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TOWARDS A MULTIDISCIPLINARY APPROACH

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FREQUENCY OF DENTAL CARIES AS A PROXY INDICATOR OF MOBILITY: THE CASE OF THE KHABUR BASIN HUMAN POPULATIONS

Arkadiusz Sołtysiak

Introduction

Dental caries is a chronic disease manifested as local demineralization of enamel, cement and dentine by organic acids, leading to formation of cavities and in some cases to tooth loss. These acids are produced by oral bacterial flora (esp. *Streptococcus* sp. and other acidophile species) which process the carbohydrates included in human diet, especially sugars (Larsen 1997, 65). Usually the cariotic process is slow and it may take years until the initial local demineralisation turns into cavity and growing lession induces the pulp inflammation and eventual tooth loss.

There are many factors positively correlated with the prevalence of dental caries, but most important of all is the abundance of sugars in the diet. This relationship has been observed during the Second World War when the deficiency of sugar decreased the frequency of caries (Hillson 1996, 282) and confirmed by clinical experiments as early as 50 years ago (Gustafson *et al.* 1954). All dietary sugars, including fructose, glucose, lactose, maltose, but especially sucrose causes the rapid reduction of pH in mouth, an obvious sign of bacterial activity. Also dietary starches make a similar effect, although in their case the increase in acidity is much slower and not so high. In case of starches the cariogenic effect depends on the chewing time and the density of food: less dense food better penetrates inter-tooth areas and the prolongated chewing time increases the activity of salivary enzymes which reduce long starch molecule to maltose (Lingström *et al.* 1993). However, dense starch food has low cariogenicity. Other dietary components, as proteins and fats, have no proven relation to the occurence of dental caries (Hillson 1996, 279). Factors other than diet are not so important, although they can modify to some degree the risk of the disease. They are the level of oral hygiene, inherited factors, enamel defects, occlusion abnormalities, nutrition habits, food preparation techniques etc. Some authors observed negative correlation between dental caries and wear degree (Maat – van der Velde 1987), although it is not necessarily a general rule.

Strong relation between diet and dental caries was corroborated by numerous studies on ancient human populations. Transition between hunting-gathering and agriculture in many regions was followed by the increase in caries frequency (Larsen 1995; Hillson 1996, 283); this tendency is especially clear in the New World, which is explained as the effect of higher cariogenicity of maize compared with Old World's wheat and barley (Lubell *et al.* 1994). Another world-wide phenomenon is the higher frequency of caries in females, interpreted as the result of greater relative importance of plant components in their diet as compared with more animal-based male food. There are also other factors potentially contributing to this effect (as e.g. inter-sex difference in tooth eruption time) but their contribution to the overall tendency was never proven (Larsen 1997, 72–76).

Some authors observed the correlation between caries frequency and the social status, although in that case the results are ambiguous. Sometimes the representatives of higher class had more cariotic teeth which was explained as effect of their broader access to softer, refine foods (Larsen 1997, 76). However, in the medieval population of Zalavár (Hungary) the frequency of caries in higher class members was lower. It is not possible to compare it with written sources, but there is a hypothesis that such a difference was a result of more intensive consumption of meat and animal products by the upper class. Some later historical and ethnographical data support this explanation (Frayer 1984). Such ambiguity of observations makes the social differences in caries frequency a difficult subject of research and the careful comparison with historical/archaeological sources seems necessary.

Theoretical model

Strong and direct dependence of the dental caries on diet makes possible the construction of theoretical epidemiological model of this disease in a population of known dietary habits. The present paper discusses such a model for the Khabur basin in north-eastern Syria, and checks its validity with use of dental sample from three archaeological sites (Tell Brak, Tell Barri, and Tell Arbid) which represent more than 4000 years of history, from Chalcolithic to Islamic period.

Peoples inhabiting ancient Mesopotamia after the Neolithic exercised two main subsistence strategies: plant cultivation, including dry farming in the north and irrigation agriculture in the alluvial plain of Euphrates and Tigris, as well as animal husbandry: transhumant pastoralism in the marginal areas or small-scale village herding in cultivable regions. Both strategies were present in the Khabur basin, which is a part of dry farming steppe zone in northern Mesopotamia. Most important cereals planted in that region were 2-row barley and wheat (Wirth 1962, Karte 6; Gibson 1974, 10; Nissen 1988, 60). The animal husbandry was based chiefly on sheep and goat herding, cattle and pigs were raised in much lesser number (Potts 1997). Pastoralists have occupied chiefly the marginal areas, where the precipitation was too low for agriculture, but still enabled any plant vegetation (Vardiman 1977, 16). In dry farming area the mixed strategy of agriculture and animal husbandry was very helpful, especially in the marginal zones where the surpluses of grain collected in wet years may have been used for animal breeding and in case of a dry year the meat of the animals secured the subsistence of the farmers (Lees – Bates 1974, 18). Hence the border between agriculture and herding was more blurred here than in other areas of the Near East (Hesse 1995, 209) and some authors gave such situation the term of dimorphic society (Rowton 1974, 1980).

Diet of populations inhabiting the Khabur basin was supplemented by some vegetables and meat of occasionally hunted wild animals, but in general all kinds of food potentially produced or collected in that area are not cariogenic. The cereals were consumed chiefly in form of hard bread baked in *tannurs*, typical Near Eastern ovens which are abundantly witnessed both in archaeological record from Neolithic on, and in present-day Syria. Such way of preparation accelerates dental wear but prevents caries. There are only three possible sources of sugars which are attested in the Near East and potentially could cause dental caries in local population: dates, figs, and honey.

