Impact of National Income and Inequality on Sugar and Caries Relationship

M. Masood^a Y. Masood^b T. Newton^c

^aCenter of Studies for Community Dentistry and ^bCenter of Studies for Oral and Maxillofacial Surgery, Faculty of Dentistry, Universiti Teknologi MARA, Shah Alam, Malaysia; ^cUnit of Dental Public Health and Oral Health Services Research, King's College Dental Institute, King's College London, London, UK

Key Words

Dental caries • Income inequality • National income

Abstract

Objective: The aim of this study was to examine the impact that national income and income inequality in high and low income countries have on the relationship between dental caries and sugar consumption. **Methods:** An ecological study design was used in this study of 73 countries. The mean decayed, missing, or filled permanent teeth (DMFT) for 12-year-old children were obtained from the WHO Oral Health Country/Area Profile Programme. United Nations Food and Agricultural Organization data were used for per capita sugar consumption. Gross national incomes per capita based on purchasing power parity and the Gini coefficient were obtained from World Bank data. Bivariate and multivariate linear regression analysis was performed to estimate the associations between mean DMFT and per capita sugar consumption in different income and income inequality countries. **Results:** Bivariate and multivariate regression analysis showed that countries with a high national income and low income inequality have a strong negative association between sugar consumption and caries ($B = -2.80$, $R^2 =$

0.17), whereas countries with a low income and high income inequality have a strong positive relationship between DMFT and per capita sugar consumption ($B = -0.89$, $R^2 = 0.20$). **Conclusion:** The relationship between per capita consumption of sugar and dental caries is modified by the absolute level of income of the country, but not by the level of income inequality within a country.

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Dental caries is characterized as a pandemic and is considered a highly prevalent chronic disease that afflict humans of all ages and in all regions of the world, particularly in developing and underdeveloped countries [Harel-Raviv et al., 1996; Masood et al., 2012]. It has profound significance for both individuals and the community because of its often severe, though nonfatal, consequences [Edelstein, 2006]. Eradicating dental caries is considered a major challenge for oral health care professionals because of the complex interplay of social, behavioral, cultural, dietary, and biological risk factors that are associated with its initiation and progression [Ismail et al., 1997; Barondess, 2000]. A wealth of evidence from many different types of investigation, including human

studies, animal experiments and experimental studies, has shown that sugars are the most important dietary etiological cause of dental caries [Sheiham, 2001; Moynihan, 2002, 2005; Sayegh et al., 2002; Sanders, 2004]. An understanding of the epidemiology of caries and its etiological factors is key to understanding the possible opportunities and probable new public health approaches to diminish the caries burden worldwide [Holst, 2005].

The WHO report on oral health in 2003 observed that developing countries have lower levels of caries experience, while developed countries have higher ones [Petersen, 2003]. However, trend lines for the last 30 years are diametrically different for developing and developed nations; there has been a decline in dental caries experience in developed countries while the consumption of sugar has remained substantially unchanged, whereas developing countries have experienced ongoing increments in dental caries experience [Zero, 2004; Maltz et al., 2010]. The WHO has attributed these differences to the increasing availability of sugar in the diet in developing countries and, in contrast, the introduction of fluoride and dental public health interventions in developed countries [Petersen et al., 2005].

This relationship between sugar consumption and caries in high income countries was long viewed as being virtually linear: the more sugar a population consumed, the greater the prevalence and severity of caries was presumed to be [Burt and Pai, 2001]. However, recent evidence questions this, e.g. the per capita consumption of sugar in the USA and some other countries has risen over the last 30 years or so and continues to rise, while caries experience in the permanent dentition has declined [WHO, 2003]. In view of this, it is reasonable to think that this linear ecological relationship has been affected by evident factors (e.g. extensive exposure to fluoride) and some unexplored factors (e.g. national income and income inequality) [Burt and Pai, 2001].

