Review
Genetics and Theology

EXAMINING GENETIC LOAD: AN ISLAMIC PERSPECTIVE

ARTHUR SANIOTIS*
MACIEJ HENNEBERG**

SUMMARY: The topic of genetic load has been theorised by various authors. Genetic load refers to the reduction of population fitness due to accumulation of deleterious genes. Genetic load points to a decline in population fitness when compared to a 'standard' population. Having provided an explanation of genetic load, this article will locate genetic load in relation to historic and demographic changes. Moreover, it will discuss genetic understandings from the Qur'an and hadith. It will be argued that Islam possesses sound genetic concepts for informing Muslims about life on earth as well as choosing future spouses. Consanguineous marriage which is still prevalent in some Muslim countries, will also be examined, and will elicit recent scientific research in order to understand some of social and cultural factors for this cultural practice.

Key words: Genetics, Islam, theology, Qur'an.

INTRODUCTION

What is Genetic Load?

The topic of genetic load has been theorised by various authors (1-7). Genetic load refers to the reduction of population fitness due to deleterious mutations. The noted biologist Theodosius Dobzhansky states that the accumulation of deleterious mutant genes constitutes a genetic load (3). Genetic load is a pejorative term describing a situation in which there is a load of 'wrong' genes affecting a gene pool of the human population. Genetic load points to a decline in population fitness when compared to a 'standard' population (7). The standard population is defined as carrying an optimum genotype, where no mutations arise (7). In this way, the fittest individuals are those which have the highest number of progeny. Therefore, harmful mutations to an individual's genotype may reduce his/her fitness over generational time if such mutations are non-optimal. Similarly, Lynch and Gabriel argue that deleterious mutations reduce reproductive rates of individuals (6). However, this is not always the case. Schizophrenia which is present in approximately 1% of human populations has persisted in the human genotype for millennia. One may presume here that having schizophrenia does not necessarily exclude an affected individual from reproducing. From an evolutionary viewpoint, schizophrenia and bi-polar depression may have possibly conferred benefits to individuals living in ancestral environments which are considered to be maladaptive in modern societies (8).

*Visiting Research Fellow, School of Medical Sciences, The University of Adelaide and International Member, Center for Evolutionary Medicine, University of Zürich, Australia.

**Wood Jones Professor of Anthropological and Comparative Anatomy, School of Medical Sciences, The University of Adelaide and Centre for Evolutionary Medicine, University of Zürich, Australia.

