Determinants of infant mortality and representation in bioarchaeological samples: a review

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The data that supports the findings of this study are available in the supplementary material of this article.

ABSTRACT

In bioarchaeological contexts, a complex relationship exists between infant representation in the age-at-death distribution, gestational and young child mortality rates, and the total fertility rate. The representation of infants in a skeletal sample may be influenced by a range of social, biological and archaeological factors. To better understand the interactions between representation, fertility and mortality, this study evaluates the relationship between infant-juvenile age-at-death proportions, fertility rates, and a range of gestational and early childhood mortality measures. The statistical component of this study found the correlation between fertility rates and infant-juvenile proportions was stronger than with any mortality rate variable of interest. This suggests that the proportion of infants in a mortuary sample is a stronger indicator of fertility than it is of infant-juvenile mortality. Social, biological and archaeological variables potentially influencing infant representation in skeletal samples are discussed and a strongly contextualised and holistic approach to infant and juvenile mortality is recommended.

1   INTRODUCTION

It is widely accepted and well-evidenced that fertility has a greater influence on the age at death distribution than fluctuations in mortality (Bocquet-Appel & Masset, 1982; Buikstra, Konigsberg, & Bullington, 1986; Corruccini, Brandon, & Handler, 1989; Johansson & Horowitz, 1986; Konigsberg & Frankenberg, 1994; Milner, Humpf & Harpending, 1989; Paine, 1989; Sattenspiel & Harpending, 1983). This holds particularly true for infants, where a larger number of infants born results in a larger absolute number of deceased infants, while the rate of death (the infant mortality rate) may remain stable. Notwithstanding, the infant mortality rate may increase for other reasons associated with increased fertility, such as high order and multiple order (e.g. twins, triplets) births (Kiely, Kleinman & Kiely, 1992), young and geriatric pregnancies (Fall et al., 2015; Lisonkova, Pare & Joseph, 2013), and capacity for care (Frankenberg, 1995, Magnani et al., 1996 and Rutherford et al., 2008; Stanley et al., 2016). As such, even where infant representation in the mortuary sample is accurate, it may be difficult to extract the influence of infant mortality on infant representation from the complex interrelationship with fertility and associated social and biological correlates.

Infant mortality is of great interest in bioarchaeological research. It would seem logical that the proportion of deceased infants in a sample tells us something about infant mortality and that the absence of modern healthcare would have a significant impact on the survivorship of infants, both premature and full term. Investigations of infant mortality may serve to enhance narratives surrounding the life experience of parents and children and sociocultural aspects of a community, as well as broader contributions regarding population dynamics, the impacts of disease, and the influence of environment and ecology on a vulnerable demographic. Additionally, it may be of interest to delineate between the number of deceased infants in a mortuary sample and the rate of infant mortality at various developmental stages, as mortality risk factors change with gestational and postnatal age. By exploring the range of potential influences on infant representation in the mortuary sample[1] and infant mortality[2], we may be able to gain valuable insights into sociocultural, biological, archaeological and demographic interactions.

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[1] Also referred to as infant representation in the age-at-death distribution, the proportion of deceased infants, the proportion of infants in the sample, and the death proportion notations D0-14/D and D0/D hereafter.

[2] Also referred to as the mortality rate and infant deaths hereafter.

This paper aims to evaluate the relationship between infant representation in the age-at-death distribution, the infant mortality rate, and fertility rate, to better understand the interplay of population dynamics. It then discusses the social, biological and archaeological determinants of infant representation in mortuary samples and infant mortality more broadly, noting the complex relationship between variables.

2   MATERIALS AND METHODS

The approach taken to analysing the relationship between infant representation in the age at death distribution, infant mortality and fertility was to statistically evaluate relationships of interest using United Nations (2021) national-level population data. United Nations (2021) data are used due to their greater accuracy, precision and volume over archaeological data, and comparability is based on the premise of uniformitarianism proposed by Howell (1976) and recently reaffirmed by French and Chamberlain (2021). Several relationships were investigated to gain a holistic understanding of the relationship between deaths at various stages of development and fertility. Firstly, if infant representation in the age at death distribution is indicative of infant mortality, we would expect to see a stronger relationship between the proportion of deceased infants and infant mortality rate, than between the proportion of deceased infants and total fertility rate. To examine this, simple linear regression was applied to the total fertility rate, the D0-14/D proportion which has been used as an estimator of fertility (McFadden and Oxenham, 2018a) and the D0/D proportion (the number of deaths aged 0<1 years divided by the total number of deaths) (independent variables) and, as dependent variables in individual analyses, the infant mortality rate, under-5 years mortality rate, neonate mortality rate, stillborn (defined as 28+ weeks in utero up to the time of birth, but not post birth) rate, and late foetal (28+ weeks in utero and prior to signs of birthing commencement) mortality rate (all measured as per 1,000 live births for the corresponding year).