Income inequality and absolute national income have effects on population health and on mortality rates [Subramanian et al., 2003; Wilkinson and Pickett, 2006]. Higher levels of income inequality and a low absolute income are linked to higher all-cause mortality risks [Lochner et al., 2001], and health-deteriorating behaviors [Diez-Roux et al., 2000]. The distribution of income in a given society might affect health via material and behavioral factors, such as diet and smoking [Sabbah et al., 2010]. Some suggest that income inequality affects health through a process of social comparison, status competition, and individuals' feelings of relative deprivation [Wilkinson and Pickett, 2006; Kondo et al., 2008], with

consequent psycho-neuroendocrine and behavioral pathways [Lynch et al., 2004]. Income inequality has also been linked to a decline in social capital and trust, behavioral and psychological consequences, and disinvestment in public resources such as education and health care, as the interests of the rich diverge from those of the poor [Kim et al., 2008]. The withdrawal of such resources for health is thought to lead to the negative effects observed. We postulate that the absolute national income and country level income inequality is related to dental caries in the same manner that it relates to general health and modifies the relationship of sugar consumption and dental caries.

The hypothesis of this study is that the amount of sugar consumption in countries with a higher national income and low levels of income inequality has less association with dental caries than in countries with a low national income and high income inequalities, where strong associations should be observed. The objective of this study was to examine the impact that national income and income inequality in high and low income countries have on the relationship between dental caries and sugar consumption.

Methods

An ecological study design was used to test the relationship between the dental caries level [mean decayed, missing, or filled permanent teeth (DMFT)] and per capita sugar consumption stratified by gross national income-purchasing power parity (GNI-PPP) and income inequality (Gini coefficient) in 73 high and low income countries.

Dental Caries (Mean DMFT)

National statistics on dental caries levels expressed as mean DMFT for 12-year-old children were obtained from the WHO Oral Health Country/Area Profile Programme (CAPP) [WHO, 2004]. The CAPP was established at the WHO Collaborating Centre for Education, Training, and Research at the Faculty of Odontology, Malmö, Sweden, in 1995. It provides specific details of dental caries levels and other oral health-related data for more than 175 countries from national surveys conducted after 1966. Each country survey followed WHO guidelines to measure the dental caries level. DMFT were assessed under indirect natural daylight with dental mirrors, wooden spatulas, and community periodontal index probes in the study. Tooth surfaces were dried with gauze. The oral examinations were carried out in regular nondental chairs.

Per Capita Sugar Consumption

The United Nations Food and Agricultural Organization (UNFAO) food balance sheets were used to obtain data estimates of per capita sugar consumption including a variety of simple car-

bohydrates. We used the UNFAO category 'sugar and sweeteners + (total)' and 'food supply quantity (kg/capita/year)' to extract the data from database for all of the countries [UNFAO, 2010]. The category sugar and sweeteners includes a variety of monosaccharides and disaccharides mainly consisting of sucrose (from sugar beet or cane), glucose, honey, or high fructose corn syrup. Such foods are high in fructose concentration, either free or as part of a disaccharide (i.e. sucrose). This nutrient exposure information was extracted for the year 2004 corresponding to the midpoint of the time when dental caries data was collected (2000–2008). It could be argued that sugar consumption before 2000 might be the most useful measurement point given the typical developmental progress of caries; however, we assumed that the relative sugar intake is fairly constant over the years and adopted the midpoint as a reasonable estimate of the typical intake of sugar. The per capita added sugar consumption is calculated by subtracting the sum of added sugar imported and produced from the total added sugar exported or used for industry. The quantity that remains has therefore 'disappeared' and is assumed to have been consumed. Food balance sheet data, therefore, do not account for food either not consumed or wasted.

National Income

The economic development level is measured by the GNI per capita based on PPP obtained from the World Bank data and statistics tables [World Bank, 2010]. The GNI-PPP is the GNI converted to international dollars using PPP rates. Countries were classified into high and low income countries based on the GNI-PPP. Countries with per capita incomes lower than USD 6,000 were considered low income countries, and countries with per capita incomes greater than USD 6,000 were considered high income countries [Sembajwe et al., 2010]. While more recent GNI-PPP data is available, we opted to use data from 2004 as they represent a midpoint for the dental caries level data used in this analysis (2000–2008). Statistical analysis in this paper was conducted after categorizing countries as low and high income countries separately.

