REDUCTION OF TOOTH SIZE IN THE KHABUR BASIN (NORTHERN MESOPOTAMIA)

ARKADIUSZ SOŁTYSIAK,
DEPARTMENT OF HISTORICAL ANTHROPOLOGY, INSTITUTE OF ARCHAEOLOGY, WARSAW UNIVERSITY, WARSZAWA, POLAND

Abstract: Temporal reduction in crown diameters has been observed in various human populations, especially between the Upper Paleolithic and Neolithic. There are many models explaining this tendency, most of them using the concept of directional selection. This concept was tested on dental samples from several archaeological sites of northern Mesopotamia, ranging from the Pre-Pottery Neolithic to the Iron Age. Changes in average permanent tooth size in that period are striking, although their pattern is unexpected: from the Neolithic till the Chalcolithic the tooth size remained more or less stable (or even somewhat increased) and the process of reduction (by 20–25% in crown diameters) started in the Late Chalcolithic (ca. 4000 BCE) and continued to the Iron Age. Such a pattern supports The Late Chalcolithic was the period of rapid urbanisation and profound changes in the social, economical and technological systems. The shift from small-scale village economy to large-scale centralized dry farming and sheep/goat herding was followed by a re-shaping of food storage, distribution and preparation techniques and this change may have induced directional selection towards smaller teeth in the studied local population.
Key words: dental anthropology, tooth size, microevolution, northern Mesopotamia

Introduction

Temporal changes in tooth size are one of most frequently discussed topics in dental anthropology (cf. Hillson 1996:83–85). There was an observed long-term dental reduction within the *Hominidae* (cf. Larsen 1997:245) and in the course of the history of *H. sapiens* as well. Crown diameters are highly heritable and more than 80% of their covariation is due to additive genetic factors (Kieser 1990, Townsend et al. 1994, cf. Hillson 1996:79). For that reason most authors explain changes in tooth size in terms of directional selection, although such factors as the impact of the mother's health during pregnancy (Garn et al. 1979) or general nutritional status at the time of tooth formation (Goodman et al. 1989) are sometimes considered to influence dental measurements (cf. Lindsten 2003:12).

Reduction of tooth size has been observed in various parts of the world, but in the greatest degree in Europe and South China (Brace 1976:209). This trend was noted also in populations of the Near East, and interpreted as an effect of transition from hunting-gathering to agriculture (Smith et al. 1984:113, cf. Smith 1989). Change in subsistence strategy, despite the actual evolutionary mechanism it may have incited, was frequently considered as the cause of tooth size reduction as the foraging populations had larger teeth than the farmers (cf. Larsen 1997:245).

There are four models explaining the mechanism of tooth size reduction. Most controversial is the *Probable Mutation Effect Hypothesis* proposed by C.L. Brace (1964, 1976) who claimed that the use of tools and advanced food preparation techniques removed selective pressure and allowed tooth reduction by random mutations. Introduction of agriculture was an important event in that model, not for the change of subsistence strategy but because it was connected with a crucial change in food preparation habits (Brace 1976:209, Brace et al. 1991:51). The removal of selection pressure on the robust chewing apparatus has been accepted also by Patricia Smith as an explanation for the dental reduction between the Middle Palaeolithic and Bronze Ages in the Levant (Smith et al. 1984), but many authors criticised this model because it explained the trend not in terms of directional selection but as a lack of selection which is hardly consistent with the theory of evolution (cf. Kieser 1990:54–58).

The second is the *Allometric Hypothesis* that correlates tooth size reduction with overall body size reduction in the Upper Palaeolithic. Also this model emphasized technological changes that had favoured the smaller, more energy efficient hunters (Frayer 1978, cf. Angel 1975). The constant rate of the trend and a lack of sharp decline in the early agricultural populations inhabiting the Near East were interpreted as a support for the Allometric Hypothesis (Hadow and Lovell 2003). However, this model has been also strongly criticised because there is weak or even zero correlation between body and tooth size (cf. Kieser 1990:53, Brace et al. 1991:37).

Gloria y'Edynak has proposed the *Jaw Reduction Hypothesis* (1978, 1989) based originally on the observations of Mesolithic foragers in the Balkan Peninsula. There was no evidence of a dietary change but reduction in tooth size was considerable. The causative agent in this model was food softening which forced a reduction of the masticatory apparatus (being more ecosensitive than tooth size, cf. Lindsten 2003:12) while malocclusion together with dental pathologies resulting from this reduction acted as a selective pressure to reduce tooth size. The Jaw Reduction Hypothesis is supported by observations of facial shortening in the human phylogenesis (cf. Kieser 1990:52), correlated with dental reduction within the *Hominidae*. However, it is unclear whether such mechanism may also be regarded as valid in short-term tooth size changes.

