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## Nutrition Society Medal Lecture

# The interrelationship between diet and oral health

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Diet and nutrition impact on many oral diseases, in particular dental caries. Consumption of fluoridated water coupled with a reduction in non-milk extrinsic sugar intake is an effective means of caries prevention. However, studies on the fluoride concentration of bottled waters suggest increased consumption of these waters, in preference to fluoridated tap water, would lead to a marked decrease in caries protection. Concerns have been raised about the bioavailability of fluoride from artificially-fluoridated water compared with naturally-fluoridated water. This issue has been addressed in a human experimental study that has indicated that any differences in fluoride bioavailability are small compared with the naturally-occurring variability in fluoride absorption. Research has unequivocally shown sugars to be the main aetiological factor for dental caries, and information on intakes guides health promotion. Repeat dietary surveys of English children over three decades indicate that levels of sugars intake have remained stable, while sources of sugars have changed considerably, with the contribution from soft drinks more than doubling since 1980. Dental caries eventually leads to tooth loss, which in turn impairs chewing ability causing avoidance of hard and fibrous foods including fruits, vegetables and whole grains. A very low intake (<12 g/d) of NSP and fruit and vegetables has been found in edentulous subjects. Provision of prostheses alone fails to improve diet. However, initial studies indicate that customised dietary advice at the time of denture provision results in increased consumption of fruits and vegetables, and positive movement through the stages of change. Feasible means of integrating dietary counselling into the dental setting warrants further investigation.

**Diet: Dental caries: Fluoridated water: Dietary sugars: Tooth loss**

Oral health has often been viewed in isolation from the rest of the body and from general health. In the past dental health professionals have focused largely on local reparative treatment of oral disease. However, modern-day dentistry places increased emphasis on disease prevention and recognises the importance of the interrelationship between health of the teeth and oral tissues and the general health of the body. It is well established that a good diet is essential for the development and maintenance of healthy teeth, but healthy teeth are important in enabling the consumption of a varied and healthy diet throughout the life cycle.

Despite being associated with a low mortality rate, dental diseases are very expensive to treat. The direct cost of treating dental disease in the UK is approximately £$2 \times 10^9$/year, an amount that exceeds the cost of treating many other chronic diet-related diseases, including CVD, cancer and osteoporosis (Sheiham, 2001). In addition to being costly to treat, dental diseases cause unnecessary pain and anxiety, and eventually may lead to loss of teeth. Tooth loss, in turn, impairs chewing function and may result in the consumption of a limited diet of poor nutritional quality and may impact on diet-related quality of life.

Nutrition and diet impact on oral health in many ways. Diet is a major aetiological factor for dental caries and enamel erosion, and nutritional status impacts on the development of the teeth and the host's resistance to many oral conditions, including periodontal diseases and oral cancer. To cover the entire topic of the interrelationship between diet and oral health is beyond the scope of the present paper, which focuses on three main areas: water

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fluoridation; intake and sources of dietary sugars; the dietary impact of tooth loss. Recent reviews on other aspects of diet and oral health are provided by Sheiham (2001) and Moynihan & Petersen (2004).

## Dental caries

Ancient civilisations in China and Greece believed that dental caries was caused by worms that drank the blood of the teeth and fed on the roots of the jaw! Many theories of causation of dental caries have emerged over the years. However, today the aetiology of dental caries is well established and is caused by the localised demineralisation of dental hard tissues (enamel and dentine) by organic acids produced by plaque bacteria through the anaerobic metabolism of dietary sugars.

Dental caries was rare before sugars were introduced into the diet in the middle of the 19th century. The disease was epidemic in the 20th century up until the 1970s, but levels steadily declined in the last three decades of the century as a result of increased exposure to fluoride. Despite the favourable trend in caries decline in industrialised countries, levels of decay remain unacceptably high in many countries and there is evidence to indicate that improvements have now stabilised. In young children in the UK levels of dental caries are increasing (Pitts *et al*. 2004*b*). A recent survey of 5-year-old children conducted by the British Association for the Study of Community Dentistry has shown that 40 % of 5-year-olds in England and Wales have dental caries, with an average of 1·52 teeth per child affected. Fig. 1 shows British Association for the Study of Community Dentistry survey data (Pitts *et al*. 2004*a*) for the mean number of decayed, missing and filled permanent teeth in 14-year-old children in England and Wales from 1990 through to 2002, and indicates how the trend for a decline in caries has now stabilised, with an average of 1·5 decayed, missing and filled permanent teeth per child. Despite a relatively low average number of decayed, missing and filled permanent teeth, 50 % of 14-year-olds in England and Wales (Pitts *et al.* 2004*a*) and 50 % of 12-year-olds in the Republic of Ireland are affected by decay (Whelton *et al*. 2003). Dental caries is a progressive disease and levels in European adults are very high. Even in fluoridated areas of the Republic of Ireland the average number of decayed, missing and filled permanent teeth for the 35–44-year-old age-group is 18·9 and in the UK it is 19·0 (the WHO considers a level of ≥14·0 to be very high; Marthaler, 1996; World Health Organization, 1996). In industrialised countries there is a trend towards increased retention of the dentition into older age. However, as the gums recede in the process of ageing, the dentine of the roots becomes exposed and is vulnerable to root caries. Thus, dental caries persists throughout the life cycle and preventive strategies remain of paramount importance.

