Could consanguineous marriage provide a cultural alleviation for the obstetric dilemma?

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Abstract

In placental mammals, a poor fit between the physical dimensions of the fetus and maternal pelvis increases the likelihood of obstructed labour. This problem is especially relevant to humans, as our species demonstrates both unique adaptations in pelvic shape and structure associated with bipedalism, and fetal encephalization. Natural selection is expected to have favoured adaptations that reduce the chances of such mismatch within individual mother-offspring dyads. Here, I hypothesise that the cultural practice of consanguineous marriage may have been favoured, on account of increasing the genetic similarity between mothers and offspring and hence the correlation between maternal and fetal physical dimensions. These benefits could be amplified if consanguineous marriage was accompanied by assortative mating for height. An additional benefit of consanguineous marriage for childbirth is the slight reduction in birth size of such offspring compared to non-consanguineous unions. Although the offspring of consanguineous unions have elevated risks of morbidity and mortality, these risks are moderate and the practice could still have been favoured by selection if the reduction in maternal mortality was greater than the increased mortality among individual offspring. This hypothesis could be tested directly by investigating whether rates of obstructed labour are lower in individuals and populations practising consanguineous marriage. At a broader level, phylogenetic analysis could be conducted to test whether consanguineous marriage appears to have originated in the areas where intensive agriculture was first practiced, as adult height typically fell in such populations, potentially exacerbating the risk of obstructed labour.

Introduction

Over the long-term, hominin evolution was characterised by the emergence of two key physical traits – bipedal locomotion and increased brain size. These two traits have long been considered to have mutual implications for each other. The emergence of bipedal locomotion was associated with major changes in the morphology of the pelvis, while the trend to encephalisation in the genus *Homo* resulted in contemporary humans having an adult brain roughly three times larger than would be predicted for a non-human ape of similar body size (1). Although much of this enhanced brain size develops in post-natal life, humans also have a relatively large brain at birth (2).

In the 1960s, the anthropologist Sherburn Washburn suggested that these two evolutionary processes had generated an 'obstetric dilemma', due to selective pressures acting on maternal pelvic dimensions being antagonistic to those acting on fetal brain size (3). Specifically, he proposed that a narrower pelvis would be favoured for bipedal locomotion, whereas a wider pelvis would facilitate the delivery of large-brained offspring. Given that early forms of hominin bipedality evolved millions of years before the emergence of *Homo*, fetal encephalisation must have evolved in the context of a pelvis already somewhat adapted to bipedality.

Washburn suggested that this obstetric dilemma was partially solved by reducing the duration of pregnancy, allowing delivery of the fetus with less brain growth completed, and thus reducing the difficulty of passing the fetal head through the maternal pelvis during delivery. However, that such resolution is not perfect is evident from the fact that childbirth complications persist in a proportion of women in contemporary populations.

Recently, the utility of the obstetric dilemma hypothesis has been reconsidered from several perspectives. An alternative selective pressure shaping the typical endpoint of human pregnancy has been proposed, namely a ceiling in the maternal capacity to provide nutritional support to the fetus (4). Others have reported that variability in maternal pelvic dimensions does not have major implications for the energetic efficiency of locomotion (5).

Nevertheless, rates of maternal morbidity and mortality associated with obstructed labour remain high in many countries (6, 7), and alternative hypotheses are needed to explain this persistent burden of ill-health. There is typically a tight fit between the size of the neonate and the dimensions of the pelvis, and the fetus tends to rotate in complex manner as it passes through the birth canal (8, 9). Giving birth is typically a protracted and painful process in humans, though this may have been exacerbated by the widespread adoption of sub-optimal birthing procedures (10). A near-universal characteristic of human childbirth is that social support is required (11).

From a different perspective, Wells and colleagues have suggested that the obstetric dilemma is not a fixed scenario, but rather a variable one that reflects variability in the somatic phenotype of both mother and offspring (2). The obstetric dilemma can be re-conceived as a 'coordination problem' between the two phenotypes, in which the penalty for poor coordination between the parties is a complicated delivery (12). On this basis, the obstetric dilemma may therefore vary between ethnic and geographic populations, within populations, and within individual women across their reproductive career. In turn, the coordination problem may potentially be resolved through several mechanisms acting on different time-scales, including genetic adaptation, phenotypic plasticity and cultural practices. For example, evidence suggests that stabilizing selection does not limit variability in the female pelvic canal (13), and that genetic constraints over this trait may have reduced over time (14).

A complementary perspective has been developed by Mitteroecker and colleagues (15), focusing on the interaction between a normal distribution in the disparity between maternal pelvic dimensions and offspring size, and a highly asymmetric 'cliff-edge' fitness function whereby fitness is zero if neonatal size exceeds a certain threshold. According to this perspective, weak selection favouring larger neonatal size and narrower pelvic dimensions results in a proportion of the population exceeding the cliff-edge, resulting in obstructed labour.

Population differences in pelvic shape are likely to reflect genetic variability, though this may reflect both positive selection and neutral evolution (16, 17). The role of genes in the obstetric dilemma is also demonstrated empirically by the consequences of the two parents having different genetic potential for growth, which is predicted to reduce the 'coordination' between maternal and fetal size. Within populations, the disparity in height between a short mother and tall father is associated with an increased risk of cesarean section (18). Across populations, likewise, unions between South Asian mothers and European fathers result in offspring with higher birth weight relative to those of two South Asian parents (19) and have an increased risk of cesarean section, whereas no such risk is associated with the smaller offspring of South Asian fathers and European mothers (20). In each case, the implication is that a high paternal 'growth drive' expressed by the fetus can overwhelm the maternal pelvic capacity for delivery. However, over the long-term, populations appear able to adapt pelvic dimensions to variability in body size, as for example shown by the relatively wide pelvic dimensions of foragers with small body size from Southern Africa in the later Stone Age (21).

