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# Cariogenicity Depends More on Diet than the Prevailing Mutans Streptococcal Species

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**Abstract.** This review aims to compare the occurrence and distribution of mutans streptococci in Africa, Europe, and North America and in addition will try to offer explanations for existing relationships among salivary mutans streptococci counts, dietary patterns, and dental caries. The literature reveals that salivary mutans streptococci counts in child populations of the three continents are comparable. The distribution of mutans streptococci species, with a predominance of *S. mutans* followed by *S. sobrinus*, and the virtual absence of other mutans streptococci species are also comparable. Although it is widely believed that diet has an important effect on mutans streptococci counts, this review provides evidence that this does not hold true when variations in dietary patterns are moderate, as they normally are in real-life situations. Since the diets of the child populations in the three continents vary moderately, a strong dietary-induced effect on salivary mutans streptococci counts cannot be expected. The observed analogous salivary mutans streptococci counts in these child populations are thus 'not surprising' but are in accordance with the conceptual expectation. The differences in caries experience in children of the three continents cannot be explained by the prevailing mutans streptococci species but instead should be attributed to differences in the cariogenicity of the various diets. The fact that the cariogenicity of the diet determines the development of dental caries while hardly affecting the mutans streptococci counts explains the limited value of the latter as an indicator of dental caries. The reviewed literature shows that mutans streptococci are ubiquitous in children aged 7 years and older in Africa, Europe, and North America. Mutans streptococci should therefore be considered as belonging to the indigenous microflora of the human mouth.

**Key words:** mutans streptococci, dental caries, diet, Africa, epidemiology.

## Introduction

The cariogenic properties of mutans streptococci (Edwardsson, 1970) and their relationship with caries (van Houte, 1980) and with sugar intake (de Stoppelaar *et al.*, 1970) have led to the belief that mutans streptococci are the main bacterial cause of dental caries (Emilson and Krasse, 1985; Loesche, 1986). Particularly, the correlation between caries and mutans streptococci in industrialized countries, which is assumed to be caused by high levels of sucrose intake, has been generalized. This does not necessarily hold true for populations of non-industrialized countries where dietary patterns are different. Several studies on the prevalence of mutans streptococci in African populations have reported high prevalences of mutans streptococci and high salivary mutans streptococci levels (Carlsson, 1989). These findings were considered 'unexpected', since caries and sugar intake are both low on the African continent. The widespread occurrence of mutans streptococci together with a low caries prevalence in African populations has led to suggestions that these populations may harbor different species of the mutans streptococci group or less cariogenic types.

In this paper, the literature on mutans streptococci in Africa is reviewed, and comparisons are made with the occurrence of mutans streptococci in Europe and North America to verify whether claims of 'high levels of mutans streptococci in Africa' are an accurate characterization of the occurrence of mutans streptococci on that continent. Special attention is focused on the effect of diet on mutans streptococci, in an attempt to explain the occurrence of mutans streptococci in African populations with a low caries experience.

## Selection criteria for included studies on the occurrence of mutans streptococci

A total of 14 studies on mutans streptococci in African populations could be traced. Those dealing with mutans streptococci in dental plaque (Kelstrup *et al.*, 1974; Nutt and

van Wyk, 1978; Kilian *et al.*, 1979; Farghaly *et al.*, 1984; Matee *et al.*, 1993a) are not included in the comparison. Plaque samples are not very suitable for determining the oral load of mutans streptococci, due to the large variation in mutans streptococci counts between tooth surfaces (Lindquist and Emilson, 1990). Since it is quite impossible to select a suitable plaque sampling site for assessment of the mutans streptococci oral load, saliva samples were taken to overcome this problem. It has been demonstrated that the mutans streptococci counts in saliva reflect the overall colonization of mutans streptococci on the dentition (Köhler *et al.*, 1981; Emilson, 1983). The salivary mutans streptococci count can be considered as an 'average' for the individual oral load of mutans streptococci (Togelius *et al.*, 1984), and therefore only studies dealing with salivary mutans streptococci counts have been included in the comparison between populations.

Different methods of sampling, cultivation, and quantification of salivary mutans streptococci have been described in the literature. Several studies have demonstrated that the viable counts of mutans streptococci with the spatula method, the tongue loop method, the strip mutans test, and the dip-slide test are all highly correlated with the mutans streptococci counts of the conventional paraffin-stimulated saliva sample on selective agar plates (Köhler and Bratthall, 1979; Alaluusua *et al.*, 1984; Beighton, 1986; Emilson and Krasse, 1986; Jensen and Bratthall, 1989). The observed variation in mutans streptococci counts between methods seems to be of the same magnitude as the reported intra-individual variation (Togelius *et al.*, 1984). It seems therefore justified to compare salivary mutans streptococci counts from various studies where these

different methods were applied.

Nine studies on salivary mutans streptococci counts in African populations, conducted by means of the methods mentioned above, have been included in this review for comparison with studies on salivary mutans streptococci counts in populations in Europe and North America. The 9 studies on African populations were all performed with children. Their ages varied considerably. It is well-documented that mutans streptococci numbers increase gradually with age as the number of teeth and retentive sites increases (Catalanotto *et al.*, 1975; Berkowitz *et al.*, 1980; Togelius and Bratthall, 1982). To make comparisons meaningful, we classified the examined populations according to the following age groups: (1) average age from 1 to 5; (2) average age from 5 to 12; and (3) average age from 12 to 19. These age groups represent the deciduous dentition, the mixed dentition, and the permanent dentition, respectively.

### Salivary mutans streptococci counts in African, European, and North American children

In a recent study in Tanzania among 1-to-2.5-year-old children, salivary mutans streptococci were detected in 94% of the caries-active children and in 53% of the caries-free children. High counts ( $\geq 10^6$ ) of salivary mutans streptococci were found in 6% of the caries-free children and in 29% of the caries-active children (Matee *et al.*, 1992a). The only two other reports on salivary mutans streptococci counts among pre-school children in Africa are from South Africa. The sample in one study (Chosack *et al.*, 1988) consisted of urban black, colored, and Indian and rural black 3-to-5-year-old pre-school children, whereas the sample in the other study

