L.G. Do^{1*}, A.J. Spencer¹, G.D. Slade^{1,2},
D.H. Ha¹, K.F. Roberts-Thomson¹,
and P. Liu¹

¹Australian Research Centre for Population Oral Health, School of Dentistry, The University of Adelaide, 122 Frome Street, Australia 5000; and ²Department of Dental Ecology, UNC School of Dentistry, CB #7450, Chapel Hill, NC 27599-7450, USA; *corresponding author, loc.do@adelaide.edu.au

J Dent Res 89(9):959-964, 2010

ABSTRACT

It is important that we monitor socio-economic inequality in health. Inequality in child oral health has been expected to widen because of widening socio-economic inequality. This study aimed to evaluate trends in income-related inequality in caries experience of Australian children. Cross-sectional studies in 1992/93 and 2002/03 collected data on deciduous caries experience of 5- to 10-year-olds and permanent caries experience of 6- to 12-year-olds. Household composition and income was used to calculate quartiles of equivalized income. Slope Index of Inequality (SII), Concentration Index (CI), and regression-based rate ratios were used to quantify income-related inequality and to evaluate trends. Income-related inequality in caries experience was evident regardless of time and dentition. The three indicators of inequality indicate a significant increase in income-related inequality in child deciduous caries experience during the decade. The income inequality in permanent caries experience did not change significantly. Income inequalities increased in deciduous teeth, but not in permanent teeth, among Australian children.

KEY WORDS: inequality, caries, children, Australia, trend.

Trend of Income-related Inequality of Child Oral Health in Australia

INTRODUCTION

The oral health of children in developed countries has improved significantly recently due largely to population preventive approaches such as water fluoridation and the use of fluoridated toothpaste as well as better access to dental care (Spencer *et al.*, 1996; DHHS, 2000). The overall caries experience among the child population of Western countries is generally low. However, some groups of children in any population still carry a much larger burden of the disease compared with other groups (Spencer, 1997).

Socio-economic inequalities in oral health have been reported to be widespread in the developed world (Watt and Sheiham, 1999; DHHS, 2000; Locker, 2000). In each population, groups at the lower end of the socio-economic scale had a higher burden of the disease compared with those who were socio-economically well-off. In Australia, Slade *et al.* (1996) reported that children from low-household-income groups had a significantly higher mean number of decayed, missing, and filled deciduous (dmfs) and permanent (DMFS) tooth surfaces than children from high-income groups after adjustment for exposure to fluoride in water. That inequality remained despite children in the study having access to universal and fully subsidized dental care through the School Dental Service (SDS), which ensured that access to dental care was not affected by family socio-economic status.

Monitoring the trend of SES inequality in health over time is important in our understanding of the effects of socio-economic changes on health and in the evaluation of health policy to prevent the disease or reduce the inequality. There have been reports of widening socio-economic inequality in Australia that may have a direct impact on the SES gradient in health, including the oral health of children (Hetzl *et al.*, 2004). A widening trend of SES inequality in other aspects of health in this past decade has been reported in Australia (Najman *et al.*, 2006; Korda *et al.*, 2007) and other countries (Mishra *et al.*, 2004; Fawcett *et al.*, 2005; Blakely *et al.*, 2008).

The inequality in oral health distribution among Brazilian 12-year-old children, measured by the Gini index, was reported to increase (Antunes *et al.*, 2005). However, the Gini index, “an index of inequality in strict sense” (Wagstaff, 2002), is not a true measure of the socio-economic gradient in oral health. Rather, it reflects the overall inequality in the population’s total caries experience.