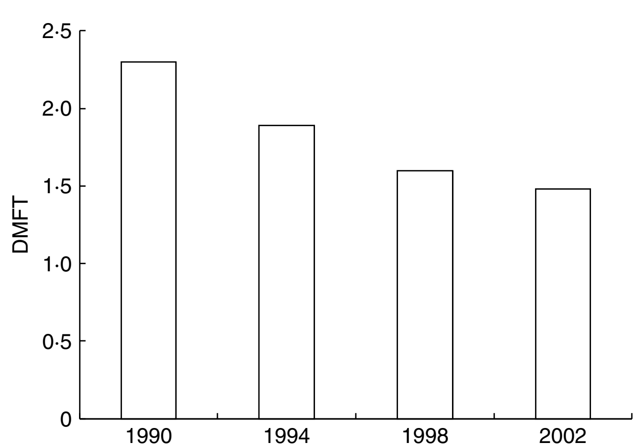


**Fig. 1.** Changes in the number of decayed, missing and filled permanent teeth (DMFT) of 14-year-old children in England and Wales since 1990; results of a survey conducted by the British Association for the Study of Community Dentistry. (Data from Pitts *et al.* 2004*a*.)

## Dietary fluoride and water fluoridation

Increased exposure to fluoride is largely responsible for the reduction in dental caries that has occurred over the past three decades. Dietary fluoride principally comes from drinking water, but seafood and tea leaves are also rich sources.

Ingested fluoride becomes incorporated into enamel during tooth formation, increasing the resistance of the tooth to decay. This pre-eruptive mode of action affects the primary dentition *in utero* and the permanent dentition up to the age of 6 years. However, the main protection from dietary fluoride is the lifelong localised intra-oral effect. Fluoride promotes the remineralisation of damaged enamel with resistant fluoroappatite and also inhibits bacterial metabolism of sugars (Murray, 2003). The benefits to the teeth of exposure to fluoride are therefore lifelong.

Where natural water supplies are low in fluoride, it may be added to an optimum concentration of 1 mg/l as a caries-preventive measure. Murray *et al*. (1991) have reviewed the published data on the effect of water fluoridation on caries and have concluded that on average water fluoridation reduces dental caries by 50 %. Water fluoridation is a cost-effective public health measure because it reaches the entire population. In a study of 5-year-old children residing in north east England Carmichael *et al*. (1989) have demonstrated that water fluoridation is effective in reducing dental caries across social classes and, in terms of the number of teeth saved per child, the benefits are greatest in the lower social classes. This finding is important because UK national surveys have indicated that those from lower social classes have higher levels of dental diseases, poorer oral hygiene practice and are less likely to attend the dentist (O'Brien, 1994).

In the USA, as well as the Republic of Ireland, 67 % of the population receives drinking water with an optimum fluoride concentration for caries prevention. However, widespread water fluoridation has not been universally adopted, and at present only approximately 13 % of the UK receives water that provides the optimum fluoride content of approximately 1 mg/l. Evidence for the safety and efficacy of drinking fluoridated water is largely based on data from populations consuming naturally-fluoridated water, because of the limited number of years of exposure

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to artificial fluoridation. Whether this evidence can be extrapolated to populations receiving artificially-fluoridated water is unknown. This issue has been raised by a systematic review on the safety of water fluoridation conducted by the University of York Centre for Reviews and Disseminations (McDonagh *et al*. 2002), which has concluded that there is insufficient evidence to draw a conclusion regarding the differences in effects of naturally- and artificially-fluoridated waters. The UK Medical Research Council Working Group report on water fluoridation and health (Medical Research Council, 2002) has concluded 'new studies are needed to investigate the bioavailability and absorption of fluoride from naturally fluoridated and artificially fluoridated drinking water, also looking at the effect of water hardness. This is particularly important because if bioavailability is the same, many of the findings relating to natural fluoride can also be related to artificial fluoride'. Two important issues that need to be addressed are therefore source of fluoride and water hardness.

In view of the Medical Research Council (2002) recommendation, a double-blinded human experimental study of cross-over design has been conducted, with the aim of comparing the bioavailability of fluoride from artificially-fluoridated water with that of naturally-fluoridated water, and investigating any effect of water hardness on the bioavailability of fluoride (Maguire *et al*. 2005). Bioavailability of fluoride was assessed in twenty healthy adult volunteers aged 20–35 years by measuring the change in plasma fluoride concentration up to 8 h following ingestion of 500 ml naturally-fluoridated hard water, naturally-fluoridated soft water, artificially-fluoridated hard water or artificially-fluoridated soft water. The peak plasma concentration and the area under the curve for plasma concentration of fluoride *v*. time were measured.