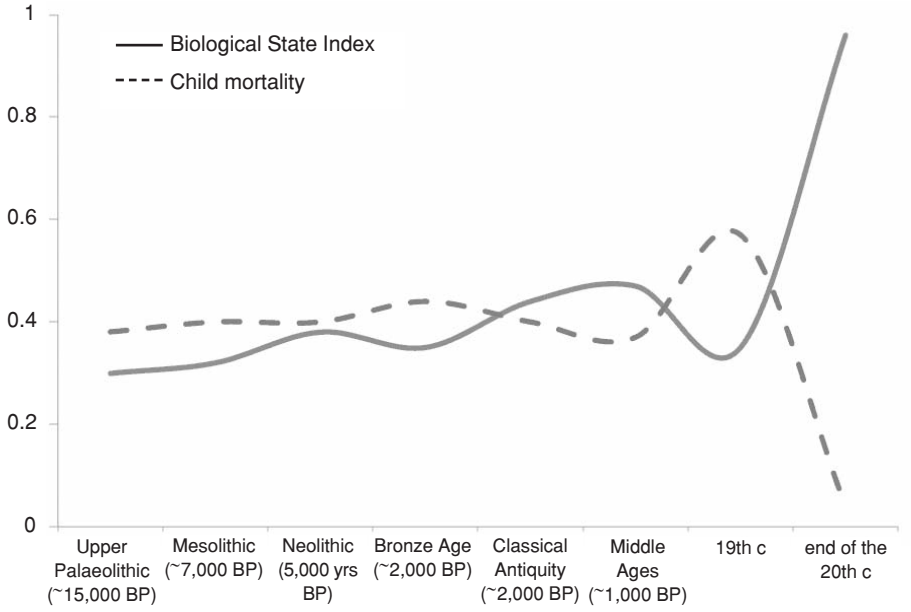

Figure 1: Changes in the opportunity for natural selection and in the child mortality in the recent history of humankind. The opportunity for natural selection is measured as the Biological State Index (39). The index expresses an opportunity for an average individual born into a population to pass on genes to the next generation. Index value of 1.0 means that there is no opportunity for natural selection through differential mortality because all individuals survive until the end of their reproductive period. Note that until very recently an individual had less than 50% chance to pass on genes to the next generation. Thus natural selection had an ample opportunity to eliminate defective genes introduced by mutations (36-41).

Having provided an explanation of genetic load, this article will locate genetic load in relation to historic and demographic changes. For example, modern public health interventions have improved the survival rates of individuals who have unfavourable genetic conditions. Furthermore, some genetic conditions which may have mitigated an individual's survival in ancestral times can be treated by modern medicine. The third section will discuss genetic understandings from the Qur'an and *hadith*. This section will show that Islam possesses sound genetic concepts for informing Muslims about life on earth as well as choosing future spouses. The last section will provide a brief discussion on consanguineous marriage which is still prevalent in some Muslim countries, and will elicit recent scientific research in order to understand some of social and cultural factors for this cultural practice.

Historic and Demographic Changes Which Have Increased Genetic Load

The opportunity for both natural selection through differential mortality and differential fertility decreased in the 100 years or so following demographic changes, which some people call demographic revolution. It has been characterised by low rates of mortality and fertility; there is much less opportunity for any deleterious mutations to be removed from the gene pool by natural selection. Some of this opportunity for selection still remains but it is now less than 1% compared with more than 50% in the past (Figure 1).

Substantial changes have occurred since the time of the Industrial Revolution depending on the population, within the last century and a half – in some populations slightly earlier; in some populations slightly later. In terms of differential mortality, the main component has been the reduction of premature mortality of infants, juveniles and young adults. This has been now largely eliminated in developed societies. Newborn life expectancies that were hovering around 20-25 years in most countries until the mid-19th century are now exceeding 80 years. Infant mortality rates that were as high as 20% are now reduced to much less than 1%. It has been noticed a long time ago in the 1930s already and then in the 1950s, and it is remaining a fact. The intra-uterine selection and some other pre-natal selections still remain strong. Henneberg

Table 1: Changes in human morphological characters in Europe in the recent past. Cranial index is the ratio of maximum cranial width to the maximum cranial length. The rate of change is measured in Darwins as d = (lnX1–lnX2)/t, where X1 is the initial value and X2 is the final value. All data have been derived from Henneberg 2006 (42).

Trait	Initial value	Final value	Time period	Rate (Darwins)
Cranial capacity	1456 ml	1350 ml	Last 7000 yrs	-10.8
Cranial index	73.0 %	80.5 %	Last 1500 yrs	+65.2
Stature	1.60 m	1.70 m	Last 100 yrs	+606.2

contends that microevolutionary modifications to the human genome that manifest phenotypically have been relatively fast (i.e. <100 generations), and that this microevolution has been due to cultural phenomena (Table 1) (10).

The relaxation of natural selection in many contemporary societies has been influenced by medical interventions which have allowed individuals to survive and reproduce (11. 12). Although medical interventions have led to a steady increase of the human lifespan, the 'associated accumulation of unfavourable genes' in human populations may have 'decreased human capacity to survive without medical intervention' (11). A case in point is phenylketonuria which is a genetically caused condition (a recessive allele) in which a child has a metabolic defect leading to the production of high levels of the amino acid, phenylalanine. High levels of phenylalanine can affect normal physical and mental development in children. In the past there was no treatment for phenylketonuria so babies that were born with phenylketonuria died during childhood. Modern treatments for phenylketonuria are based on a diet which does not contain amino acids that can be converted to phenylalanine. Therefore, the metabolic defects which are associated with phenylketonuria are less significant.

The probability of random mutation destroying a gene is much greater than the probability of random mutation enhancing and improving it. A mutation is deleterious if it negatively affects the life of an individual. What affected life or livelihood or even survival of an individual during the Palaeolithic or early Neolithic periods may no longer be affecting it now. To use the very simplistic example, a gene that produces colour blindness was probably unfavourable in hunting and gathering populations but now is of minor significance.