Income Inequality

The Gini coefficient was used as an indicator of household income inequality within a country. Information on the Gini coefficient was imported from the World Bank data and statistics databases for year 2004 [World Bank, 2010]. Countries with a Gini coefficient of 36 or more were considered to have high income inequality and those with a Gini coefficient below 36 were considered to have low income inequality [Sembajwe et al., 2010].

Data Analysis

Countries with dental caries level data from surveys older than the year 2000 were excluded, which reduced the number of eligible countries to 85. Among these 85 countries, data on per capita sugar consumption was not available for 3 countries and GNI-PPP was not available for 1 country (St. Lucas), leaving 81 countries that had comparable data on dental caries levels and per capita sugar consumption with data on GNI-PPP. Of these 81 countries, the Gini coefficient was not available for 8 countries and as a result the number of countries was 73 for analysis in income inequality categories. SPSS version 17 was used to perform all statistical analysis. Bivariate linear regression analysis was performed to estimate the associations between dental caries levels

(mean DMFT) and per capita sugar consumption in different income and income inequality groups. A subsequent multiple regression analysis was carried out to determine the association between the dental caries level and per capita sugar consumption, national income, and income inequality. GNI-PPP and the Gini coefficient were log-transformed to enable a better fit to the outcome measures. Analysis was performed by dividing all of the countries into groups firstly on the basis of national income (GNI-PPP), secondly on the basis of income inequality (Gini coefficient), and finally on the basis of quartiles of the combination of national income and income inequality.

Results

The worldwide DMFT ranged from 0.3 in Tanzania to 5.9 in Saudi Arabia, with an overall mean of 1.82 (SD $\pm$ 1.14). Among the low income countries group, Tanzania had the lowest DMFT (0.3), and Guatemala had the highest (5.2), with a mean of 2.0 (SD $\pm$ 1.20). However, high income countries had a slightly lower mean of 1.6 (SD $\pm$ 1.06). An insignificant difference in the mean DMFT was found between high (1.89, SD $\pm$ 1.21) and low (1.82, SD $\pm$ 1.91) income inequality countries. The per capita added sugar consumption varied more than fifteen-fold, with the lowest consumption in Ethiopia (4.10 kg/capita/year) and the highest in Singapore (73.4 kg/capita/year) with a mean of 34.33 kg/capita/year (SD = 15.56). High income countries had a higher mean sugar consumption (40.96 + SD = 12.63) than low income countries (28.18 + SD = 15.63). There was no significant difference in the mean sugar consumption level of high and low income inequality countries.

Bivariate and multivariate regression analysis showed a significant negative relationship between DMFT and sugar consumption in high income countries, whereas in low income countries this relationship was positive in the bivariate model but was reversed and nonsignificant when the model was adjusted for GNI-PPP and the Gini coefficient. GNI-PPP showed a highly significant association with DMFT in both bivariate and multivariate models in both high and low income countries (table 1; fig. 1). Approximately 25% of the variation in DMFT was explained by GNI-PPP in both low and high income countries, whereas, when countries were divided into high and low income inequality groups, sugar consumption and GNI-PPP were not associated with mean DMFT. Income inequality at the country level, indicated by the Gini coefficient, was not significantly associated with DMFT in low income inequality countries but was positive and significantly associated in the high income inequality countries group (table 1; fig. 2).

Fig. 1. Scatter plots showing the relationship between mean DMFT and per capita sugar consumption in high and low income countries. **a** Low income (GNI-PPP <USD 6,000) countries. **b** High income (GNI-PPP >USD 6,000) countries.

Fig. 2. Scatter plots showing the relationship between mean DMFT and per capita sugar consumption in high and low income inequality countries. **a** High income inequality (Gini coefficient >36.0) countries. **b** Low income inequality (Gini coefficient <36.0) countries.