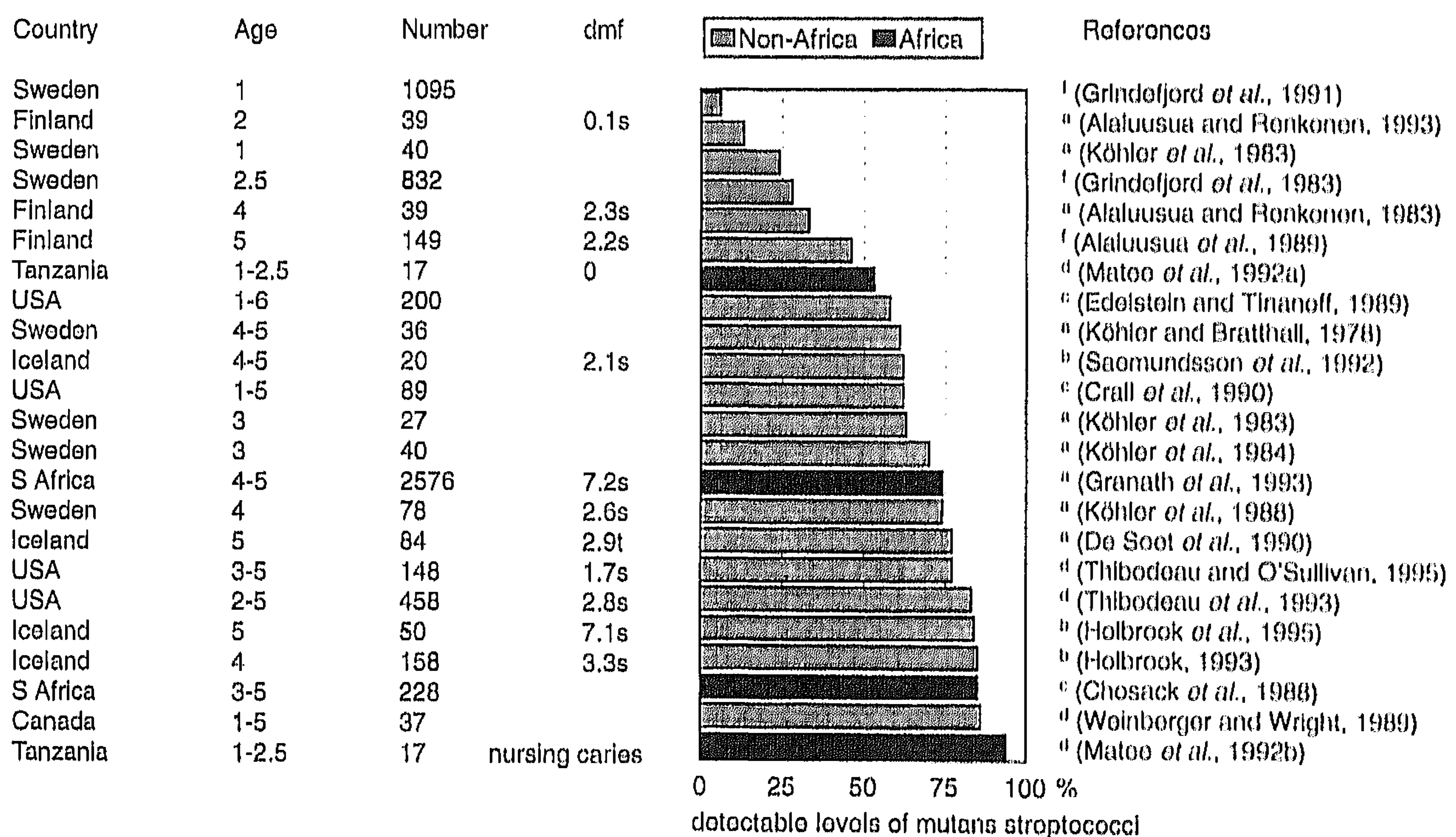


Figure 1. Sequential order by proportion of pre-school children with detectable levels of mutans streptococci in their saliva. <sup>1</sup>Paraffin-stimulated saliva and <sup>2</sup>tongue loop saliva sample (Beighton, 1986) on conventional selective agar plate; <sup>3</sup>spatula method (Köhler and Bratthall, 1979); <sup>4</sup>spatula tongue-pressed method (Weinberger and Wright, 1989); <sup>5</sup>Strip mutans<sup>®</sup> test (Jensen and Bratthall, 1989); <sup>6</sup>dipslide scoring method (Alaluusua *et al.*, 1984).