Common measures of socio-economic inequality in health are indices that have satisfied the three basic requirements (van Doorslaer *et al.*, 1997): (i) that it reflects the socio-economic dimension to inequalities in health; (ii) that it reflects the experience of the entire population; and (iii) that it is sensitive to changes in the distribution of the population across socio-economic groups. Two indices that satisfy those criteria are the Slope Index of Inequality (SII) of absolute inequality (Pamuk, 1985; Kunst and Mackenbach, 1994a,b) and the Concentration Index (CI), measuring relative inequality in health (Wagstaff

DOI: 10.1177/0022034510371280

Received January 28, 2009; Last revision March 14, 2010;
Accepted March 25, 2010

© International & American Associations for Dental Research

et al., 1991). There is a review of those indices for use in dental research (Cheng *et al.*, 2008), which has set out an agenda for research in the measurement of socio-economic inequality in oral health. However, there has been no attempt to quantify and evaluate trends of inequality in child oral health using these standard indices, since it requires comparable data to be collected at different time periods.

This study aimed to quantify and evaluate the trends in socio-economic inequality, defined as income-related inequality, in oral health of Australian children during the decade 1992/93 to 2002/03.

METHODS

To analyze temporal trends of SES inequality in Australian children, we used data collected in two similarly conducted cross-sectional studies in South Australia and Queensland: the Child Fluoride Study (CFS) Mark 1 (1992/93) (Slade *et al.*, 1995) and Mark 2 (2002/03), which were developed and supervised by the same researchers (Spencer and Slade) at the University of Adelaide.

The CFS series were population-based studies with multi-stage, stratified, random sample selection. Data on the oral health of children who attended the SDS for routine dental care were collected and archived as clinical records. Parental questionnaires collected household income and household size to enable SES to be classified. Details of the study design and data collection process have been described elsewhere (Slade *et al.*, 1995; Do and Spencer, 2007). These two CFS studies are referred to henceforth as the 1992/93 and 2002/03 studies.

Ethical approval was received from the University of Adelaide's Human Research Ethics Committee. Parental signed informed consent was requested for clinical data extraction. Analysis was conducted with SAS 9.1.

Data Variables

Dependent Variable

The outcome measure for the analysis was dental caries experience collected routinely at dental visits by the children to the SDS clinics. Examinations were conducted by clinical staff who received uniform training materials and guidelines in observing and recording caries. Training in examination for caries and in recording caries experience was provided to the SDS staff prior to each round of the CFS series. Dental caries was defined at cavitated level as decayed, filled, or missing tooth surfaces. For this analysis, deciduous caries experience (dmfs) was used for 5- to 10-year-old children, while permanent caries experience (DMFS) was for 6- to 12-year-old children.

The dmfs/DMFS scores were adjusted for age and sex of the children in the analysis. Data were reweighted to correct for different sampling ratios to facilitate direct comparison of the estimates between the two times.

Explanatory Variables

The main explanatory variable was household income collected from parental questionnaires. A list of income ranges used in Census by the Australian Bureau of Statistics (ABS) was used to collect total household income before tax. Ten and eight income ranges were used in the 1992/93 and 2002/03 studies, respectively.

The numbers of adults and children in the household dependent on that income were also collected. Estimates of equivalized income were calculated according to the ABS formula:

$$\text{Equivalized income} = \frac{\text{Mid-point of income range}}{1 + 0.5 \times (\text{No. of adults} - 1) + 0.3 \times (\text{No. of children})}$$

We used the equivalized income estimates to group the sample into time-specific quartiles using the most approximate values.

Measures of Socio-economic Inequality

We measured socio-economic inequality in child oral health using the standard indices of socio-economic inequality in health: the Slope Index of Inequality (SII), representing the absolute effect (Pamuk, 1985; Kunst and Mackenbach, 1994a,b), and the Concentration Index (CI), representing the relative effect (Wagstaff *et al.*, 1991). We also calculated regression-based rate ratios between the lower income quartiles relative to the highest income quartile. This is defined as a sophisticated regression-based index of effect, which measures the relative difference between the lower levels of socio-economic hierarchy with the highest SES group (Mackenbach and Kunst, 1997).

