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Correlates of dental caries in 12-year-old children in Europe: a cross-sectional analysis

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Objective To investigate, from current cross-sectional data, the relationships between dental caries experience of 12-year-old children in 29 countries of Europe and four independent variables: national wealth (GDP), expressed as purchasing power parity (PPPx1,000US$)/capita/year; population per active dentist; sugar consumption, expressed as Kg/capita/year; and volume sales of toothpaste, expressed as litres/capita/year. ***Method*** Most of the data were abstracted from relevant websites. Information on toothpaste sales was from personal communication and obtainable for 16 countries of Western Europe only. Relationships were examined using Spearman's rank correlation method. ***Results*** Mean DMFT showed a strong negative association with national GDP (rho = -0.729, $p < 0.01$), whilst toothpaste sales showed a statistically significant positive association with GDP (rho = 0.599, $p < 0.05$) as did sugar consumption (rho = 0.575, $p < 0.01$). Paradoxically, caries experience yielded a strong negative correlation with sugar consumption (rho = -0.561, $p < 0.01$) such that ranked increases in mean DMFT were significantly associated with decreasing levels of sugar consumption. None of the other rank correlations was statistically significant. ***Conclusions*** Unavoidable shortcomings of the available data and their incompleteness meant that any conclusions that could be drawn were speculative. A possible explanation for the anomalous association of low mean DMFT with high sugar consumption in Western Europe is that the extensive use of, mainly fluoride containing, toothpaste neutralises the potential damage from high sugar consumption. Use of sugar principally as a commercial food or drink additive in modern times, with potential for buffering of its acidic fermentation products, together with a possibly more rapid oral clearance of sugar in additive form, may also be a contributory factor.

Key words: Correlation, dental caries, national wealth, population per dentist, sugar consumption, toothpaste sales

Introduction

Over the past two decades a substantial fall in dental caries experience of 5- and 12-year-old children has been recorded in most European countries. In some, the decline evidently started as early as the mid 1970s. However, in many other countries dependable data were not collected and published before the early 1980s (Downer *et al*., 2005; Marthaler, 1996). Against the trend, the caries experience of 12-year-olds from 1990 onwards, among some poorer countries of the former eastern European block, appears to have worsened (Downer *et al*., 2005). The purpose of this study was to examine current caries levels in the countries of Europe, including the EU, EEA, Romania (an EU candidate country) and Switzerland, and to explore the relationships between caries experience of their 12-year-old child populations and a number of independent variables – correlates of caries – for most of which national statistics were largely available.

A number of host and environmental factors are related to caries experience in the individual. These include age, gender, dietary proclivities, fluoride exposure, dental attendance pattern, urban versus rural domicile, geographic region, and socio-economic status (Downer, 1991). The influence of these factors is also apparent when viewed from a population perspective. To cite the most obvious example, as far as both the individual and the wider population are concerned, the relationship between cumulative caries experience and age scarcely requires elaboration. At national level, for some of the other variables, there is evidence from longitudinal observations of United Kingdom data in particular, of the effects of reducing sugar consumption and the rapid infiltration of the oral hygiene products market by fluoride toothpaste on changes in caries experience in succeeding cohorts of children during the 1970s and 1980s (Downer, 1999). The effect of fluoridation of domestic water supplies in the UK, covering some 10% of the population, has not made such a substantial impact, its benefits tending to be masked by the more noticeable effect of the widespread use of fluoride toothpaste. Nevertheless, at regional level the considerably lower than expected prevalence of caries in fluoridated areas such as Birmingham and large parts of the West Midlands is readily apparent (British Fluoridation Society, 2004). Dental attendance pattern - which is indirectly related to the availability of dental services and dental personnel - also influences to some extent DMF and its components in populations and at an individual level, notably in terms of the care index; the ratio of filled teeth to total caries experience (Downer *et al*., 2005; O'Brien, 1994). With regard to several of the other factors known to affect caries levels, most cannot be expressed as a single national index figure as they relate to demarcated subsets of populations. Statistics on

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four well established correlates of caries are, however, collated by various agencies for individual countries and can be investigated. These formed the core of the relationships explored here.

The main objective was to test the null hypotheses that mean dental caries experience of 12-year-old children reported at national level for 29 countries of Europe is not related significantly to their national wealth, to population per active dentist, to national sugar consumption or to national toothpaste volume sales.