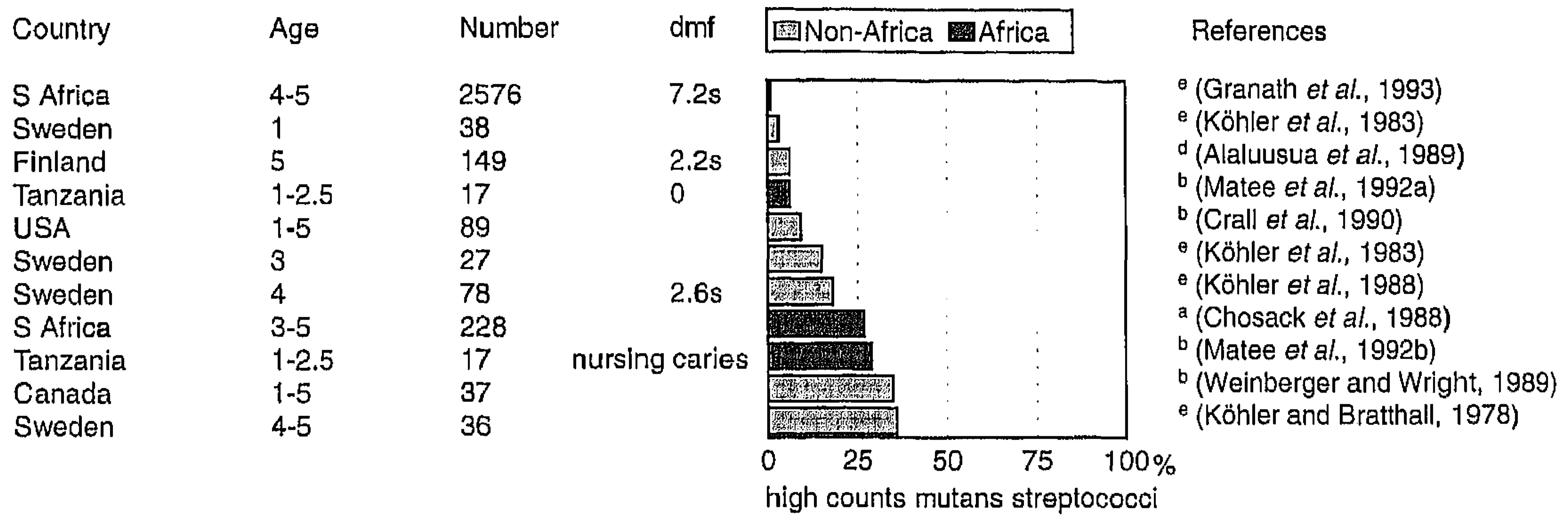


Figure 2. Sequential order by proportion of pre-school children with high counts of mutans streptococci in their saliva. High counts  $\geq 10^6$  colony-forming units (CFU) with <sup>a</sup>the spatula method (Köhler and Bratthall, 1979), <sup>b</sup>the spatula tongue-pressed method (Weinberger and Wright, 1989), <sup>c</sup>the Strip mutans<sup>®</sup> test (Jensen and Bratthall, 1989), and <sup>d</sup>the dipslide score '3' (Alaluusua *et al.*, 1984) correspond roughly with  $\geq 10^6$  CFU/mL saliva with <sup>e</sup>the paraffin-stimulated saliva and <sup>f</sup>the tongue loop saliva sample (Beighton, 1986) on conventional selective agar plate.

(Granath *et al.*, 1993) consisted of the same ethnic groups of 4-to-5-year-old pre-school children as well as 4-to-5-year-old urban whites. Salivary mutans streptococci were detected in 85% and 74% of the pre-school children, respectively. One percent of the children in the study by Granath *et al.* (1993) and 27% of the children in the study by Chosack *et al.* (1988) showed high counts ( $\geq 10^6$ ) of salivary mutans streptococci.

A large number of studies on salivary mutans streptococci counts in pre-school children in the industrialized countries of Europe and North America could be traced. The prevalence of salivary mutans streptococci in pre-school children in Africa is illustrated sequentially together with data from Europe and North America in Fig. 1. It shows prevalences of salivary mutans streptococci in African pre-school child populations lying within the range of prevalences observed in Europe and North America. To compare the oral loads of mutans streptococci of these pre-school children more extensively, we plotted the proportions of children with high salivary mutans streptococci counts ( $\geq$

$10^6$ ) sequentially (Fig. 2). The results indicate that the proportions of African pre-school children with high mutans streptococci counts are within the range of proportions found in pre-school children in industrialized countries.

Three studies have been performed in Africa on salivary mutans streptococci counts in the 5-to-12-year age group. The studies in Mozambique (Carlsson *et al.*, 1985) and Sudan (Carlsson *et al.*, 1987) included only rural populations, while the survey in Tanzania (Matee *et al.*, 1985) consisted of both rural and urban populations. Fig. 3 illustrates prevalences of salivary mutans streptococci from these three African studies and from studies traced in Europe and North America. Fig. 4 presents the proportions of children with high salivary mutans streptococci counts. Figs. 3 and 4 indicate that the data from Africa are within the range of data from the industrialized countries.

Three studies have been conducted in Africa on salivary mutans streptococci counts in the 12-to-19-year age group. The data from these studies, together with data from studies

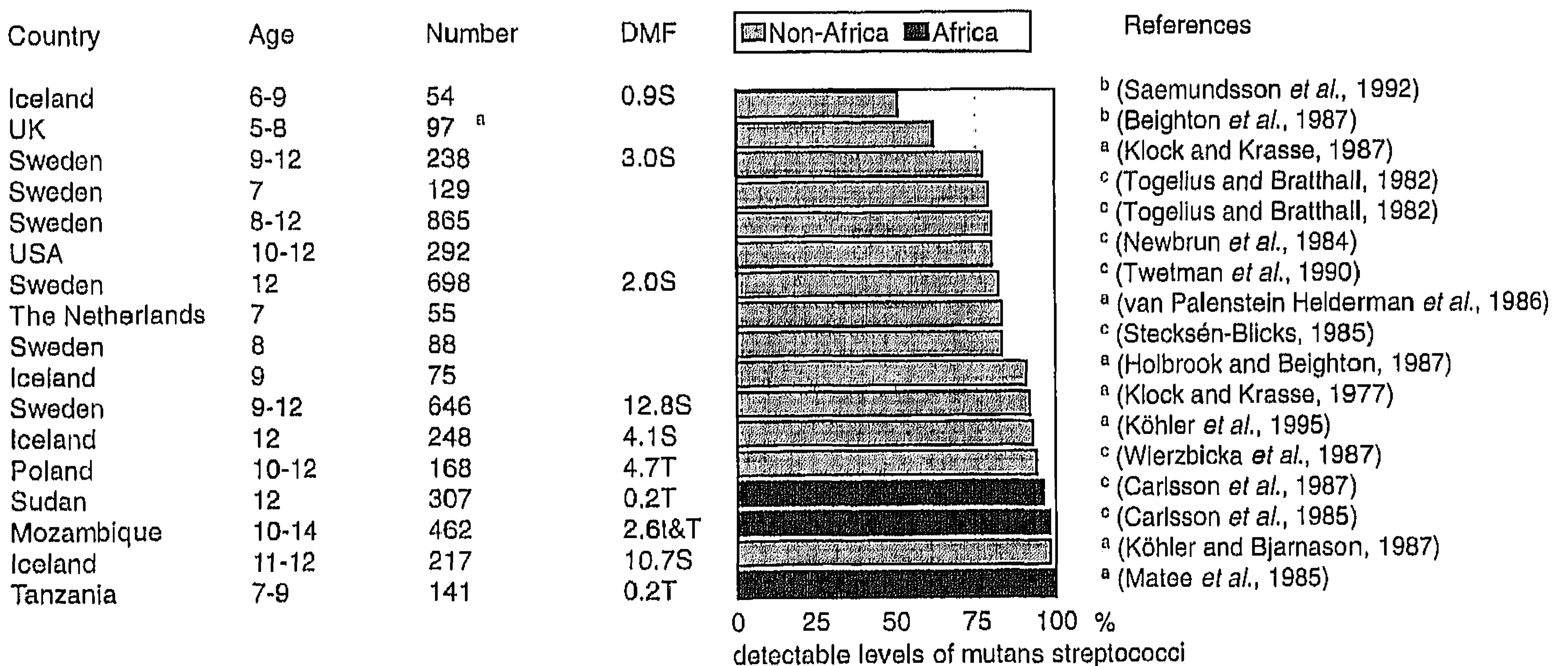


Figure 3. Sequential order by proportion of children with a mixed dentition showing detectable levels of mutans streptococci in their saliva. For explanation of footnotes, see legend to Fig. 1.