The SII can be used to reflect the socio-economic dimension to inequalities in health. The approach involves calculating the mean health status or ill-health status of each socio-economic group and then ranking classes by their socio-economic status (not by their health) (Pamuk, 1985; Kunst and Mackenbach, 1994a,b). The SII represents the absolute effect on health of moving from the lowest socio-economic level through to the highest. The SII can be calculated by Weighted Least Squares to avoid heteroscedasticity of the error term (Wagstaff *et al.*, 1991).

The CI (Wagstaff *et al.*, 1991) is based on the "concentration curve", where the x axis represents the cumulative proportion of individuals by socio-economic level, beginning with the lowest and ending with those whose level is highest, while the y axis represents the cumulative total proportion of ill-health in these individuals. Its values range from -1 to +1, with negative values indicating a favor toward the well-off and positive values indicating a favor toward the worse-off.

The SII and the CI values take into account both the population size and the relative socio-economic positions of groups (Mackenbach and Kunst, 1997). The CI has the disadvantage of lacking a straightforward interpretation. However, Koolman and van Doorslaer (2004) showed that by multiplying the absolute value of CI by 75, it can easily be translated into the percentage redistribution required from the advantaged group to the disadvantaged group to make estimated inequality equal to zero, *i.e.*, the linear redistribution of the health variable from the advantaged half to the disadvantaged half of the population to remove health differences (CI = 0).

RESULTS

Study Sample Characteristics

There was similar distribution of the study sample by sex in each age group in either year (Table 1). The distribution of the children by quartiles of equivalized income was similar in either

Table 1. Study Sample Characteristics

	5 to 10 yrs old		6 to 12 yrs old	
	1992/93	2002/03	1992/93	2002/03
Sex, n (%)				
Male	7252 (51.2)	3589 (51.1)	8237 (50.9)	4086 (51.4)
Female	6869 (48.8)	3279 (48.9)	7877 (49.1)	3789 (48.6)
Quartiles of equivalized income, n (%)				
1 (lowest)	3275 (23.8)	1480 (24.3)	3737 (24.4)	1719 (23.9)
2	3286 (24.1)	1630 (25.2)	3606 (25.1)	1861 (23.4)
3	3073 (23.5)	1454 (22.7)	3481 (22.7)	1638 (23.2)
4 (highest)	3624 (28.7)	1841 (27.8)	4242 (27.9)	2111 (29.5)

There were missing values of reported household income.

Income was collected based on a range of values. Therefore, the cut-off values for quartiles might not fall exactly at 25%.

study. There was relatively smaller variation around the quartile marks in the 1992/93 study than that in the recent study.

Income-related Inequality in Oral Health

The caries experience of these children is presented by quartiles of equivalized income (Figs. 1a, 1b). Overall, there was classic evidence of an income-related gradient in child oral health. There was a trend of lower caries experience associated with higher household income regardless of dentition or time of study. For every level of income, the next higher income quartile had a lower recorded caries experience. The largest inter-quartile difference was observed between the two lowest income quartiles.

The income-related inequalities in child oral health were confirmed statistically by the standard indicators of socio-economic inequality (Table 2). The lower income groups had consistently higher rates of having higher caries experience, regardless of dentition types in either study (Figs. 1a, 1b; Table 2). The difference between the lowest and adjacent quartiles was considerably larger than that between other quartiles.

Income-related Inequality in Oral Health – Trend over Time

When the two studies were compared, the gradient in deciduous caries experience showed a more obvious change (Fig. 1a). Compared with the 1992/93 study (continuous line), caries experience of the lowest quartile in 2002/03 did not change, while that of the other three quartiles was significantly lower. The widening gap was evident by both relative and absolute indicators. The reduction of caries experience of respective quartiles of equivalized income was larger in the higher income quartiles, whereas there was an increase in caries experience among the lowest income group. Hence, the gradient of income-related inequality in deciduous caries in this population was steeper in the later study. The absolute difference in deciduous caries experience between the lowest and the highest income groups, as measured by the SII, has become larger in the recent study as compared with the earlier study [from 2.69 (2.55-2.83) to 3.31 (3.04-3.58)] (Table 2).