Dates contain 75% of sugar and are most widespread cariogenic kind of food in the Near East (for its cariogenicity cf. Stephan 1966). They were consumed as early as ca. 5000 BCE in western shores of the Persian Gulf (Potts 2002) and their cultivation in southern Mesopotamia started in mid-fourth millennium (Renfrew 1995). Some Bronze and Iron Age populations of eastern Arabian Peninsula were heavily affected by dental caries as well as *ante-mortem* tooth loss and it is generally related by the modern scholars to the abundance of dates in that area (e.g. Højgaard 1986; Schutkowski – Herrmann 1987; Littleton – Frohlich 1989, 1993; Nelson – Lukacs – Yule 1999).

There is a great number of written sources, representations, and archaeological finds proving that date cultivation in southern Mesopotamia since mid-third millennium was widespread (Ellison 1977, 1981; Potts 1997), although there is also opinion that date palm was planted only for court and temple consumption (Limet 1987). For sure the saline soils of the alluvial plain and the abundance of water were favourable for growing of this tree. In date palm groves also other fruit trees were planted, including pomegranates, figs, apples, and grapes (Potts 1997, 69–70). All these other possible sources of sugars were however much more rare and they may be classified as luxury food. There are some sources indicating that date palms ripen in the Middle Ages and perhaps in Neo-Assyrian period as far north as in area of Mosul (Le Strange 1905, 90; Ball – Tucker – Wilkinson 1989, 9) but in general these trees do not bear fruits north of the alluvial plain of Euphrates and Tigris, although are present and ripe abundantly in the oases of the Syrian Desert, chiefly in Palmyra. For sure the Khabur basin is located far too north and is far too dry for effective palm tree growing and date cropping.

More probable source of sugar in that area are figs which do not need so much water for growing and are common in the eastern shores of the Mediterranean Sea. Fig pips were found in Early Neolithic sites in western Syria (e.g. Tell Aswad) but there is no direct evidence of their cultivation in the Khabur basin (Zohary – Hopf 1994). It is possible that a few fig trees were planted in the valley of Khabur and perhaps in some wadis, but it is unlikely that they were numerous enough to raise the frequency of dental caries in considerable way. Other fruits mentioned by texts from Mari, Nuzi, and Assyrian sites, namely pears, plums, apricots, and pomegranates (Ellison 1977), for sure were not at all or only sporadically grown in the Khabur basin, because their cultivation would demand intensive irrigation, very difficult and ineffective in that region.

Last possible source of sugar in northern Mesopotamia is honey. There are some documents from Mari (ca. 1800 BCE) mentioning honey imported from north-western Syria (and possibly coming from Anatolia). No source mentions local honey production in Mesopotamia and it is unlikely that bees were ever kept in this region (Dalley 2002; Limet 1987).

This review of archaeological and textual evidence indicates quite clearly that the diet of inhabitants of Khabour basin was deprived of highly cariogenic components and based almost exclusively on hard starky and animal food, and that potentially cariogenic kinds of food had to be imported from abroad: dates from southern Mesopotamia or oases of Arabia, honey from Anatolia or (potentially) from Zagros Mountains, figs from the Levant. It may be expected then that the caries frequency in human populations of this region should be low, without gender or social differences, assuming that cereals and animal food were both easily accessible and of equally small cariogenicity. However, there may be observed some variability in caries frequency due to differences in mobility: isolated populations feeding only on local resources should have potentially less carious teeth that more mobile populations taking a part in inter-regional trade and/or having higher migration rate. It is possible then to use the frequency of dental caries as a proxy indicator of mobility: both the mobility of resources (i.e. large scale importing of cariogenic food) and the mobility of people (immigration from regions abundant with cariogenic food).

It is well known fact that the level of mobility gradually increased during the history of mankind. In case of Mesopotamia inter-regional trade was exercised as early as in fourth millennium BC, but considerable intensification of exchange of goods was related to the establishment of super-regional empires by Assyrian, Babylonian, and Persian kings in first millennium BC, and next to the beginning of Muslim Caliphate in the 7th century CE. Also the migration rates were raised in the empires due to the deportation policy initiated by Neo-Assyrian kings (Oded 1979) and movements of troops, but also as the reflection of more easy travel inside the borders of large state.

Summing up this review, the expected frequency of dental caries in the Khabur basin is low before the first millennium BC and gradually rising in the time of super-regional empires, but never reaching the level typical for populations living in regions abundant in cariogenic food. Such theoretical model may be now tested with use of archaeological dental sample.

Material and method

The sample studied in the present paper contains 1573 permanent teeth of at least 122 individuals buried in three archaeological sites excavated in the Khabur basin: Tell Brak, Tell Barri and Tell Arbid (location of these sites is shown on Fig. 1). All teeth were studied in Syria, during the autumn excavation seasons in 2001–2005. The number of individuals from seven chronological sub-samples is given in Table 1. Most numerous sub-samples are the Early Bronze Age and the Middle Bronze Age (first chiefly in Tell Brak, second in Tell Arbid), other sub-samples are very small and this fact implies that the results of any statistical analysis must be treated with great care. Apart of M3, the average frequency of teeth per individual ranges from 33.6% (right I_1) to 55.7% (both M_2); detailed frequency of all teeth is presented in the Table 2. Greater number of lower teeth (especially from the left side) is caused by the sample from a large pit found in Tell Brak and filled with broken and mixed bones and teeth of many individuals, without long bones and crania but with mandibles. Apart from this bias, also sides of the skeletons were not equally represented. Dental sample from this single pit includes 104 mandibular teeth (53 molars, 24 premolars, 11 canines, 16 incisors) and only 15 maxillary teeth (2 premolars, 3 canines, and 10 incisors) belonging to at least 28 individuals. Most other teeth were found in more regular burial contexts, singular (rarely multiple) pit, chamber or jar graves.