Although fasting plasma fluoride concentrations show wide within- and between-subject variation, on average, consumption of the various fluoridated waters results in a 70 % increase in plasma fluoride concentration. Fig. 2 presents the mean values and 95 % CI for the maximum plasma fluoride concentration reached following consumption of the four fluoridated waters. Fig. 3 shows the mean and 95 % CI values for the area under the curve for plasma fluoride concentration *v*. time for ≤8 h following ingestion of the four fluoridated waters. There are no marked differences between the fluoridated waters for the maximum fluoride concentration reached or for the area under the curve for 0–8 h after ingestion (analysis of covariance). These data are the first to compare the bioavailability of naturally-fluoridated water with that of artificially-fluoridated water in a human experimental study. The findings indicate that any differences in the bioavailability of fluoride between drinking waters in which the fluoride is present naturally or added, or the waters are hard or soft, are likely to be small compared with the naturally-occurring within- and between-subject variation in fluoride absorption.

Traditionally, tap water has contributed ≤50 % of the water intake in the UK (Hopkin & Ellis, 1980; Rugg-Gunn *et al*. 1987). However, more recently there has been a trend towards increased consumption of bottled waters, largely as a result of increased consumption of food away from home and concerns over the taste and quality of water (British Nutrition Foundation, 2002). In the UK $800 \times 10^6$ litres bottled water were consumed in 1995, and this level rose to approximately $1400 \times 10^6$ litres in 2000 (Tate & Lyle Speciality Sweeteners, 2001), with a further 70 % increase predicted by 2005 (British Nutrition Foundation, 2002). There are currently no regulations concerning the fluoride content of bottled water in Europe, and concentrations of fluoride are seldom declared on bottle labels. Thus, an analysis of the fluoride content of bottled still waters available in the UK has been carried out and, using data on current

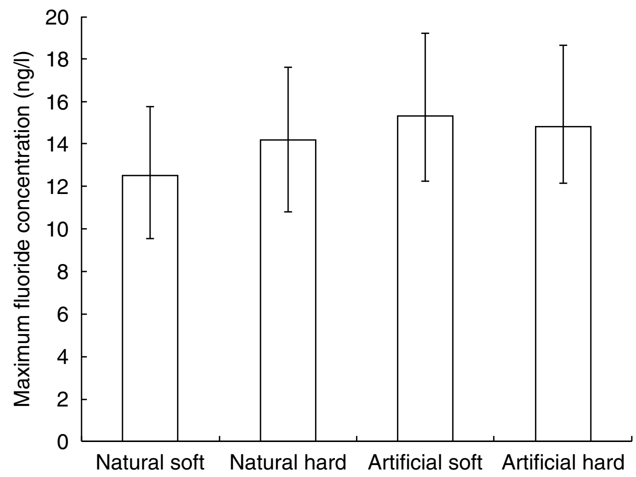


**Fig. 2.** Maximum plasma fluoride concentrations (ng/l) reached by twenty healthy adult volunteers aged 20–35 years following consumption of 500 ml naturally-fluoridated hard, naturally-fluoridated soft, artificially-fluoridated hard or artificially-fluoridated soft water containing 1 mg fluoride/l. Values are corrected for baseline plasma fluoride concentration and dose (i.e. fluoride concentration of individual waters). Values are means and 95 % CI represented by vertical bars for twenty subjects. (From Maguire *et al*. 2005.)

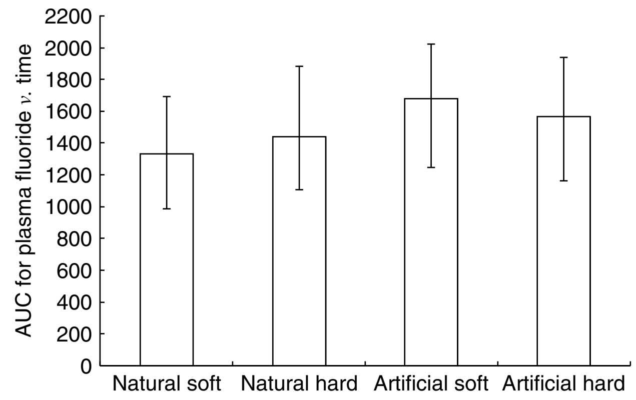


**Fig. 3.** Area under the curve (AUC) for plasma fluoride concentration *v*. time (0–8 h) for twenty healthy adult volunteers aged 20–35 years following consumption of 500 ml naturally-fluoridated hard, naturally-fluoridated soft, artificially-fluoridated hard or artificially-fluoridated soft water containing 1 mg fluoride/l. Values are corrected for baseline plasma fluoride concentration and dose (i.e. fluoride concentration of individual waters). Values are means and 95 % CI represented by vertical bars for twenty subjects. (From Maguire *et al*. 2005.)

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water intake by children, the potential effect on fluoride intake of switching from fluoridated tap water to bottled water has been estimated (Zohouri *et al*. 2003). Twenty-five samples of water were identified and the fluoride content of three separate batch numbers was measured in duplicate. The fluoride content was found to be relatively low (mean concentration 0·08 (range 0·01–0·37) mg/l; Table 1). Based on levels of water consumption by children taken from the National Diet and Nutrition Survey of Children Aged 4–18 Years (Gregory & Lowe, 2000) and using the mean value obtained for the fluoride concentration of bottled water, it was estimated that drinking bottled water in preference to fluoridated tap water would result in a 40 % reduction in intake of fluoride; potentially a marked reduction in caries protection.