Human Genetic Understandings in Islam

Although Islam originated in the 7th century Bedouin society, both the Qur'an and the hadith (Prophetic traditions) elucidate genetic concepts. The Qur'an unequivocally states that Allah created the diversity in fauna and flora, and that this multiplicity of species is a way of fostering understanding into the beauty and richness of creation. Diversity is the principle which informs the Divine creative will.

See you not that Allah sends down rain from the sky? With it We then bring out produce of various colors. And in the mountains are tracts white and red, of various shades of color, and black intense in hue. And so amongst men and crawling creatures and cattle, are they of various colors. Those truly fear Allah, among His Servants, who have knowledge: for Allah is Exalted in Might, Oft-Forgiving (Fatir 35:27-28).

The Qur'an also points out that human diversity was instigated by Allah in order for humans to learn from each other and appreciate their unity.

O people, We have created you from a male and a female and made you into races and tribes so that you may know each other. Surely the most honored of you in the sight of God is the one who is the most righteous of you (49:13).

According to many authentic *hadith*, the Prophet Muhammad possessed an understanding of genetics in relation to finding future spouses. The Prophet warns that individuals should show caution about mate selection. According to one *hadith* the Prophet states: 'Choose well your mates (for your semen), marry with equal, suitable and fitting individuals.' (13-15). In another *hadith* attributed to the Prophet he notes: 'Choose well your mates because characters are maskable (can be masked), choose well for your semen and marry with rivals. Choose well who is going to beget your children because characters are maskable.' (13). Ghareeb points out that this *hadith* refers that *`irq* or gene is associated with phenotypic traits such as skin colour and hereditable disease traits. The concept of *`irq* is further explained in the following *hadith*:

There came a person to the Prophet from Banu Fazara and said: My wife has given birth to a child who is black, whereupon Allah's Apostle said: Have you any camels? He said: Yes. He again said: What is this [sic: read their] colour? He said: They are red. He said: Is there a dusky one among them? He said: Yes, there are dusky ones among them. He said: How has it come about? He said: It is perhaps the strain (`irq) to which it has reverted, whereupon he (the Prophet) said: It is perhaps the strain (`irq) to which he (the child) has reverted (17, 18).

The *hadith* also prohibits marriage with individuals who are mentally retarded. This prohibition should be understood according to the cultural milieu of the 7th century Bedouin society which emphasised the integrity of familial lineages. Thus, potentially deleterious genetic mutations diminished family fitness. Moreover, avoidance of mating with mentally retarded individuals had the effect of decreasing the frequency of genetically inherited diseases, thereby reducing the genetic load (19).

There is a growing body of scientific literature that highlights the interplay between genes and environment. Studies have shown that behavioural traits such as marital status, socioeconomic status and substance addiction are influenced by gene-environment interactions (20, 21). Differing environments mediate gene expressions which affect physical and mental health or illness. For example, research indicates that there is a correlation between marital status and the GABRA2 gene which is implicated in alcohol dependence in some individuals. In this scenario, individuals with high-risk GABRA2 genotype are more likely to be influenced by alcohol addiction (21). Moreover, many studies have identified the relationship between human disease and gene-environment interplay. The recent completion of the Human Genome Project may provide scientists further insight into the gene-environment interplay (22). A case in point is the pan-human obesity phenomenon which affects over one billion individuals. Some evolutionary scientists maintain that recent changes in diet and lifestyle factors have exacerbated being obese and overweight. Evolutionary medicine points out that there has been a growing mismatch between the human genome and modern environments which are dissimilar from ancestral living conditions. Stearns *et al.* argue that 'because biological evolution is much slower than cultural change, much disease arises from the mismatch of our bodies to modern environments (23). These theorists maintain that the ancestral diet was calorically low and consisted of wild meat, fish and plants. The ancestral diet was also rich in complex carbohydrates and fibre while low in sugar and fat (24). In contrast, contemporary diets tend to be much higher in simple carbohydrate, fat, sugar and sodium. It has even been theorised that present human penchant for sweet and fatty foods is a carry-over from the ancestral diet in which such foods were highly prized due to their high caloric volume and relative inaccessibility (25). What is interesting here is the association between the gene-environment interplay and obesity which could be contributing to genetic load. For example, it has been estimated that 70%-80% of obese American adolescents will become obese adults, often with associated co-morbidities (i.e. cardiovascular disease, type 2 diabetes, psychosocial disorders) (26). Changes in human diet and lifestyle may be decreasing individual human fitness with subsequent genetic implications.

