On dental caries and socioeconomy in Swedish children and adolescents

Clinical and register-based studies

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ABSTRACT

The overall aim was to analyze the dental caries experience among Swedish children and adolescents and explore it with respect to demographic and socioeconomic factors. **Study I** is a longitudinal clinical study of 271 children, followed from three to six years of age (2003-6), with the aim to analyze initial and manifest caries in the primary dentition. **Studies II–IV** are cross-sectional registry studies of 300,988 children and adolescents, 3–19 years of age (2007-9). **Study II** investigated caries with reference to age, gender and geographical area. **Study III** explored the associations of individual multiple socioeconomic factors on the caries experience. **Study IV** analyzed the variability in caries experience at different area levels with respect to individual demography and socioeconomics. The results showed that young children with an early caries experience had a high risk of disease progression and initial carious lesions constituted a large share of the disease burden (**Study I**). Among 18- and 19-year-olds, only one-third had no manifest caries experience. The disease burden was highly skewed at all ages. Females had a higher risk of a caries experience than males before their teens, with a reverse pattern during the teenage years (**Study II**). Multiple socioeconomic factors had a significant association with the caries experience among children and adolescents, especially the youngest children (**Study III**). Small geographical areas explained more of the variance in caries experience compared with the more aggregated level dental clinics (**Study IV**). In conclusion, disparities in caries experience among Swedish children and adolescents were found with a skewed distribution, within age groups, between genders, between residential areas and in relation to individual socioeconomic status. The findings may serve as a basis for allocating resources in dentistry with the goal/ambition to achieve greater equity of dental health.

Keywords: DMF indices, demography, epidemiology, gender, incidence, parents, preschool child, prevalence, residence characteristics, socioeconomic factor.

SAMMANFATTNING PÅ SVENSKA

Det övergripande syftet med avhandlingen var att analysera barns och ungdomars kariesförekomst och att undersöka kariesförekomsten i relation till demografiska och socioekonomiska faktorer.

Studie I är en longitudinell klinisk studie med 271 3-åriga barn som följdes under fyra år (2003-6). Syftet var att analysera initial och manifest kariesförekomst och kariesutvecklingen i det primära bettet. **Studie II–IV** är tvärsnittsstudier baserat på register avseende 300 988 barn och ungdomar i åldrarna 3 till 19 år (2007-9). I **Studie II** var syftet att undersöka kariesförekomsten avseende ålder, kön och boendeområde. Syftet i **Studie III** var att undersöka individuella multipla socioekonomiska faktorers association till kariesförekomsten bland barn och ungdomar. I **Studie IV** var syftet att analysera variationen i kariesförekomst på olika geografiska nivåer med avseende på demografi och socioekonomi.

Resultaten visade att de små barn som tidigt utvecklade karies hade hög risk för fortsatt karies progression. Initiala kariesskador utgjorde en betydande andel av kariesförekomsten bland de yngsta barnen (**Studie I**). Bland 18- och 19-åriga ungdomar var det endast cirka en tredjedel som inte hade manifesta kariesskador. Kariesförekomsten var kraftigt snedfördelad i alla åldrar. Flickor uppvisade fler kariesskador än pojkar före tonåren med ett omvänt mönster under tonåren, då pojkar hade fler kariesskador än flickor. Barn och ungdomar på landsbygden hade lägre risk för karies jämfört med de som bodde i större städer eller i en storstad (**Studie II**). Socioekonomiska faktorer hade starka associationer till kariesförekomsten bland barn och ungdomar, framförallt bland de yngsta barnen (**Studie III**). Små geografiska områden (small areas for market statistics, SAMS) förklarade mer av variationen i kariesförekomst jämfört med större geografiska områden (tandvårdsklinikers områden) (**Studie IV**). Sammanfattningsvis fanns ojämlikheter i kariesförekomsten bland barn och ungdomar med skev fördelning inom åldersgrupper, mellan könen, mellan bostadsområden och i relation till individuell socioekonomisk status. Resultaten kan tjäna som underlag för fördelning av resurser inom tandvård med målet/ambitionen att uppnå bättre jämlikhet i tandhälsa.