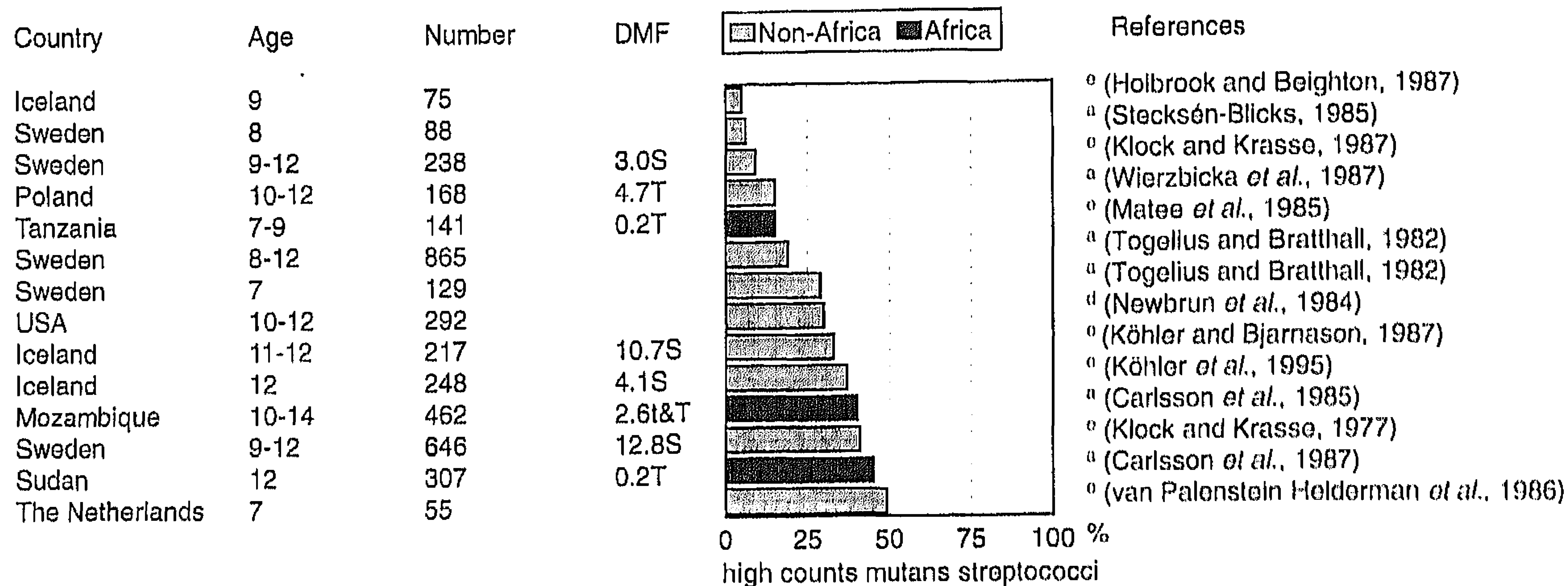


Figure 4. Sequential order by proportion of children with a mixed dentition showing high counts of mutans streptococci in their saliva. For explanation of footnotes, see legend to Fig. 2.

traced in Europe and North America, are plotted in Figs. 5 and 6 as in previous Figs. The data show comparable prevalences of salivary mutans streptococci, but children in this age group in Africa may have higher oral loads of mutans streptococci than their counterparts in Europe and North America.

Summarizing, all child populations examined, ages 7 years and older, showed a prevalence of salivary mutans streptococci higher than 70%, whereas 83% of these populations showed a prevalence of more than 80%. When the detection level is taken into account, it can be concluded that mutans streptococci are ubiquitous in these child populations. Mutans streptococci should therefore be considered as belonging to the indigenous oral microflora.

The prevalences of mutans streptococci and of high oral loads of mutans streptococci in African, European, and North American children (Figs. 1-6) do not indicate major differences among the children of the different continents, but instead seem to be similar.

#### Ecological determinants of mutans streptococci in dental plaque

The generally held view that diet and, more particularly, sugar consumption are major determinants of mutans streptococci counts raises the question about the regulating mechanism responsible for comparable oral loads of mutans streptococci in the child populations of the three continents where dietary patterns are different.

Mutans streptococci have two unique properties which, under certain conditions, may provide them with a competitive advantage in the ecology of dental plaque. First, in the presence of sucrose, mutans streptococci are able to synthesize a sticky extracellular glucan. This property is believed to facilitate the adherence of mutans streptococci to the tooth surface and enables sticky colonies to be formed (van Houte, 1980). Second, under a regime of frequent sugar consumption by the host and consecutive frequent acidic episodes in dental plaque, the relatively high acidity tolerance of mutans streptococci may provide them with a selective growth advantage over other plaque microorganisms (Marsh, 1989).

Several frequently quoted studies in animals (Michalek *et al.*, 1977) and in humans (Krasse *et al.*, 1967; Minah *et al.*, 1981), in support of the evidence of a specific sucrose-mediated glucan effect on mutans streptococci, may also show a non-specific pH-mediated growth effect on mutans streptococci, since these studies were not designed to study both effects separately. Evidence regarding a specific sucrose-stimulating effect on mutans streptococci is equivocal. Animal studies investigating the effect of feeding with either a glucose or a sucrose diet on mutans streptococci (van Houte *et al.*, 1976; van der Hoeven and Rogers, 1983) showed a stimulating effect of sucrose per se on mutans streptococci counts, but other studies did not show a similar effect (Mikx *et al.*, 1976). In rats, mutans streptococci isolates from Africa were established in high counts in the absence of sucrose on either a glucose, lactose, or a starch diet (Matee *et al.*, 1993a).

In humans, consumption of increased amounts of either sucrose or glucose indicated that sucrose enhanced dental plaque accumulation compared with glucose (Carlsson and Egelberg, 1965), but it did not selectively affect the mutans streptococci counts in dental plaque (Carlsson, 1967). Neither did restricted sucrose consumption by individuals suffering from hereditary fructose intolerance and congenital sucrose deficiency dramatically affect mutans streptococci counts (van Houte and Duchin, 1975; Hoover *et al.*, 1980). Collectively, the data do not indicate sucrose-mediated glucan formation as an important selective stimulant of mutans streptococci in dental plaque.