Table 1. Comparison of bivariate and multivariable models of DMFT with per capita sugar consumption (kg), national income (GNI-PPP), and income inequality (Gini) as potential explanatory variables

Explanatory variables	Bivariate models			Multivariable model	
	estimate	SE	R ²	estimate	SE
<i>High income countries</i>					
Sugar	-1.17*	0.49	0.129	-1.09*	0.52
GNI-PPP	-1.36***	0.37	0.257	-1.80***	0.44
Gini	0.97	1.01	0.028	1.15	0.88
				adjusted R ² = 0.47	
<i>Low income countries</i>					
Sugar	0.60*	0.25	0.131	-0.17	0.42
GNI-PPP	0.70***	0.19	0.249	0.82*	0.34
Gini	0.50	0.96	0.007	0.18	0.87
				adjusted R ² = 0.25	
<i>High income inequality countries</i>					
Sugar	0.26	0.30	0.020	0.34	0.47
GNI-PPP	0.07	0.17	0.004	-0.07	0.27
Gini	3.21*	1.37	0.135	3.16*	1.40
				adjusted R ² = 0.15	
<i>Low income inequality countries</i>					
Sugar	-0.02	0.31	0.0001	0.096	0.56
GNI-PPP	-0.04	0.17	0.001	-0.06	0.32
Gini	1.52	1.83	0.02	1.50	1.91
				adjusted R ² = 0.02	
* p < 0.05; *** p < 0.001.					

* p < 0.05; *** p < 0.001.

Table 2. Comparison of bivariate and multivariable models of DMFT with per capita sugar consumption (kg), GNI-PPP, and income inequality (Gini) as potential explanatory variables, in countries grouped according to national income and income inequality

Explanatory variables	Bivariate models			Multivariable model	
	estimate	SE	R ²	estimate	SE
<i>Low income high income inequality countries</i>					
Sugar	0.89*	0.36	0.20	0.54	0.67
GNI-PPP	0.64*	0.26	0.19	0.28	0.50
Gini	2.01	1.9	0.04	0.58	1.94
				adjusted R ² = 0.21	
<i>Low income low income inequality countries</i>					
Sugar	0.38	0.41	0.08	-0.96	0.51
GNI-PPP	0.83**	0.29	0.45	1.51**	0.44
Gini	-0.56	5.45	0.001	-0.74	4.04
				adjusted R ² = 0.62	
<i>High income high income inequality countries</i>					
Sugar	-1.24	0.57	0.37	-0.68	0.50
GNI-PPP	-1.37*	0.54	0.44	-0.43	0.64
Gini	4.92*	0.02	0.58	3.10	2.05
				adjusted R ² = 0.70	
<i>High income low income inequality countries</i>					
Sugar	-2.80*	1.30	0.17	-2.02	1.03
GNI-PPP	-2.30***	0.54	0.45	-2.21***	0.56
Gini	1.75	2.03	0.033	-0.82	1.57
				adjusted R ² = 0.54	

* p < 0.05; ** p < 0.01; *** p < 0.001.

* p < 0.05; ** p < 0.01; *** p < 0.001.

Table 2 shows the regression analysis when the countries were divided into four groups according to national income and income inequality. Countries with a high income level and low income inequality have a strong negative association between sugar consumption and caries, whereas countries with a low income and high income inequality have a positive relationship between DMFT and per capita sugar consumption in both bivariate and multivariate models (table 2; fig. 3). GNI-PPP was significantly associated with the mean DMFT in all the bivariate models in all four groups of countries, whereas the Gini coefficient was significantly associated with the mean DMFT only in the low national income and low income inequality countries group. The multivariate model in the high income and high income inequality countries group showed the 70% of the variation in mean DMFT was explained by sugar consumption, GNI-PPP, and the Gini coefficient.