LIST OF PAPERS

This thesis is based on the following studies, referred to in the text by their Roman numerals.

I. André Kramer AC, Skeie M, Skaare A, Espelid I, Östberg AL. Caries increment in primary teeth from 3 to 6 years of age: a longitudinal study. Eur Arch Paediatr Dent 2014;15(3):167-173.

II. André Kramer AC, Hakeberg M, Petzold M, Östberg AL. Demographic factors and dental health of Swedish children and adolescents. Acta Odontol Scand 2016; 74(3):178-175.

III. André Kramer AC, Petzold M, Hakeberg M, Östberg AL. Multiple socioeconomic factors and dental caries in Swedish children and adolescents. Caries Res 2017; 52(1-2): 42-50.

IV. André Kramer AC, Pivodic A, Hakeberg M, Östberg AL. Multilevel analysis of dental caries in Swedish children and adolescents in relation to socioeconomic status. *Pending revision.*

CONTENT

ABBREVIATIONS

CI	Confidence Interval
deft	decayed extracted filled teeth
DT	Decayed Teeth
DFT	Decayed Filled Teeth
DSa	Decayed Surfaces approximally
DFSa	Decayed Filled Surfaces approximally
NBHW	The National Board of Health and Welfare
ICC	Intra Cluster Correlation
OR	Odds Ratio
PDS	Public Dental Service
RR	Risk Ratio
SAMS	Small Areas for Market Statistics
SCB	Statistics Sweden
SD	Standard Deviation
SES	Socioeconomic status
WHO	World Health Organization

1 INTRODUCTION

The World Health Organization (WHO) has defined health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO, 2014). This means that health is a multidimensional concept. This view of health includes symptoms and physical ability as well as emotional and social well-being. The term also includes dental health as an important component (WHO, 2012). Even though the caries disease can be prevented, it still represents a significant health problem. Swedish children and adolescents have good dental health in an international perspective. Caries developed early in life is a predictor of continued disease later in life. For this reason, it is important to explore and analyze the disease, its patterns and possible causes scientifically, to prevent the disease and potential suffering, and to use societal resources for dental care in the best possible way.

1.1 Dental caries

The WHO confirmed dental caries, otherwise known as tooth decay, as the single most common oral condition worldwide in 2012 (WHO, 2012). It is a continuous process, caused by specific bacteria that turn carbohydrates into acid and dissolve the minerals in the tooth. The dental biofilm plays an important role on tooth surfaces if left undisturbed, as the microbial activity results in pH fluctuations when carbohydrates are added, which may cause development of caries. Thus, unfavorable oral and dietary habits contribute to caries development (Fejerskov, et al., 2015). In addition, genetic differences in the susceptibility to caries between individuals have also been explored. Studies have shown that despite good dietary habits, good oral hygiene and preventive measures, some individuals develop caries lesions and, vice versa, some individuals with high sugar intake and lack of good oral hygiene do not develop caries lesions. The findings are associated with the composition of the saliva and the S. Mutans bacterium (Esberg et al., 2017; Strömberg et al., 2017). The caries disease ranges from the early stages beneath the surface of the enamel to severe loss of the complete tooth tissue, and can affect all parts of the tooth: the enamel, the dentine and the cementum (Fejerskov et al., 2015). The different stages of caries are often dichotomized into initial caries and manifest caries (WHO, 2013). The initial stages of the disease are reversible and the tooth can be re-mineralized with preventive measures such as fluoride usage, a controlled diet and oral hygiene. The manifest lesion is not reversible and is commonly treated with removal of the decayed tooth substance that is replaced with a filling, or, if the tooth is too destroyed by decay, extraction of the tooth may be required.

A restored tooth has an increased risk of secondary caries lesions in the future (Fejerskov et al., 2015).

However, the biological factors – bacteria and carbohydrates – are not enough to explain the disease. Dental caries is a multifactorial disease where biological factors and behavioral and ecological determinants are involved in a complicated interaction and contribute to the risk of developing the disease (Selwitz et al., 2007).