Site	Chalcolithic	Early Bronze	Middle Bronze	Late Bronze	Neo-Assyrian	Achaemenian	Islamic times	Σ
Tell Arbid	–	10	18	4	–	1	5	38
Tell Barri	–	6	2	1	9	6	–	24
Tell Brak	9	51	–	–	–	–	–	60
Σ	9	67	20	5	9	7	5	122

Table 1. Number of individuals per site and per chronological unit.

There are many methods of counting the frequency of caries. For modern dental samples often used is the DMF index (number of teeth with a cavity, lost or filled) or DMFS index (number of tooth surfaces instead of whole teeth) counted for an individual or average DMF/DMFS index for a sample (Hillson 1996, 280). Both indices assume that whole maxilla and mandible may be observed and for that reason are unsuitable for fragmentary archaeological samples. More detailed methods of scoring cariotic teeth with regard of the initial place of demineralization were developed for studies on the archaeological dental samples (e.g. Moore – Corbett 1971) but only a few authors used them in practice. Most widespread method is the simple count of all cariotic teeth number divided by the number of all teeth, i.e. the general percent frequency of cariotic teeth. Such frequency is always biased by the simple fact that

Tooth	Maxilla		Mandible		Σ
	R	L	R	L	
M3	27	30	38	40	135
M2	45	45	68	68	226
M1	49	53	67	64	233
P2	48	45	56	59	208
P1	49	44	55	59	207
C	48	44	50	56	198
I2	50	45	43	49	187
I1	46	48	41	44	179
Σ	362	354	418	439	1573

Table 2. Number of teeth studied.

the caries is usually observed more frequently in molars and rarely in incisors, whereas the pattern of tooth preservation in archaeological samples is not uniform and the interference of these two patterns is a considerable source of error. This bias may be reduced with use of simple recalculation method based on the assumption that the frequency of caries in *post-mortem* lost teeth was the same as in preserved sample (Erdal – Duyar 1999). Some authors count not the percent frequency of cariotic teeth in the whole dental sample but the percent frequency of individuals with at least one cariotic tooth (Hillson 2001). However, use of such a method is limited only to perfectly preserved skeletal remains with complete dentition.

Carious lesions are quite easy to recognize in an archaeological sample, but more problematic is the scoring of initial and final phase of the disease. Changes of colour characteristic for first phase of tooth demineralization are easy to mistake with effects of *post-mortem* biochemical processes. Also scoring of *ante-mortem* tooth loss is problematic for two reasons. First, in archaeological samples an alveolar process is sometimes broken or missing. Second, not every tooth is lost because of caries; some abscesses are the result of other dental diseases, chiefly the periodontal disease.

In the present study only the cavities were scored with use of more detailed system based partially on the recommendations by Simon Hillson (2001) and including the position of the lesion (root, CEJ, enamel), its side (buccal, lingual, medial, distal, occlusal), maximum and minimum dimensions (in millimetres). Since the sample size is small, such detailed description was turned into simple 4-step scale (0 = no caries, 1 = lesion with max. diameter < 2 mm, 2 = lesion between 2 and 6 mm, 3 = lesion wider than 6 mm). For each sample weighted mean frequency (later referred as WMF) was counted as the mean of caries frequencies in pooled anterior teeth (I and C) and separate posterior teeth (P and M). Such method of counting the frequency of caries has two advantages: 1) it levels the pattern of *post-mortem* tooth loss, 2) the anterior teeth are rarely cariotic in most samples and their pooling makes more clear the inter-population differences in posterior teeth. Observed differences in caries frequency are checked with χ^2 test. There is one methodological problem which must be mentioned: the teeth are treated here as separate, although some degree of inter-individual correlation must be assumed (since cariogenic or not-cariogenic conditions are similar in whole mouth of a given individual). Because the nature of this correlation is not well known, it is impossible to propose a reliable practical method of its treatment.

Results

Dental sample obtained at three sites and covering seven periods may be potentially divided into 21 sub-samples. Actually it is impossible to compare the frequency of caries between sites in most periods and only Early Bronze Age sample is numerous enough to be divided into five sub-samples: one from Tell Arbid, one from Tell Barri and three from various excavated areas at Tell Brak (including also mixed bones from already mentioned pit in Area TC). Definition of chronological samples studied in the present paper is presented in Table 3. Table 4 contains the numbers of teeth in each sample classified according to the 4-step scale. As expected, the frequency of cariotic teeth appeared to be low (83/1573 = 5.3% in the whole sample). For each chronological sample the value of WMF was counted (Table 5) and all these values were presented in the diagram including also the chronological information (Fig. 2).

Sample	Chronology	Site
A	Chalcolithic	Tell Brak TW + CH
Ba	Early Bronze Age	Tell Brak TC
Bb	Early Bronze Age	Tell Brak FS + T2
Bc	Early Bronze Age	Tell Brak TC (mixed bones)
C	Early Bronze Age	Tell Barri
D	Early Bronze Age	Tell Arbid
E	Middle Bronze Age	Tell Arbid (+ Tell Barri)
F	Late Bronze Age	Tell Arbid (+ Tell Barri)
G	Neo-Assyrian	Tell Barri
H	Achaemenian + Hellenistic	Tell Barri (+ Tell Arbid)
I	Islamic	Tell Arbid

Table 3. Definition of chronological samples.

	I1				I2				C				P1				P2				M1				M2				M3			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
A	7		1		12				14		1		13				14				10		2		13				6			
Ba	33				28				28				29				28				30	1			29		2		13	2		2
Bb	15				18				17				21				20	1			17		1		17		1		13			1
Bc	12				14				14				11				14		1		21				25	1			6			
C	17				14				19				18		1		17		1		13			2	9	3	3	1	10	2	3	
D	19				20				21				22				24		1		23		1		21		1	1	20			
E	30				37				35				43	1			43		1		55	2	1		48	1	1		24	2	2	
F	4				3				8				7				5				6				6		1		3			
G	23				21				19				21				15				22		1		21		1		11	1	2	
H	10				12				17	1	1		17		2		16		3		14	1	2	2	6	3	2	2	7	2	3	
I	8				8				3				1				2				2		4		6		1		2			
Σ		0	1	0		0	0	0		1	2	0		1	3	0		1	7	0		4	12	4		8	13	4		9	10	3

Table 4. Frequency of non-cariotic and cariotic teeth in chronological samples.