The years and data included in the analyses were determined based on their availability: mortality rates for different ages from 28 weeks in-utero through to 5 years of age have only been recorded by the United Nations (2021) for single years in many cases. Where more than one year was recorded, multiple years were included in the analysis, but correlations were examined by each individual year to avoid auto-correlation. Age at death data were obtained for the years that corresponded to the infant (2010-2015), under-5 (2010-2015), neonate (2010 and 2012), stillborn (2009) and late foetal (2010 and 2015) mortality rates. Where data were reported as an average for a range (e.g. 2010-2015) the D0/D and D0-14/D ratios were also

averaged across years 2010, 2012 and 2015. The number of countries with sufficient data for inclusion ranged from 46 (for one late foetal mortality sample) to 97 (for infant mortality and under 5 years mortality). Late foetal mortality was reported as raw values and was therefore divided by the total number of births for that year and multiplied by 1000 to convert this to a rate (this is in alignment with stillbirth, neonate and infant mortality rates which are reported per 1000 births). Descriptive statistics are reported in **Table 1**.

Table 1. Descriptive statistics of datasets analysed

3   RESULTS

Simple linear regression identified the D0-14/D proportion as having the strongest correlation with the under 5-years mortality rate (**Table 2**). This is in accordance with the expected outcome, as the target group (0-5 year olds) is represented within the D0-14/D proportion. While correlations with D0/D and total fertility rate were found to be weaker, the difference between r-values was not statistically significant in any case. The strong correlation between the D0-14/D and D0/D ratios suggests that infant representation is the most stable and significant contributor to the D0-14/D ratio.

Table 2. Correlation matrix for under 5-years mortality rate 2010-2015 (all values p<0.05)

Based on the results of simple linear regression, the infant mortality rate correlated most strongly with the D0-14/D ratio (**Table 3**). Interestingly, it correlated more highly than the proportion of deceased infants (D0/D), though the difference was not statistically significant. In contrast, the difference between correlations for the D0-14/D ratio and total fertility rate were statistically significant ($p<0.05$ one-tailed).

Table 3. Correlation matrix for infant mortality rate 2010-2015 (all values p<0.05)

Similar results were found for neonate mortality (**Tables 4 and 5**).

Table 4. Correlation matrix for neonate mortality rate 2010 (all values p<0.05)

Table 5. Correlation matrix for neonate mortality rate 2012 (all values p<0.05)

The stillbirth rate showed a weaker but still significant relationship with the D0-14/D proportion. Again, this was the strongest predictor of the three independent variables but was closely followed by the D0/D proportion and the total fertility rate showed a similarly moderate correlation.

Table 6. Correlation matrix for stillbirth rate 2009 (all values p<0.05)

As indicated by late foetal mortality, there appears to be a trend of decreasing predictive power of both the D0-14/D and D0/D proportions with decreasing age at death (**Tables 7 and 8**).

Table 7. Correlation matrix for late foetal mortality rate 2010 (all values p<0.05 except *not significant p>0.05)

Table 8. Correlation matrix for late foetal mortality rate 2015 (all values p<0.05)

Overall, the best predictor of early subadult mortality was the D0-14/D proportion with the D0/D proportion performing marginally better for neonatal and late foetal mortality rates. Scatter plots for all analyses are provided in the Supplementary Information.

4 DISCUSSION

4.1 Elucidating the Relationship between Representation in the Age at Death Distribution, Total Fertility and Infant Mortality Rates

As would be expected, the D0-14/D ratio had greater predictive power for the older aged mortality rates, specifically neonates, infants and under 5 years of age. This is because these individuals contribute considerably to the numerator of the equation. Notwithstanding, correlations reached a maximum of r=0.77 which still leaves a substantial degree (minimum ~40%) of variation to be explained. In nearly all cases (with the exception being neonate mortality from 2012, see **Table 5**), the correlation between the total fertility rate and both D0-14/D and D0/D proportions was stronger than with the infant mortality rate of interest, suggesting that the proportion of infants in a mortuary sample is a stronger indicator of fertility than it is of infant mortality rates at all gestational and postnatal ages. Conversely, this suggests that the ratios tested are not particularly effective proxies for infant and juvenile mortality.