In order to facilitate the main objective, two secondary objectives were proposed:

1) to examine the relationship for European countries between three dental caries indices: mean DMFT, caries prevalence (percentage with mean DMFT ≥ 1.00) and mean DMFT for children with DMFT ≥ 1.00, and to establish which was the most appropriate index for the purposes of the main analyses.
2) to examine the frequency distributions of the national data for the dependent variable (caries experience) and the four independent variables specified (correlates) in order to elucidate their statistical properties and determine the most appropriate method for analysing their inter-relationships.

Method

Data sources

National statistics on dental caries prevalence and experience, and on three of the selected independent variables, were obtained from relevant websites:

- dental caries - Council of European Chief Dental Officers (2005) and World Health Organization (2005),
- national Gross Domestic Product (GDP) expressed as purchasing power parity (PPP) in US$x1,000 - CIA (2005),
- population per active dentist - Council of European Chief Dental Officers (2005);
- national sugar consumption (sugar disappearance from the market) expressed as kilograms per capita per annum - Food and Agriculture Organization (2005).

Statistics on the fourth selected variable, volume sales of toothpaste expressed as litres per capita for all brands, were obtained from Colgate Palmolive Europe (2005) by personal communication. The data from websites were abstracted in December 2005. The data on toothpaste comprised unpublished reported estimates of volume sales of all branded products for 2005. The data were the latest available, although some of the website information related to earlier years. The precise reference dates were quoted in the original source material.

Data analysis

The statistics analysed represented secondary aggregated data for each country. The data were not normally distributed and for two of the variables, they were incomplete. For these reasons the relationships between the four independent variables and mean DMFT at 12 years, the selected dependent variable, were analysed by the distribution-free Spearman's rank correlation coefficient method, parametric techniques such as partial correlation being considered inappropriate. However, for examining the relationship between the three caries indices, a linear regression approach was regarded as permissible. Data were analysed using SPSS 13 and Microsoft Excel software.

Results

Table 1 presents the data for three caries indices (mean DMFT at 12 years, caries prevalence and mean DMFT for children with DMFT ≥ 1.00) for the countries included. As can be seen, some of the information for Hungary, Latvia, Luxembourg, Romania and Switzerland was incomplete. The data sources are shown at the foot of the table. Table 2 contains comparative national data for the dependent variable (mean DMFT at 12 years, ranked according to magnitude) and the independent variables, Gross Domestic Product (GDP), expressed as purchasing power parity (PPPx1,000US$); population per active dentist; and sugar consumption, expressed as Kg per capita per year. These are presented by country in the same order as the ranked mean DMFT scores. Items of data for certain countries were again not available. Volume sales of toothpaste, expressed, as litres per capita per year, are also presented in Table 2 for 16 countries of Western Europe; those for which these data were available.

Relationship between dental caries indices

The linear regression of mean DMFT on dental caries prevalence (%) derived from Table 1 gave the relationship:

Mean DMFT = {0.051 x Prevalence (%)} – 1.219
The correlation coefficient was: $r = 0.853$ ($p < 0.001$), (rho = 0.831).

The linear regression of mean DMFT on mean DMFT for those with caries experience was expressed by:

Mean DMFT = (1.070 x mean DMFT ≥ 1.00) – 1.356
The correlation coefficient was: $r = 0.913$ ($p < 0.001$), (rho = 0.869).

In examining the relationship between dental caries levels and the four independent variables in order to test the main hypotheses of the study, correlation coefficients were computed initially using each of the three caries indices. Mean DMFT generally showed the strongest association with the independent variables and was therefore preferred.

Dental caries levels and associated factors across Europe

It is evident from Table 2 and Figure 1 that 12-year-old children in Denmark, the Netherlands, Switzerland and the United Kingdom (UK) had the lowest mean DMFT at 12 years (< 0.90), while the former Eastern block countries Hungary, Poland, Slovakia and Romania had the highest (3.80–7.30).

As regards national wealth, it is apparent from Table 2 and Figure 2 that Luxembourg, Norway and Switzerland

Table 1. Mean DMFT, caries prevalence (%) and Mean DMFT for those with caries at age 12 years for the countries of Europe

Country	*Mean DMFT at 12 Years*[1]	*Caries Prevalence (%)*[2]	*Mean DMFT for those with caries*
Austria	1.0	42	2.4
Belgium	1.1	75	1.5
Cyprus	1.8	50	3.6
Czech Rep	2.5	71	3.5
Denmark	0.9	45	2.0
Estonia	2.7	75	3.6
Finland	1.2	65	1.9
France	1.9	61	3.1
Germany	1.2	58	2.1
Greece	2.2	72	3.1
Hungary	3.8	~	~
Iceland	1.5	52	2.9
Ireland	1.1	49	2.2
Italy	2.1	64	3.3
Latvia	3.5	~	~
Lithuania	3.6	84	4.3
Luxembourg	3.0	~	~
Malta	1.6	56	2.9
Netherlands	0.8	32	2.5
Norway	1.5	52	2.9
Poland	3.8	87	4.4
Portugal	1.5	53	2.8
Romania	7.3	~	~
Slovakia	4.3	88	4.9
Slovenia	1.8	60	3.0
Spain	1.1	43	2.6
Sweden	1.1	37	3.0
Switzerland	0.9	~	~
UK	0.9	38	2.4

Sources: [1] World Health Organization (2005).
[2] Council of European Chief Dental Officers (2005).