The fourth model is the *Selective Compromise Hypothesis* (Calcagno and Gibson 1991), to some degree similar to the previous one. It is based on the assumption that large teeth in small alveolar tissue make potential health risk, eg. due to periodontal disease, impactions and infections. Such infections are potentially life-threatening in populations consuming soft cariogenic food and for that reason teeth may be under selection for reduction. Obversely, in populations consuming a higly abrasive diet small teeth would be get worn too rapidly and also in this case pulp exposure would allow potential infections. For that reason tooth size may be considered as an effect of selective compromise in a given environment. This hypothesis was based on the observation of fossil hominids but because of assuming a high rate of selective pressure, it may be used also in the explanation of dental reduction in recent populations.

Peter W. Lucas observed that in mammals tooth size is related to food particle volume, particle size and shape rather than to body size (2004:172). This observation supports all models based on the assumption that tooth size reduction was associated with changes in food preparation techniques. Research based on a world-wide dental sample and employing Principal Component Analysis has revealed that dental reduction is not a uniform process and its rate varies for the individual teeth and their different dimensions (Harris and Rathbun 1991). However, the temporal reduction of premolar and molar size in the various parts of the world is evident and in spite of the often neglected possibility that, at least in part, this trend may have been caused by local population movements or genetic drift, most scholars agree that some kind of selective pressure related to changes in food preparation technique was the most important agent in the observed tooth size reduction.

This paper is not focused on theoretical models but presents new fieldwork data, which may be useful in further discussion on the relationship between technical improvements in food preparation and the changes in tooth size. Although not very numerous, the sample of the permanent teeth studied here is quite useful for two reasons: 1) it has been collected in the archaeological sites located in so-called "Fertile Crescent" where agriculture was introduced for the first time in the Old World, 2) it covers many chronological levels and for that reason not only the general trend but also possible short-term fluctuations may be observed, which is crucial in the evaluation of the proposed models.

Material and Methods

The dental sample studied in the present paper is based chiefly on human remains discovered at four archaeological sites excavated between 1995 and 2005 in the upper Khabur basin (north-eastern Syria, see Fig. 2-17).

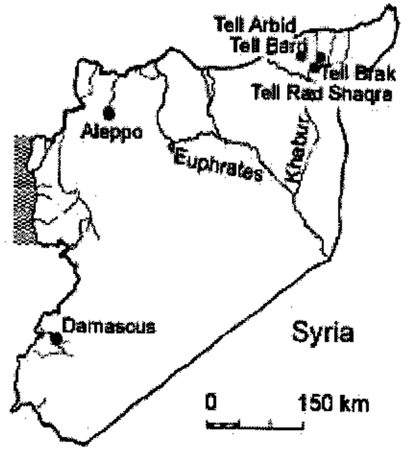

Figure 2-17: Map of Syria with indicated sites of origin of the studied dental samples.

These sites were inhabited by human populations for many centuries and also human teeth have been found at many levels from the Late Chalcolithic (ca. 4000 BCE) to the Hellenistic period (ca. 200 BCE). Since the sample was lacking teeth from the earlier periods, it was supplemented by the already published material from the nearby areas of eastern Syria and northern Iraq: Zawi Chemi (Proto-Neolithic), Tell Halula (Pre-Pottery Neolithic), and Tell Hassuna (Early Chalcolithic). Measurements of teeth are also available from the early sites excavated in Palestine, Anatolia, and western Iran, but because of their distance from the Khabour basin and different ecological settings they were not included in the present research. In some cases the individuals were dated quite precisely but to get reliable statistical results they were divided into five general chronological sub-samples: Neolithic (ca. 9000–5000 BCE), Chalcolithic (ca. 5000–3000 BCE), Early Bronze Age (EBA, ca. 3000–2100 BCE), Middle Bronze Age (MBA, with few individuals from the Late Bronze Age, ca. 2100–1200 BCE), and Iron Age (ca. 1200–200 BCE). EBA sample from some pits in Area TC at Tell Brak was distinguished because there were mixed remains of many individuals without a clear cultural context. A more detailed description of all the chronological samples is given in Table 2-3.