One evolutionary solution to the 'coordination problem' is thus a reduced influence of genetic factors on fetal growth in late pregnancy (12). Consistent with this argument, the genetic heritability of human birth weight is reported to be around ~30% (22-24). Furthermore, among the individual alleles associated with birth weight variability, very few generate a large magnitude of effect (25). Strikingly, the heritability of fetal growth in *earlier* pregnancy is quite high, as is the heritability of infant growth (24, 26). Collectively, this evidence suggests that the regulatory effect of genes on growth relaxes shortly before birth, allowing the fetus to respond through plastic mechanisms to its nutritional supply during late pregnancy. Mechanistically, this could be achieved by the fetus responding dynamically to markers of maternal fuel supply such as metabolic rate and dietary composition (27, 28), though in general this issue remains poorly understood.

Within each mother-child dyad, therefore, fetal growth must be coordinated with the pelvic dimensions of the mother in order to maximise chances of a successful delivery. The challenge for this coordination process is that any plasticity in the development of the maternal pelvis is expressed broadly one generation before any plasticity in the growth of the fetus (12). Environmental factors acting on the mother may be very different to those acting on the fetus, and may generate variability in maternal glycemic control during pregnancy that impacts offspring birth size (29). In contemporary populations, this scenario is especially relevant to mothers with obesity or diabetes (30).

In support of this hypothesis, across many populations both short maternal stature and high maternal body mass index (BMI) increase the risk of cesarean delivery (30). In a large recent surveys from India, the combination of maternal short stature and high BMI compounded these risks, supporting the notion that delivery is more difficult when the dimensions of the maternal pelvis are constrained in early life, while growth of the fetus has been promoted by excessive maternal fuel transfer (31). Similar findings have been obtained from a range of other low-/middle-income countries (Wells et al., submitted).

Given the enhanced risk for poor coordination when environments undergo rapid change, Wells and colleagues proposed that the obstetric dilemma might have become more severe following the origins of agriculture (2). Due to a combination of changes in diet and living conditions, the emergence of agriculture has been associated in many different global regions with substantial falls in adult height, associated with changes in dietary intake (32, 33). For example, a shift from hunting to cereal-based farming is expected to have changed the ratio of dietary carbohydrate to protein, which could in turn have impacted fetal growth patterns (28) as well as adult height (34). Moreover, newly sedentary communities are considered likely to have experienced unprecedented levels of infections. Since immune function is energetically costly (35), higher levels of infections may have favoured higher levels of neonatal body fat (36). Thus, the emergence of agriculture may have brought together the 'toxic' combination of shorter mothers with smaller pelvic dimensions, and larger neonates with higher levels of body fat.

Evidence in support of this hypothesis is very limited, however the archaeological record indicates that levels of perinatal mortality were substantially higher in early agricultural populations compared to Holocene foragers (2). The evidence from contemporary India, that the rate of caesareans is greatest in short women with greater body fat, also supports the hypothesis mechanistically (31).

Aside from genetic and plastic mechanisms for relieving the obstetric dilemma, another possibility relates to cultural factors. Among South Asian populations, for example, the practice of 'eating down' during pregnancy is common and is explicitly held to make childbirth easier (37). Here, I consider a different cultural response, which might not necessarily have been consciously selected, but which might still relieve the magnitude of the obstetric dilemma. This mechanism comprises consanguineous marriages, in particular between first cousins, which are predicted to increase genetic similarity between the two parents.

The distribution of cousin marriage

Consanguineous unions remain common globally, accounting for roughly 10% of unions in the world's population (38). The practice is believed to date back at least to biblical times, and is especially widespread in North Africa, the Middle East and the Indian subcontinent (**Figure 1**) (38, 39). Particularly high rates are seen in countries such as Qatar (54%), Saudi Arabia (56%), Pakistan (55-59%) and some south Indian urban communities (40). The most common form of consanguinity relates to first cousins, and such marriages are the focus of this review, though other forms are also discussed.

Insert Figure 1 near here

The factors that predispose to consanguineous unions are various. In many populations the practice has a religious basis, but there are also indications that it predates some of the religions that currently favour it, such as Islam. Social preferences for cousin unions are also common, as it promotes shared values relating to religion, tradition and ethnic background. Such unions are often thought to promote the maintenance of family ties and marriage stability, and to reduce rates of marital disharmony which may adversely affect community relations. The practice may also help preserve wealth in families, and could also benefit the parents of brides by reducing the need for dowry payments (40). From an evolutionary perspective, consanguineous marriages have been proposed to maintain the population frequency of genes that are protective against malaria. Supporting this hypothesis, the population level of inbreeding shows a geographical correlation with the intensity of malaria infestation (41).

Alongside these social, cultural and biological benefits, consanguineous marriage may also impose physiological costs as a consequence of rare deleterious or lethal alleles pairing within the same individual. Consanguineous marriages have higher than typical rates of congenital malformations in the offspring, relating for example to inborn errors of metabolism (38, 39). They increase the incidence of various forms of non-communicable disease, and might also affect fertility rates. Finally, they are associated with higher rates of neonatal, infant and young child mortality (42-44). Nevertheless, recent research shows that the magnitude of these health penalties is lower than has been commonly assumed (38), and they are reconsidered below with reference to potential counter-balancing effects on maternal mortality.

Implications of cousin marriage for the obstetric dilemma

From a theoretical perspective, consanguineous marriages have the potential to reduce the magnitude of the obstetric dilemma. The pattern of gene transfer in first cousin marriages and uncle-niece marriages is shown in **Figure 2**. Genes pass from grandparents to both cousins, who share 12.5% of genes by descent, and thus contribute genes in common to the fetus. This means that paternal genes in the fetus increase the genetic correlation between fetus and mother, potentially decreasing any 'mismatch' between fetal growth potential and the dimensions of the maternal pelvis. Uncles and nieces share 25% of genes, hence marriage between these family members further increases the genetic correlation between fetus and mother. Any improvement in the physical match between mother and offspring could be enhanced by assortative mating for height between cousins. In practice, differences in genetic relatedness between parents in consanguineous versus non-consanguineous unions may differ from the theoretical predictions derived from such simple pedigree studies, as partners may share ancestral genes at a larger proportion of loci as a consequence of multiple generations of consanguineous unions (45). Nevertheless, even if the magnitude of effect is variable, the general principle remains valid.