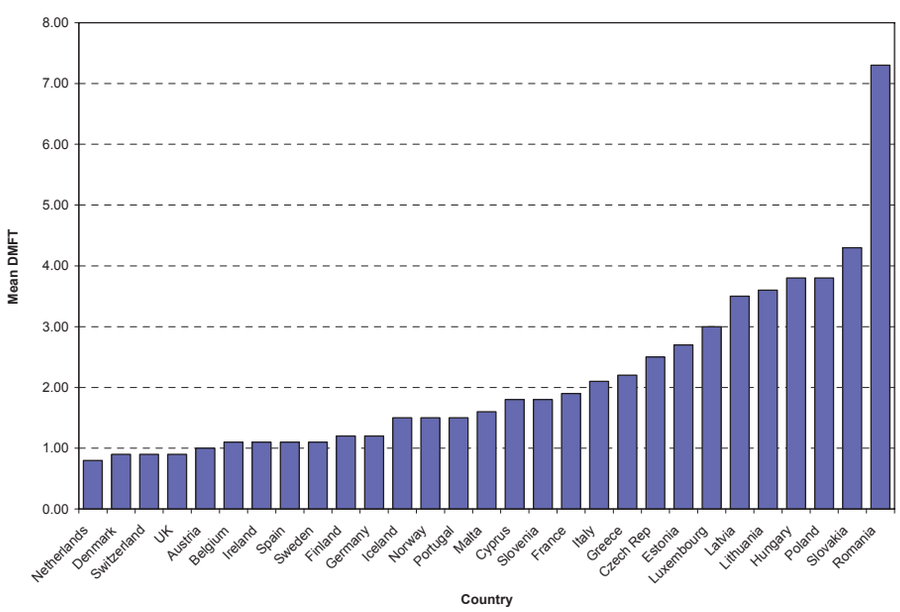

Figure 1. *Mean DMFT at 12 years ranked for countries of Europe*

Table 2. Mean DMFT at 12 years ranked from low to high for the countries of Europe with four independent variables: GDP as Purchasing Power Parity (PPP) in US$ x 1,000; population per active dentist; annual sugar consumption in Kg per capita per year; volume purchase of toothpaste in litres per capita per year.

Country	*Mean DMFT at 12 Years* [1]	*GDP as PPP US$x1000* [2]	*Population per dentist* [3]	*Sugar Kg/capita/year* [4]	*Toothpaste l/capita/year* [5]
Netherlands	0.8	31.2	2230	43.1	0.34
Denmark	0.9	31.6	1084	36.0	0.35
Switzerland	0.9	35.4	1718	45.8	0.25
UK	0.9	31.5	2180	37.2	0.34
Austria	1.0	31.8	2115	38.2	0.32
Belgium	1.1	31.4	1211	46.2	0.23
Ireland	1.1	33.2	2145	34.8	0.48
Spain	1.1	25.1	2210	30.4	0.22
Sweden	1.1	29.8	1170	40.0	0.29
Finland	1.2	29.6	1161	28.4	0.23
Germany	1.2	28.0	1291	33.7	0.34
Iceland	1.5	32.4	1023	40.1	~
Norway	1.5	38.6	1150	38.9	0.34
Portugal	1.5	19.3	2003	28.5	0.21
Malta	1.6	18.7	2795	41.2	~
Cyprus	1.8	22.3	1166	~	~
Slovenia	1.8	20.7	1603	11.6	~
France	1.9	29.3	1511	33.0	0.29
Italy	2.1	27.9	1139	27.4	0.33
Greece	2.2	22.0	820	29.0	0.19
Czech Rep	2.5	18.4	1512	35.3	~
Estonia	2.7	13.2	1311	27.7	~
Luxembourg	3.0	61.2	1556	~	~
Latvia	3.5	11.9	1455	28.9	~
Lithuania	3.6	12.6	1113	24.6	~
Hungary	3.8	15.6	2105	32.4	~
Poland	3.8	12.6	1550	41.0	~
Slovakia	4.3	14.4	1880	28.6	~
Romania	7.3	8.2	2562	22.5	~