Figure 1. Dental caries experience by income and time. (a) Age- and sex-adjusted mean dmfs scores by quartiles of equivalized household income in the 1992/93 and 2002/03 studies. (b) Age- and sex-adjusted mean DMFS scores by quartiles of equivalized household income in the 1992/93 and 2002/03 studies. For both (a) and (b), quartiles of equivalized income: 1, lowest; 4, highest.

Table 2. Indicators of Income-related Inequality in Child Oral Health in 1992/93 and 2002/03 in Australia

	1992/93	2002/03
Deciduous dmfs (5 to 10 yrs old)		
Quartiles of equivalized income, rate ratios (95% CI)		
1 (Lowest)	1.73 (1.62, 1.86)	2.25 (2.03, 2.49)
2	1.42 (1.32, 1.53)	1.46 (1.30, 1.62)
3	1.19 (1.11, 1.28)	1.21 (1.08, 1.36)
4 (Highest)	1	1
Slope Index of Inequality, SII (95% CI)	2.69 (2.55, 2.83)	3.31 (3.04, 3.58)
Permanent DMFS (6 to 12 yrs old)		
Quartiles of equivalized income, rate ratios (95% CI)		
1 (Lowest)	1.64 (1.52, 1.77)	1.38 (1.23, 1.55)
2	1.24 (1.14, 1.34)	1.24 (1.10, 1.39)
3	1.22 (1.12, 1.32)	0.99 (0.87, 1.12)
4 (Highest)	1	1
Slope Index of Inequality, SII (95% CI)	0.38 (0.34, 0.42)	0.33 (0.28, 0.38)

Data weighted to represent population distribution at each time-point. dmfs/DMFS scores adjusted for age and sex. 95% CI: confidence intervals. Rate ratios calculated by Poisson regression. Relative Index of Inequality: relative difference as rate ratios between the lowest and the highest income groups. Larger values indicate larger inequality. Slope Index of Inequality: absolute rate differences between the lowest and the highest income groups.

In 2002/03, mean dmfs was more than two-fold greater in the lowest quartile relative to the highest quartile [dmfs ratio = 2.4 (95%CI: 2.1-2.6)], which was a significantly larger relative difference than in 1992/93 [dmfs ratio = 1.8 (95%CI: 1.6-1.9)]. Inequality in DMFS did not differ significantly between 2002/03 [DMFS ratio = 1.5 (95%CI: 1.3-1.6)] and 1992/93 [DMFS ratio = 1.6 (95%CI: 1.5-1.8)].

The deviation from equal distribution of the disease was obviously larger in the 2002/03 measure of deciduous caries according to the CI (Figs. 2a, 2b). Compared with Fig. 1a, the Concentration curve in Fig. 2b appeared farther away from the diagonal at the lower end of the SES scale, indicating increased accumulation of the disease at this end. The estimated percent redistribution required from the highest to the lowest income groups to make estimated income-related inequality in deciduous caries experience equal zero increased from 9.5% to 13.7% after a decade. The CI values for the permanent dentition did not indicate change over time in socio-economic inequality (Figs. 2c, 2d).

DISCUSSION

The measurement of socio-economic inequality in health, including oral health, is important in informing social and health-related policy. It is believed that this article is one of the first few to quantify and provide time-comparative analysis of income-related inequality in child oral health using well-conceptualized measures of socio-economic inequality in health. The use of measures of absolute (SII) and relative inequality (CI and regression-based rate ratios) between the income groups suited the study's objective.

Our findings add to the evidence of an association between socio-economic status, measured as income, and child oral health (Locker, 2000; Petersen, 2005; Slade *et al.*, 2006). This association persisted in either time or type of dentition analysis. The socio-economic gradient in child oral health has been clearly demonstrated. The mechanism behind socio-economic inequality in health is often complex. There is a further scope for evaluating the role of contextual and compositional factors in explaining the inequality in child oral health with our data.