Insert Figure 2 near here

As argued above, the heritability of weight is reduced at birth in comparison with mid-pregnancy and early childhood, but approximately 30% of birth weight variability is still explained by genetic factors (22-24). The notion that genetic factors contribute to variability in both size at birth and adulthood is supported indirectly by numerous studies reporting (a) correlations between size at birth and adult weight and height (46-48), (b) correlations of parental weight and height with birth size of the offspring, though weight correlations are typically stronger for mothers than fathers (49-52), and (c) associations of inter-ethnic genetic heritage with both size at birth and adult size (19, 53). Phenotypic plasticity undoubtedly contributes to the majority of these correlations, such as those between birth size and adult size (54), but there is also emerging direct evidence for genetic contributions to these relationships.

First, correlations of paternal height with offspring birth size may indicate more robust evidence for a genetic contribution (50), though epigenetic mechanisms contributing to such correlations should not be discounted. Second, in a meta-analysis of 43 studies of 69,308 individuals of European descent, two out of seven loci linked with birth weight variability were also associated with adult height (25). Finally, a Mendelian randomization analysis of 3,485 mother/infant pairs from birth cohorts in three Nordic countries showed that the association between maternal height and offspring birth weight was primarily explained by fetal genotype, rather than a causal effect of maternal height acting as an environmental influence on fetal growth (55). Collectively, these studies indicate that both paternal and maternal alleles, expressed in the fetus, explain a proportion of variability in birth size. In turn, this suggests that cousin marriage, by increasing the similarity of the two parents' genotypes, could reduce the likelihood of disparity between fetal size and the dimensions of the maternal pelvis.

This hypothesis is further supported by data on the phenotypic correlations between cousins who marry. For example, in a study of 1500 arranged marriages in Islamabad, Pakistan, the correlation in height between spouses was 0.36, with some indication that the correlation was greater in couples of low compared to high socio-economic status, and higher in those marrying before 1960 than among those marrying after 1970 (56). This similarity in height may have been actively sought by both families, to confirm with cultural norms of 'suitability' (57).

Maternal height has important implications for the obstetric dilemma, as the dimensions of the pelvis have been shown in several populations to scale with adult female height (58, 59)(Shirley et al., unpublished data), and in numerous populations, taller women have lower risks of obstructed labour (Wells 2017). In a study of Guatemalan mothers, for example, the highest risk of caesarean delivery was observed for the combination of short mothers delivering neonates with large head girth (60). However, these associations may reflect both genetic effects and phenotypic plasticity, and the extent to which pelvic dimensions are determined by genotype remains poorly understood.

Comparing 30 monozygotic and 30 dizygotic twin to estimate the heritability of pelvic dimensions directly, Sharma concluded that 60 to 80% of the variability was genetic, though the data were challenging to interpret (61). Intra-individual correlations in pelvic shape and head girth indicate genetic links between these traits, which may be advantageous for childbirth (62, 63). In a study from Northern Ireland, daughters who were taller than their mothers also had larger pelvic dimensions (64). Among young nulliparous South Asian women living in the UK, both tibia length, and an index of total stature that is statistically independent of tibia length, were positively associated with 6 pelvic dimensions (Shirley et al., unpublished data). Length of the tibia is generally regarded as being especially sensitive to environmental conditions in early life (65, 66), hence this study suggests that better growth in early childhood benefits adult pelvic capacity.

Beyond potentially improving the genetic match between maternal and offspring growth traits, consanguineous marriages also demonstrate evidence for modest reductions in the magnitude of fetal growth, relative to non-cousin marriages. In an analysis of 10,829 births in Beirut, Lebanon first cousin unions were associated with a 1.5% deficit in birth weight (equivalent to ~55g) adjusting for gestational age (67). **Figure 3** illustrates differences in birth weight relative to non-consanguineous marriages for both first cousin and uncle-niece marriage. Though the data are not sufficiently complete to allow a formal meta-analysis, both types of consanguineous marriage show a modest reduction of ~75 g in birth weight, equivalent to ~0.15 z-scores. Equivalent deficits in neonatal head circumference are -0.02 cm for first cousin marriages and -0.40 cm for uncle-niece marriages. According to a recent meta-analysis, the offspring of cousin unions demonstrate an increased risk of low birth weight (OR 1.36, 95%CI 1.03, 1.69) (68).

Insert Figure 3 near here

One possibility is that such differences in birth size may reflect the slightly earlier ages at marriage and first birth that are typical of women in consanguineous relative to non-consanguineous unions. For example, in a study from South India, women in first cousin and uncle-niece marriages delivered their first child 1.1 and 1.4 years earlier, respectively, relative to mothers in non-consanguineous unions (45). However, such reductions in birth size could also emerge through selection favouring genes contributing directly to birth weight. Another possibility is that selection might act on genes expressed in the placenta. Unlike genes in the fetus, those in the placenta cannot reproduce themselves directly, and their fitness is therefore entirely due to inclusive fitness effects (69). Although sharing 100% of its genes with the fetus, placental genes will achieve zero fitness if the trajectory of fetal development results in death of both fetus and mother, whereas it may achieve fitness pay-offs if the fetus dies but the mother survives. In the latter case, the placental genes have a 25% chance of being in the mother's subsequent fetus and placenta even if the father is not the same, and 50% if the father is the same. On this basis, placental genes might be those subject to natural selection through the medium of consanguineous marriage.

Implications for fitness

The evolutionary implications of cosanguineous marriages can now be considered. The obstetric dilemma is potentially a strong selective pressure, due to its potential to induce both maternal and perinatal mortality. Although maternal mortality has been substantially reduced in recent decades, there were 340,000 deaths globally in 2008 (7), and obstructed labour is one of the four most common causes, amounting to 12% of maternal mortality worldwide (70). Moreover, if the mother survives obstructed labour, painful and debilitating consequences are common (71) and may reduce subsequent fertility substantially.