Maximum mesiodistal and buccolingual diameters were taken as a tooth would be in normal position. A sliding Profix calliper produced by with an 0.02

mm accuracy has been used, but the measurements were done with 0.1 mm accuracy. All data were gathered in Syria, in the dig houses of the archaeological expeditions. Only posterior teeth with no or moderate wear were included (premolars and molars 1–6 degree according to Murphy 1959). Negative correlation between anterior and posterior teeth was reported in the literature (Kieser 1990) and measurements of the anterior teeth have not been taken into account because of their lesser relation to food quality and problems with the reliability of measurements on teeth with even small attrition.

No correction for approximate wear was used, but teeth with marked approximate wear were not included (cf. Goose 1963:126, Hillson 1996:71). Tooth asymmetry was not considered here, although some authors suggest that it may be related to stress level (cf. Larsen 1997:27). However, only left teeth were measured and right ones only if the left side was missing. Observer error is acceptable (a mean difference of 0.11 mm with a standard deviation of 0.106, n=42) and shows no distribution difference between molars and premolars and between mesiodistal and buccolingual diameters although there is a significant difference between the upper and lower jaw ($t=2.204$, $p<0.05$). Mandibular teeth are measured with a considerably greater error rate (a mean difference of 0.14 in the mandible against that of 0.07 in the maxilla).

Since many teeth are missing, no generalised figures as Total Crown Area or Molar Crown Area were used. Instead, a robustness index (RI) was counted for each posterior tooth as well as a mean standardised robustness index, mean standardised molar measurement and mean standardised premolar measurement for each individual and then for each chronological sample. A strong positive correlation between all pairs of measurements made such standardised mean indices reliable even in case of many missing values. Differences between chronological levels and all other defined sub-samples were tested by ANOVA with Bonferroni post-hoc tests.

Table 2-3. Number of individuals from the respective sites and periods.

Site	Neolithic	Chalcolithic	EBA	MBA	Iron Age	?	Reference
Tell Arbid			9	21	1	31	this study
Tell Barri			7	3	16	26	this study
Tell Brak		14	31			45	this study
Tell Brak TC			25–71			25–71	this study
Tell Halula	6					6	Anfruns et al. 1996
Tell Hassuna		3				3	Coon 1950
Tell R. Shaqra			5			5	this study
Zawi Chemi	5					5	Ferembach 1970
?	11	17	77–123	24	17	146–192	

Results

The first step was the Principal Component Analysis (PCA) to check the reliability of the mean standardised measurements for each individual with missing values. PCA extending to all measurements of the posterior teeth resulted in four factors with eigenvalues >1: the first one explained 56.7% of the variance, the remaining three others only ones between 5 and 8%. All measurements were positively and highly correlated with the first factor which may be thus interpreted as a size factor. In case of PCA for robustness indices the first factor explained 75% of the variance, the others were negligible (eigenvalues <1). Such results point to the reliability of mean standardised values, especially those calculated for the RIs.

In human dentition the dimorphic differences are small and significant only in some populations for the lower and upper canines (Garn et al. 1964). Since the bones of the studied individuals were usually in a poor state of preservation, reliable sex diagnosis based on pelvis or skull morphology was rarely possible. However, in the most numerous EBA chronological sample the difference in tooth size between sexes could be analyzed by the t-test. In all cases the differences were statistically insignificant, only in P_1 the female teeth appeared surprisingly more robust than male ones ($t=2.18$, $p=0.05$). Since the degree of dimorphism in premolars is the lowest of all, this result is obviously a statistical artefact resulting from the small sample size and difficulties in sex diagnosis.

For the two most numerous chronological samples the differences between sites were checked and in both cases they were proven insignificant (EBA sample contained individuals from 5 sites, $n=95$, $F=0.58$, $p=0.68$; MBA sample contained individuals from 2 sites, $n=24$, $t=0.03$). This result points to a homogeneity of the samples in the Khabur basin at the defined chronological levels.

The differences between the chronological samples for the mean standardised values are shown in Table 2-4 and in Figure 2-18.

Table 2-4. Mean standardised values of RIs and measurements of molars and premolars in five chronological samples.