Our findings indicated that socio-economic inequality in deciduous caries experience of the child population has widened in the decade studied (1992/93–2002/03). It should be noted that this trend was measured relatively between hierarchical levels of socio-economic status, defined by income. The improvement in child oral health during the period was SES-differential. There was a faster reduction in deciduous caries experience observed in the highest income group. That difference resulted in the widened gap in oral health status between the income groups.

The socio-economic inequality in permanent caries experience remained unchanged over time. Possible explanations for this difference in the trends between the dentitions include a higher level of deciduous caries experience where change was more likely to be detected. Also, deciduous caries experience may be more sensitive to changes in the socio-economic conditions or to changes in behaviors toward oral health preventive programs in the last decade, especially an observed reduction in the consumption of fluoridated public water and an increase in the consumption of carbonated drinks (AIHW, 2007).

The observed widened income-related inequality in deciduous caries experience has added to the recent evidence of divergent trends of health by SES (Mishra *et al.*, 2004; Page *et al.*, 2006; Korda *et al.*, 2007; Blakely *et al.*, 2008). There are several possible reasons for the observed widened inequality in oral health. Water fluoridation was found to decrease SES inequality in oral health (Slade *et al.*, 1995). However, there has been no increase in the proportion of the population exposed to this measure during the decade. Other oral health preventive measures require active participation of the population. Actual “wealth” might have increased at a faster rate at the higher end of the SES scale. High SES families might have better access to and greater adoption of oral health preventive information.

The study findings should be considered in the context of its potential limitations. Caries data were collected by a large number of uncalibrated clinicians. However, the clinicians used uniform manuals developed by oral epidemiologists in collaboration with the School Dental Services. Before the studies began, the clinicians were trained in the use of criteria and methods required for observing surface-level caries experience. Also, analyses were based on threshold of caries lesions, which can be reliably diagnosed in routine clinical conditions supplemented by diagnostic equipment such as x-ray according to standard clinical requirements.

Overall, our analysis demonstrates that an income-related inequality in oral health existed in the Australian child population. That inequality appeared to widen in the last decade. It is suggested that monitoring socio-economic inequality in health, including oral health, is important in informing appropriate policy. Population

oral health policies aiming to improve the overall oral health of the population need to target socio-economic inequality. Furthermore, those policies may need to be tailored to suit different socio-economic groups.

ACKNOWLEDGMENTS

This work was supported by NHMRC grants and by the South Australian and Queensland Dental Service.