Despite the indisputable benefit of fluoride in reducing caries, it has not eliminated it. Fluoride repairs the damage caused by acids produced by plaque bacteria but does not remove the cause of caries, i.e. dietary sugars. Prevention requires both optimum exposure to fluoride and a reduction in sugars intake, two factors that have been shown to have an additive effect on caries prevention (Weaver, 1950).

Every kind of study, from experimental studies *in vitro* to human intervention studies, has confirmed the important role of both the amount and frequency of sugars consumption in the development of dental caries (Sheiham, 2001; Moynihan & Petersen, 2004). The recently-published World Health Organization/Food and Agriculture Organization (2003) report on diet, nutrition and the prevention of chronic diseases has concluded that there is convincing evidence that both the amount and frequency of free sugars consumption are associated with an increased risk of dental caries. Further reductions in dental decay are unlikely to occur without a reduction in free-sugars consumption. Free sugars include all sugars added by the manufacturer, during cooking and by the consumer plus the sugars naturally present in juices, syrups and honey, and in the UK they are referred to as non-milk extrinsic sugars. The current recommended safe threshold for free sugars consumption is >10 % total energy (World Health Organization/Food and Agriculture Organization, 2003), which equates to 15–20 kg per person per year or 40–55 g per person per d. This threshold is based on studies that have repeatedly shown that when intake of sugars are below this level dental caries levels are low (Schulerud, 1950; Takeuchi, 1962; Buttner, 1971; Scheinin *et al*. 1976; Sreebny, 1982; Sheiham, 1983; Woodward & Walker, 1994; Miyazaki & Morimoto, 1996; Ruxton *et al*. 1999). It is also recommended that foods containing free sugars are not consumed more than four times per d (Sheiham, 2001; World Health Organization, 2003; Moynihan & Petersen, 2004), because when frequency of intake exceeds four times per d the amount consumed exceeds the threshold of 15–20 kg/year. These recommendations are in line with the UK dietary reference value for non-milk extrinsic sugars (Department of Health, 1991) of <10 % energy intake.

Information on the level of intake and dietary sources of free sugars enables dietary goals to be monitored and also

**Table 1.** Fluoride content of still bottled waters (from Zohouri *et al*. 2003)
(Values are means and standard deviations for six samples)

| Still bottled water brand | Type of water | Country of origin | Fluoride level (mg/l) | |
|---|---|---|---|---|
| | | | Mean | SD |
| Activ | Natural | France | 0·14 | 0·02 |
| Boots | Natural | Wales | 0·04 | 0·01 |
| Brecon Carreg | Natural | Wales | 0·04 | 0·01 |
| Buxton | Natural | England | 0·14 | 0·02 |
| Caledonian, Sainsbury | Natural | Scotland | 0·06 | 0·01 |
| Deeside, ASDA | Spring | Scotland | 0·37 | 0·14 |
| Eden Falls, ASDA | Natural | England | 0·03 | 0·01 |
| English Mountain Spring | Spring | England | 0·02 | 0·00 |
| Evian | Natural | France | 0·06 | 0·01 |
| Glenburn, ASDA | Spring | Scotland | 0·06 | 0·01 |
| Glencairn, Safeway | Spring | Scotland | 0·03 | 0·00 |
| Hadrian | Spring | England | 0·10 | 0·01 |
| Highland | Natural | Scotland | 0·05 | 0·01 |
| Mirabel, Marks & Spencer | Spring | Canada | 0·12 | 0·01 |
| Naya | Spring | Canada | 0·11 | 0·01 |
| Perthshire, Tesco | Spring | Scotland | 0·04 | 0·01 |
| Pierval | Spring | France | 0·08 | 0·01 |
| Shropshire, Sainsbury | Natural | England | 0·05 | 0·01 |
| St. George's Well | Natural | England | 0·05 | 0·01 |
| Strathmore | Spring | Scotland | 0·11 | 0·00 |
| Superdrug | Spring | Ireland | 0·04 | 0·04 |
| Table water, Sainsbury | Distilled | England | 0·01 | 0·01 |
| Val Blanc | Natural | France | 0·03 | 0·01 |
| Vittel | Spring | France | 0·12 | 0·02 |
| Volvic | Natural | France | 0·20 | 0·03 |
| All | – | – | 0·08 | 0·08 |

informs health education. As health education is best provided in terms of foods consumed, it is also important to have information on the sources of free sugars in the diet. Information on the intake of sugars by children exists for a number of countries (Table 2). In the UK the National Diet and Nutrition Survey of Young People Aged 4–18 Years, conducted in 1997, has reported the mean consumption of non-milk extrinsic sugars to be 90 g/d, contributing 17% to energy intake (Gregory & Lowe, 2000). Studies of children in Denmark and Germany have shown 'added sugars' to contribute 14% to total energy intake (Kersting *et al*. 1998; Lyhne & Ovesen, 1999). Strain *et al*. (1994) have reported that total sugars provide approximately 20% of the energy intake in 12-year-old children in Northern Ireland. Outside Europe, George *et al*. (1993) have reported that total sugars contribute 26% to energy intake in New Zealanders aged 10–11 years, and in North American children aged 12–19 years added sugars contribute 16–17% of energy intake (Munoz *et al*. 1997). Although information on total sugars intake is only available in some instances, it has generally been shown that free sugars contribute approximately 75% to total sugars intake (Rugg-Gunn *et al*. 2005). Data from a number of countries therefore indicate that the level of free sugars consumption by children greatly exceeds the recommended threshold of 10% energy.