Instead, frequent drops in pH caused by carbohydrate metabolism may play a more significant role in the ecology of mutans streptococci in dental plaque. Evidence in support of this regulating mechanism can be derived from *in vitro* studies showing an increase in acid-tolerant mutans streptococci at the expense of less-acid-tolerant species in a mixed-culture chemostat system under a regime of regular carbohydrate-mediated pH drops (Bradshaw *et al.*, 1989). Indirect evidence for a pH-regulating system in plaque ecology *in vivo* comes from humans suffering from xerostomia who harbor high numbers of acid-tolerant mutans streptococci (Dreizen and Brown, 1976). The

Country	Age	Number	DMF
Nigeria	12-14	501	
USA	10-15	541	4.6S
Iceland	10-16	114	7.5S
Finland	12-17	123	6.7S
Sweden	13	388	5.7S
Sweden	13	91	
Sweden	13-14	101	15.8S
Sweden	12-15	167	
Finland	13	841	3.8S
Sweden	13-14	58	
Scotland	12-14	372	
Sudan	12-14	120	1.7T
Kenya	15-19	149	1.5S

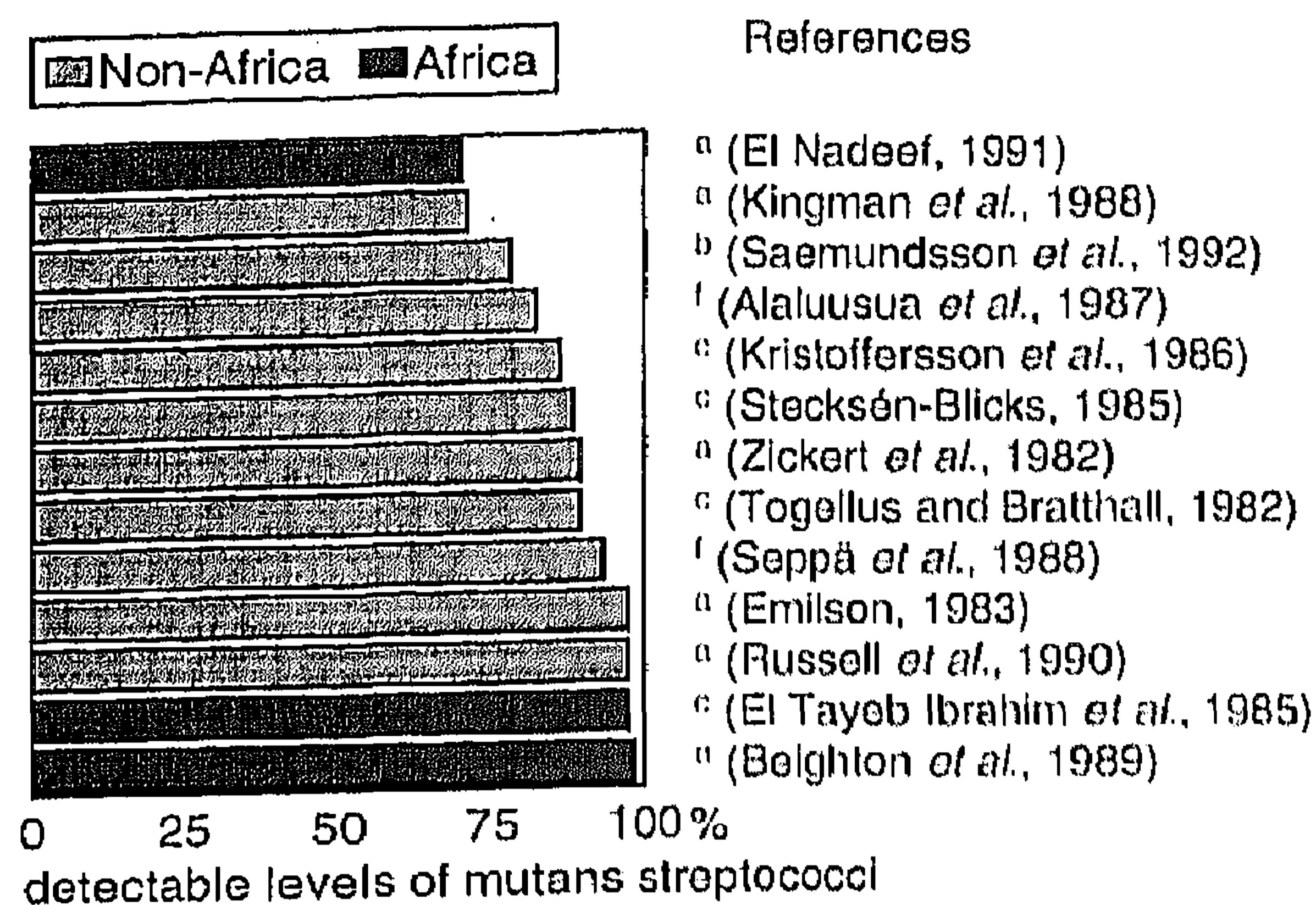


Figure 5. Sequential order by proportion of children with a permanent dentition showing detectable levels of mutans streptococci in their saliva. For explanation of footnotes, see legend to Fig. 1.

reduced buffering capacity of saliva, resulting in lower and prolonged Stephan curves in dental plaque, seems to provide the acid-tolerant mutans streptococci with a growth advantage over other plaque bacteria. The reported strong negative correlation between mutans streptococci counts and salivary secretion rate (Klock and Krasse, 1977; Seppä *et al.*, 1988) also supports this regulating mechanism. The recent observation of high mutans streptococci counts in dental plaque of children who were breast-fed at will during the night in the virtual absence of sucrose (Matee *et al.*, 1992a, 1994) provides additional support for the view that frequent drops in pH caused by consumption of carbohydrates (in this case lactose, during the night, when saliva flow is reduced) may be a more important ecological determinant for mutans streptococci than the sucrose-mediated glucan synthesis.

#### Dietary effects on mutans streptococci

Breast-feeding at will during the night represents an extreme condition resulting in high mutans streptococci counts in the dental plaque of young children. Bottle-feeding at will and during the night represents similarly extreme dietary conditions, and matching high mutans streptococci counts in dental plaque have been observed (van Houte *et al.*, 1982). An inverse extreme dietary condition was created during an experiment where individuals refrained from consuming carbohydrates. After three weeks of almost total abstinence of carbohydrates (< 1 mg/day), mutans streptococci counts in dental plaque of the participants dropped to almost undetectable levels but sharply increased after the subjects had resumed consumption of carbohydrates (de Stoppelaar *et al.*, 1970). This study by de Stoppelaar *et al.* (1970) has been quoted frequently as evidence in support of the regulating effect of diet on mutans streptococci counts in the mouth, but the fact that the study represents an extreme dietary condition has been ignored. Therefore, it should not be quoted in support of the view that real-life changes in the diet may induce dramatic shifts in mutans streptococci counts. Nevertheless, the findings provide evidence that mutans streptococci are

dependent on dietary carbohydrates and that, under extreme dietary conditions, in the case of either excess or absence of carbohydrates, their counts change dramatically.