A further interpretation of this finding is that while the total fertility rate has a relationship with infant mortality, the predictive power is supportive of a more complex interplay of variables. Correlations between infant mortality rates and total fertility rate did not exceed r=0.67 (<50% explanatory power) and were relatively stable across stillborn, neonate, infant and under 5 years of age mortality rates. It is important to note that the total fertility rate is correlated with a range of other factors such as socioeconomic status, malnourishment and disease, access to care, etc, which interact with one another and are known risk factors for infant mortality. Therefore, the influence of fertility on infant mortality rates is highly complex and should not be considered causal without supporting evidence. In order to visualise these relationships, **Figure 1** demonstrates the differences in age-at-death distribution for high and low fertility, and high

and low infant mortality populations based on United Nations (2021) data. Notably, infant mortality and total fertility rates correlate so highly in low infant mortality, low fertility populations (in this example, Japan and Iceland), that there is little difference observed in the age-at-death distributions. In contrast, there are significant differences between the high fertility and high infant mortality population and the moderate fertility and high infant mortality population; most pertinent to this study, is that Mali has a higher proportion of deaths in the 0-4 year age category than Sierra Leone, despite Mali having a lower infant mortality rate. This example visualises the differential effects of infant mortality and fertility on proportional infant representation in the age-at-death distribution.

Figure 1. Proportional age-at-death distribution for four countries of differing infant mortality and fertility rates using United Nations (2021) data. TFR is total fertility rate and IMR is infant mortality rate.

Having noted this, the mechanisms driving fertility may present an increased mortality risk to infants. While high order births are known to pose a risk to mothers, multiple order (e.g. twins, triplets) births are frequently associated with poorer morbidity and mortality outcomes for infants (Kiely, Kleinman & Kiely, 1992); both high order and multiple order pregnancies may influence a higher fertility rate. An increased reproductive lifespan including both young and geriatric pregnancies is also commonly associated with high fertility rates, with pregnancies in both categories having a higher risk of infant death than the core reproductive years (widely regarded to be 20-34 years) (Fall et al., 2015; Lisonkova, Pare & Joseph, 2013). Shortening of the interpregnancy interval is frequently cited as a cause of increased fertility in association with sedentism and agricultural intensification, and this too has been found to increase the risk of infant mortality, particularly where the interval is less than six months (McKinney et al., 2017). Therefore, we advocate for cautious but holistic consideration of the relationship between fertility and infant mortality, in the context of social, biological and environmental influences.

Noting the limited insights into infant mortality afforded by infant representation in the mortuary sample, it is essential to consider the factors that may influence both mortality and representation amongst infants. If any confidence is to be given to the evaluation of infant mortality through time, we must seek a holistic and well-considered approach incorporating our understanding of modern infant mortality with the available (often limited) data from the archaeological record. The subsequent sections outline some of the key variables for

consideration when approaching infant mortality in past populations, including determinants of mortality *and* determinants of representation.

4.2 *Biological Determinants of Infant Mortality: Genetic Conditions, Disease and Sex Bias*

The major biological determinants of infant mortality change with gestational and postnatal age. In the early stages of pregnancy, chromosomal abnormalities account for a substantial proportion of miscarriages, reportedly between 50-85% of first trimester losses (Jurkovic, Overton & Bender-Atik, 2013), while congenital conditions (of which chromosomal abnormalities are a subset) account for only 8-12% of late foetal deaths (Bell et al., 2004). A number of other causes of late foetal loss have been identified, including antepartum haemorrhage and pre-eclampsia, however, over a quarter of deaths remain unexplained (Bell et al., 2004). For neonates, congenital abnormalities account for only 7% of deaths, with pre-term births, sepsis/pneumonia and asphyxia accounting for 76% of deaths combined (27%, 26% and 23% respectively) (Simmons et al., 2010). Many of these conditions would not have been treatable in the past and likely presented a far greater mortality risk to both infants and mothers. While skeletal evidence of cause of death is scarce, such biological causes should be considered in the context of gestational and postnatal age. The delineation of foetuses from infants, and pre-, peri- and post-natal death in bioarchaeology has been argued for by Halcrow (2020) on similar grounds.

While gender and status influences are discussed below, biological sex biases in infant morbidity and mortality are also known to occur. Examining mortality data from the United States (1999-2008) for all-cause deaths in individuals aged under 20 years, Balsara et al. (2013) found males experienced increased mortality compared to females at all ages from birth (relative risk ratio of 1.44 across all ages). The sex-based bias was found to extend to gestational age, with male infants experiencing higher mortality across all weeks of age. Evaluating the data in greater detail, male juveniles were reportedly at higher risk of morbidity and mortality associated with infectious and parasitic (RR 1.14), digestive (RR 1.29), and nutritional and metabolic (RR 1.17) diseases (Balsara et al., 2013). A number of studies have reported sex ratios in spontaneous abortion and neonate death to be biased towards males (Byrne & Warburton, 1987; Hassold, Quillen & Yamane, 1983; Jakobovits, 1991; Karlsson et al., 2019; Waldron, 1998). This holds true for chromosomally abnormal and normal foetuses and infants (Hassold, Quillen & Yamane, 1983; James, 2015).

Nevertheless, sociocultural influences may negate the biological susceptibility of male juveniles particularly in the under 1-4 years of age mortality group, where in many countries female mortality is reported to reach equivalent, or exceed, male mortality (Iqbal et al., 2018; Karlsson et al., 2019; United Nations, 2011). While sex is not commonly estimated for infants and children in bioarchaeological samples due to the absence of reliable macroscopic techniques, future research utilising ancient DNA and proteomics may seek to evaluate the sex differential in infant and juvenile mortality.