From an Islamic perspective, current obesity and overweight rates are symptomatic of excessive behaviours which have become habitual and may be counteracted through moderation. Islam's encouragement of behavioural moderation in this instance may assist in curtailing future genetic load. Moderation in Islam in relation to food is characterised by Muslim penchant to share meals, thereby diminishing the amount which an individual eats. Commensality is not only an expression of unity between Muslims but also promotes health.

Consanguineous Marriage and Genetic Load

According to Bittles, consanguineous marriage may account for up to 50% of marriages in some populations (27). While consanguineous marriage is prevalent in Africa, the Middle East and Asia there has been little quantitative research available (28). Present estimation concludes that at least 10.4% of the world population are related as either first or second cousins (28). In some countries consanguineous marriage has exceeded the previous generation, possibly indicating higher survival rates which increase the number of biological relatives who can marry (28).

Consanguineous unions are sanctioned in Judaism, Islam, Buddhism and Hinduism. Consequently, many ethnic groups within these religions practice consanguinity without any apparent social opprobrium. Consanguineous unions are mentioned in the book of Leviticus 18, 7-18, as part of Judaic social rules. Christian prohibitions against consanguinity began in the 6th and 7th

centuries (29), while there are marital restrictions concerning biological relatives in the Orthodox and Catholic churches which derive from the 16th century reformation (30).

Although consanguineous unions were commonplace in Europe, attitudes towards them changed by the late 19th century. This was partly due to Charles Darwin's concern about the safety of consanguineous marriage. Three of Darwin's children had died prematurely, prompting him to question his own consanguineous union. By the late 19th century European public attitudes towards consanguineous marriage changed. This attitudinal transformation was confirmed by scientific studies which suggested that there was a higher incidence of genetic abnormalities in children of consanguineous unions. The practice of consanguineous marriage has recently spurned controversy, predominantly in Western countries where the practice is largely stigmatised. The media have also been influential in forming the public concerns regarding consanguineous marriage. Recent articles in *The New York Times* (2009) and *The Independent* (2008), such as 'Shaking Off the Shame' and 'There's Nothing Wrong With Cousins Getting Married, Scientists Say' discuss some of the myths ascribed to consanguineous marriage. Similarly, Mark Ottenheimer, in his 1996 book titled, *Forbidden Relatives: The American Myth of Cousin Marriage*, depicts the entrenchment of anti-consanguinity attitudes in American society. Currently, in the United States 24 states prohibit consanguineous marriage. The two articles suggest that a reason why there may be a change in Western attitudes towards consanguineous marriage is due to increasing scientific research that indicates that birth defects to offspring from such marriages are relatively small. Previous socially based assertions of consanguineous marriages derived from simplistic understandings of genetics. Moreover, social changes to consanguineous marriages may also stem from a relaxation of social stigma related to the perceived 'incestual' nature of such unions. According to Professor Spencer from the University of Otago, laws preventing consanguineous unions in many American states were designed to discriminate against migrants and the rural poor. Additionally, such changes may reflect a broader change in social mores regarding procreation in which middle aged women are increasingly having babies. As Professor Spencer points out, 'Women over the age of 40 have a similar risk of having children with birth defects and no one is suggesting they should be prevented from reproducing.' (31).

In Islam, consanguineous marriage is permitted. The Qur'an (4:22-24) gives an account of which women a man may marry. The passages do not prohibit consanguineous marriage. Moreover, the Prophet married his daughter Fatima to his cousin Ali ibn Talib. The Prophet was also married to his first cousin Zaynab, whose mother was Umaymah, the daughter of his grandfather`Abd al-Muttalib. Ali ibn Talib's (fourth righteous caliph in Islam) daughter Zaynab married her first cousin Abd Allah, who was the son of his brother Ja`far b. Abî Tâlib. However, the Prophet also encouraged his companions to marry women from different tribes, thereby allowing Muslims marital preferences.