Discussion

This study sought to explore the effect of national income and income inequality on the relationship between per capita sugar consumption and dental caries. Early research [Burt and Pai, 2001] suggested a simple positive linear relationship between sugar consumption and caries such that the greater the per capita consumption of sugar is, the higher the average DMFT for a nation is. The findings described here suggest that the nature of the relationship between per capita sugar consumption and DMFT is dependent upon the income level and income inequality of the nation. For high income countries, regardless of the level of income inequality, per capita sugar consumption is negatively related to caries prevalence – high levels of sugar consumption are related to lower levels of caries. In contrast, for low income countries, caries rates increased as the per capita sugar con-

Fig. 3. Scatter plots showing the relationship between mean DMFT and per capita sugar consumption in quartiles of the combination of national income and income inequality. **a** Low national income (GNI-PPP < USD 6,000) and low income inequality (Gini coefficient < 36.0) countries. **b** High national income (GNI-

PPP > USD 6,000) and low income inequality (Gini coefficient < 36.0) countries. **c** Low national income (GNI-PPP < USD 6,000) and high income inequality (Gini coefficient > 36.0) countries. **d** High national income (GNI-PPP > USD 6,000) and high income inequality (Gini coefficient > 36.0) countries.

sumption went up. This study found that the magnitude of the association between mean DMFT and sugar consumption is much weaker than previous data have suggested [Woodward and Walker, 1994]. Moreover, national income and income inequality further weakens the relationship; table 2 shows that the exponential regression coefficient gets smaller in multilevel models involving income level and income inequality.

These findings suggest that models of social inequalities that lay emphasis on social comparison as a mechanism for determining social inequalities do not apply in the case of caries [Lynch et al., 2004; Kondo et al., 2008]. Rather, it would seem to be the case that a third factor, such as access to resources for health, may mediate high sugar consumption and low caries rates, supporting materialist models [Sisson, 2007]. For example, wealthy societies may not only have diets high in sugar, but also have access to fluoride and oral healthcare [Kim et al., 2008]. Interestingly, outliers such as Saudi Arabia, with unexpectedly high mean DMFT given their average sugar consumption, may be due to the lack of water fluoridation in that area owing to the difficulties encountered as a result of the lack of a central water supply. Conversely, Singapore and Switzerland are the two countries with the highest per capita sugar consumptions but have relatively low caries levels. Nearly 100% of the population is covered by water fluoridation in Singapore and by salt fluoridation in Switzerland. This might be a possible reason for this high tolerance to sugar in both countries [Petersen, 2012]. The negative relation of caries and sugar in high income countries may be attributed to the presence of fluoride in various forms (either water or toothpaste).

This ecological study has some shortcomings, which means that the findings should be interpreted with caution. In an ecological study such as this there are inevitable difficulties in ensuring the reliability and validity of the measures, especially given the range of different groups involved in data collection [Sabbah et al., 2010]. This would apply particularly to the data on caries prevalence. Furthermore the data were often collected at different time points which may have introduced some degree of variation in the measurement. Although data reported on CAPP are considered as country estimates, most of these surveys were taken from specific localities within countries and, in some cases, several regional study results have been pooled to provide a total country estimate. The international standards given by the World Health Organization were used to perform these epidemiologic surveys including methods of data collection, calibration, and reliability. Another limitation of this

study was the use of country estimates of disappeared sugar [Maltz et al., 2010]. It is widely recognized that it is difficult to obtain accurate consumption data and there is no consensus on the most valid methods of measuring dietary intake [Burt and Pai, 2001]. While the amount of sugar consumption is certainly related to the prevalence of dental caries, the manner and pattern of use are also important factors [Zero, 2004]. In developed countries much sugar is used in manufactured foods or other goods, whereas in emerging economies sugar cane or raw sugar is frequently used as a foodstuff.

This study provides evidence that caries is a multifaceted disease associated with economic development. The most dramatic difference in the association of DMFT and sugar consumption was found between the high and low income countries, suggesting that sugar has less of an effect in developed nations where there is access to fluoride and established preventive oral health schemes addressing lifestyle and environmental factors [Edelstein, 2006]. On the other hand, low income countries showed a positive association between DMFT and sugar consumption, which may be due to a lack of access to fluoride and little or no implementation of preventive oral health schemes.

Conclusion

The relationship between per capita consumption of sugar and dental caries is modified by the absolute level of income of the country, but not by the level of income inequality within a country.

Disclosure Statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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