As shown in **Figure 2**, cousins share one in eight inherited alleles from a common ancestor, such that their children are homozygous at 1/16 of all alleles. Uncles and nieces share one in four alleles by common descent, hence their children are homozygous at 1/8 of all alleles. Adult height shows very high levels of heritability, typically 80 to 90% in European populations on the basis of twin studies (72). Over 200 genes have now been associated with variability in height, all of them contributing a relatively small magnitude of effect (73). For the sake of argument, each height-associated allele is considered here to contribute an identical increment to total height. I further assume that these genes contribute both to maternal pelvic dimensions, and to fetal growth potential, though the lower heritability of birth weight compared to that of adult height must be taken into account.

The reduced disparity between maternal pelvic dimensions and fetal size predicted by cousin marriage, as well as the slightly lower birth weight of cousin marriage compared to non-consanguineous matings, are in combination expected to reduce the proportion of mother-fetus dyads exceeding the cliff-edge fitness function (**Figure 4**). These benefits are assumed to further vary according to the degree of assortative mating on parental height, which would amplify the similarity between maternal and offspring size.

Insert Figure 4 near here

As highlighted above, consanguineous unions produce reproductive penalties as well as benefits, most obviously through elevated rates of morbidity and mortality among the offspring in early life due to metabolic abnormalities. Nevertheless, the practice could still be favoured if the benefits for maternal survival outweighed the increased risk of mortality among individual offspring. Obviously, adult mothers are much harder to replace than neonates, and their mortality therefore has much greater effect on the fitness of individual genes. Moreover, the costs of metabolic abnormalities in individual offspring would likewise be counter-balanced by the lower risk of childbirth complications. Finally, some studies have reported higher rates of fertility, and of surviving offspring, among women in consanguineous compared to non-consanguineous unions (74, 75), though these may be indirect effects mediated by factors such as socio-economic status, contraception use, religious conviction and compensation for pregnancy losses.

Any tendency for cosanguineous marriages to have higher rates of maternal and offspring survival would be expected to increase the frequency of this cultural trait in the population through complementary mechanisms. Conscious recognition of such benefits could lead to active favouring of the practice, while in the absence of conscious recognition, the trait could still spread in association with the higher proportion of surviving offspring relative to non-cosanguineous marriages. However, in both cases, potential costs of cosanguineous marriages would also inhibit the spread of the trait for similar reasons.

Multi-generational effects

According to the arguments set out above, consanguineous unions could have reduced the likelihood of obstructed labour in any given generation, relative to non-consanguineous unions. But assuming the practice spread in the population, what would be the longer-term impact of consanguineous unions being repeated across multiple generations? There could be complementary effects.

On the one hand, favourable genes could become more concentrated within families, in consequences of frequent consanguineous unions among recent ancestors. Any genes that made childbirth more risky might also have been selected out of the gene pool at an accelerated rate through the same mechanism. On this basis, childbirth complications could reduce in frequency over time as the genetic benefits described above accumulate within lineages.

On the other hand, the small reduction in birth size might propagate to similar reductions in adult size. Since height and pelvic dimensions are correlated as discussed above, this effect could paradoxically exacerbate the risks of obstructed labour in the next generation. This could lead to an antagonistic scenario, where the practice of consanguineous marriages reduces the risk of childbirth at any given time, but drives slow secular declines in adult height that then increase selection on the cultural practice as a solution. In other words, marriage patterns could have contributed to the long-term declines in adult height and pelvic dimensions in populations from regions such as India (76, 77), which in turn are associated with projected long-term declines in birth weight (78).

Specific predictions of the hypothesis

The over-arching hypothesis set out here is that consanguineous marriages may have been favoured, due to the increased genetic relatedness of mother and offspring reducing the likelihood of childbirth complications. This broad hypothesis generates several specific predictions that merit further work.

First, I hypothesise that the risks of obstructed labour should be lower for the offspring of consanguineous unions compared to those of non-consanguineous unions. So far, one study reported a reduced rate of cesarean sections among Cousin marriages (79), but current evidence is insufficient to test this hypothesis.

Second, the hypothesis that consanguineous is associated with modest reductions in birth size is already supported, as shown by the meta-analyses illustrated in Figure 3. Further work could explore whether this indicates an adaptation in placental genes as opposed to genes directly associated with fetal growth.

Third, I hypothesise that the practice of consanguineous marriages should have been favoured amongst populations encountering prolonged ecological shocks associated with declines in maternal size, which might make childbirth more challenging. One such example is the origins of intensive agriculture, as discussed above, while another is the decline in height experience by some populations during the early stages of industrialisation (80). Mathematical modelling could be used to evaluate how fast the practice might have spread in such circumstances give the lower mortality risks associated with it. Such modelling could take into account the increased infant morbidity and mortality associated with consanguineous marriages.

Fourth, following the above proposition, I hypothesise that the distribution of cousin marriage should have its highest density in the geographical regions where intensive grain agriculture first developed. **Figure 5** illustrates the geographical distribution of the major different types of human subsistence in 2000 BC. This historical period is used for convenience, allowing the distribution of early agricultural societies to be visualised, but subsistence mode distributions are known to have shifted both before and after this date. The higher densities of contemporary cousin marriage illustrated in Figure 1 show substantial concordance with the distribution of complex agriculture or state societies in 2000 BC. Contemporary cousin marriage also maps onto the past distribution of nomadic pastoralists, who may have transported the custom from early state societies into new geographical regions through regular migration patterns. Possible benefits of cousin marriage for pastoralists might differ from those of farmers, and might for example relate to the transmission of property, in particular animal herds, across generations within families. This geographical distribution hypothesis might be tested by reconstructing a phylogenetic tree of cousin marriage

(81), using data on its prevalence in contemporary ethnic groups and their likely ancestral relationships.

