the upper and lower limbs in an extended position implies a limitation, or even a total restriction, of natural movements during the first months of life. Keeping the upper limb in extension is, in fact, completely contrary to the natural position documented for the newborn (Figure 5). Studies on infant motor skills have shown that, in order to adapt to the gravity of their new environment, infants spontaneously adopt "anti-gravity" positions, characterised by trunk hypotonia and limb hypertonia (Bullinger, 1998; Grenier, 2000).

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<tr>
<th>Control sample</th>
<th>Lateral view</th>
<th>Antero-posterior view</th>
<th>Cross-sectional view</th>
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<td>Sample with saline injection</td>
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<td>Sample with botox injection</td>
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Figure 4. Micro-CT isosurfaces of an animal humeral head, red: tendon insertion; gp: growth plate; a: articular surface; modified after Thomopoulos et al. (2007, p.1159)
The flexion of the upper and lower limbs in the first weeks of life is therefore a necessary requirement for maintaining a state of balance in the child, a state that the child instinctively achieves. It can therefore be considered that swaddling, by restricting these flexion positions, would exert an extremely strong constraint on the limbs - and in particular the upper limbs. By restricting flexion of forearm, pressures are exerted in particular on the main flexor and supinator muscle of the forearm, i.e. the M. biceps brachii, and therefore on its distal attachment, the bicipital tuberosity. This practice could therefore be likely to have a major impact on the development of enthesis.

This restriction on movement could therefore constitute both a "marker of inactivity" and a criterion of infant vitality, since it would reflect both immobilization and survival of the infant over at least a few weeks post-partum. Its location on the radius could be linked to the maintained extension of the upper limb and, by restricting the more natural physiological position of the newborn, would imply a very strong constraint on the insertion of the M. biceps brachii, the main flexor and supinator of the forearm. This opens up a number of perspectives for identifying biological/cultural interactions from an early age.

III. Morbidity criterion

III.1. Cervical supernumerary ribs, a criterion for morbidity to be used in future studies

The cervical rib is a supernumerary rib located on the fifth, sixth, or seventh cervical vertebrae and can be unilateral or bilateral (Adson and Coffey, 1927). This non-metric anatomical variant is considered to be of a genetic origin and is well documented in current

Figure 5. Anti-gravity flexion positions of the newborn, a: lateral decubitus, b: dorsal decubitus ; c: procubitus, drawing after http://g.bb.free.fr/index.php?rep=cocon&page=cagr modified by C-E Fisher
adult populations (Gruber, 1869; Le Double, 1912; Patterson, 1940; Barnes, 1994). Its first description dates back to late antiquity with the writings of Galen, Greek physician and philosopher who wrote a seminal work on human anatomy (Boudon-Millot, 2012).

While the adult cervical rib is very well documented in medical and anthropological contexts, it has only very recently become an object of study in immature populations (Chan et al., 2013). It was originally identified in immature individuals during medical or forensic examinations (Southam and Bythell, 1924; Menarguez Carretero and Campo Munoz, 1967; Grønvall and Graem, 1989). Although the frequencies of this trait in perinatal series are increasingly well documented, many questions remain open about its origin, development, and morphological variability.

Although there was no archaeological series of immature individuals evincing a high frequency of cervical ribs, the results of the excavations of necropolis 8B-51 on the Island of Saï now make it possible to provide new data on its occurrence and context.

The purpose of this part of the study was twofold:

(i) to document the morphological variability of the cervical rib in perinates using a previously unstudied archaeological assemblage from 8B-51 at Kerma,

(ii) to obtain and compare the frequencies of appearance of this trait in archaeological and virtual samples as well as relative to adult populations based previously published scientific literature in order to discuss the variability in expression of this trait in the perinatal age group.

For the archaeological sample, of the total of 64 immature individuals from 8B-51 cemetery, at least 28 very premature babies and 1-2-year-old infants had unilateral or bilateral cervical ribs of the 7th cervical vertebra, which corresponds to a frequency of 44% (Table 126). Among the 54 individuals in the perinate group, 24 have this characteristic, which also corresponds to a frequency of 44%. Observation of the elements of the Island of Saï collection made it possible to propose a classification according to macroscopic morphological criteria, based on a study of the general morphology of left and right ribs (Figure 6).

For the virtual sample, of the 313 subjects with observable cervical vertebrae, 85 have unilateral or bilateral cervical ribs, which corresponds to 27% of the individuals in the virtual sample. Of these 85 subjects, 59 (69%) expressed the trait bilaterally. Unilateral ribs are not characterised by preferential expression on either side (number of left-side=12 and number of right-side=14). No individual has a cervical rib in the cervical vertebrae above C7.

Frequencies were analysed based on clinical studies, including first and foremost information on subject mortality. The results demonstrate that 60 of the 146 subjects who died before 2 months post-partum (41%) possessed cervical ribs, compared to 25 of the 181 living subjects at the end of this period (12%). A total of 71% (60 / 85) of individuals with cervical ribs died before 2 months post-partum. Similarly, 62 of 166 subjects with serious abnormalities (37%) had cervical ribs, compared to 12 of 135 subjects with minor abnormalities or for whom no serious abnormalities or pathology were identified (14%). According to the results obtained in this study, the frequencies of the supernumerary cervical ribs in the archaeological
assemblage from cemetery 8B-51 (44%) are remarkably close to the frequencies observed among the deceased individuals of the virtual sample of modern individuals from Marseille (41%). However, both are extremely high compared to those observed in the adult samples of various origins. The recurrence of this non-metric trait among the latter is indeed a subject extensively covered in the medical literature, with documented frequencies of around 1% of the population.