Chronology	Robustness Index			Molars			Premolars		
	n	Mean	SE	n	Mean	SE	n	Mean	SE
Neolithic	11	0.256	0.268	11	0.157	0.234	3	0.636	0.487
Chalcolithic	15	0.546	0.229	12	0.451	0.224	6	0.379	0.345
Early Bronze Age	95	-0.067	0.091	86	-0.015	0.084	61	-0.050	0.108
Middle Bronze Age	24	-0.084	0.181	23	-0.097	0.162	18	0.013	0.199
Iron Age	17	-0.518	0.216	16	-0.466	0.194	17	-0.381	0.205
F=			3.19			2.61			1.56
p=			0.015			0.038			0.191

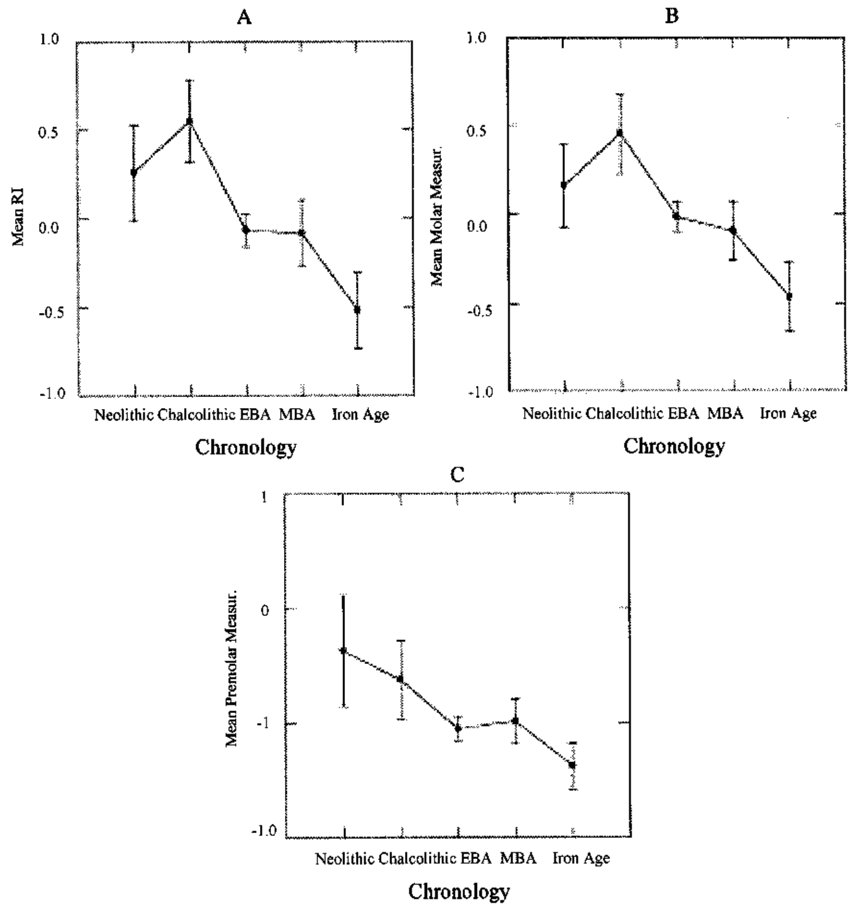

Figure 2-18: Differences in tooth size between chronological samples. A: mean standardised Robustness Indices, B: mean standardised molar measurements, C: mean standardised premolar measurements.

Trends in the RIs and molar measurements are very similar: tooth size somewhat increased from the Neolithic to the Chalcolithic and then started to decrease, especially between the Chalcolithic and EBA, and between MBA and the Iron Age. In case of both figures the differences are statistically significant (the Bonferroni test between the Chalcolithic and Iron Ages gave $p<0.05$). Also premolar size decreased, although in this case the differences are not statistically significant and the diagram shows a somewhat different trend with a more regular reduction (also between Neolithic and Chalcolithic samples) and a similar restraint between EBA and MBA.

In the discussion about the various models of tooth size reduction the differences in dental measurements in the various age classes may be very important, since under a case of strong directional selection due to dental pathologies tooth size in younger individuals should be greater in average than in older individuals. It was possible to check this hypothesis in the most numerous EBA sample that was divided into four age classes (Table 2-5, Fig. 2-19). Age was diagnosed by pelvic morphology (pubic symphysis and auricular surface), ossification/epiphysis fusion, and suture closure.