Insert Figure 5 near here

Fifth, I hypothesise that multi-generational effects of consanguineous unions could have had a mixture of effects, for example accumulating greater mother-offspring genetic correlation over generations, but also driving down adult size through selection for smaller birth size. Again, mathematical modelling could be used to evaluate this issue.

The conceptual approach presented above pays no attention to whether a consanguineous union is between a man and his father's brother's daughter (a practice strongly favoured in the Middle East) or his mother's brother's daughter (preferential in South India) (45). Current data prevent this issue being analysed in detail, but should the hypotheses above be supported, future work could explore whether the results vary in association with this axis of variability. For example, whereas coefficients of inbreeding are identical for all types of cousin in relation to autosomal loci, they differ for X-chromosomal loci, being zero when the female partner is the husband's father's brother's daughter, and 0.125 when she is husband's mother's brother's daughter (45).

Discussion

Previously, a geographical correlation has been observed between the level of consanguineous unions and the intensity of malaria, indicating that the practice might preserve alleles that increase protection against malaria (41). Complementary to this hypothesis, I suggest that cosanguineous unions remain common in a broad region of the world associated with the origins of grain agriculture, though also in areas formerly characterised by nomadic pastoralism. In these regions, height has tended to decrease substantially over the subsequent millennia (33, 82, 83), the most extreme example being a decline of 15-20 cm in India (76). Any equivalent trend in fetal dimensions may have been smaller, however. The increased risk of infectious diseases may have selected in favour of greater neonatal adiposity (2), while neonatal head girth is a relatively conservative trait (84) and may have responded much more weakly to ecological trends. Records of birth injuries such as fistulae have been observed in ancient Egyptian mummies, and the Ebers papyrus described possible cures for urinary incontinence, a common outcome of birth injury (85). There is also occasional archaeological evidence of fetuses remaining within the maternal pelvis ('obstetric death') from ancient Egypt and Greece (86, 87).

As argued above, the practice of cousin marriage, especially if complemented by assortative mating for height, could potentially have reduced the likelihood of obstructed labour in populations struggling to express their genetic growth potential, by decreasing the likelihood that paternal growth-promoting genes in the fetus challenge the delivery-capacity of the maternal pelvis. Such benefits might be greatest in uncle-niece marriages, where the genetic similarity between the two parents is even greater.

An intriguing possibility is that these benefits, of raising the genetic similarity between mothers and offspring, might be further enhanced by epigenetic effects. Nutritional exposures during pregnancy have been shown to alter the DNA methylation of genes regulating growth (88). If alleles associated with adult height and pelvic dimensions carried an epigenetic imprint from nutritional experience in recent ancestors, then cousins could potentially share not only a given height allele but also its magnitude of expression. This epigenetic matching might be of particular value during secular declines in height associated with severe famines, but would depend on the epigenetic mark being replicated across at least two generations, so that the developmental experience of the two cousins was further expressed in their offspring.

In uncle-niece marriages, epigenetic variability in sperm quality could potentially allow even greater fine-tuning over such signalling. Studies have shown that nutritional experience in adolescence affects sperm quality and offspring phenotype (89, 90). Hence, in some circumstances the niece could receive epigenetic information that was a response to ecological conditions occurring more recently than her own fetal life and infancy.

All of these mechanisms are at present speculative. The aim of this article has been simply to set out a theoretical rationale whereby cousin marriage might impact the obstetric dilemma, and propose that the spread of this cultural trait could have been stimulated by downward secular trends in height that are well documented to have occurred around the origins of intensive agriculture. The fact that consanguineous marriage is practiced across several different religions suggests that it has some fundamental benefits that emerged early in the agricultural era. Moreover, the fact that property rights may also have developed around the same time in the early stages of farming could have allowed consanguineous marriage to be consciously selected for land inheritance, while also being unconsciously selected through its impact on survival and fertility. Future work could test how rapidly cousin marriage might have spread within populations, if it had the benefits of reducing maternal mortality during periods when the obstetric dilemma was exacerbated as suggested here.

Conflict of interest statement

The author declares no conflict of interest.

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Legends for illustrations

Figure 1. Rates of consanguineous marriage worldwide (restricted to second-cousin or closer marriages). Map based on the approach of Bittles and Black (38), updated by these authors with data for 2015.

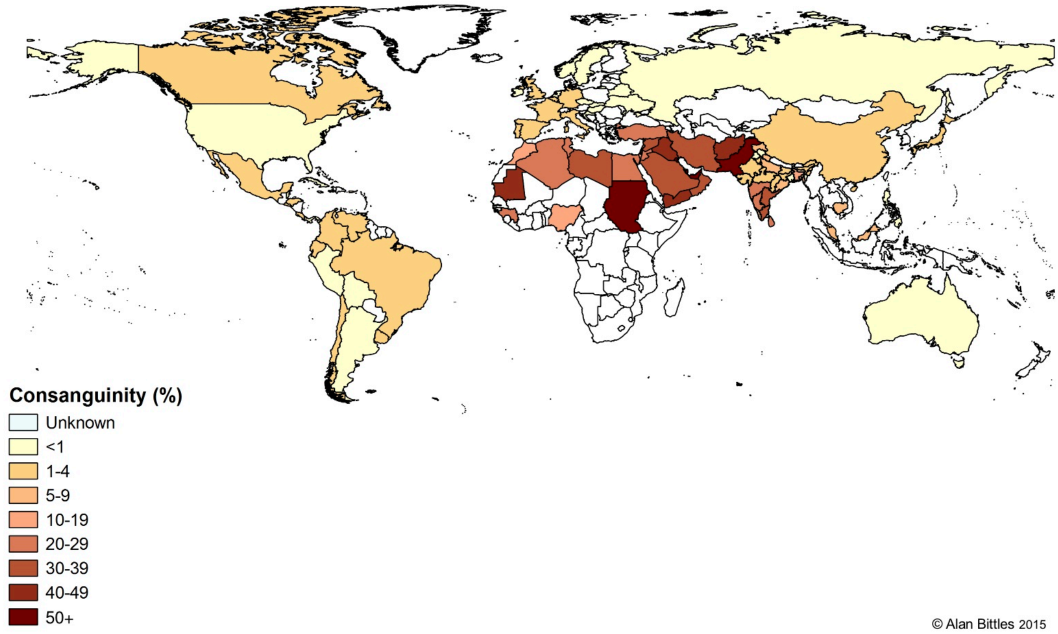
Figure 2. Implications of first cousin and uncle-niece marriage for the degree of genetic similarity between mother and offspring. Compared to non-consanguineous marriages, paternal genes in the fetus are more likely to match maternal genes in the mother.