1.1.1 Diagnosis of and measures in dental caries

The study of the epidemiology of caries in populations requires a measurement tool. The widely used DMF system (Decayed Missing Filled) was first described in the late 1930s (Klein and Knutson, 1938). The index is used to measure manifest dental caries in both the primary dentition (dmf) and the permanent dentition (DMF). The D component stands for decayed teeth, the M component represents loss due to caries and the F component denotes teeth that have previously been filled, having been decayed before the restoration. The index can be applied at tooth level (dmft/DMFT) or at tooth surface level (dmfs/DMFS). Current disease can be recorded at tooth level only (dt/DT) or at approximal surface level (dsa/DSa). Later, initial caries lesions in different stages as well as different stages of manifest lesions are now included in the diagnosis and measurements of caries (Amarante et al., 1998; Espelid et al., 1990; Pitts and Fyffe, 1988). In addition, there are diagnosis systems that distinguish between caries progress in active or inactive lesions (Nyvad et al., 1999; Pitts, 2004; Frencken et al., 2011; Ismail et al, 2015a).

There is no global consensus on the assessment criteria for caries, but the WHO recommends member states to conduct oral health examinations for surveillance. To ensure that the incidence and prevalence of dental caries continue to be relevant to public health they recommend that the DMFT or the DMFS system be applied. There are also differences in the ability to report caries epidemiology between different countries and WHO regions, for example, between high-income and developing countries (WHO, 2013; Lagerweij and Van Loveren 2015).

1.1.2 Caries prevalence and distribution globally

Despite the substantial decline in caries across many populations in recent decades, dental caries continues to be a major health challenge in most countries in the world, affecting people of all ages. The WHO has reported that 60–90% of schoolchildren and the majority of adults are affected by caries (WHO, 2012). Untreated caries in the permanent teeth affected around

2.4 billion people of all ages and 621 million children had untreated caries in the primary dentition, which leaves dental caries as one of the most prevalent health conditions worldwide (Kassebaum et al., 2015).

A report from the National Health and Nutrition Examination Survey (NHANES) in the United States showed that every third preschool child had dental caries in the primary dentition, and among older children and adolescents, nearly three in five had dental caries experience in the permanent dentition (Dye et al., 2015). The disease is prevalent in several Asian countries, while in African countries it is probably less common (Petersen, 2005). Countries in Central and Eastern Europe have reported a higher caries prevalence than western and northern European countries (Marthaler, 2004; Downer et al., 2005; WHO, 2018). Also, variations in the caries experience between population groups within countries have been confirmed across European countries. Children of low SES and immigrants from outside Western Europe generally have high caries levels. The smallest variations in mean dmft values were seen in Denmark, Finland and Norway, and the greatest in Poland, Slovakia and Albania (Marthaler et al., 1996; Marthaler 2004).

Global population movements with refugees and migrants moving across borders are today the greatest in 20 years. Migrants often experience difficulties accessing both health and dental services in the new country (Reza et al., 2016; Williams et al., 2016; Riggs et al., 2017). The disparity in dental health between native-born and children from foreign countries places demands on the dental health service to adapt dental care to different needs in an appropriate manner (Riggs et al., 2017).

1.1.3 Caries prevalence in Sweden

At the end of the 19th century, the Swedish Dental Association estimated that only seven percent of Swedish schoolchildren had no decayed teeth, and absence from school due to dental infections was common and a major problem. Temporarily improved dental health during World War II was related to sugar restrictions (Lindblom, 2004; Ordell, 2012).

From the middle of the last century, the proportion of children and adolescents with caries experience has decreased. This can be associated with the introduction of fluoridated toothpaste, preventive programs and fluoride rinse programs in schools in the early 1960s (Lindblom, 2004). Since 1985, the National Board of Health and Welfare (NBHW) has compiled data on manifest caries at certain ages (3, 6, 12 and 19 years). In recent years, the dramatic increase in caries-free children has leveled out and stagnation has been noted, especially among six-year-olds (**Figure 1**) (Socialstyrelsen,

2010, 2016, 2017a). Repeated cross-sectional studies in the Swedish city Jönköping have shown has shown a remarkable increase in caries-free children and adolescents over a 40-year period, from 35% in 1973 to 79% in 2013 for three-year-olds, and during the same time period, the mean number of decayed filled tooth surfaces was reduced in 15-year-olds, from 27.7 to 3.0 (Hugoson et al., 1988; Hugoson et al., 2008; Koch et al., 2017).