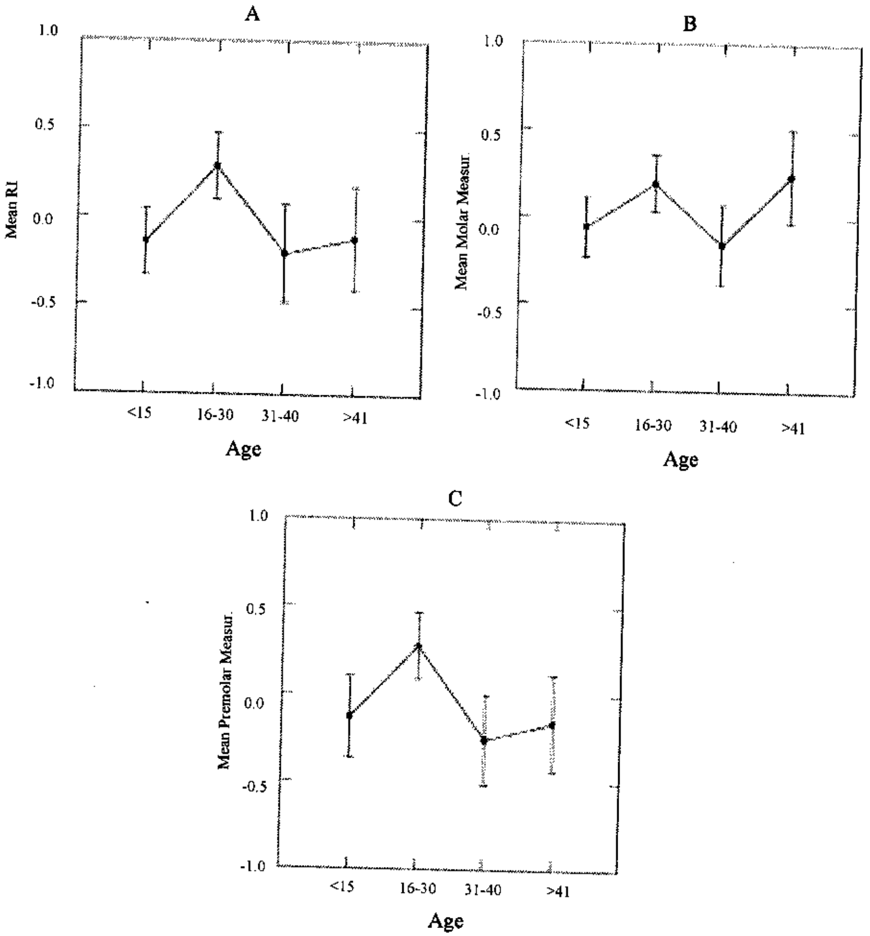

Figure 2-19: Differences in tooth size between age classes in the EBA sample: A: mean standardised Robustness Indices, B: mean standardised molar measurements C: mean standardised premolar measurements.

Table 2-5. Mean standardised values of RIs and measurements of molars and premolars in the age classes of the EBA sample.

Age class	Robustness Index			Molars			Premolars		
	n	Mean	SE	n	Mean	SE	n	Mean	SE
less than 15 years	22	-0.138	0.189	20	-0.064	0.172	11	-0.134	0.233
16-30 years	23	0.292	0.185	22	0.192	0.164	17	0.272	0.188
31-40 years	10	-0.201	0.281	11	-0.159	0.232	9	-0.256	0.258
more than 41 years	9	-0.115	0.296	8	0.240	0.272	8	-0.160	0.274
F=			1.22			0.83			1.25
p=			0.309			0.482			0.305

The observed differences in the age classes were not statistically significant in any of the three mean values used in the present study. However, the weak pattern is comparable in the molars and premolars: the teeth of children are smaller than those of the juveniles and young adults. There is a marked decrease between the young and middle-aged adults and an increase in the oldest individuals, much more marked in the molars. Such a pattern suggests that dental wear did not affect strongly the measurements.

Discussion and Conclusions

The pattern of tooth size reduction observed in northern Mesopotamia is analogous to the trend that may be deduced from the few published reports on human remains from southern Mesopotamia. Carleton Coon reported that the inhabitants of the Chalcolithic site Eridu had very large teeth (Coon 1949) while tooth measurements from Kish provided by Ted Rathbun are smaller and show a decrease between Early Bronze and Iron Age (Rathbun 1975).