Figure 3. Differences in birth size of the offspring of consanguineous marriages relative to nonconsanguineous marriages, for (a) weight and (b) head circumference. Data from the following references: (87-99).

Figure 4. Implications of cousin marriage for the cliff-edge selection model of Mitteroecker et al., (15). The diagram shows how a normal distribution of the disparity between neonatal size and the size of the maternal pelvic canal results in a proportion of mother-offspring dyads exceeding the 'cliff-edge' fitness function. Under the scenario of cousin marriage, the increased genetic similarity between mother and fetus narrows the distribution of this disparity, while also shifting the entire distribution slightly downwards. As a result, a smaller proportion of the population exceed the cliff-edge function. These effects may be amplified further by uncle-niece marriage. Diagram adapted and redrawn with permission from reference 15.

Figure 5. Map illustrating the geographical distribution of different subsistence modes in the Old World in the 3rd millennium BC. Regions with high contemporary prevalence of consanguineous marriages in Figure 2 are largely either those with complex agriculture in the 3rd millennium BC, or those with nomadic pastoralism. This is consistent with the hypothesis that the practice originated in agricultural societies and was then distributed further by nomadic movements of pastoralists, possible for different reasons. Source: Wikimedia Commons.

Figure 1



Consanguinity (%)
Unknown
<1
1-4
5-9
10-19
20-29
30-39
40-49
50+
© Alan Bittles 2015

Figure 2

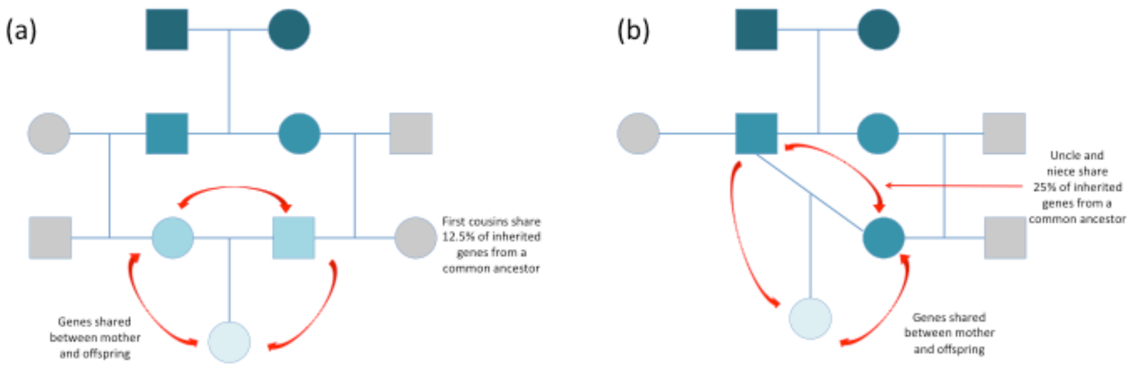

(a)
First cousins share 12.5% of inherited genes from a common ancestor
Genes shared between mother and offspring
(b)
Uncle and niece share 25% of inherited genes from a common ancestor
Genes shared between mother and offspring

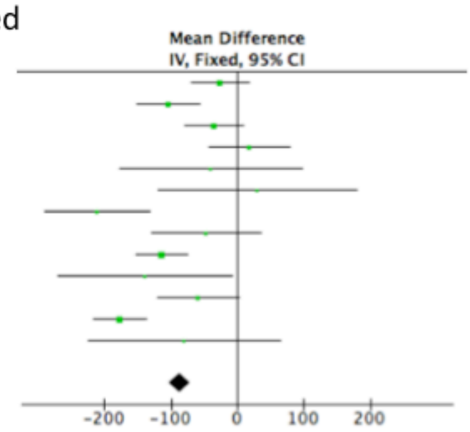
Figure 3

Birth weight

Offspring of first cousin marriages versus unrelated

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight
India low SES (Kulkarni 1990)	2,774	248	178	2,800	488	1630	13.8%
India mid/high SES (Kulkarni 1990)	2,883	284	194	2,987	429	1088	11.6%
India rural (Rao 1990)	2,737	834	1991	2,772	827	4449	13.5%
India urban (Rao 1980)	2,885	887	989	2,867	848	4251	7.0%
Inida (Sibert 1979)	2,794	498	61	2,834	407	196	1.4%
Iran (Nafissi 2010)	3,240	520	57	3,210	822	628	1.2%
Israel (Jaber 1997)	3,112	620	358	3,323	614	689	4.2%
Lebanon (Khlat 1989)	3,291	469	146	3,338	451	790	3.8%
Norway (Magnus 1985)	3,377	660	1605	3,491	617	3190	17.3%
Saudi Arabia (Al-Abdulkareem 1998)	2,968	954	267	3,107	822	628	1.5%
Saudi Arabia (Belal 2018)	2,908	510	383	2,967	514	876	6.9%
Turkey (Basaran 1994)	3,086	266	318	3,263	665	2357	16.5%
UK Pakistani (Honeyman 1987)	3,178	511	122	3,258	501	76	1.2%
Total (95% CI)			**6669**			**20848**	**100.0%**