Sources: [1] World Health Organization (2005)
[2] CIA (2005)
[3] Council of European Chief Dental Officers (2005)
[4] Food and Agriculture Organization (2005)
[5] Colgate Palmolive Europe (2005)

Table 3. Correlation matrix (Spearman's rho) for mean DMFT at 12 years as dependent variable and related independent variables

	Mean DMFT	GDP cap/year (PPP)	Population per dentist	Sugar Kg/cap/yr
GDP cap/yr PPP	-0.729**			
Population per dentist	-0.082	-0.120		
Sugar Kg/cap/yr	-0.561**	0.575**	0.101	
Toothpaste l/cap/yr	-0.405	0.599*	0.117	0.273

Values of N:
Mean DMFT; GDP cap/year (PPP); Population per dentist = 29
Sugar Kg/cap/yr = 27
Toothpaste l/cap/yr = 16

* $p<0.05$; ** $p<0.01$

had the highest purchasing power parity (PPP) measured in thousands of US$ ($61.20, $38.60 and $35.40 respectively), whereas the new EU accession (former Eastern block) countries, Latvia, Lithuania and Poland, and the candidate country Romania, had the lowest ($11.90, $12.60 and $8.20 respectively). Table 2 also indicates, together with Figure 3, that Denmark and Iceland had the lowest populations per dentist at just over 1,000 people per active dental practitioner. Sugar consumption (Table 2, Figure 4) was highest in Belgium, Switzerland and the Netherlands, at over 43 Kg per head per year, nearly four times higher than that of the lowest consumer, Slovenia, with 11.60 Kg per head. For 16 countries of Western Europe, for which data were available (Table 2, Figure 5), the highest estimated volume sales of toothpaste for the year 2005 were in Denmark at 0.35 litres per head. The lowest were in Greece at 0.19 litres.

Relationships between the variables

Table 3 consists of a matrix of Spearman's rank correlation coefficients (rho) between mean DMFT at 12 years, as dependent variable and the four correlates of caries (GDP per capita, population per dentist, sugar consumption and volume sales of toothpaste). Also presented are the correlation coefficients for the relationships among the four independent variables.

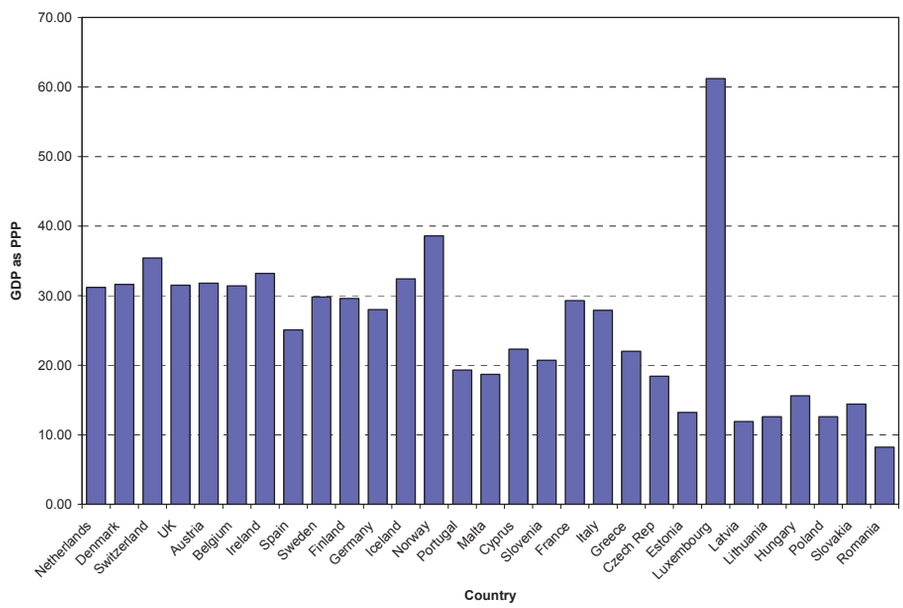

Figure 2. *Gross Domestic Product (GDP) as purchasing power parity (PPP) in US$ x 1,000 for countries of Europe*