	I+C	P1	P2	M1	M2	M3	WMF
A	0.06	0.00	0.00	0.17	0.00	0.00	0.038
Ba	0.00	0.00	0.00	0.03	0.06	0.24	0.055
Bb	0.00	0.00	0.05	0.06	0.06	0.07	0.040
Bc	0.00	0.00	0.07	0.00	0.04	0.00	0.018
C	0.00	0.05	0.11	0.13	0.44	0.33	0.177
D	0.00	0.00	0.04	0.04	0.09	0.00	0.028
E	0.00	0.02	0.02	0.05	0.04	0.14	0.045
F	0.00	0.00	0.00	0.00	0.14	0.00	0.023
G	0.00	0.00	0.00	0.04	0.05	0.21	0.050
H	0.05	0.11	0.16	0.26	0.54	0.42	0.257
I	0.00	0.00	0.00	0.67	0.14	0.00	0.135

Table 5. Weighted mean frequency (WMF) of caries in the chronological samples.

The general pattern of caries frequencies is consistent with the theoretical model. In all but one chronological samples before Neo-Assyrian period WMF is lower than 0.055 and it may be assumed that the value of 0.06 (i.e. 4.5% as not-weighted frequency) is the upper limit of caries frequency in isolated agricultural population inhabiting the Khabur basin. Two latest samples show much higher WMF value, although Islamic sample is very small and not reliable. However, the frequency of caries in Achaemenian Tell Barri is more than four times higher than WMF value of 0.06 and such result is for sure not accidental. There are only two anomalies in the pattern which were not predicted by the model: very high WMF value in the Early Bronze sample from Tell Barri (three times above the level of 0.06; for pooled molars from Early Bronze Tell Arbid and Tell Brak against Tell Barri $\chi^2=27.83$, $p<0.001$) and low value in Neo-Assyrian sample from the same site. Especially the first anomaly was completely unexpected. Before further discussion, the possibility of its origin in sex or age bias in the sample was checked.

Sex distribution in all samples is presented in Table 6. The samples were divided into two groups: first one included eight low caries frequency samples, the second three high caries frequency samples (C, H, I). No difference in sex distribution between these groups was detected ($\chi^2=0.15$, $p<0.9$) and it may be concluded that the difference in caries frequency was not caused by sex bias.

Sex	A	Ba	Bb	Bc	C	D	E	F	G	H	I	Σ
?	6	3	9	28	1	3	5	2	6	3	1	67
F	1	2	2	0	3	5	6	3	1	1	3	27
M	2	5	2	0	2	2	9	0	2	3	1	28
Σ	9	10	13	28	6	10	20	5	9	7	5	122

Table 6. Sex distribution in the chronological samples.

Table 7 presents age distribution in the chronological samples. Age diagnosis was based on pubic symphysis, auricular surface, and cranial suture closure. In that case the difference between low and high frequency samples appeared to be statistically significant in spite of small sample size ($\chi^2=8.97$, $p<0.05$). Since the chronic nature of caries makes it potentially more prevalent in older than in younger individuals, such result suggested that the difference in WMF value may reflect simply the differences in average age of individuals, and not changes in diet. To check out this possibility, WMF values for all separate age classes were counted irrespective of sample (Tables 8 and 9) and WMF values expected for real frequencies of defined age classes in each sample were confronted with the original WMF values (Table 10).

Age	A	Ba	Bb	Bc	C	D	E	F	G	H	I	Σ
α (<15)	1	4	2	2	**0**	0	4	1	3	**0**	**0**	17
β (15–30)	1	2	0	0	**0**	4	7	3	0	**0**	**4**	21
γ (30–40)	1	2	0	0	**1**	0	3	0	1	**1**	**0**	9
δ (>40)	1	0	0	0	**3**	3	2	0	2	**3**	**0**	14
ε (adult)	5	2	11	26	**2**	3	4	1	3	**3**	**1**	61
Total	9	10	13	28	**6**	10	20	5	9	**7**	**5**	122

Table 7. Age distribution in the chronological samples.

	I1				**I2**				**C**				**P1**				**P2**				**M1**				**M2**				**M3**			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
α	33				33				29				25				21				40	1	1		33				3			
β	46				47				42				45				44				48	1	5		49		4		30	2	1	2
γ	24				24				28				25		1		25		1		28				20	1	1	1	14	2	1	
δ	23				25				29	1	1		32	1	1		34		3		28		1		22	2	4	2	19	1	3	
ε	52		1		58				67		1		76		1		75	1	3		69	2	5	4	77	5	4	1	47	4	5	1
		0	1	0		0	0	0		1	2	0		1	3	0		1	7	0		4	12	4		8	13	4		9	10	3

Table 8: Frequency of non-cariotic and cariotic teeth in age classes (for symbols cf. Table 7).

	I+C	P1	P2	M1	M2	M3	WMF
α	0.00	0.00	0.00	0.05	0.00	0.00	0.008
β	0.00	0.00	0.00	0.11	0.08	0.14	0.055
γ	0.00	0.04	0.04	0.00	0.13	0.18	0.065
δ	0.03	0.06	0.08	0.03	0.27	0.17	0.107
ε	0.01	0.01	0.05	0.14	0.11	0.18	0.083

Table 9. Weighted mean frequency (WMF) of caries in the age classes (for symbols cf. Table 7).