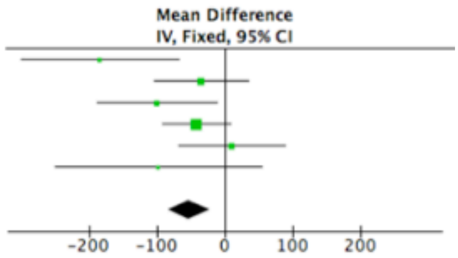
Heterogeneity: $Chi^2 = 61.08$, df = 12 ($P < 0.00001$); $I^2 = 80\%$
Test for overall effect: $Z = 10.46$ ($P < 0.00001$)



Offspring of uncle-niece marriages versus unrelated

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight
India (Sibert 1979)	2,650	371	52	2,834	407	196	7.3%
India low SES (Kulkarni 1990)	2,765	621	350	2,800	488	1630	20.5%
India mid/high SES (Kulkarni 1990)	2,887	593	190	2,987	429	1088	12.7%
India rural (Rao 1980)	2,730	810	1308	2,772	827	4449	39.1%
India urban (Rao 1980)	2,877	726	371	2,867	848	4251	16.1%
Morocco (Fried 1974)	3,371	542	67	3,469	362	81	4.3%
Total (95% CI)			**2338**			**11695**	**100.0%**

Heterogeneity: $Chi^2 = 9.28$, df = 5 ($P = 0.10$); $I^2 = 46\%$
Test for overall effect: $Z = 3.27$ ($P = 0.001$)

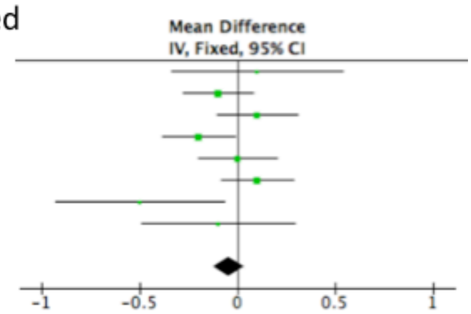


Birth head circumference

Offspring of first cousin marriages versus unrelated

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight
India (Sibert 1979)	33.4	1.5	61	33.3	1.6	196	3.4%
India low SES (Kulkarni 1990)	33.5	1.1	178	33.6	1.6	1630	20.1%
India mid/high SES (Kulkarni 1990)	34	1.3	194	33.9	1.6	1088	15.2%
India rural (Rao 1980)	33.5	3.6	1991	33.7	3.3	4449	18.8%
India urban (Rao 1980)	33.9	2.8	989	33.9	3.3	4251	16.0%
Israel (Jaber 1997)	34.5	1.6	358	34.4	1.1	689	18.9%
Turkey (Basaran 1994)	34.4	3.4	318	34.9	5.3	2357	3.5%
UK Pakistani (Honeyman 1987)	34.4	1.6	122	34.5	1.2	76	4.2%
Total (95% CI)			**4211**			**14736**	**100.0%**

Heterogeneity: $Chi^2 = 12.28$, df = 7 ($P = 0.09$); $I^2 = 43\%$
Test for overall effect: $Z = 1.02$ ($P = 0.31$)



Offspring of uncle-niece marriages versus unrelated

Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight
India (Sibert 1979)	32.7	1.3	61	33.3	1.6	196	7.2%
India low SES (Kulkarni 1990)	33.4	2.6	350	33.6	1.6	1630	14.0%
India mid/high SES (Kulkarni 1990)	33	1	190	33.9	1.6	1088	38.4%
India rural (Rao 1980)	33.5	3.3	1308	33.7	3.3	4449	27.2%
India urban (Rao 1980)	33.9	2.7	371	33.9	3.3	4251	13.2%
Total (95% CI)			**2280**			**11614**	**100.0%**

Heterogeneity: $Chi^2 = 44.89$, df = 4 ($P < 0.00001$); $I^2 = 91\%$
Test for overall effect: $Z = 8.71$ ($P < 0.00001$)