## Trends in sugars intake

There is very little information available on trends in sugars consumption and dietary sources over time. Data from a longitudinal study of German children aged 2–18 years shows that levels of added sugars intake have remained stable over the 15-year period from 1985, contributing on average 11–13% of the energy intake (Alexy *et al*. 2002). A repeat cross-sectional survey of the diets of English children aged 11–12 years was conducted in 1980, 1990 and again in 2000 on a sample of approximately 400 children attending the same seven middle schools in north east England (Fletcher *et al*. 2004). Dietary information was collected by means of 2 × 3 d food diaries, and intakes of total sugars, non-milk extrinsic sugars and sources of dietary sugars were derived. Fig. 4 shows the mean percentage energy obtained from total sugars and non-milk extrinsic sugars in 1980, 1990 and 2000. Total sugars provide approximately 22% of the energy intake in all three surveys and non-milk extrinsic sugars provide 16% of the energy in 1980 and 2000 and 17% in 1990, with no significant difference between surveys (Rugg-Gunn *et al*.

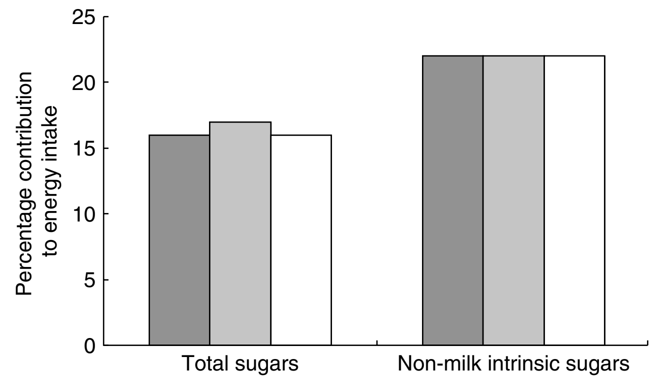


**Fig. 4.** Percentage contribution of total sugars and non-milk extrinsic sugars to energy intake in the diets of children aged 11–12 years from north east England in 1980 (▩), 1990 (▩) and 2000 (□). (From Rugg-Gunn *et al.* 2005.)

2005). Over the same time period there was a 5% decrease in the percentage energy provided by fat, the energy being replaced with starch, indicating a favourable adjustment to the macronutrient profile of the diet (Fletcher *et al*. 2004). However, despite stable levels of dietary sugars intake there have been considerable changes in the sources of dietary sugars over the 20-year period. Fig. 5 shows the percentage contribution of various food groups to total sugars intake in 1980, 1990 and 2000. Over the past 20 years the contribution of soft drinks, biscuits and cakes and breakfast cereals to total sugars intake has risen significantly. In 1980 soft drinks contributed 15% to total sugars intake; this percentage has over doubled in the 20-year period to 37 in 2000. Similarly, the contribution of breakfast cereals to sugars intake has risen from 2% to 7%. Intake of sugars from confectionery, table sugar and puddings has declined over the 20-year period. However, confectionery has remained a major source, providing 23% of the total sugars in 2000, and together with soft drinks provides approximately 60% of total sugars. These findings are consistent with those of other surveys from industrialised countries, which indicate that children are consuming more sugars than recommended and that the principal dietary sources are confectionery and soft drinks (Crawley, 1993; George *et al*. 1993; Gregory & Lowe, 2000; Guthrie & Morton, 2000). The observation that the majority of free sugars is provided by confectionery and soft drinks is of concern, since these items tend to be consumed frequently and between meals when they are most likely to be detrimental to teeth (Levine & Stillman-Lowe, 2004).

**Table 2.** Sugars intake by children

| Authors | Country | Age-group (years) | Sugars intake (%) | Comments |
|---|---|---|---|---|
| Gregory *et al.* (2000) | UK | 11–14 | 17 (Boys)<br>16 (Girls) | Non-milk extrinsic sugars |
| Lyhne *et al.* (1999) | Denmark | 11–14 | 14 | Added sugars |
| Kersting *et al.* (1998) | Germany | 11–12 | 14 | Added sugars |
| Munoz *et al.* (1997) | USA | 12–19 | 16–17 | Added sugars |
| Strain *et al.* (1994) | Northern Ireland | 12 | 20 | Total sugars |
| George *et al.* (1993) | New Zealand | 10–11 | 26 | Total sugars |