	WMF	**expected**	**difference**
A	0.038	0.059	0.021
Ba	0.055	0.034	–0.021
C	0.177	0.097	**–0.080**
D	0.028	0.077	0.049
E	0.045	0.052	0.007
F	0.023	0.043	0.020
G	0.050	0.051	0.001
H	0.257	0.097	**–0.160**
I	0.135	0.055	**–0.080**

Table 10. Original WMF values and WMF values expected for age classes frequency in the sample. Two samples with prevalence of general "adult" category are not included.

The result of such comparison seems to support the explanation that difference between low and high caries frequency samples is simply a reflection of much greater frequency of older individuals in the latter. In spite of small sample size, there is statistically significant correlation between original and expected values (Pearson's $r = 0.74$, Bonferroni's $p = 0.022$, Bartlett's $\chi^2=5.17$ with $p<0.05$). Table 9, above, shows clearly that the frequency of caries rises with age and children have almost no cariotic teeth, while in oldest individuals (40 or more years) the frequency of caries is two times higher than in younger adults. However, there is one dubious point in such reasoning: the expected WMF values of high caries frequency samples are systematically lower than the original values. Taking into account the small sample size, it still makes the possibility that not the differences in caries frequency between age classes caused the differences between chronological samples, but inversely — age bias of the samples (in that case incidentally higher age in Early Bronze and Achemaenian samples from Tell Brak) imitated differences in caries frequency between age classes. To answer this question, the WMF values for oldest individuals (age class δ) from pooled low and high caries frequency samples were counted and compared (Tables 11 and 12).

	I1				**I2**				**C**				**P1**				**P2**				**M1**				**M2**				**M3**			
	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3	0	1	2	3
H	9				8				12	1			11		1		12		3		11		1		5	2	3	1	5	1	2	
L	14				17				17		1		21	1			22				17				17		1	1	14		1	
		0	0	0		0	0	0		1	1	0		1	1	0		0	3	0		0	1	0		2	4	2		1	3	0

Table 11. Frequency of non-cariotic and cariotic teeth in individuals >40 years old in high (H) and low (L) caries frequency samples.

	I+C	**P1**	**P2**	**M1**	**M2**	**M3**	**WMF**
High	0.03	0.08	0.20	0.08	0.55	0.38	0.220
Low	0.02	0.05	0.00	0.00	0.11	0.07	0.042

Table 12. Weighted mean frequency (WMF) of caries counted for Table 11.

The difference in caries frequency between oldest individuals from low and high frequency samples for pooled molars is statistically significant (χ^2=10.05, p<0.01) and it is clear that the WMF value for oldest individuals from low frequency samples does not exceed the level of 0.06. Thus, the differences between low and high frequency samples may have resulted from the age bias only to a small degree and much more likely incidentally high average age in high caries frequency samples biased the distribution of caries in age classes. It does not mean that there is no relation between caries frequency and the age, but it seems that the greatest difference is between children/adolescents (in which time after teeth eruption was too short to make disease visible) and adults. The difference in frequency of caries between adult age classes may be neglected. Illusion of its significance was caused by the small sample size and the fact that the high caries frequency chronological samples C and H included almost half of all studied oldest individuals and only 7% of younger adults.

Comparative data

Previous studies on dental caries in Mesopotamia and surrounding areas are rare and in most cases limited to one or two sentences just mentioning the disease. The only exception is the western shore of the Persian Gulf where the inter-population differences in frequency of dental caries were exceptionally strong and this tendency became a subject of many papers (cf. Blau 1999). For that reason it is difficult to compare the results of the present study with other regions, what would make possible to test the model of mobility in a proper way.

Most abundant data on frequency of dental caries come from eastern Arabia, the region considered as the original habitat of the date palm. There are sharp contrasts in the dental samples from that area: in Mesolithic Ra's al-Hamra no one teeth from 600 had carious lesion (Macchiarelli 1989), in Umm an-Nar (ca. 2500 BC) there were only 7 carious teeth per 108 individuals (Højgaard 1981), in two sites in Bahrain dated to 750–450 BC one carious tooth out of 615 (Jarman 1977). On the other side, there is much higher frequency of caries and ante-mortem tooth loss in Janussan on Bahrain dated to ca. 2000 BC (Højgaard 1983; 1984; 1986), 18.4% carious teeth in Samad Oasis (ca. 100 BC–893 CE) and at least one abscess in every preserved maxilla and mandible (Nelson – Lukacs – Yule 1999), 24% carious teeth and also considerable tooth loss in Sharm (Blau 1999). In Shimal around 29% teeth were lost but the frequency of caries in remaining ones was quite small (Vogt *et al.* 1989) which is interpreted as the result of heavy and rapid carious infections. Most detailed study of dentition in Bahrain population revealed very high rate of caries per individual: 49% in the Bronze Age, 35.5% in the Iron Age, and as high as 83.3% in Islamic period (Littleton – Frohlich 1989). High frequency in some samples for sure points to the intensive consumption of dates (Kunter 1981) and the sharp difference between low and high caries frequency samples is interpreted as the reflection of two subsistence strategies: one based on agriculture and date palm growing, the second on the exploitation of the marine resources which are much less cariogenic.

Further north is southern Mesopotamia, potentially also the region of more cariogenic food. A general review of caries frequency in various sites of southern Mesopotamia compared with other regions of Southwestern Asia has been published by Ted Rathbun (1984) who stated that the carious lesions are common here, although their frequencies are very variable. Both in Iran and Mesopotamia males had higher rates of caries, but the Bronze Age samples from Kish and Nippur studied by Rathbun shown lower frequencies than contemporary samples from the Iranian Plateau.