In relation to some Muslim countries, consanguineous marriage is a preferred form of marriage for many families Consanguineous marriage is particularly practiced among Middle Eastern and South Asian populations. Some Muslim migrant populations also prefer consanguineous unions. For example, consanguinity marriage rates among Pakistani migrants in the United Kingdom are as high as 50%. In general, Muslim regulations on consanguineous marriage parallel Judaic laws. While uncle-niece marriages are disallowed in Islam, double first cousin marriages are permitted (27). The coefficient of inbreeding in such marriages is (F = 0.125) (27). The analysis of 38 populations 'placed a mean excess mortality at the first cousin level' at 4% (27). Approximately, there are 3.5% excess deaths from consanguineous unions when compared to 4.4% of the global excess mortality (28). The mean value of 3.5% of excess deaths from consanguineous unions may be subject to downward revision as design techniques improve (28). While research reveals higher rates of consanguinity-associated mortality, this was mainly due to a 'lack of control for the negative correlation between consanguinity and socioeconomic status' (28). Research done on the relationship between consanguinity and complex disease has produced varied results, mainly due to the lack of 'standardised assessment protocols' (28). The American Collaborative Study of Congenital Malformation found that among 34,190 newborns there was an association between consanguinity only for bilateral oral facial clefts, hydrocephalus and postaxial polydactyly (28, 32). Similarly, a Pakistani demographic and health survey found that consanguineous progeny 'had statistically odd ratios for neonatal, postnatal and infant mortality of 1.36, 1.28 and 1.32, respectively' (27).

Consanguinity must be examined in relation to various cultural and socio-demographic variables in determining mortality and morbidity rates during infancy and early childhood (27). Preference of consanguineous marriage is influenced by complex socio-cultural factors, such as the desirability in keeping material assets within the family lineage, strengthening kin-based ties, and maintenance of kin group identity. Moreover, consanguineous marriage is often viewed as a more reliable marital option since potential spouses can be more readily scrutinised. In Bangladesh, consanguinity is related to the practice of dowry which directly reduces the agency cost (33). Such a dowry system is viable in order to alleviate catastrophic payments, particularly where a family has multiple daughters who need marriage dowries. Hussain contends that consanguineous marriages are preferred as they are widely believed to offer the best method for ensuring compatibility between husband and wife, and wife and mother-in-law (34). Additionally, consanguineous unions are widely preferred since 'undisclosed problems regarding health or other unfavourable social characteristics of either bride or groom will be effectively avoided' (33).

Given the high preference for consanguineous marriage among Muslims, social, cultural and economic factors that encourage this practice need further investigation (28). This also includes the material benefits which women can accumulate from consanguineous unions (28). The social structure of some Muslim societies such as Bangladesh favour consanguineous marriage which guards against catastrophic dowry payments. The practice of *bint 'amm* (marriage between paternal cousins) among Arab Muslims not only reflects religious and cultural preferences, but may have been implemented as part of reformed inheritance laws during the time of the Prophet (28, 35). Possibly, the inclusion of more genetic education and counselling may prove beneficial for cousins contemplating marriage. While scientific debate continues about the potential genetic load of consanguineous marriage, failure to address the over-riding social and cultural factors which encourage this form of marriage will only increase misunderstanding.

CONCLUSION

This article has discussed aspects of genetic load from an Islamic perspective. While genetic load is predicted to be a foreseeable problem in the future, medical interventions may be used to curtail genetic-based diseases. As it has been shown, current medical technologies have been able to treat some genetic-based diseases. It is hoped that this trend will increase.

The assumption that genetic load is influenced by consanguineous unions has not been verified by evidence-based research. On the contrary, research shows that consanguineous marriage among Muslims for a period of 1400 years has not had a deleterious effect on the Muslim gene pool. However, while consanguineous unions are still controversial among some scientists, concerns about unfavourable genetic effects of such unions are still largely unknown due to insufficient and non-standardised research, which does not take into account social and cultural factors for their persistence.