4.3 Social Determinants of Infant Mortality and Representation: Care, Status and Differential Burial, and Infanticide

4.3.1 Care

Care, whether provided by family members, medical practitioners or other wellbeing-related roles, is of paramount importance to infant survival. Parental care has a strong influence on infant and juvenile health outcomes and differential treatment may results from sociocultural biases (Oxenham and Willis, 2016). Alemayehu et al. (2019) reported female infants in rural Southern Ethiopia were at greater risk of anaemia (which can increase susceptibility to infection and other disease, and heightens the risk of mortality) as a result of gender bias in feeding practices and care. Care-seeking behaviour may also have a gender bias, with a meta-analysis from Southeast Asia suggesting that excess female neonate mortality may be the result of slower or less frequent care-seeking (Ismail et al., 2019).

Access to healthcare plays a significant role in maternal and infant mortality. Many studies have examined access to modern healthcare for mothers, neonates and infants, with findings broadly indicative of a reduced risk of mortality with fewer boundaries to access (whether physical, such as distance, or sociocultural, such as economic status and government policy on provision of care) (Frankenberg, 1995; Magnani et al., 1996; Rutherford et al., 2008). As modern healthcare clearly did not influence infant mortality in the deep past, the role of traditional birth attendants and wellbeing practitioners is of greater interest in the bioarchaeological context. In a study in Kenya, Stanley et al. (2016) found traditional birth attendants reduced the risk of infant mortality even further than modern healthcare. Other studies have found that medical training of traditional birth attendants, particularly in emergency response and hygiene, reduces infant mortality in comparison to untrained birth attendants (Gill et al., 2011; Saravan et al., 2014). Cultural stigma, such as discarding

colostrum, also may have a detrimental impact of infant survivorship (Saravan et al., 2014). Less is known about the efficacy of traditional interventions during later infancy and childhood.

The potential for the identification of care in prehistoric communities with respect to perinatal through to older children is discussed at length by Oxenham and Willis (2016). Moreover, the potential for a range of positive and negative infant morbidity and mortality outcomes with regard to parental/carer interventions need to be recognised as influencing the shape of a subsequent mortality distribution. Whether one's aim is to identify differential parental nurturing behaviours, extra-nurturing infant care, evidence for infanticide or signatures of institutionalised midwifery, close attention to the archaeological context of an assemblage and the prevalence and nature of childhood health/ill health in the context of infant mortality form the critical parameters of study. A substantial body of literature has been developed on the topic of infant care, its drivers and outcomes. Halcrow et al. (2020) proposed an interdisciplinary approach, incorporating human behavioural ecology and evolutionary theory, to better understanding the motivations and implications of infant care in the past particularly with regards to the intersection of social and biological aspects. In the seminal volume by Gowland and Halcrow (2020) *The Mother-Infant Nexus in Anthropology*, contributors explore the conceptualisation of infants, the maternal bond, and biocultural approaches to maternal and indeed infant experience. A portion of the collective works examine the finer detail of care, including feeding and weaning practices, social connectivity including gaze and touch, and sleep arrangements. Halcrow (2020) proposed that future bioarchaeological approaches to care should broaden the scope from health-related (e.g., in response to pathology, malnourishment, etc.) care to all aspects of wellbeing including emotional support. There is clearly a wealth of literature from a multitude of disciplines on the complexities of infant care and, although it can be challenging to conclusively identify evidence for infant care in the past, it would seem an interdisciplinary, theoretically-informed approach to this socially and biologically intersectional topic is the most promising way forwards.

4.3.2 Status and Differential Burial

Status (broadly defined here as preferential access to resources) and differential burial are socioculturally intertwined variables, with independent implications for mortality and representation respectively. In death, status may influence mortuary practices (while accepting this is a contentious issue in the funerary archaeology literature), while in life it may impact upon the risk of disease and death based on the developmental environment, specifically

maternal, pre and postnatal health. Status may be a defining factor in access to resources and care, living conditions and exposure to disease, and a host of other determinants of psychological and physiological wellbeing.