In general, the data from southern Mesopotamia are ambiguous. Carleton Coon observed intensive caries and abscesses in Chalcolithic sample from Eridu (Coon 1949), but in roughly contemporary Ubaid there were only three cariotic teeth per 16 individuals (Keith 1927, 239). No caries but many abscesses were observed in Early Bronze Age sample from Ur (Keith 1927; Molleson – Hodgson 2003, 124), six individuals per 56 had cariotic teeth in Kish (Carbonell 1965), two cases of caries were observed in small sample from Nippur (Rathbun – Mallin 1978). In Isin some cariotic teeth were present in Old Babylonian sample, but the disease was more frequent in Islamic times (Ziegelmayer 1987; 1992). In Parthian sample from Tell Sabra one individual per seven had cariotic teeth, in Islamic sample three per 32 (Burger – Heinrich 1989). It seems likely then that the frequency of caries in southern Mesopotamia was low (except perhaps few sites) and increased in the Islamic period. It supports the hypothesis that the growing of dates was not widespread before Islamic times and more intensive consumption of dates was common only in few sites (as perhaps Eridu if Coon's observation was right) or limited to some social classes.

Only very general data are available also for Neolithic sites from Northern Mesopotamia and it seems likely that the frequency of caries in that period was low: four carious teeth per seven individuals in Zawi Chemi (Ferembach 1970), one carious tooth per four individuals in Tell Halula (Anfruns – Majò – Oms 1996), three carious teeth per six individuals in Jarmo (Dahlberg 1960), very small rate of caries in Abu Hureyra (Molleson 2000, 309), no caries in one individual from Tell Mureybet (Özbek 1976). Information about the intensity of caries in later periods is even more scarce. In Late Chalcolithic Anatolian site of Alaca Hüyük 4 per 10 individuals had carious teeth (Şenyürek 1952, 192). In the middle Euphrates valley the frequency of caries considerably increased between Middle Bronze Age and first millennium CE. In first period the frequency of caries in M2 and M3 was below 5% and no caries observed in M1, in the second period the frequency in M1 raised to 7%, in M2 to more than 13%, and only in M3 decreased to 3% (Jaskulska – Soltysiak 2002). Small sample of four females belonging to royal family and buried in Nimrud revealed only one case of caries but frequent periodontal disease (Schulz – Kunter 1998). In Yorgan Tepa (3rd century CE) caries was observed in 10 individuals per 11 (Ehrich 1939, 579), which is exceptionally high value for the region and looks suspicious. Most detailed study of dental caries so far has been done on the sample of 297 individuals from Tell Sheikh Hamad dated to Parthian/Roman period (Witzel – Schutkowski – Ehlken 2000). The frequency of caries was small (4.9% in the sample of 1698 teeth) and roughly comparable with WMF values for low frequency samples from the Khabur basin.

Discussion

The model connecting the frequency of dental caries with level of mobility seems adequate to the populations of Khabur basin. There are only two anomalies: high frequency of caries in Early Bronze Age Tell Barri and low frequency in Neo-Assyrian sample from the same site. The first case is particularly unexpected, because in other EBA samples from the region the frequency of caries is low and in this respect teeth from Tell Barri resemble more some dental samples from Arabia than any other early North Mesopotamia sample. Only closer examination of archaeological context of that sample may give some clues to this peculiarity.

EBA dental sample from Tell Barri includes the teeth of six individuals, among them two from Level 42 (Early Jazirah II, ca. 2700–2600 BC) and three from Level 39 (Early Jazirah IIIa, ca. 2600–2500 BC). All these skeletons were diagnosed as middle-aged and older individuals. Three graves from the later period (Nos. 1302, 1307, 1515) were well equipped with luxury goods as ritual mace, bronze objects, bichrome and metallic ware vessels and their excavator believes they contained the remains of elite members (Valentini 2006). In contrast, two older burials (Nos 1526 and 1554) were simple pits without any grave goods, but dug out inside a complex of shrines. It may be expected then that the frequency of caries was increased by the individuals of higher social status who could have access to imported luxury cariogenic food. Actually the tendency is reversed: in three individuals from Level 39 the frequency of caries is only slightly over other EBA samples (WMF=0.07) and the majority of cariotic teeth belonged to two females from the Level 42 (see Table 13), and in this very small sample the WMF value is even higher than in Achaemenian period (WMF=0.29). Especially in M2 and M3 the prevalence of caries is striking (Fig. 3), and particularly in individual No. 1554 the disease was advanced (Fig. 4). In spite of extremely small sample size, the difference between Levels 39 and 42 is statistically significant (for pooled molars $\chi^2=11.53$, $p<0.001$). Although increased caries frequency was observed in alleged elite members, as compared to EBA samples from Tell Brak and Tell Arbid, the social status model is irrelevant here.

No.	**Maxilla**																**Mandible**															
	Right								Left								Right								Left							
	M3	M2	M1	P2	P1	C	I2	I1	I1	I2	C	P1	P2	M1	M2	M3	M3	M2	M1	P2	P1	C	I2	I1	I1	I2	C	P1	P2	M1	M2	M3
1526	2	.	.	.	.	.	.	.			.	.	.	.	2	2	X	2	.	.	.	.	.	.	.		.	.	.	.	1	X
1554	.			.	.	.	.	.	.	.	.	.	.		1	1	2	.	3	.	.	.			.		.	.	.	3	2	.
1302				X	.	.	.	.	.	.	.	.				.	.	1	X	.	.	.	.	.	.	.	.	.	.	.	.	.
1307	.	.	.	.	2	.		.	.		.	.	.	.			.	.	.	.	.	.	.	.		.	.	.	.	.	.	.
1515	.	.	.	.	.	.	.	.	.	.	.	.	.	.	3	1	.	.	.	.			.	.	.	.	.	.	.	.	.	
1142		X	X										.																2	X	X	X

Table 13. Distribution of caries and AMTL in Early Bronze Age sample from Tell Barri.