The most interesting point in the present study is a stabilisation or even increase in the dental dimensions during the Neolithic. Peak tooth size was observed in the Chalcolithic and it was only later that dental measurements gradually decreased. Such a pattern – although unexpected at first view – is quite consistent with the archaeological data. Neolithic primitive farmers ate chiefly cereals prepared by stony millets that made food hard and extremely abrasive (cf. Molleson 1994). Such a diet was widespread also in the Chalcolithic and there are examples of extremely worn teeth from that period (cf. Keith 1927). In the Late Chalcolithic, after ca. 4000 BCE, the situation changed dramatically: first in the south, then in the north of Mesopotamia population size increased and the previously scattered settlements of self-reliable farmers had been replaced by a stratified network of sites with growing urban centres covering up to 200 hectares (as Uruk in the south or Tell Brak in the north). These were inhabited by a hierarchical society that had developed a much more complicated economy based on the cultivation of cereals and vegetables and associated with the large-scale herding of sheep and goats. A sophisticated system of food distribution was introduced that time. Changes in pottery (e.g. the famous bevelled-rim bowls) and other artifacts suggest that also the techniques of food preparation were strongly modified. Social organisation developed in that period kept existing almost till the end of the Sumero-Babylonian civilisation (Huot 1982, Nissen 1988).

The highly abrasive diet of the primitive Neolithic farmers was then contemporary with at least an inhibition of further tooth size reduction and with the introduction of a new social organisation using a more sophisticated system of food storage, redistribution and preparation that coincided with an acceleration of reduction. This could hardly be due to chance. Although reliable data on the changes in craniofacial dimension are not available owing to a poor state of bone preservation in the region, the pattern observed in the Khabur basin supports the Selective Compromise Hypothesis that assumes that both the increase and decrease of tooth size may be a result of directional selection, depending on the abrasiveness of the diet. However, no direct evidence of any kind of directional selection has been available so far and it is a very important problem because the quite high rate in tooth size reduction (on average 20–25% in less than 4,000 years) points to a rather strong selective force that should have been then easy to observe.

Age distribution of the tooth dimensions in the studied EBA sample does not support the hypothesis of directional selection because the teeth of the youngest individuals are smaller than those of the juveniles and young adults. This difference is certainly not due to dental wear because also progressing attrition decreases tooth size. Such an effect may be mistaken for directional selection but not the contrary one. In a few studies a negative secular trend was observed in tooth size (cf. Kieser 1990:58), and it may also be the case here. Another explanation, namely, that it was an effect of selection for larger teeth, seems to be unlikely by taking into account the observed temporal trend. It must be kept in mind, however, that the sample was small and included individuals from an extended period of time and living at five sites. Only a more spatially and chronologically homogeneous and larger set of data will allow a reliable test of the hypothesis of directional selection.

Acknowledgements

Unpublished data from the following sites were used here: Tell Arbid and Tell Rad Shaqra (excavations directed by Piotr Bielinski, Warsaw University), Tell Barri (Raffaella Pierobon-Benoit, Naples University), and Tell Brak (Joan Oates, Cambridge University). Many thanks are due to the directors and staff of all these archaeological

expeditions. The present study was partially financed by a research grant from the funds for scientific research in years 2006–2008 (grant No. 1 H01H 038 26).

References

Anfruns, J., Majò, T. and Oms, J.I., 1996, Los restos humanos del neolítico precerámico. In: Molist Montaña, M. (Ed.) *Tell Halula (Siria). Un yacimiento neolítico del valle medio del Éufrates. Campañas de 1991 y 1992*, Madrid, 161–173.

Angel, J.L., 1975, Paleoecology, paleodemography and health. In: Polgar, S. (Ed.) *Population, Ecology and Social Evolution*, The Hague and Chicago, 167–190.

Brace, C.L., 1964, The probable mutation effect. *American Naturalist*, **97**, 39–49.

—. 1976, Tooth reduction in the Orient. *Asian Perspectives*, **19**, 203–219.

Brace, C.L., Smith, S.L. and Hunt, K.D., 1991, What big teeth you had grandma! Human tooth size, past and present. In: Kelly, M.A. and Larsen, C.S. (Eds) *Advances in Dental Anthropology*, New York: Wiley-Liss, 33–57.

Calcagno, J.M. and Gibson, K.R., 1991, *Selective compromise: Evolutionary trends and mechanisms in hominid tooth size*. In: Kelly, M.A. and Larsen, C.S. (Eds) *Advances in Dental Anthropology*, New York: Wiley-Liss, 59–76.

Coon, C.S., 1949, The Eridu crania. A preliminary report. *Sumer*, **5**, 103–106.