Socioeconomic and sociodemographic status influences foetal health via stresses and exposures during pregnancy and via both the mother and direct effects on infants following birth. Research by Caserta et al. (2015) found higher rates of miscarriage in socially disadvantaged immigrants than local Italian women. Genetic causes were dismissed due to the immigrant population being ethnically diverse, and it was suggested that higher rates of psychological and physiological stress may be responsible. In a Nigerian study over five years, post-neonatal mortality up to 5 years of age was found to be positively associated with uneducated mothers, rural living and poor households, indicative of socioeconomic disadvantage more broadly (Ezeh et al., 2015). Similarly, Hosseinpoor et al. (2006) reported household economic status and education status of the mother were the largest social contributors to infant mortality disparity. In the United States, successful reduction in infant mortality overall has been tarnished by an increasing disparity based on socioeconomic status: neonatal and postneonatal mortality risks in the lowest socioeconomic groups increased from 36% and 57% respectively in 1986-1989 to 43% and 96% in 1995-2000 (Singh & Koghan, 2007). Status in bioarchaeological samples must be cautiously interpreted, but may be inferred from a range of indicators, such as mortuary practices, evidence of differential access to resources, and differential health outcomes.

There are a number of social determinants which may impact whether pre-terms, stillbirths, and infants are accurately represented in a cemetery sample. One such social determinate is differential burial practices of infants. Subadults, particularly the very young, can be the recipients of differentiated burial treatments in the past, and this may include being spatially excluded from formalised cemeteries (Lewis 2007; Kamp 2001; Scott 1999). For instance, at the Bronze Age cemetery of Mokrin, no individuals under the age of one were found (Rega 1997). This was also the case in early Mycenaean Greece (Lebegyev 2009). In Roman Britain, neonatal infants were excluded from formal cemeteries, and are often found buried in domestic and settlement contexts (Moore 2009). In medieval Europe, infants who died before being baptised were excluded from burial in Christian cemeteries (Hausmair 2017), a practice which would have led to the creation of informal burial grounds for excluded infants. Irish cillini are one well-researched example of this, with the practice continuing into the mid-20th century (Donnelly and Murphy 2018). As observed by Murphy (2011), however, often such practices

are driven by religious institutions, while family members may not have treated the burials as different from the cemetery-main. This adds to the complexity of understanding differential burial treatment, as such practices do not represent (and may misrepresent) the array of perceptions of infant death and responses to it.

There are a number of hypotheses that attempt to explain why infants may be differentially buried. Most of these arguments tend to revolve around socially constructed concepts of personhood. In some societies, it has been argued, infants are not considered to be a complete person or 'human' until they have lived past a particular developmental or cultural milestone, and as such, they are not afforded the same mortuary treatment as adults (Rawson 2003; Scott 1999; Smith and Kahila 1992; Ucko 1969). For instance, in ancient Rome, infants were not named until they were at least 8 (for females) or 9 (for males) days old, and no formal mourning was prescribed for children who died in their first year (Rawson 2003). The delays in officially naming and mourning infants (and therefore also conferring them a complete human identity) is thus argued to be a cultural response to the high number of infant deaths that occur in this timeframe (Gowland et al. 2014). In turn, this delay in being recognised as a person within a society presents itself as differentiation in mortuary practices and therefore the archaeological record (Halcrow et al. 2008).

It is important to note, however, that similar to concepts of childhood, reactions to infant death are determined by a number of factors, including individual psychology, capacity to deal with grief, and social constraints of the wider community (Cannon and Cook 2015) and even parental choice in otherwise prescriptive approaches to mourning or elevated levels of infant morbidity and mortality (Oxenham et al. 2008; Oxenham and Willis 2016). There is good evidence for cross-cultural differences in responses to infant death, the jolting nature of which can cause a seeming disparity between physically-evidenced burial rites and the emotional experience of those connected to the infant (Gowland, 2020). As such, there is no single reason for the differential burial of infants. Additionally, differential burial practices are not necessarily an indicator of lower status or a lack of care for the interred infant (Oxenham et al. 2008). Even seemingly clandestine burials may, almost paradoxically, represent great care and concern for the interred infant. Roman British infants, for example, are often found buried in non-formal domestic or settlement contexts, but the burials are "not the random disposal of the unwanted or marginalised, but the result of careful choices and decisions relating to concepts associated with the physical remains of the child" (Moore 2009: 48). A similar conclusion was

found at the site of Lepenski Vir. At the site, infants were found buried beneath the floors in houses, and this was interpreted as a protective gesture towards the infant (Borić and Stefanović 2004). Consequently, archaeologists should take care in how they interpret the differential burial of infants.

4.3.3 Infanticide

Infanticide is another social determinate which may also have an effect on whether infants are accurately represented within cemetery contexts. Infanticide has a deep history, with ethnographic and historical evidence demonstrating that it has been practiced by many cultures over time (Mays 2014; Gilmore and Halcrow 2014; Bonsall 2013; Lewis 2007). Typically, infanticide is carried out shortly following birth, and may occur because of economic, social, or religious reasons (Mays 2014; Bonsall 2013; Smith and Kahila 1992). Infanticide is a contentious topic within bioarchaeology, at least partly because the practice cannot be directly demonstrated in the archaeological record. It is important to note that most written records and ethnographic studies attesting to infanticide describe methods that would leave no archaeological trace. Commonly described methods of infanticide include suffocation, exposure, drowning and neglect (Scott 1999; Langer 1974). These methods would leave no trace on the infant's skeleton, and as such, bioarchaeologists have had to find proxy methods to investigate questions of infanticide in the past (Mays 2014).