Although genetic technologies are not discouraged in Islam, the precedent of 'do no harm' remains the guiding principle of Islamic scholars on genetic matters. While The Qur'an and the *hadith* are not scientific treatises, they do point to the notions of equilibrium, balance and symmetry found throughout nature, including the human body. The basis of such ideas continues to inform Muslim understandings on genetics. Increasing research on genetic load may provide further scientific insight into the gene-environment interplay. Possibly, an Islamic approach towards understanding genetic load can offer an important heuristic framework.

REFERENCES

1. Crow JF. Some possibilities for measuring selection intensities in man. Human Biol 1958; 30:1-13.

2. Crow JF. Mutation and selective balance as factors influencing population fitness. In: Molecular Genetics and human Disease, Gardner Li., ed. Springfield: Charles C Thomas, 1960.

3. Dobzhansky T. Genetic loads in natural populations. Science 1957; 126:191-194.

4. Wallace B, Dobzhansky T. Radiation, Genes and Man. New York: Henry Holt, 1959.

5. Lynch M, Gabriel W. Mutation load and the survival of small populations. Evolution 1990; 44 : 1725-1737.

6. Muller HJ. Our load of mutations. Am J Hum Genet 1950; 2:111-176.

7. Sanghvi LD. The concept of genetic load: a critique. Am J Hum Genet 1963; 15:298-309.

8. Gilbert P. Evolutionary psychopathology: why isn't the mind designed better than it is? British J Med Psyc 1998; 71:353-373.

9. Saniotis A, Henneberg M. Medicine could be constructing human bodies in the future. Medical Hypothesis 2011; 77:560-564.

10. Henneberg M. The influence of natural selection on brachycephalization in Poland. Studies in Physical Anthropology 1976; 2:3-19.

11. Stephan CN, Henneberg M. Medicine may be reducing the human capacity to survive. Medical Hypotheses 2001; 57:633-637.

12. Medawar PB. Do advances in medicine lead to genetic deterioration? In: Natural Selection in Human Populations, Bajema CJ, ed New York: Robert E, Krieger Publishing Co, pp 300-308. 1971.

13. Al-Albany, Mohammad Nasser Al-Din. Sahih Sunan Ibn Maja. Maktab Al-Tarbiya Al-Araby Li-Diwal Al-Khalij Al-Araby. 1st Edition. 1407 H (No. 1615). http://www.dorar.net/enc/hadith

14. Al-Bayhaqi, Ahmad Ibn Al-Hussein. Al-Sunan Al-Kobra. Dar El-Kutub Al-Elmiyya. Revision by Mohammad Ata, Beirut, Lebanon, 1st edition, (133/7), 1994.

15. Al-Thahaby, Mohammad Ibn Ahmad Ibn Othman. Al-Mohathab Fi-Ikhtisar Al-Sunan Al-Kobra lil-Bayhaqy. Revision by Yasser Ibraheem Mohammad. Dar el-Watan Lil-Nasher. 1st edition, 1422 H.

16. Ghareeb BAA. Human genetics and Islam: scientific and medical aspects. JIMA 2011; 43:83-90.

17. Sahīh Muslim. Kitāb al-Li` ān. ladīth no. 1500. Available from muhaddith.org

18. Sahīh Muslim. Siddiqui AH (translator). Book 9, Number 3574: Available from http://www.usc.edu/schoolscollege/crcc/engagement/resources/texts/muslim/hadith/muslim/009.smt.html#-009.3574.

19. Ghareeb BAA. Genetics of diseases, ethics and beauty in selection of mates (an Islamic perspective). Medical Journal of Islamic World Academy of Sciences 2010; 18:155-164.

20. Jaffee SR, Price TS. Gene-environment correlations: a review of the evidence and implication for prevention of mental disease. Molecular Psychiatry 2007; 12:432-442.

21. Dick DM, Agrawal A, Schuckit MA, Bierut L, Hinrichs A, Fox L, Mullaney J, Cloninger CR, Hesselbrock V, Nurnberger JI. Jr, Almasy L, Foroud T, Porjesz B, Edenberg H, Begleiter H. Marital status, alcohol dependence, and GABRA2: evidence for gene-environment correlation and interaction. Journal of Studies of Alcohol and Drugs 2006; 67:185-194.