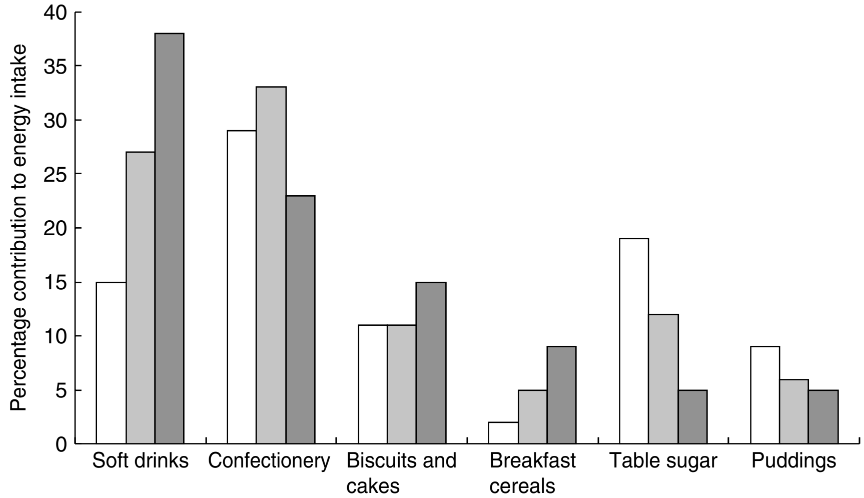


**Fig. 5.** Percentage contribution of different food types to total sugars intake in the diets of children aged 11–12 years from north east England in 1980 (□), 1990 (■) and 2000 (■). (From Rugg-Gunn *et al.* 2005.)

The World Health Organization/Food and Agriculture Organization (2003) report has recommended a diet that is high in fruits and vegetables and starch-rich staple foods and low in fat and free sugars. Consumption of this type of diet is likely to be associated with low levels of dental caries. However, effective means of promoting these dietary recommendations in the dental setting need to be identified. Currently, in the UK children receive limited dietary advice from their dental practice. The dental health survey of the National Diet and Nutrition Survey of Young Children Aged 1·5–4·5 Years has found that <40% of the parents of young children have received any advice concerning diet and teeth (Hinds & Gregory, 1995). A survey of UK dentists has identified lack of knowledge, time, space and money as barriers to providing dietary advice in the dental setting (Barton *et al.* 2001). These issues need to be addressed for effective dietary intervention at the level of the individual.

## The impact of tooth loss on diet and nutrition

The World Health Organization/Food and Agriculture Organization (2003) dietary recommendations promote increased consumption of fruits and vegetables and wholegrain foods for the prevention of a number of chronic conditions, including obesity, CVD, cancer and diabetes. However, consumption of such foods may be impeded in those individuals with compromised chewing ability. With advances in modern-day dentistry it is difficult to conceive that only 50 years ago a common 21st birthday present for girls was a full set of dentures! Today, many individuals retain their teeth for life; nonetheless, edentulism (having no natural teeth) is far from eradicated.

Edentulism is still common in older adult populations throughout the world (Moynihan & Petersen, 2003). In the UK (Kelly *et al.* 2000) and the Republic of Ireland (O'Mullane & Whelton, 1994) 46 and 48% respectively of the population aged ≥65 years are edentulous and rely on plastic prostheses for chewing function. Furthermore, there are many individuals with fewer than the twenty natural teeth that are thought necessary for adequate chewing function (Hildebrandt *et al.* 1997). This factor, coupled with the rapid growth globally in the section of the population aged ≥65 years, means that tooth loss is going to continue to affect a sizable proportion of the population for the foreseeable future.

Tooth loss is associated with a reduction in both measured (Yukstas & Emerson, 1964; Krall *et al.* 1998) and perceived (Rusen *et al.* 1993) chewing function. The chewing function of an individual with dentures is only one-fifth of that of a dentate individual with twenty or more natural teeth (Michael *et al.* 1990). Early studies have reported that loss of functional dentition results in chewing difficulties and selective food avoidance, raising concern that this situation may lead to compromised nutritional intake (Berry, 1972; Heath, 1972; Ettinger, 1973; Osterberg & Steen, 1982; Wayner & Chauncey, 1983). Foods avoided include those that are hard to chew, e.g. raw vegetables and wholegrain breads, and foods containing seeds and pips such as tomatoes, grapes and raspberries (Berry, 1972; Ettinger, 1973; Wayner & Chauncey, 1983). Osterberg & Steen (1982) have reported that elderly Swedish women with poorer dental function have lower intakes of vegetables and some fruits than those with good dental function, and a higher proportion of edentulous subjects have insufficient nutrient intakes compared with those who have natural teeth.