One study, by Smith and Kahila (1992) utilized long bone and tooth measurements to estimate the ages of approximately 100 infants found in a sewer context in Roman-Byzantine Ashkelon. Their results found that the remains belonged to neonates who were all the same age at death; this peak around the time of birth is argued to represent the possible practice of infanticide, as infanticide tends to happen closely around birth, while a more varied range of age-at-deaths would be more indicative of death from natural causes (Smith and Kahila 1992). Mays and Colleagues (e.g. Mays 1993; Mays and Eyers 2011) have also employed similar methodologies on a number of sites in Roman Britain and come to similar conclusions. At Hambledeen, for example, up to 97 infants were found buried at a villa site. Age estimates using long bones were carried out where possible, and the results indicated a strong peak around the time of birth. This, the authors argue, is similar to the distribution at Ashkelon, and supports the conclusion that remains represent infanticide victims (Mays and Eyers 2011). It should be noted that the prevalence of infanticide in Roman Britain, particularly for the sites listed above, is disputed (e.g. Bonsall 2013; Gowland et al. 2014; Gowland and Chamberlain 2002).

While long bone lengths as an indicator of chronological age are more accurate for foetuses and infants than they are for older children (Buckberry 2018), there are still limitations to these kinds of approaches when investigating infanticide. First of all, these studies are assuming that peaks of high mortality around the time of birth are indicative of infanticide. Labour is recognised as the most dangerous stage of pregnancy, for both mother and infant, and the following few days after the birth are high risk as well (Bonsall 2013; Scott 1999; Gowland et al. 2014). Even older infants still remain at risk from a number of both intrinsic and extrinsic factors, including heightened susceptibility to disease (Gilmore and Halcrow 2014; Lewis 2007; Scott 1999). High rates of neonatal mortality in the past may therefore simply reflect natural mortality rates of a population.

Secondly, these approaches also assume that victims of infanticide are even being buried in the first place. If an infant has died after being exposed, for example, it is unlikely that the family would have reclaimed the remains for burial (Gowland et al. 2014). More likely, infants that were victims of infanticide would have been disposed of in a more indifferent way, rather than being buried in formal cemeteries, thus leading to invisibility in the archaeological record (Bonsall 2013; Gowland et al. 2014). As such, examples of cemetery contexts containing large amounts of infant burials, especially in societies where infanticide is practiced, is probably less indicative of infanticide, and more suggestive that the interred infants were wanted. In any case, if the differential burial of infants or infanticide are occurring within a culture, then these practices will have an impact upon the archaeological record. This will be further explored in the archaeological determinants section of this discussion. A last point to be made in regard to infanticide is that the frequency of its true occurrence throughout the past is highly contentious, as literary and oral evidence, and more recent perceptions all suggest that infanticide is and was historically widely condemned, perceived as an undesirable and painful necessity in some cases, or treated with ambivalence (see Spinelli (2004) for a summary).

4.4 *Archaeological Determinants of Infant Representation: Preservation and Recovery*

In addition to social and biological factors, archaeological determinants, namely preservation and recovery, will also have an impact on whether pre-terms, stillbirths, and infants are accurately represented in a cemetery sample. It is often said that subadult remains, particularly infants and foetuses, suffer from poor preservation or complete deterioration in the archaeological record (Lewis 2007). This in turn contributes to the historical lack of academic attention paid to children in the past (Lewis 2007; Manifold 2015; Djurić et al. 2011). It is

argued that numerous intrinsic factors of subadult bone, including high porosity, lower mineral content and density, and general smaller size, make them especially elevated rates of decomposition in a range of burial environments (Guy et al. 1997; Buckberry 2000; Lewis 2007; Djurić et al. 2011). Indeed, such intrinsic characteristics of subadult bone make them more susceptible to extrinsic factors, such as soil pH, groundwater chemistry, temperature, and disturbance by fauna or flora (Henderson 1987; Gordon and Buikstra 1981; Lewis 2007; Buckberry 2000; Scheuer and Black 2000). Combined, these factors lead to the poor preservation or absence of infants and foetuses observed in the archaeological record.

However, these assumptions regarding subadult preservation cannot be taken for granted. For instance, there are many geographically and temporally distinct sites where large numbers of infant remains have been recovered (Lewis 2007). It has also been noted that wherever bone preservation is good, subadult remains are generally recovered, in some cases with no visible under-representation (Buckberry 2000; Mays 2010). Furthermore, even at sites where bone preservation has been poor, infant skeletons have been found (Scott 1999). There is also evidence which suggests that intrinsic factors of subadult bone may not always be the cause of their poor preservation. Stojanowski and Colleagues (2002) found little variation in the preservation of remains, in regard to sex or age. However, they did find that the vertical depth of a burial did influence preservation quality (Stojanowski et al. 2002). Additionally, Manifold (2015) found that compared to older children, those under the age of two were less affected by otherwise destructive taphonomic processes. All of this demonstrates that the effects of different burial environments can be difficult to predict, and that there is no reason to blindly assume that infants will not be preserved at any given archaeological site.