Apart from these extreme dietary conditions, the question remains whether moderate variations in diet, as they generally occur in real-life situations, could have induced the observed large differences in the number of salivary mutans streptococci between individuals. Studies on self-reported sugar consumption have shown only weak correlations between sugar consumption and oral loads of mutans streptococci (Kristoffersson *et al.*, 1986; Stecksén-Blicks, 1987; Seppä *et al.*, 1988; Sundin and Granath, 1992). It has been reported that urban Indian and urban white preschool children in South Africa consume sweet snacks and sweet drinks twice as frequently as do their rural black counterparts, but oral loads of mutans streptococci were comparable between these groups (Granath *et al.*, 1993).

Information on self-reported sugar intake probably is not very reliable, and hence dietary intervention studies have been performed to assess the effect of dietary sugar on mutans streptococci counts. Two clinical trials on the effect of dietary sucrose on mutans streptococci counts, where a sucrose-rich diet (115 g/day sucrose) was consumed during a period of 12 days, resulted in a three-fold but not statistically significant increase in mutans streptococci counts in dental plaque, compared with a period of low dietary sucrose (15 g/day) intake (Folke *et al.*, 1972; Staat *et al.*, 1975). The first two clinical trials (Scheie *et al.*, 1984a; Minah *et al.*, 1985) on the effect of sucrose on salivary mutans streptococci counts could not demonstrate significant changes in oral loads of mutans streptococci after three weeks with 8 to 12 between-meal-sucrose moments compared with a three-week period with 0 to 3 between-meal-sucrose moments. A recent study (Wennerholm *et al.*, 1995) where sugar intake was restricted to less than two moments a day during 6 weeks showed a slight but not significant reduction in the mutans streptococci oral load. Only two studies (Kristoffersson and Birkhed, 1987; Andrién and Köhler, 1992) have reported statistically significant two- to five-fold reductions in the oral load of mutans streptococci after 6-to-8-week periods of restricted sugar intake.

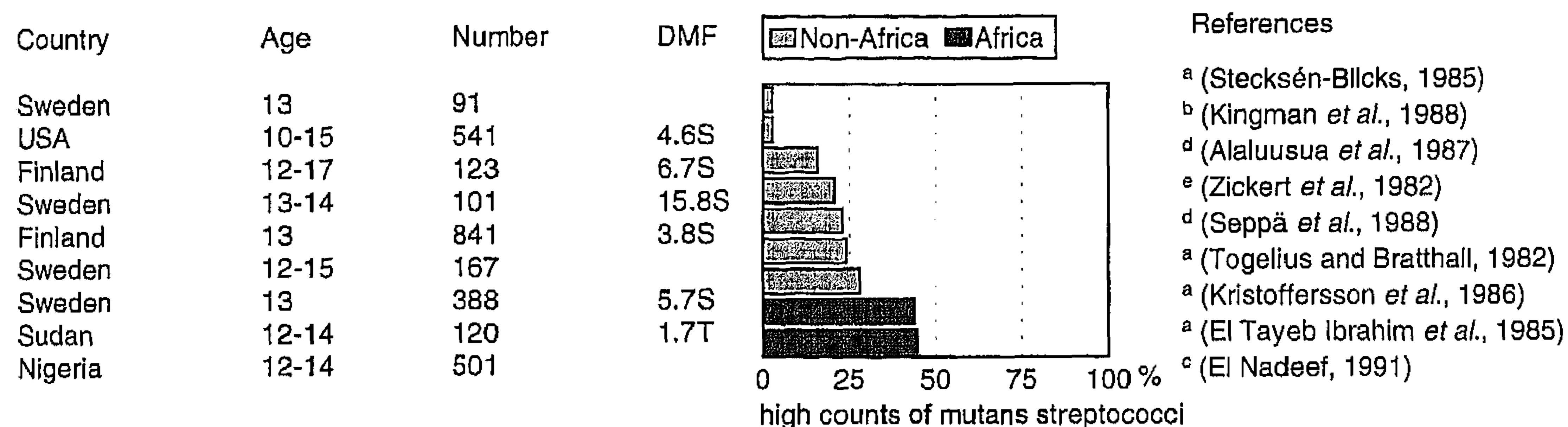


Figure 6. Sequential order by proportion of children with a permanent dentition showing high counts of mutans streptococci in their saliva. For explanation of footnotes, see legend to Fig. 2.

The clinical trials were conducted over relatively short periods, and in some studies the problem of compliance regarding the sugar restriction can be posed, implying limitations for proper extrapolation. Nevertheless, the results so far, showing weak correlations between mutans streptococci counts and dietary parameters, do not provide evidence to support the view that differences in dietary patterns are responsible for the large inter-individual variation of up to  $10^5$ -fold in salivary mutans streptococci counts. The observed analogy between occurrence and distribution of mutans streptococci is in accordance with evidence provided in the literature that moderate differences in dietary patterns, as they occur between the continents, do not produce significant effects on mutans streptococci counts.

#### Diet of African children and the widespread distribution of mutans streptococci

The main source of nutrition for young African children in the countries mentioned is breast-feeding. Nursing bottles are rare and usually available only in urban areas. In rural areas in Tanzania, from 30 to 50% of the young children are still breast-fed at the age of 2 years (Matee *et al.*, 1994). Supplementary feeding starts when they are between one and nine months of age (Matee *et al.*, 1992b) and consists of porridge made of maize, sorghum, millet, and cassava flours in unrefined or slightly refined forms. Beyond the age of two years, children are usually weaned and introduced to semi-solid foods which are mainly starchy. The daily intake frequency of cooked starch was 2.2 and that of mono- and disaccharide sugars 1.5 among 1-to-4-year-old pre-school children (Matee *et al.*, 1994). A dietary survey among 7-to-9-year-old children in rural areas in Tanzania revealed that the average moments of daily intake of fruits, sweet snacks, and sweet beverages were 2.2, 1.5, and 0.8, respectively. The consumption of sweets among urban counterparts was slightly higher (Frencken *et al.*, 1986a). Similar dietary patterns that are high in starchy foods and low in fruits and sweet intake have been reported in neighboring Kenya (van Steenberg *et al.*, 1984) and in Mozambique and Sudan (Carlsson, 1989). In East and West Africa, the predominance of starch in foods becomes more pronounced in older children and adults, who derive more than 75% of their

daily energy requirement from starch (Enwonwu, 1988).