Despite repeated reports of the avoidance of fruits, vegetables and coarse breads by dentally-compromised subjects, it was not until the early 1990s that intake of NSP by edentulous subjects was investigated (Moynihan *et al.* 1994). The intake of NSP by edentulous adults aged 40–60 years attending Newcastle Dental Hospital was assessed by a detailed dietary history method (based on their usual food consumption for 1 week) and compared with that of an age-matched group of dentate adults (with twenty or more natural teeth) from a similar socio-economic background. A prospective method of dietary assessment was avoided because of the potential effects of concurrent dental treatment on usual food intake. Subjects were also classified according to whether their intake of NSP was very low (<12 g/d), low (12–17 g/d) or acceptable (≥18 g/d). As hypothesised, the median intake of NSP was found to be markedly lower in the edentulous group (10·4 g/d) compared with the dentate group (15·3 g/d). Fig. 6 shows the percentages of edentulous and dentate subjects allocated to the three categories of intake. Of the edentulous subjects 56 % were found to have a daily intake of NSP of ≤12 g, a level associated with a low stool weight and an increased risk of gastrointestinal disorders (Department of Health, 1991). These findings have been confirmed by subsequent studies in both Canada and the USA (Laurin *et al*. 1994; Joshipura *et al*. 1996), indicating that edentulous individuals are at risk of a low intake of NSP and the health consequences of this intake.

Both the oral health and the dietary components of the National Diet and Nutrition Survey of People Aged 65 Years and Over were investigated in a representative sample of 753 free-living older adults (Steele *et al*. 1998). The original oral health report highlights the lower intakes of NSP of the edentulous group compared with the dentate group. Further analysis of data from this survey relating to dental status and fruit and vegetable intake has been conducted (Moynihan *et al*. 2000*b*; Dhaliwal *et al*. 2002). Multivariate linear regression analysis was used to investigate the relationship between total fruit and vegetable intake and explanatory variables, including dental status, and socio-demographic factors. Multivariate logistic regression analysis was used to determine the impact of dental status on the relative odds of an individual achieving the current target to consume ≥400 g fruit and vegetables per d (Department of Health, 1994). Total fruit and vegetable intake (excluding potatoes, but including ≤80 g juice) was dichotomised at a level of 400 g/d into a variable indicating whether or not this threshold had been met. The independent variables used include oral health data and socio-demographic variables. Fruit and vegetable intake was found to be 116 g/d lower in the edentulous group compared with the dentate group with twenty or more teeth, a difference that was significant ($P<0·001$).

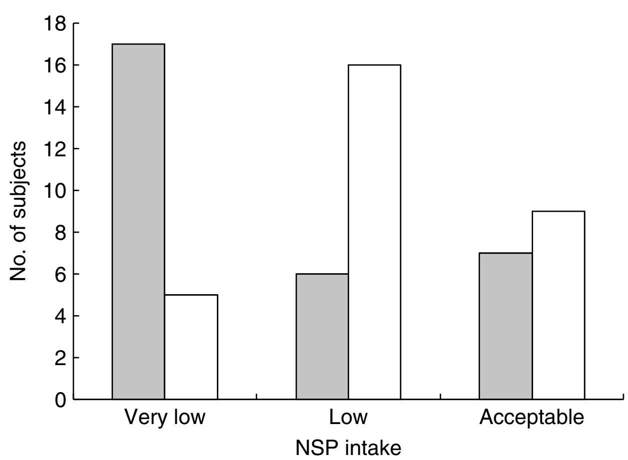


**Fig. 6.** The number of edentulous subjects aged 40–60 years attending Newcastle Dental Hospital (▩) who had acceptable (>18 g/d), low (12–18 g/d) and very low (<12 g/d) intakes of NSP (assessed by a detailed dietary history method) compared with that for an age-matched group of dentate subjects (□). Values are means for thirty subjects per group. (From Moynihan *et al*. 1994.)

Fig. 7 shows the percentage of subjects that achieved the target for fruit and vegetable consumption, grouped according to dental status. Only 9 % of the edentulous group and 13 % of the group who had between one and twenty teeth were found to consume ≥400 g fruit and vegetables per d. However, 30 % of the group who had more than twenty teeth were found to meet the target. Multivariate logistic regression shows that increasing number of posterior teeth, education beyond school and non-manual social class are associated with meeting the recommended target for fruit and vegetable consumption. The odds ratio for number of posterior contacting pairs of teeth is 1·1, indicating that each additional pair of posterior contacting teeth increases the chance of achieving 400 g/d by 10 %, assuming a linear relationship. Thus, with ten pairs of teeth (as might be present in a dentate subject) an individual would be three times as likely as an individual with no posterior contacting teeth of achieving the 400 g recommendation.

To be able to eat better is one of the main reasons for the provision of dental prostheses, the other reasons being aesthetics and speech. Thus, it is reasonable to hypothesise that prosthetic rehabilitation will lead to improved eating ability and, subsequently, improved dietary intake. The effect of prosthetic rehabilitation of partially-dentate patients on chewing ability and nutrient intake has been investigated in thirty patients fitted with conventional partial dentures and thirty patients fitted with a more novel resin-bonded bridge that adds one additional posterior contact to the upper dental arch (Moynihan *et al*. 2000*a*). Perceived chewing function was assessed by questionnaire and intake of nutrients was derived from 2 × 3 d food diaries at baseline, and at 3 and 12 months following provision of the prosthesis. Although both groups of patients reported a marked improvement in chewing ability post treatment, no significant dietary improvement was