In addition to preservation issues, subadult remains may also be subject to recovery issues. One significant major issue with the recovery of infant remains can be limited experience on the part of the excavator. The small size and unfused nature of subadult remains may lead to a failure to recognise and therefore retrieve skeletal elements, leading to incomplete recovery of individuals (Lewis 2007; Scheuer and Black 2000; Buckberry 2000; Henderson 1987). Subadult remains are also more prone to discolouration in the soil, making them harder to notice (Lewis 2007). Additionally, the bioturbation of soil may also obscure grave cuts, and this factor, combined with a possible lack of grave goods, may mean that an excavator is not even aware they are digging through a subadult burial (Halcrow et al. 2008). There have also been cases where subadult remains have been previously erroneously identified as animal

bones (see Liston and Papadopoulos 2004 for an example). Further, one recent study found that mesh size contributes significantly to the recovery of infant remains, with 1.0mm mesh only causing a 0.2% loss, while 6.4mm mesh caused a 63.2% loss (Pokines and De La Paz 2016).

It should also be remembered that social determinants may also have an effect on recovery rates. If infants are being differentially buried, for example, then their remains may not be in the same part of the cemetery as the adults. Therefore, infants may not be recovered if only part of the cemetery is being excavated (Lewis 2007; Halcrow et al. 2008). Similarly, if subadults are being buried in shallower graves than those of adults (e.g. Cave and Oxenham 2017), then their graves are more likely to be disturbed, in turn leading to preservation and recovery issues.

The high potential for underrepresentation of infants in the archaeological record has significant consequences for both the study of infants themselves and for palaeodemographic proxies. Walker, Johnson and Lambert (1988) compared the representation of deceased juveniles based on cemetery records (where they accounted for 32% of the population) with representation in the excavated cemetery sample (representing just 6% of the cemetery sample), finding a significant disparity between those interred and those recovered during excavation. Examining the impacts of this on palaeodemographic estimators, McFadden and Oxenham (2019) tested the accuracy of fertility and population increase estimators under several underenumeration scenarios and reported that infant underenumeration in excess of 25% significantly compromised the accuracy of estimators. As such, the underrepresentation of infants in skeletal assemblages has significant impacts for bioarchaeological research broadly and must be carefully assessed.

CONCLUSIONS

This paper aimed to evaluate the relationship between infant representation in the age-at-death distribution, gestational and young child mortality rates, and the total fertility rate, to better understand the interactions between these population measures. The analyses within this study ultimately found that the correlation between the total fertility rate and both D0-14/D and D0/D proportions was stronger than with any of the gestational or infant mortality variables of interest. This indicates that the proportion of infants in a mortuary sample is a stronger indicator of fertility than it is of infant mortality at all gestational and postnatal ages. Notwithstanding, there was a significant relationship between infant representation in the age-at-death distribution and most gestational and young child mortality rates examined in this study. While

not exhaustive, this paper has touched on a range of social, biological and archaeological determinates of infant mortality and infant representation in mortuary samples, demonstrating the complexity of evaluating early death in the past. Such variables are inherently linked with each other and, as such, holistic and comprehensive approaches to these important avenues of bioarchaeological research are required.