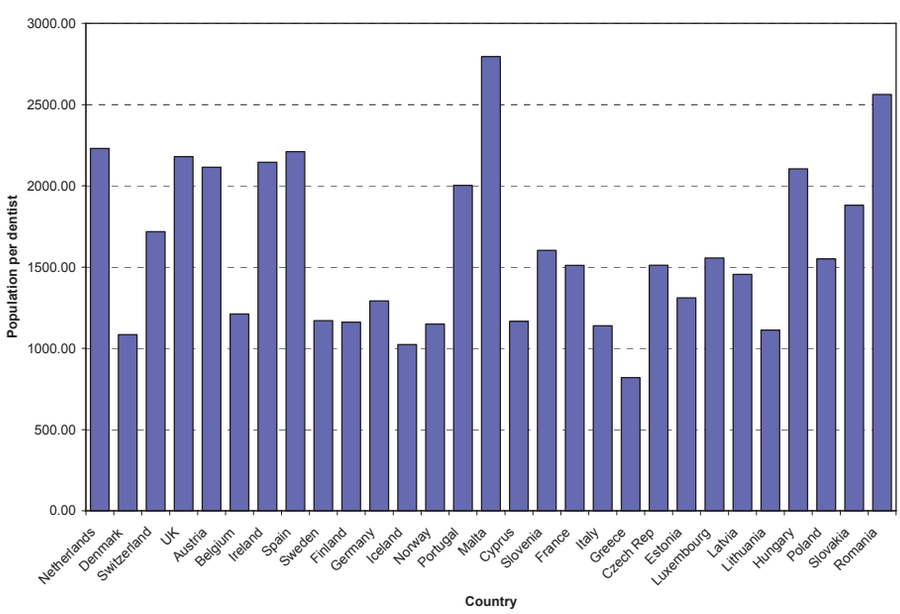

Figure 3. *Population per active dentist for countries of Europe*

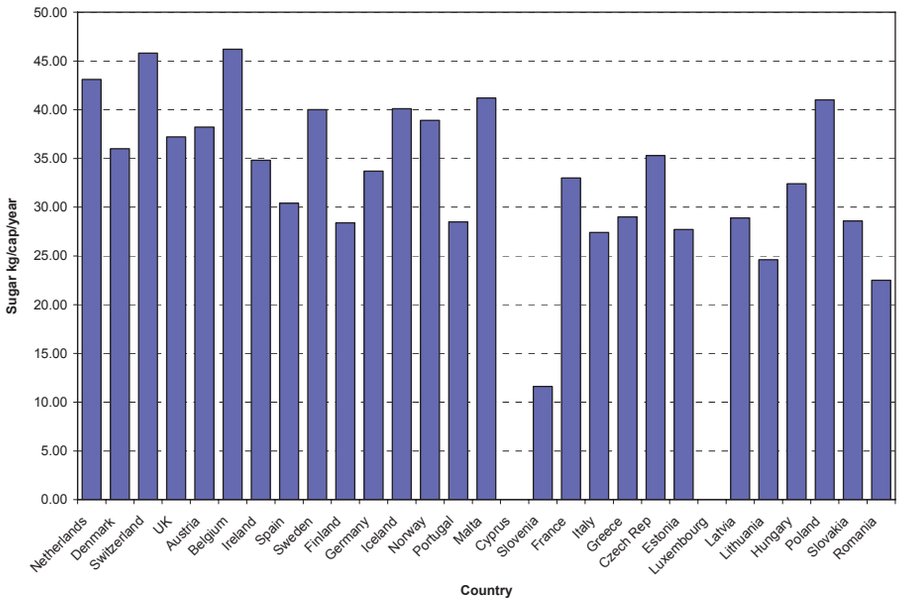

Figure 4. *Sugar consumption Kg/capita/year for countries of Europe*

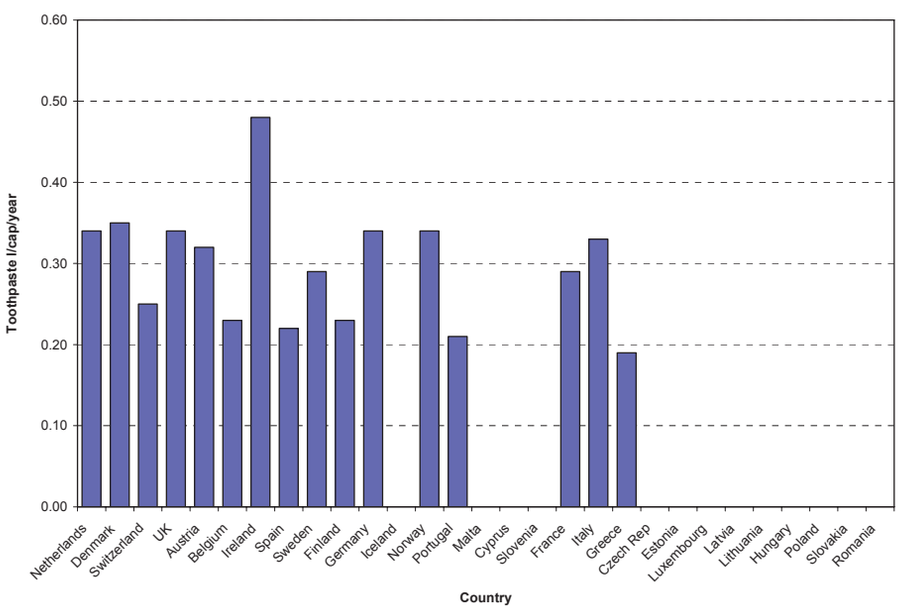

Figure 5. *Volume sales of toothpaste litres/capita/year for countries of Europe*

It can be seen that the strongest association was that between caries experience and GDP (rho = -0.729, $p < 0.01$). Contrary to expectation, sugar consumption also yielded a statistically significant negative correlation with caries experience (rho = -0.561, $p < 0.01$) such that as national sugar consumption increased, population mean DMFT decreased. Toothpaste sales, as would be anticipated, showed a negative correlation with caries experience (rho = -0.405) although the relationship was not statistically significant.