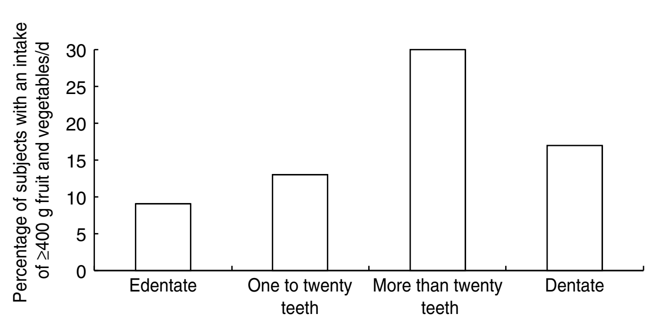


**Fig. 7.** Percentage of older adults who achieved the recommended lower threshold for fruit and vegetable intake of 400 g/d, grouped by dental status, obtained by further analysis of data from the UK National Diet and Nutrition Survey of People Aged 65 Years and Over (Steele *et al*. 1998). (From Dhaliwal *et al*. 2002.)

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**Table 3.** Affect of prosthetic rehabilitation on masticatory function, diet and nutritional intake

| Authors and year | Country | Treatment | Masticatory function | Diet and nutrient intake |
|---|---|---|---|---|
| Renaud *et al.* (1982) | Canada | Full dentures | Improved | No significant improvement |
| Gunne & Wall (1985) | Sweden | Full dentures | 65% chewed better | No significant improvement |
| Sandström & Lindquist (1987) | Finland | Full dentures | Improved | No significant improvement |
| Mobley *et al.* (1994) | USA | Full dentures | Improved | Increased intake of Ca attributed to consumption of maize tortillas |
| Sebring *et al.* (1995) | USA | Implant retained lower dentures | Improved | No significant improvement |

found. The mean intakes of NSP before, 3 months, and 12 months post treatment were found to be 10·1, 11·0 and 10·1 respectively for the group receiving a resin-bonded bridge and 10·2, 10·1 and 11·5 respectively for the group receiving a partial denture. The percentage energy intake from fat before, 3 months and 12 months following treatment were found to be 34, 38 and 36 respectively for the group receiving a bridge and 37, 39 and 39 respectively for the group receiving a partial denture. The effect of prosthetic rehabilitation on chewing ability and dietary intake has been studied by a number of other investigators in a number of different countries using a variety of types of prostheses (Table 3). These studies have repeatedly reported that prosthetic rehabilitation improves chewing function but, with the exception of one study, no improvements in dietary intake have been reported (Gunn & Wall, 1985; Sandstrom & Lindquist, 1987; Mobley *et al.* 1994; Sebring *et al.* 1995; Moynihan *et al.* 2000*a*).

The available data therefore indicate that although prosthetic rehabilitation results in improved chewing function, it does not provide sufficient drive to change what individuals eat; probably because dental function is just one of the many factors that influence food choice. In a study of older adults from low-income areas of north east England cost and optimistic bias (where the subject perceives to be eating more healthily than in reality) have been identified as important barriers to healthier eating, with problems with chewing not perceived as a major barrier, even though the majority of the study group were denture-wearers (PN Hindmarch, CE Wood, AJ Adamson, CJ Seal, JC Mathers and PJ Moynihan, unpublished results). The existence of optimistic bias suggests that without dietary advice patients may be unaware of their need to change.

Although tooth loss is not the only factor influencing dietary intake, those patients who present with tooth loss come from a population group that would undoubtedly benefit from dietary intervention. Furthermore, considering that one of the main reasons for seeking new dentures is eating problems, the dental clinic provides an opportunistic setting for dietary intervention that has been largely unexploited.

The effect of a customised dietary intervention that aims to increase fruit and vegetable consumption has been tested in a study of patients attending Newcastle Dental Hospital for new complete replacement dentures (Bradbury, 2002; Bradbury *et al.* 2003). Thirty patients received a dietary intervention at the time of receiving replacement dentures and twenty-eight patients received replacement dentures only. The dietary intervention was tailored to the patient's readiness to change, knowledge of food and health, and living situation and was also designed to address optimistic bias. Motivational interviewing techniques were used in two sessions with a nutritionist. Diet was assessed before and at 3 months following the intervention, and information on stages of change was collected by questionnaire. Fruit and vegetable consumption was found to markedly increase in the intervention group by approximately 200 g/d, and it was observed that the recipients of the intervention also show positive movement through the stages of change from pre-action to action (Bradbury *et al.* 2003). The study did not, however, investigate any sustained effect of the intervention on diet and dietary behaviour. Research is now underway to investigate the relative effectiveness of a peer-led customised dietary intervention delivered to patients receiving implant-supported overdentures compared with patients receiving conventional dentures.

## Conclusion

Diet impacts on oral health throughout the life cycle. Sugars remain a threat to dental health from infancy into old age and dietary fluoride provides lifelong protection against decay. Oral health should not be viewed in isolation from general health; the type of diet that protects against major conditions such as obesity, CVD and cancer will also protect against dental caries. Retention of natural dentition will also ensure adequate masticatory function and will aid consumption of a healthy diet into old age. While dental function is not the only factor influencing food choice, the value of good teeth for enabling the consumption of a varied diet for enjoyment of food and food-related quality of life is an important consideration for nutrition and dental health professionals.

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