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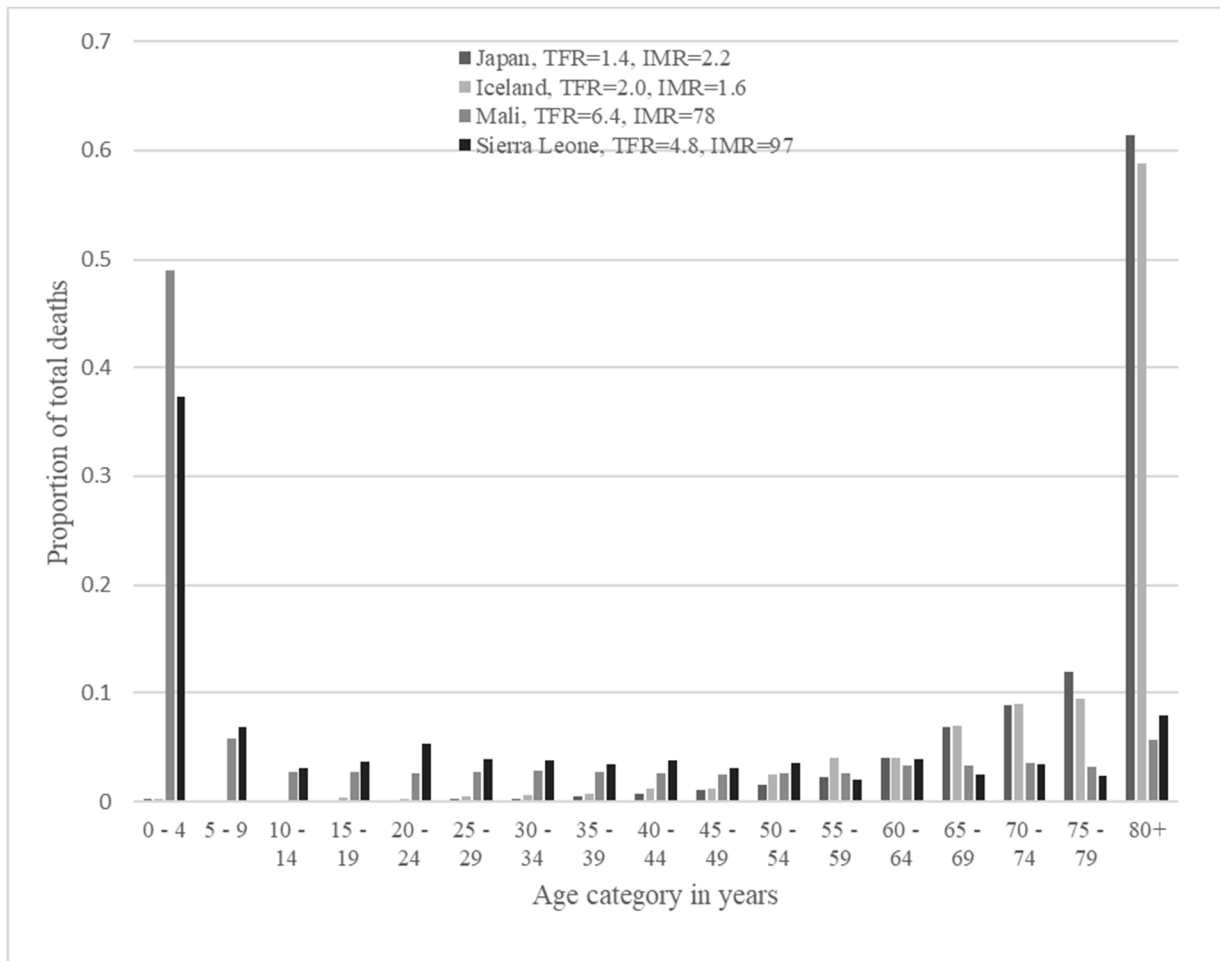
Figure 1. Proportional age-at-death distribution for four countries of differing infant mortality and fertility rates using United Nations (2021) data. TFR is total fertility rate and IMR is infant mortality rate.

Analysis	Year/s represented	Number of sampled countries	Mean mortality rate (per 1000 births)	Standard deviation
under 5-years mortality	2010-2015	97	12.27	12.03
infant mortality	2010-2015	97	9.98	9.08
neonate mortality	2010	68	6.46	5.52
	2012	58	5.28	4.06
stillbirth	2009	62	5.53	3.56
late foetal	2010	56	0.94	0.67
	2015	46	0.85	0.50

Table 1. Descriptive statistics of datasets analysed

2010-2015 under 5-years mortality	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.78	0.71	0.66
D0-14/D		0.97	0.81
D0/D			0.83

Table 2. Correlation matrix for under 5-years mortality rate 2010-2015 (all values p<0.05)

2010-2015 infant mortality	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.77	0.72	0.65
D0-14/D		0.97	0.82
D0/D			0.84

Table 3. Correlation matrix for infant mortality rate 2010-2015 (all values p<0.05)

2010 neonate mortality	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.77	0.77	0.67
D0-14/D		0.97	0.82
D0/D			0.83

Table 4. Correlation matrix for neonate mortality rate 2010 (all values p<0.05)

2012 neonate mortality	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.75	0.77	0.67
D0-14/D		0.98	0.84
D0/D			0.75

Table 5. Correlation matrix for neonate mortality rate 2012 (all values p<0.05)

2009 stillbirth	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.60	0.57	0.51
D0-14/D		0.99	0.71
D0/D			0.68

Table 6. Correlation matrix for stillbirth rate 2009 (all values p<0.05)

2010 late foetal	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.33	0.37	0.20*
D0-14/D		0.99	0.75
D0/D			0.75

Table 7. Correlation matrix for late foetal mortality rate 2010 (all values p<0.05 except *not significant p>0.05)

2015 late foetal	D0-14/D	D0/D	Total fertility rate
Mortality rate	0.56	0.57	0.41
D0-14/D		0.99	0.80
D0/D			0.80

Table 8. Correlation matrix for late foetal mortality rate 2015 (all values p<0.05)