Between the independent variables, both sugar consumption and toothpaste sales yielded statistically significant correlation coefficients with GDP (rho = -0.575, $p < 0.01$ and rho = -0.599, $p < 0.05$ respectively) which appeared to be the dominant factor influencing the other variables. None of the remaining correlation coefficients between variables was statistically significant. Figures 6, 7 and 8 consist of scatter diagrams demonstrating the relationships between national wealth and the three variables DMFT, sugar consumption and toothpaste sales.

Discussion

Characteristics of the data

Data on gross domestic product and sugar disappearance from the market were taken from authoritative, official websites. The website information abstracted on numbers of active dentists was originally derived from national official registration figures. In some instances these latter estimates appear to have been rounded and their

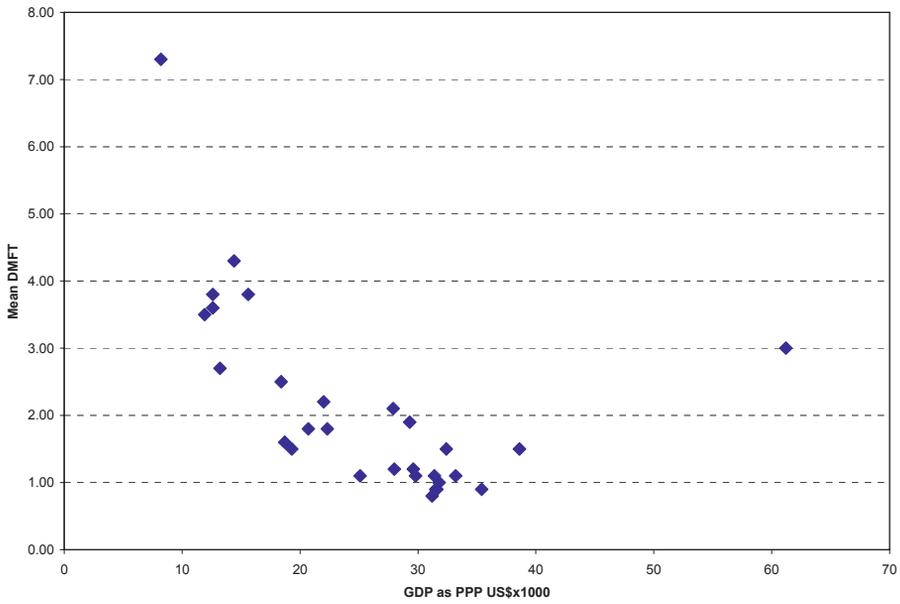

Figure 6. *Mean DMFT for countries of Europe according to their Gross Domestic Product as purchasing power parity in US$ x 1,000*