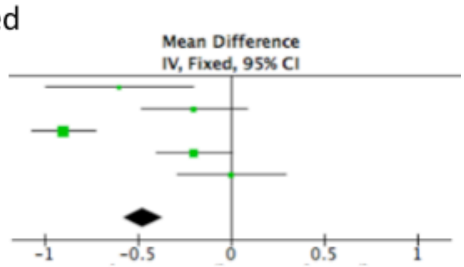
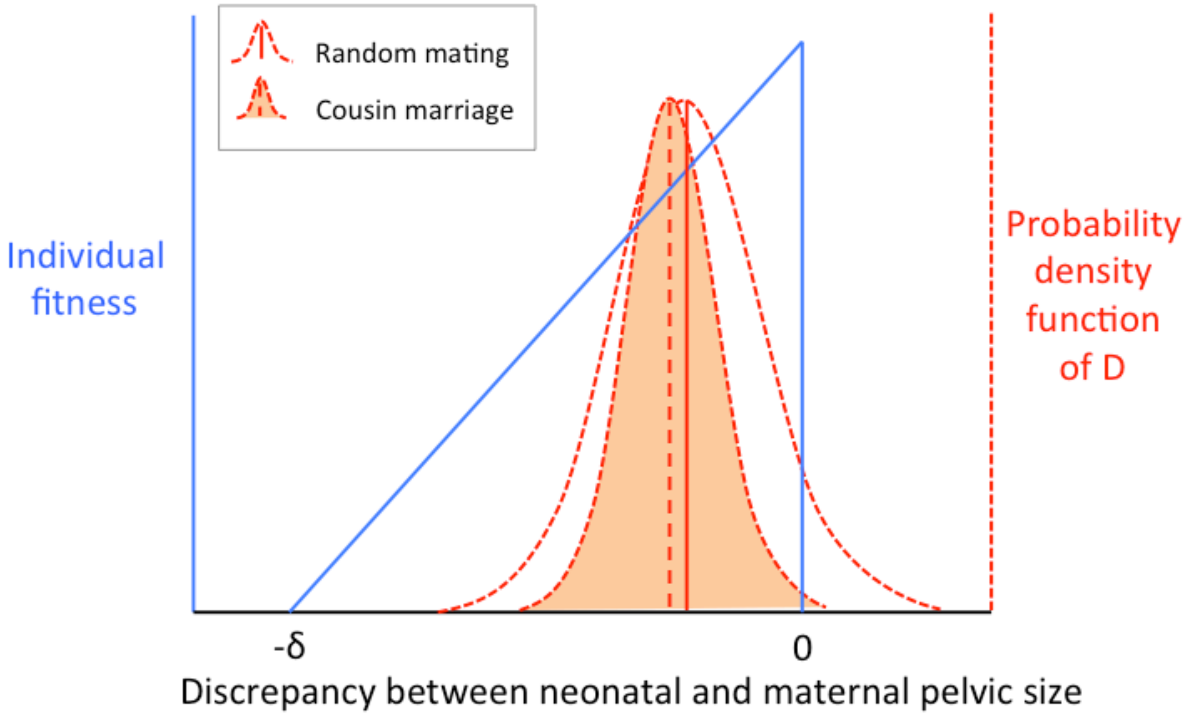
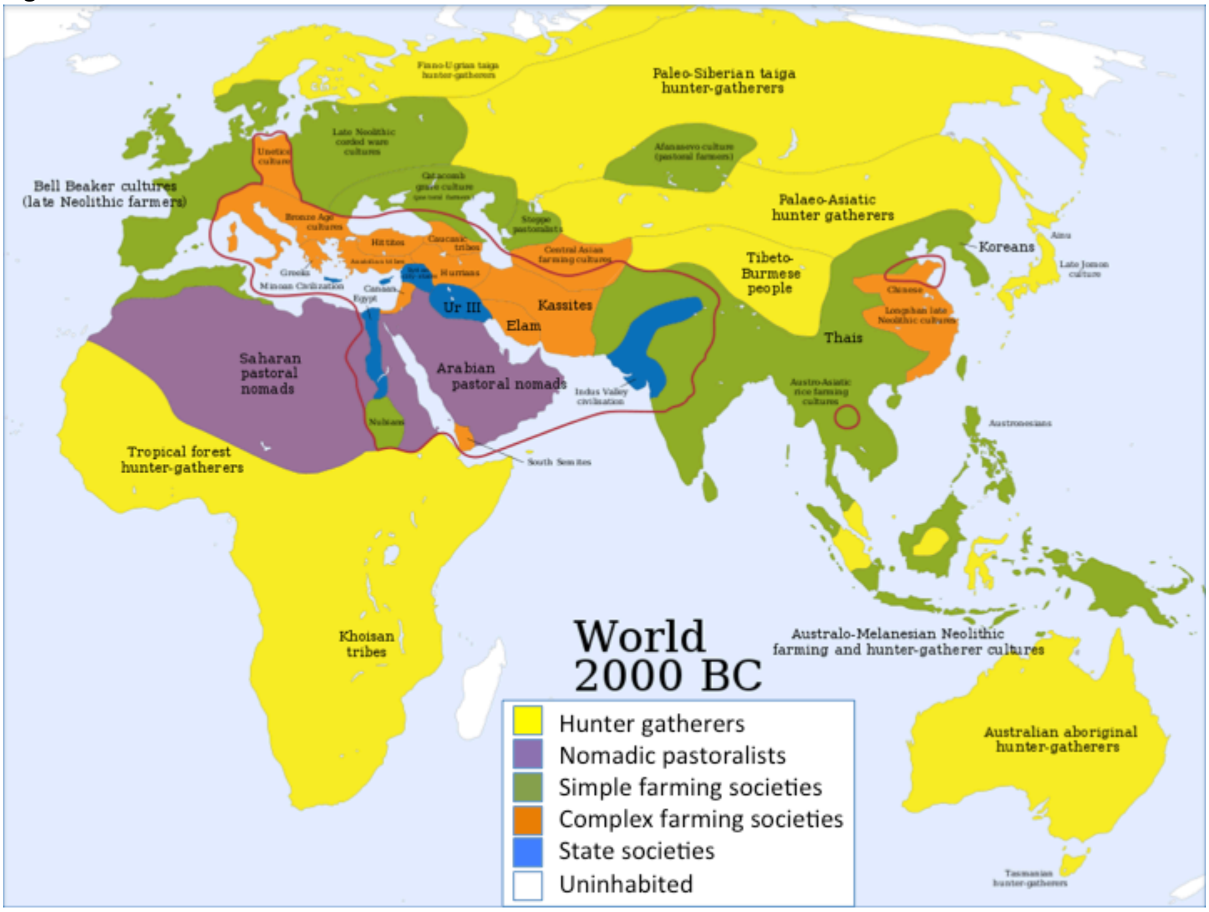


Figure 4



Random mating
Cousin marriage
Individual fitness
Probability density function of D
-δ
0
Discrepancy between neonatal and maternal pelvic size

Figure 5



Paleo-Siberian taiga
hunter-gatherers
Finno-Ugrian taiga hunter-gatherers
Late Neolithic corded ware cultures
Afanasevo culture (pastoral farmers)
Unetice culture
Bell Beaker cultures
(late Neolithic farmers)
Catacomb grave culture
Bronze Age cultures
Steppe pastoralists
Palaeo-Asiatic
hunter gatherers
Hittites
Caucasic tribes
Central Asian farming cultures
Koreans
Ainu
Late Jomon culture
Greeks
Minoan Civilization
Canaan
Egypt
Hurrians
Ur III
Kassites
Elam
Tibeto-
Burmese
people
Chinese
Longshan late Neolithic cultures
Thais
Saharan
pastoral
nomads
Arabian
pastoral nomads
Indus Valley civilisation
Austro-Asiatic rice farming cultures
Austronesians
Nubians
South Semites
Tropical forest
hunter-gatherers
Khoisan
tribes
World
2000 BC
Australo-Melanesian Neolithic
farming and hunter-gatherer cultures
Australian aboriginal
hunter-gatherers
Tasmanian hunter-gatherers
Hunter gatherers
Nomadic pastoralists
Simple farming societies
Complex farming societies
State societies
Uninhabited