—. 1950, Three skulls from Tell Hassuna. *Sumer*, **6**, 93–96.

Ferembach, D., 1970, Etude anthropologique des ossements humains proto-neolithiques de Zawi Chemi Shanidar (Irak). *Sumer*, **26**, 21–64.

Frayer, D.W., 1978, *Evolution of the dentition in Upper Paleolithic and Mesolithic Europe*. University of Kansas Publications in Anthropology, 10.

Garn, S.M., Lewis, A.B. and Kerewsky, R.S., 1964, Sex differences in tooth size. *Journal of Dental Research*, **45**, 306–311.

Goodman, A.H., Martin, D.L., Dobney, K., Martinez, A. and Chavez, A., 1989, The effect of nutritional supplementation on permanent tooth development and morphology. American Association of Physical Anthropologists, San Diego CA (abstract).

Goose, D.H., 1963, Dental measurement: An assessment of its value in anthropological studies. In: Brothwell, D.R. (Ed.) *Dental Anthropology*, Oxford: Pergamon Press, 125–148.

Garn, S.M., Osborne, R.H. and McCabe, K.D., 1979, The effect of prenatal factors on crown dimensions. *American Journal of Physical Anthropology*, **51**, 665–678.

Haddow, S. and Lovell, N., 2003, Metric analysis of permanent and deciduous teeth from Bronze Age Tell Leilan, Syria. *Dental Anthropology*, **16**, 73–80.
Harris, E.F. and Rathbun, T.A., 1991, Ethnic differences in the apportionment of tooth sizes. In: Kelly, M.A. and Larsen, C.S. (Eds) *Advances in Dental Anthropology*, New York: Wiley-Liss, 121–142.
Hillson, S., 1996, *Dental Anthropology*. Cambridge University Press.
Huot, J.-L., 1982, La naissance de l'état: l'exemple mésopotamien. In: *Archéologie au Levant. Recueil R. Saidah*, Lyon, 95–106.
Keith, A., 1927, Report on the human remains. In: Hall, R.H. and Wooley, C.L. (Eds) *Ur Excavations*, vol. 1, Oxford, 214–240.
Kieser, J.A., 1990, *Human adult odontometrics. The study of variation in adult tooth size*. Cambridge University Press.
Larsen, C.S., 1997, *Bioarchaeology. Interpreting behavior from the human skeleton*. Cambridge University Press.
Lindsten, R., 2003, *Secular changes in tooth size and dental arch dimensions in the mixed dentition*. Swedish Dental Journal Supplement, **157**, Oslo.
Lucas, P.W., 2004, *Dental functional morphology. How teeth work*. Cambridge University Press.
Molleson, T., 1994, The eloquent bones of Abu Hureyra. *Scientific American*, **8**, 60–65.
Murphy, T, 1959, Gradients of dentine exposure in human tooth attrition. *American Journal of Physical Anthropology*, **17**, 179–186.
Nissen, H.J., 1988, *The early history of the Ancient Near East. 9000–2000 B.C.* Chicago-London.
Rathbun, T.A., 1975, *A study of the physical characteristics of the ancient inhabitants of Kish, Iraq*. Miami.
Smith, P., Bar-Yosef, O. and Sillen, A., 1984, Archaeological and skeletal evidence for dietary change during the Late Pleistocene/Early Holocene in the Levant. In: Cohen, M.N. and Armelagos, G.J. (Eds) *Paleopathology at the Origins of Agriculture*, New York, 101–135.
Smith, P., 1989, The dental evidence for nutritional status in the Natufians. In: Bar-Yosef, O. and Valla, F.R. (Eds) *The Natufian culture in the Levant*, Ann Arbor, 425–432.
Townsend, G., Dempsey, P., Brown, T., Kaidonis, J. and Richards, L., 1994, Teeth, genes and the environment. *Perspectives in Human Biology*, **4**, 35–46.
y'Edynak, G., 1978, Culture, diet, and dental reduction in Mesolithic foragers-fishers of Yugoslavia. *Current Anthropology*, **19**, 616–618.
—. 1989, Yugoslav Mesolithic dental reduction. *American Journal of Physical Anthropology*, **78**, 17–36.

Mailing address: Arkadiusz Sołtysiak
Department of Historical Anthropology
Institute of Archaeology
Warsaw University
ul. Krakowskie Przedmiescie 26/28
00-927 Warszawa
Poland
A.Soltysiak@uw.edu.pl