The annual *per capita* sucrose intake provides a rough estimate of the between-meals consumption frequency of sweets. The annual *per capita* sucrose intake at the time of the mutans streptococci surveys in Tanzania, Sudan, Kenya, Mozambique, and Nigeria varied between 6 and 18 kg *per capita per year* (Renson, 1986; Frencken *et al.*, 1986b; Carlsson, 1989) and is much lower than the approximately 40 kg *per capita per year* (Marthaler, 1990) in European and North American countries where mutans streptococci prevalence studies have been performed. The low sucrose intake in these African countries is in accordance with the self-reported low consumption frequency between meals.

Summarizing, the African populations mentioned experience a change in carbohydrate intake from a diet consisting mainly of lactose to a diet high in starch around the age of 2 to 3, where sucrose and other sugars are consumed in low frequency. The dietary patterns of African, European, and North American child populations mentioned in this review are different, but not extremely so. Therefore, the absence of a clear dietary effect on salivary mutans streptococci counts in children from these three continents is in accordance with the results from epidemiological and experimental dietary studies. The frequently reported weak correlation between caries and salivary mutans streptococci counts is in accordance with the data from the literature showing weak correlations between the cariogenicity of the diet and salivary mutans streptococci counts.

#### Other factors that may affect mutans streptococci counts

Besides diet, oral hygiene, which is supposed to be poor in African children, has been suggested as a possible ecological determinant of mutans streptococci, but neither discontinuation of oral hygiene nor professional toothcleaning has shown a significant effect on salivary mutans streptococci counts (Klock and Krasse, 1978; Emilson *et al.*, 1982; Togelius *et al.*, 1984). Open caries lesions, which are prevalent in Africans, provide retention sites and could therefore be considered as an ecological factor for mutans streptococci. However, elimination of caries lesions resulted in only a slight reduction in salivary mutans streptococci counts (Scheie *et al.*, 1984b). Since none

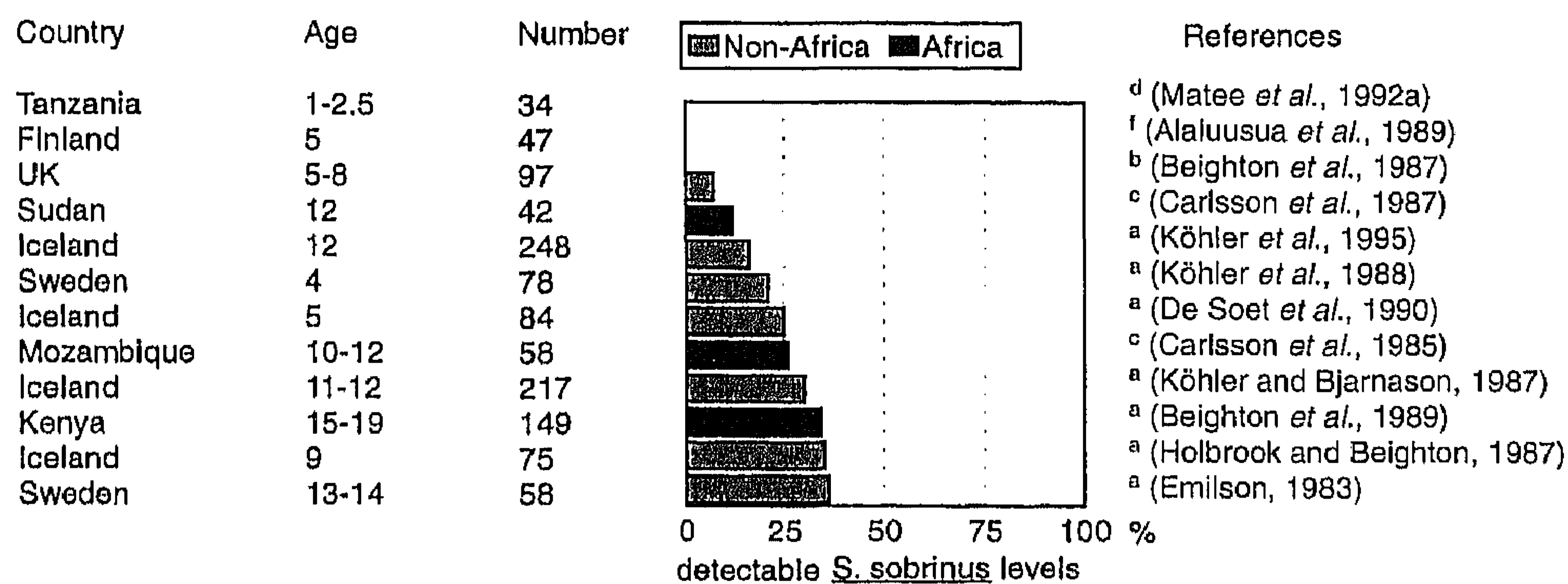


Figure 7. Sequential order by proportion of children aged between 1 and 19 years showing detectable levels of *S. sobrinus* in their saliva. For explanation of footnotes, see legend to Fig. 1.

of the factors discussed seems to be a major determinant of salivary mutans streptococci counts, other as-yet-unknown factors must play a role.

#### Caries in African children

In Africa, only a limited number of surveys has been carried out on dental caries in the primary dentition. Various levels of caries prevalence have been reported (Kerosuo and Honkala, 1991). Only one study (Kerosuo and Honkala, 1991) has compared the caries experience in pre-school children in an African country with that in a European country. The study demonstrated a much higher caries experience (dmft, 2.5) in 3-year-old Tanzanian children compared with Finnish children (dmft, 0.5). The dmft of Tanzanian children, which was 2.5 at the age of 3, remained roughly the same until the age of 7 (dmft, 2.7). The finding in Tanzania that the dmft remained constant in the 3-to-7-year age period has also been reported in Kenya and Nigeria (Kerosuo and Honkala, 1991), but is in contrast to that of Finland, where the dmft increased from 0.5 at the age of 3 to 1.9 at the age of 7. A striking finding among the Tanzanian children was the high caries score in upper incisors (Kerosuo and Honkala, 1991). Nursing caries was found to be highly prevalent among Tanzanian infants (Matee *et al.*, 1994), which may explain the high caries score in upper incisors in the sample examined by Kerosuo and Honkala (1991).