22. Hunter D. Gene-environment interactions in human diseases. Nature Reviews 2005; 6:287-298.

23. Stearns SC, Nesse RM. Govindaraju DR. Ellison PT. Evolutionary perspectives on health and medicine. PNAS 2010; 107:1691-1695.

24. Ungar PS, Grine FE, Teaford MF. Diet in early Homo: a review of the evidence and a new model of adaptive versatility. Annu Rev Anthropol 2006; 35:209-28.

25. Saniotis A. 2010 Evolutionary medicine and bioethics: an Asian perspective. Calicut Medical Journal 2010; 8:e4.1-5.

26. Reid EM. Genes load the gun, the environment pulls the trigger: obesity among children and adolescents in U.S. schools. Forum on Public Policy, 1-28, 2008.

http://forumonpublicpolicy.com/archivespring08/reid.pdf

27. Bittles AH. A background summary of consanguineous marriage. Centre for Human Genetics. Edith Cowan University. Perth, May, 2001.

28. Bittles AH, Black ML. Consanguinity, human evolution, and complex disease. PNAS 2010; 107:1779-1786.

29. Bittles AH. The bases of Western attitudes to consanguineous marriage. Dev Med Child Neurol 2003; 45:135-138.

30. Bittles AH. A community genetics perspective on consanguineous marriage. Community Genet 2008; 11:324-330.

31. Connor, Steve. There's nothing wrong with cousins getting married, scientists say. The Independent. 24 December, 2008. http://www.independent.co.uk/news/science/theres-nothing-wrong-with-cousins-getting-married-scientists-say-1210072.html

32. Rittler M, Liascovich R, López-Camelo, Castilla EE. Parental consanguinity in specific types of congenital anomalies. Am J Med Genet 2001; 108:26-43.

33. Do QT, Iyer S, Joshi S. The economics of consanguinity. World Bank Policy Research Working Paper No 4085, 2006.

34. Hussain R. Community perceptions of reasons for preference for consanguineous marriages in Pakistan. J Biosoc Sci 1999; 31:449–461.

35. Hathout H. Islamic views on some reproductive issues. In: Genetic Disorders among Arab Populations, Teebi AS, Farag TI., eds. New York: Oxford University Press, p 469-473, 1997.

36. Budnik A, Liczbinska G, Gumna I. Demographic Trends and Biological Status of Historic Populations From Central Poland: The Ostrow Lednicki Microregion. Am J Phys Anthrop 2004; 125:369-381.

37. Henneberg M, Henneberg RJ. Reconstructing Medical Knowledge in Ancient Pompeii from the Hard Evidence of Bones and Teeth. In: J Renn, G Castagnetti (eds) Homo Faber: Studies on Nature. Technology and Science at the Time of Pompeii, "L'ERMA" di Bretschneider, Rome, pp 169-187, 2002.

38. Henneberg M. Henneberg RJ. Biological characteristic of the population based on analysis of skeletal remains, [in:] JC Carter (ed.) The Chora of Metaponto: The Necropoleis, University of Texas Press, Austin, pp 503-556, 1998.

39. Henneberg M. Reproductive possibilities and estimations of the biological dynamics of earlier human populations. Journal of Human Evolution 1976; 5:41-48.

40. Saniotis A, Henneberg M. Medicine Could be Constructing Human Bodies in the Future. Medical Hypotheses 2011; 77:560-564.

41. Stephan C, Henneberg M. 2001 Medicine may be reducing the human capacity to survive. Medical Hypotheses 2001; 57: 633-637.

42. Henneberg H. The rate of human morphological microevolution and taxonomic diversity of hominids. "Essays in memory of Andrzej Wiercinski"; "Studies in Historical Anthropology" 2006; 4:49-59.

Correspondence:
Arthur Saniotis
School of Medical Sciences,
University of Adelaide,
North Terrace, Adelaide,
South Australia 5005, AUSTRALIA
e-mail: arthur.saniotis@adelaide.edu.au