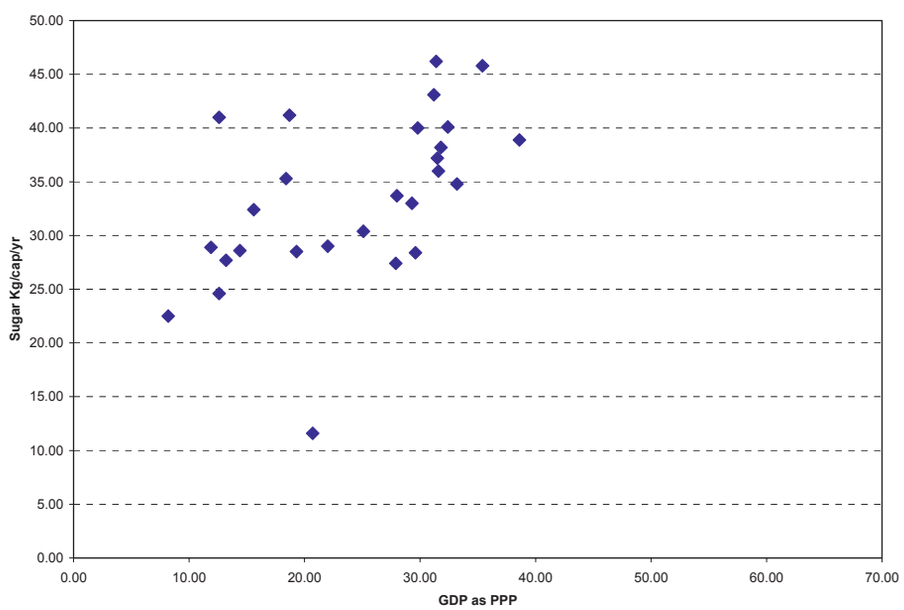

Figure 7. *Sugar consumption Kg/capita/year for countries of Europe according to their Gross Domestic Product as purchasing power parity in US$ x 1,000*

accuracy cannot be unequivocally vouched for. Data on volume sales of all brands of toothpaste were provided by a commercial source. These covered only the countries of Western Europe where most of the products originate from four main manufacturers. Comparable data for the countries of the former Eastern block were unavailable. As far as Western Europe is concerned the great majority of toothpaste marketed in recent years contains fluoride (Downer *et al*., 2005) so that volume sales can stand as a surrogate for this, the main source of population fluoride exposure. The two other notable non-natural sources of fluoride are water fluoridation, principally in Ireland where 71% of the population is covered, and to a lesser extent in the UK and Spain with some 10% of their populations covered (Downer *et al*., 2006), and fluoridated domestic table salt, amounting to 30% of the market in France, 60% in Germany, 35% in the Czech Republic and 88% in Switzerland (Marthaler, 2005a, 2005b; Marthaler and Pollak 2005). The data presented on dental caries experience were derived from epidemiological survey findings contained in the oral health data bank maintained by WHO. The variable quality and reliability of these data in terms of sampling strategy, setting, examiner performance and methods of data collection, have been commented upon previously (Downer *et al*., 2005). Moreover, many of the original surveys

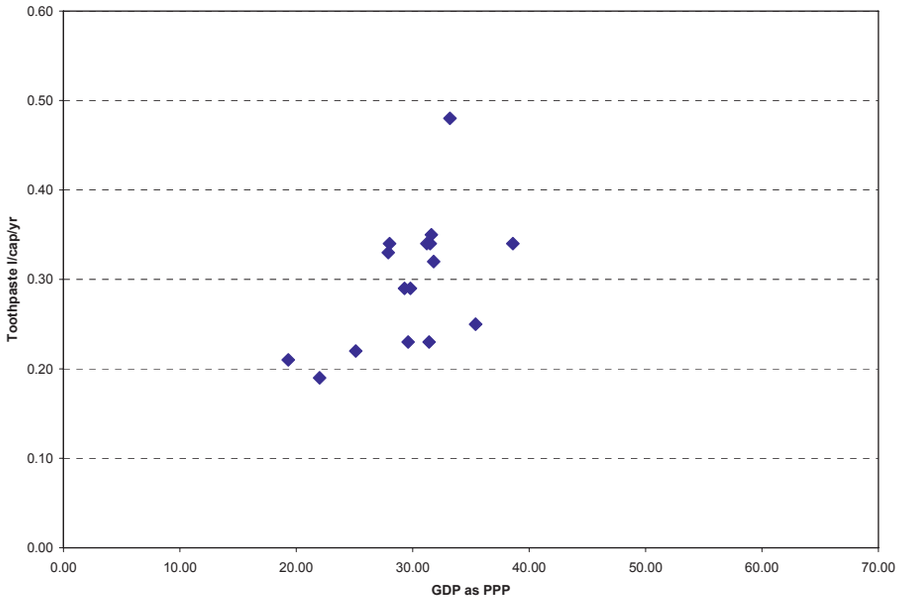

Figure 8. *Volume sales of toothpaste litres/capita/year for countries of Europe according to their Gross Domestic Product as purchasing power parity in US$ x 1,000*

from which the data were derived were carried out at different times, as the source document collating them indicates (World Health Organization 2005). Therefore they may not reflect accurately the present position of the countries involved.