More than 50 surveys have been conducted on the caries experience of 12-to-14-year-old children in Africa. The mean DMFT scores ranged between 0.1 and 2.5, with two surveys reporting a higher score of 3.2 and 3.3 (Manji and Fejerskov, 1990). The corresponding DMFT scores in European and North American countries range between 2.8 and 8.2, with most studies reporting a value greater than 4 (Holm, 1990). Thus, the two exceptionally high mean DMFT scores in Africa (3.2 and 3.3) are actually at the lower end of the scale of DMFT scores in Europe and North America.

Summarizing, 12-to-14-year-old African children experience substantially less caries than their counterparts in Western countries, but for pre-school children this difference may not exist.

#### Species distribution and cariogenicity of mutans streptococci in Africa

The low caries experience in Africa, despite high oral loads of mutans streptococci, suggests that prevailing mutans streptococci strains in Africa may belong to less cariogenic species or serotypes or may have generally low cariogenic potential. Some support for this suggestion was provided by the finding of *S. rattus* (serotype b) as the major mutans streptococci species in dental plaque in Tanzania (Kilian *et al.*, 1979) and *S. cricetus* (serotype a) and *S. rattus* as the predominant species in plaque in Egypt (Bratthall, 1972). The predominance of *S. rattus* and *S. cricetus* could not be confirmed in later surveys on African populations, although arginine-positive strains (presumed to be *S. rattus*) have been indicated in Tanzania (Matee *et al.*, 1985). These findings may have been disturbed by technical problems of identification, since it has been reported that mutans streptococci isolates hydrolyzing arginine should be treated with suspicion, since such isolates have been found to be contaminated with catalase-positive, Gram-positive cocci (Beighton *et al.*, 1991). Furthermore, the polyclonal antibodies used for identification in those studies may be disturbed by cross-reactivity among the different mutans streptococci species as well as by other oral bacteria (Hardie and Bowden, 1976; Schöller *et al.*, 1981). Similar technical difficulties may have been experienced in the South Africa study by Nutt and van Wyk (1978), where *S. cricetus* and *S. rattus* were found in a small number of individuals who otherwise harbored *S. mutans* and *S. sobrinus* as the predominant mutans streptococci species.

Subsequent studies on mutans streptococci distribution in Africa have found *S. mutans* to be the predominant species, followed by *S. sobrinus* (Farghaly *et al.*, 1984; Carlsson *et al.*, 1985, 1987; Beighton *et al.*, 1989; Matee *et al.*, 1993b). All these studies have failed to demonstrate the presence of *S. rattus* and *S. cricetus*. However, the fact that *S. cricetus* was not found in some of the above studies (Carlsson *et al.*, 1985, 1987; Beighton *et al.*, 1989), where bacitracin was applied for selective isolation, is more in accordance with the described inhibitory action of bacitracin on *S. cricetus* (Coykendall *et al.*, 1974) than with *per se* evidence for the absence of *S. cricetus* in the populations examined.



**Table.** Approximate composition of cereals and grain products commonly consumed in East Africa (per 100 grams edible portion)<sup>a</sup>

	Protein	Fat	Carbohydrates			Fiber
			Total	Mono	Poly	
Maize, yellow, immature cob	5	2.1	34	2	32	0.8
Maize, white, whole-kernel, dried	9.4	4.2	72	5	67	2
Maize, yellow, whole-kernel, dried	10	4.8	72	5	67	2
Maize, white, on cob, toasted	8	4.8	77	5	72	1.9
Maize, white, flour, 60-80% extraction	8	1	77	3	74	0.6
Maize, yellow, meal (unga wa mahindi)	9.3	3.8	72	5	67	1.9
Maize, white, meal (dona)	10	4.5	70	—	—	4.3
Millet, finger, whole-grain	7.4	1.3	73	—	—	2.6
Millet, bulrush, whole-grain	10	4	70	—	—	1.9
Millet, bulrush, flour	5.9	3.5	71	—	—	0.6
Rice, lightly milled, parboiled	7	0.5	80	—	80	0.4
Rice, milled, polished	11	3.2	72	4	68	2.4
Sorghum, whole-grain	11	3.2	72	4	68	2.4
Sorghum, flour	9.5	2.8	73	—	73	2.1
Wheat, whole, parboiled	12	1.8	71	2	69	2.2
Wheat, flour, 85% extraction	11	2	74	2	72	0.8

<sup>a</sup> Adapted from Wert *et al.* (1988).

Fig. 7 shows prevalences of *S. sobrinus* in the saliva of different African and European child populations. Prevalences of salivary *S. sobrinus* in Africa are within the range of prevalences found in Europe.

Summarizing, the predominance of *S. mutans* species and the similarity in the prevalence of *S. sobrinus*, as well as the virtual or complete absence of other mutans streptococci species in both continents, implies that the low caries experience in African children cannot be explained by the prevailing mutans streptococci species.

Mutans streptococci are ubiquitous in African, European, and North American children ages 7 and above and should therefore be considered as belonging to indigenous human oral microflora. The hypothesis that *S. mutans* and *S. sobrinus* strains from Africa may possess lower cariogenic properties than strains from Western countries could not be substantiated in animal experiments (Emilson *et al.*, 1987). Thus, the low caries experience in African countries cannot readily be attributed to a lack of virulence of the prevailing mutans streptococci.

#### Diet and caries in Africa

Two or three main meals, containing starchy foods, provide the major energy source in the East African populations where mutans streptococci studies were performed. These starchy foods hardly contain sugars, as can be deduced from the Table, showing the composition of the commonly eaten starchy products in East Africa. Starchy foods have been shown to be far less cariogenic than the mono- and disaccharides (Horton *et al.*, 1985; Schmid *et al.*, 1988). High consumption frequency plays a major role in the development of caries (Gustafsson *et al.*, 1954). Between-meal consumption is low in East African populations.

Of the sugars, sucrose is considered to be the most cariogenic, since it is the exclusive substrate for glucan

synthesis, which facilitates plaque accumulation (Carlsson and Egelberg, 1965) and seems to enhance the pH-lowering ability of plaque (van Houte, 1994). The annual sucrose intake *per capita* in East Africa ranges between 6 to 18 kg and is on the brink of the cut-off point for caries (around 15 to 20 kg), as has been suggested by Sreebny (1982). The low daily consumption frequency and the low sucrose intake explain the low caries experience in African populations. The differences in caries experience among the three continents cannot be explained by the prevailing mutans streptococci species but instead should be attributed to differences in the cariogenicity of the diets. A high salivary mutans streptococci count does not necessarily exert a cariogenic challenge, since the available dietary carbohydrates—not the mutans streptococci *per se*—are a prerequisite for the development of caries, according to the dietary carbohydrate-modified bacterial disease concept.

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