The explanation of unusually high frequency of caries in Level 42 individuals is difficult. There is one additional factor which may be taken into account. After the collapse of well developed trade network in Late Uruk period (ca. 3100 BC) for some hundred years northern and southern Mesopotamia were to some extent isolated from each other. The next phase of intensive contacts was Early Jazirah II period, when many southern motifs appeared again in the north (Valentini, personal communication). It was this time when two women with cariotic teeth were buried in Tell Barri. Thus, there are two possibilities: whether they ate cariotic food imported from abroad (and the source of this food would be most likely the south due to re-established inter-regional trade) or they migrated from region abundant in cariotic food as adults with developed disease. The second alternative is more likely due to difficulties of large scale transport in that time: it would be impossible to move for hundred kilometers such amounts of cariotic food which could cause so intensive damage.

Such way of explanation of observed anomaly would be consistent with the mobility model, but there is one important problem: the data from southern Mesopotamia are ambiguous and it is impossible to prove that it was really a region abundant in cariotic food. For that reason the above explanation is tentative only and must be checked out by more detailed studies on the prevalence of caries in the south. However, potentially the frequency of caries in North Mesopotamian skeletal samples may be an indicator of intensity of contacts between south and north, or at least between southern cities with large date palm plantations and northern treeless dry-farming zones.

The second anomaly is low frequency of caries in Neo-Assyrian sample from Tell Barri. In that case the explanation is easy: the sample was taken from a cemetery dated to 9^{th} century BC, when the Neo-Assyrian state only begun its expansion and still recovered from agrarian crisis in 11^{th}–10^{th} centuries. The graves from that period were well built and located in the context of royal palace, but possible higher social status of these individuals did not affected the frequency of caries.

Neo-Assyrian sample from Tell Barri may be compared with two another dental samples later by 2–3 centuries (Table 14), one from the capital city of Assur (cf. Soltysiak 2002), and one from Hasanlu, a site located in Iran but close to the border of Assyria (Rathbun 1972). The teeth from Assur were poorly preserved — from 13 individuals 9 were represented by less than 5 teeth — but in spite of small sample it is quite clear that the frequency of caries was low. Again, it points to not well developed trade network, in spite of deportation policy and imperial character of the state. This observation is however tentative and more samples from that period must be studied to check out the relevance of proposed model to Assyrian population. More cariotic were the teeth of Iranians from Hasanlu, although due to differences of ecological settings between plains of northern Mesopotamia and highlands of western Iran this dissimilarity cannot be explained here.

Site	I1		I2		C		P1		P2		M1		M2		M3		WMF
	0	1–3	0	1–3	0	1–3	0	1–3	0	1–3	0	1–3	0	1–3	0	1–3	
Barri	23		21		19		21		15		22	1	21	1	11	3	0.050
Assur	14		15		12		18		19		20	1	22		17		0.008
Hasanlu	110	1	123	2	145	4	159	6	151	9	130	15	125	22	67	11	0.084

Table 14. WMF values for dental samples from Neo-Assyrian period.

Conclusions

In general, the empirical data support the proposed theoretical model. Even unexpectedly high frequency of caries in EBA Tell Barri may be explained in terms of increased mobility. All studied samples were small, thus it may be concluded only in tentative way that in such peculiar region as the Khabur basin the frequency of caries may be a potentially useful source for socio-political reconstructions. There are still important gaps in our knowledge about the distribution of caries in the Near East and especially more detailed studies on dental samples from southern Mesopotamia would be helpful in developing the reliable tool for tracing the intensity of contacts between the north and the south of Mesopotamia.

Observed temporal changes in the frequency of caries may be related not to increase of the level of mobility, but to modification of food preparation techniques or to decline in oral hygiene. It is likely that these factors to some extent contributed to overall tendency, but the previous studies on dental caries show clearly that diet composition is far more important.

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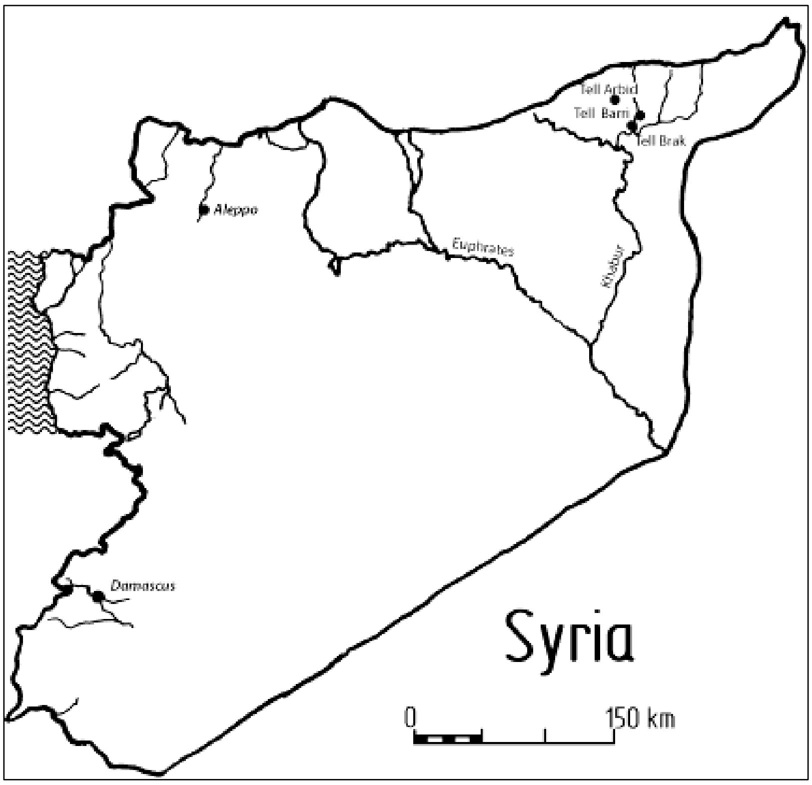

Fig. 1. Location of the sites discussed in the present study.