Ideally, to gain the most complete profile of the relationships between macro-scale, independent variables and caries experience at national level it would be necessary to utilise serial data collected over time. Whilst such data are available, for example, for GDP and sucrose consumption, the collection of dependable workforce data over the course of years, and information on toothpaste sales is more problematic. As far as data on dental caries experience are concerned, there is only information relating to three, or fewer, data points available from published reports between 1980 and 2000, inclusive, for many countries (Downer *et al*., 2005).

Notwithstanding, observed values of caries and its correlates from cross-sectional data, do not stand in isolation. They are part of continuous chains of events so that the cross-sectional observations for any given variable are not independent but are highly correlated with one another year on year. Thus observations at any particular time are conditional upon the status of that variable in the preceding years and tend to reflect relatively stable long term trends. It has been suggested that taking cross-sectional sugar consumption data, to quote a particular example, at a given time and comparing these to contemporaneous data on cumulative caries experience will give a false picture of the relationship. However, the stability of trends, so far as can be ascertained from available data, suggests that this is probably not so. A further unavoidable shortcoming is that whereas the data on the independent variables relates to national figures for whole populations, the caries data refer only to the 12-year-old age group.

Relationships between caries experience and independent variables

The recognised shortcomings of the available data and their incompleteness mean that any conclusions that may be drawn from the study are speculative. Moreover, it is hardly necessary to emphasise that the existence of a statistically significant association between two variables does not in any way prove cause and effect.

Preliminary analyses indicated that, in the case of all the relationships that were statistically significant, Spearman's rank correlation coefficients were numerically greater and yielded a higher level of significance than the corresponding results obtained using the Pearson correlation coefficient. For these data, therefore, the distribution free method provided a more efficient measure of association than the parametric method.

The strongest association demonstrated in (Table 3) was the inverse relationship between dental caries experience and national wealth expressed as purchasing power parity (rho = -0.729, $p < 0.01$). Sugar consumption and volume sales of toothpaste also yielded statistically significant correlation coefficients with PPP but in a positive direction. Population per dentist showed only very weak relationships with the other variables. In relation to caries experience, the limited role of dental treatment provision has been discussed elsewhere and will not be rehearsed further (Downer *et al*, 2005). Volume sales of toothpaste, as expected, had a negative association with mean DMFT although this was not statistically significant. However, the relevant data were only available for 16 of the wealthiest countries, serving to lower the expected correlation coefficient. The role of fluoride toothpaste in the prevention and control of caries in Western countries has also been discussed previously (Downer *et al*. 2005).

The most surprising finding, and one that requires explanation, is the strong negative association between national sugar consumption and caries experience (rho = -0.561, $p < 0.01$) yet the evidence for sugar, sucrose in particular, being the main agent causing dental caries is generally accepted (British Nutrition Foundation, 1999). At the beginning of the 1980s, mean DMFT at 12 years recorded in 47 countries produced a strong positive correlation coefficient ($r = 0.72$) with national sugar supplies (Sreebny, 1982). However, 12 years later, Woodward and Walker (1994) demonstrated that, whereas a strong positive trend existed between DMFT and sugar consumption in 61 countries classified as 'developing', the relationship no longer held for 29 countries classified as 'industrialised'. It seems from the current data that in developed Western European countries today, the situation has now reversed such that low DMFT is, paradoxically, associated with high sugar consumption. At the same time it is apparent that both low caries levels and high sugar consumption, together with large volume sales of toothpaste, are strongly correlated with consumer purchasing power which appears to be the governing factor in these relationships. It seems likely therefore that extensive use of fluoride toothpaste in Western Europe neutralises the cariogenic potential of the corresponding high sugar consumption so that average caries levels are kept low. This supposition has support from other investigators (van Loveren and Duggal, 2001). Another factor may be the form in which the sugar is ingested. Nowadays the use of packaged sugar has largely given way to its incorporation in processed foods. Major UK sources of dietary sugar (British Nutrition Foundation, 1999) are cereals, 23%; milk products, 13%; confectionery and preserves, 29%; and beverages, 17%. Taken in these forms, the sugar may be less cariogenic because of buffering of its acidic, fermentation products. This is particularly so for dairy products. Also more rapid oral clearance of sugar may occur when it is incorporated in drinks and some processed foods.

It is clear that further research is needed in order to fully investigate the counter-intuitive anomaly of dental caries levels in relation to sugar consumption suggested by this study. If researchers could obtain ready access to information on the fluoride content and volume sales of toothpaste in Eastern Europe, this would be greatly facilitated.

Acknowledgement

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