REFERENCES

- AIHW (2007). Profile of nutritional status of children and adolescents. Cat. No. PHE 89. Canberra: Australian Institute of Health and Welfare.
- Antunes JL, Jahn GM, de Camargo MA (2005). Increasing inequalities in the distribution of dental caries in the Brazilian context in Finland. *Community Dent Health* 22:94-100.
- Blakely T, Tobias M, Atkinson J (2008). Inequalities in mortality during and after restructuring of the New Zealand economy: repeated cohort studies. *BMJ* 336:371-375.
- Cheng NF, Han PZ, Gansky SA (2008). Methods and software for estimating health disparities: the case of children's oral health. *Am J Epidemiol* 168:906-914.
- DHHS (2000). Oral health in America: a report of the Surgeon General. Rockville, MD: US Department of Health and Human Services.
- Do LG, Spencer AJ (2007). Decline in the prevalence of dental fluorosis among South Australian children. *Community Dent Oral Epidemiol* 35:282-291.
- Fawcett J, Blakely T, Kunst A (2005). Are mortality differences and trends by education any better or worse in New Zealand? A comparison study with Norway, Denmark and Finland, 1980-1990s. *Eur J Epidemiol* 20:683-691.
- Hetzel D, Page A, Glover J, Tennant S (2004). Inequality in South Australia. Key determinants of wellbeing. Volume 1: The evidence. Adelaide: AIHW PHIDU.
- Koolman X, van Doorslaer E (2004). On the interpretation of a concentration index of inequality. *Health Econ* 13:649-656.
- Korda RJ, Butler JR, Clements MS, Kunitz SJ (2007). Differential impacts of health care in Australia: trend analysis of socioeconomic inequalities in avoidable mortality. *Int J Epidemiol* 36:157-165.
- Kunst AE, Mackenbach JP (1994a). International variation in the size of mortality differences associated with occupational status. *Int J Epidemiol* 23:742-750.
- Kunst AE, Mackenbach JP (1994b). The size of mortality differences associated with educational level in nine industrialized countries. *Am J Public Health* 84:932-937.
- Locker D (2000). Deprivation and oral health: a review. *Community Dent Oral Epidemiol* 28:161-169.
- Mackenbach JP, Kunst AE (1997). Measuring the magnitude of socioeconomic inequalities in health: an overview of available measures illustrated with two examples from Europe. *Soc Sci Med* 44:757-771.
- Mishra GD, Ball K, Dobson AJ, Byles JE (2004). Do socioeconomic gradients in women's health widen over time and with age? *Soc Sci Med* 58:1585-1595.
- Najman JM, Toloo G, Siskind V (2006). Socioeconomic disadvantage and changes in health risk behaviours in Australia: 1989-90 to 2001. *Bull World Health Org* 84:976-984.
- Page A, Morrell S, Taylor R, Carter G, Dudley M (2006). Divergent trends in suicide by socio-economic status in Australia. *Soc Psychiatry Psychiatr Epidemiol* 41:911-917.
- Pamuk ER (1985). Social class inequality in mortality from 1921 to 1972 in England and Wales. *Popul Stud (Camb)* 39:17-31.
- Petersen PE (2005). Sociobehavioural risk factors in dental caries—international perspectives. *Community Dent Oral Epidemiol* 33:274-279.
- Slade GD, Davies MJ, Spencer AJ, Stewart JF (1995). Associations between exposure to fluoridated drinking water and dental caries experience among children in two Australian states. *J Public Health Dent* 55:218-228.

Figure 2. Concentration curves by time and dentition. (a) Concentration curve for deciduous caries experience in 1992/93. (b) Concentration curve for deciduous caries experience in 2002/03. (c) Concentration curve for permanent caries experience in 1992/93. (d) Concentration curve for permanent caries experience in 2002/03.

^aNegative Concentration Index (CI) reflects higher caries level among lower income children.

^bPercentage redistribution required from the highest to the lowest group to make estimated income-related inequality equal to zero (Koolman and van Doorslaer, 2004).

- Slade GD, Spencer AJ, Davies MJ, Stewart JF (1996). Influence of exposure to fluoridated water on socioeconomic inequalities in children's caries experience. *Community Dent Oral Epidemiol* 24:89-100.
- Slade GD, Sanders AE, Bill CJ, Do LG (2006). Risk factors for dental caries in the five-year-old South Australian population. *Aust Dent J* 51:130-139.
- Spencer AJ (1997). Skewed distributions—new outcome measures. *Community Dent Oral Epidemiol* 25:52-59.
- Spencer AJ, Slade GD, Davies M (1996). Water fluoridation in Australia. *Community Dent Health* 13(Suppl 2):27-37.
- van Doorslaer E, Wagstaff A, Bleichrodt H, Calonge S, Gerdtham UG, Gerfin M, *et al.* (1997). Income-related inequalities in health: some international comparisons. *J Health Econ* 16:93-112.
- Wagstaff A (2002). Inequality aversion, health inequalities and health achievement. *J Health Econ* 21:627-641.
- Wagstaff A, Paci P, van Doorslaer E (1991). On the measurement of inequalities in health. *Soc Sci Med* 33:545-557.
- Watt R, Sheiham A (1999). Inequalities in oral health: a review of the evidence and recommendations for action. *Br Dent J* 187:6-12.