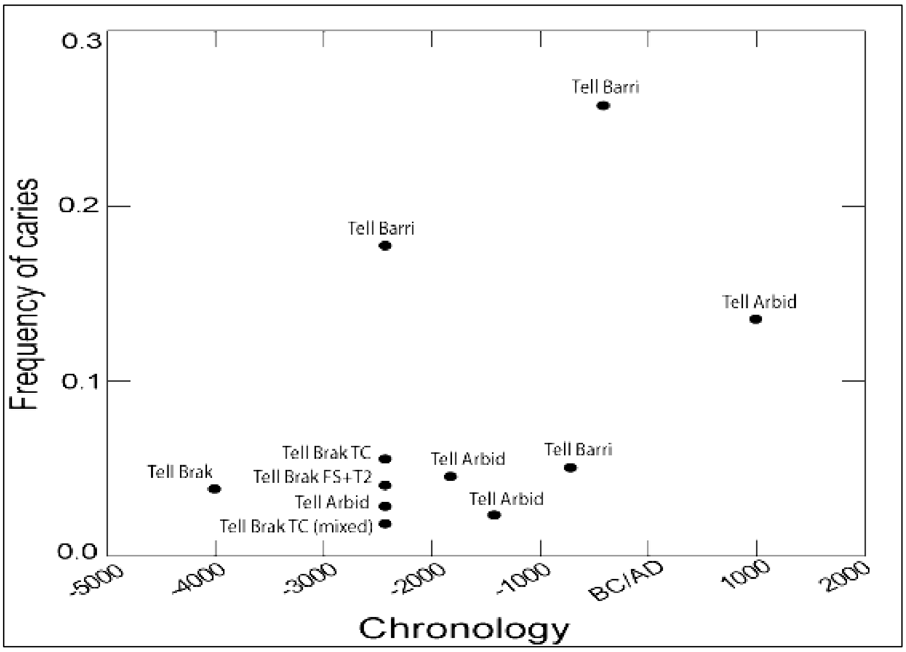

Fig. 2. Weighted mean frequency of caries in the chronological samples
(for the sake of clarity letter symbols are replaced by the names of sites mostly represented in the sample).

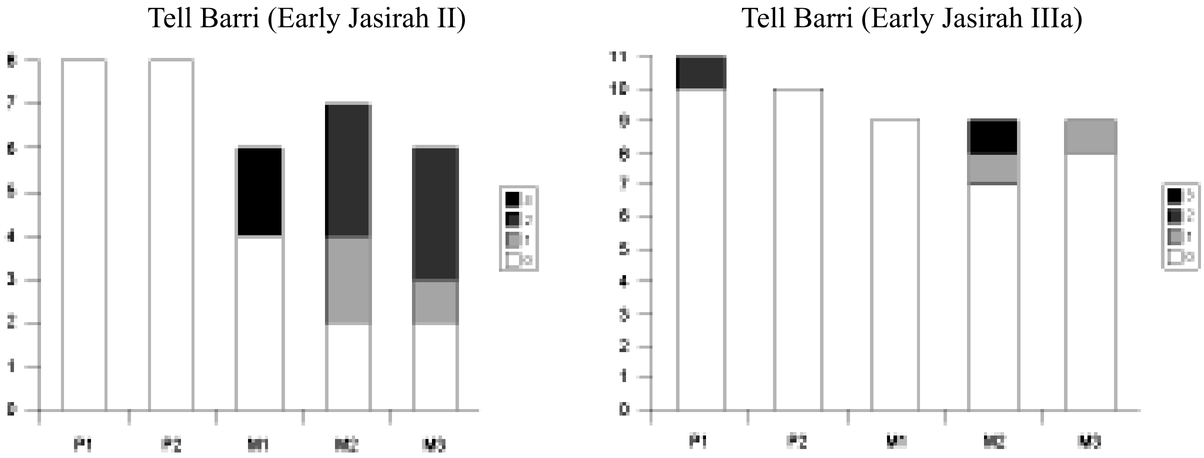

Figure 3. Frequency of caries in two compared Early Bronze Age groups from Tell Barri.

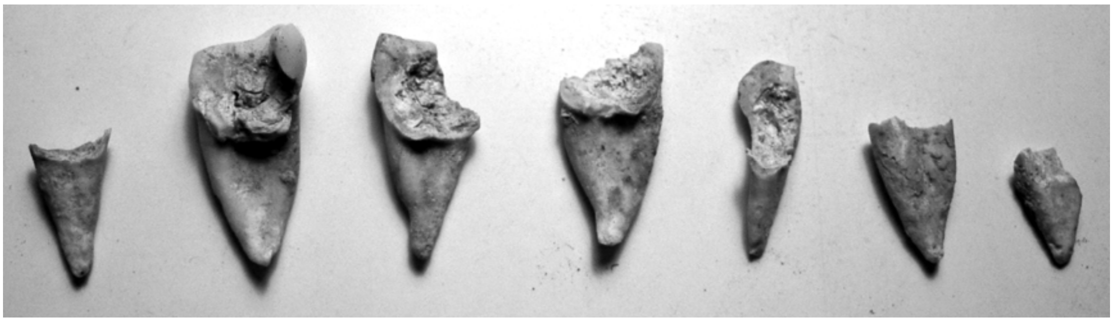

Figure 4. Cariotic teeth of a woman from grave No. 1554 at Tell Barri.