Figure 6. Morphological types of cervical ribs of individuals who died in the perinatal period, Island of Saï sample

According to the operant hypothesis, the difference in frequency between adult and immature samples can be explained by the fact that a large proportion of individuals with perinatal ribs do not actually reach adulthood. This explanation is based on studies showing an association between the presence of cervical ribs and the presence of serious developmental abnormalities. Both would be produced by early developmental mutations in Hox genes, which would imply that fetuses and newborns with cervical ribs would face an increased risk of early mortality. Although the presence of supernumerary cervical ribs does not imply a poor health status, supernumerary cervical ribs can be considered as a criterion for morbidity in the perinatal age group.
III.2. Asymmetries, a morbidity criterion to be investigated

The study of asymmetries has documented the intra-individual variability in an archaeological sample of individuals who died during the perinatal period. To our knowledge, this is the first study of this kind in a past population. The high number of variables analysed also distinguishes this study.

While there does not appear to be any difference in terms of the extent of asymmetries between the Kerma sample and the medieval sample, this does not call into question the possibility of an interpretation relating to developmental disruptions. Studies incorporating the same variables and other samples would be needed to demonstrate the validity of these results in terms of morbidity criteria in past populations. By comparing current samples representative of a theoretical "natural" population (including surviving neonates), it would be possible to infer whether the archaeological sample (and in particular the Kerma sample with high cervical rib frequencies) actually shows a higher rate of fluctuating asymmetries than expected in a population not specifically exposed to developmental disturbances. Similarly, the analysis of a sample specifically identified as facing these disturbances, such as immature individuals living in a particularly polluted region, would provide a relevant opportunity for comparison. In any case this study provides initial results on fluctuating and directional asymmetries that may be expected when studying an archaeological sample of perinates, and provides a baseline for future analysis.

IV. Social status and funerary treatments of individuals who died during the perinatal period in the populations of Blandy-les-Tours, Provins and the Island of Sai

With regard to the Kerma series, the cross-referencing of biological and archaeological information made it possible to continue the bioarchaeological study through the use of a Geographic Information System. The site extended over 150m² at the end of a wadi to the east of the Island of Saï, and was usual for being the place of burial of a considerable number of immature individuals: 66 individuals, 54 of whom died during the perinatal period, 10 as young children, and two as adults. The field database has been complemented by information from the biological study and a complete catalogue of the graves. The study confirmed and extended some of the results of Murail and colleagues (2004) and Maureille and colleagues (2006), highlighting in particular the existence of spatial organisation at the site according to age at death. The oldest children are buried in the southern and southeastern parts of the cemetery, while the graves of perinatal deaths and premature births are more concentrated in the northern and northwestern parts. The analysis showed that there are common characteristics of funerary treatments that are common to all immature age classes. With the exception of a few rare cases, all were the subject of individual primary burials. They were deposited in the ground in carefully designed pits, for the most part suited to the size of the body. Buried individuals were more often east- and northeast-facing, often in a right lateral decubitus position (a position usually documented for adults in Classic Kerma burials). The two adults buried at the northern and southern extremities of the cemetery do not show the usual disposition of adults
documented for this period, which raises the question of their status in relation to the group from which they came.

The analyses revealed that the graves of subjects who died during the perinatal period are characterised by greater variability in body positions, with more diverse orientations and positions than those of older subjects. A change in the status of these individuals appears to occur in the months following birth, although the change is not associated with a specific age. The older the child is, the more the burial acquires elements shared with those of adults, such as the inclusion of a beads, ceramics, and amulets. The child seems to be gradually treated as the adult he or she would have become, a characteristic found downstream within the Nile Valley in Egyptian civilization. Although individuals who died during the perinatal period are not strictly treated in the same way as older children and adults at other sites from the same time, all the results reflect the very special care they received, including very premature babies whose vitality at birth is not guaranteed. Many indicators show that special attention is paid to the very youngest deceased individuals, with common practices being careful preparation of the pit in order to accommodate the constrained position of the dead), as well as for certain individuals for example, the isolated deposition of faunal remains.

The biological study also revealed a high frequency of supernumerary cervical ribs, an anatomical criterion often associated with poor health and the presence of serious congenital conditions according to recent studies. The recurrence of this characteristic suggests that some individuals may have had potentially visible developmental abnormalities. According to these results, there is no evidence for the existence of a specific funerary treatment of individuals with these anomalies. Other analyses, particularly genetic analyses, would provide an interesting perspective to determine if some may indeed have had genetic abnormalities causing visible deformity and physical impairment. This type of study would be particularly interesting addressing the question of care accorded to the weakest people in this ancient society. The funerary treatments of those who died during the perinatal period found in necropolis 8B51 therefore seem very far from traditional conceptions describing a lack of interest in the death of the very young (Ariès, 1960). On the contrary, this study shows that the latter, even if they are not considered to have the same status as older individuals, enjoy full status as a member of Kerma society. The special attention paid to the deceased is visible from an early age, while the acquisition of a social identity seems to be gradual, in the weeks and months following birth.

**CONCLUSION AND RESEARCH PROSPECTUS**

All these results have contributed to demonstrating the informative potential of the biological study of subjects who died during the perinatal period, both individually and collectively. From the point of view of studying past populations, there are many possibilities for further insights and they depend essentially on the development and "democratisation" of certain methods. Obtaining an absolute dental age and observing the neonatal line in the deciduous dentition will be a priority in future work, as well as sex determination, for example with the method of analysis of dental surface acids developed by Stewart and colleagues (2017). Palaeogenetic analyses will be considered on the Sai series in order to reveal biological
affinities among individuals and compare these results with those obtained in this study. All these data will permit more detailed investigation through biological anthropological and bioarchaeological studies to address biological relatedness, morbidity, and intra-population vitality.

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