The WHO has set a goal for dental health in Europe; by 2020, 80% of six-year-olds should be caries-free and 12-year-olds should not have more than 1.5 decayed teeth (DFT), on average (WHO, 2017). Sweden reached the goal for 12-year-olds in 1995. For six-year-olds, the national average was 77% in the latest report, and eight of the county councils had reached the goal (Socialstyrelsen, 2017a).

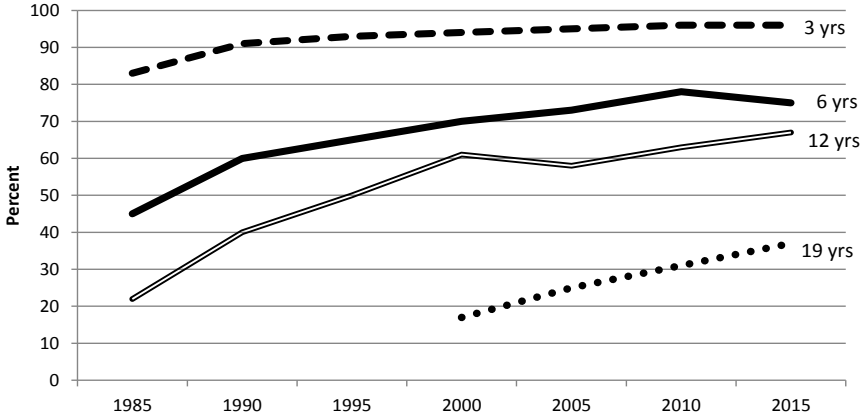


Figure 1. Proportions of 3-, 6-, 12- and 19-year-old children without manifest caries in Sweden from year 1985 to 2015 (Socialstyrelsen, 2010, 2017b).

As initial caries lesions are not included in the epidemiological compilations from the NBHW, it is important to underline that initial caries account for a large proportion of the caries disease. This was also stated by the NBHW (Socialstyrelsen, 2010). Results from Swedish studies on subsamples report the proportions of initial caries lesions to vary between 30% and 40% (Alm et al., 2007; Jacobsson et al., 2011; Isaksson et al., 2013; Bergström et al., 2014). This indicates that the total caries burden is underestimated in the national compilations.

According to reports from the NBHW, there are no gender differences in caries distribution in children and adolescents (Socialstyrelsen, 2010, 2017a). Only a few Swedish studies have analyzed possible gender differences in the dental caries experience and the pattern has been inconsistent. One study

revealed that teenage males had a significantly higher caries incidence than females and received more fillings than females during the study period (Moberg Sköld et al., 2005); however, another study found the opposite (Alm et al., 2012).

1.2 Social inequalities

1.2.1 Social inequalities and general health

Health inequality has been defined as "health differences that are avoidable, unnecessary, unjust, and unfair" (Whitehead, 1991). The global inequalities in general health are well known and despite the reduced mortality, health inequalities have increased in the last decades (WHO, 2016). There are also substantial inequalities in general health between and within countries, in both developed and developing countries (Marmot, 2005; Marmot et al., 2008; Marmot et al., 2012). General health is also influenced by health inequity, meaning that resources are unevenly distributed within a population, leading to inequalities in health. Health equity means trying to distribute resources and actions equally, in order to achieve health and well-being for all (Liburd et al., 2013).

In the "Whitehall studies", the British epidemiologist Michel Marmot found a strong association between social position and general health and mortality in government civil servants. The further down on the social ladder at work individuals find themselves, the, the greater the risk of disease and the higher the mortality rate (Marmot et al., 1991). It was later shown that the unequal distribution of disease between social classes was increasing rather than decreasing over time, which was expected as a result of the introduction of the National Health Service. The inequalities in general health were influenced by many social determinants, such as income, education, housing, employment, diet and conditions of work and not only by failings in the National Health Service (Black, 1980; Gray, 1982).

In the Nordic countries, the inequalities in morbidity between groups with lower and higher educational levels have increased since the beginning of the 70s, despite increased knowledge about inequalities (SOU 2000:91). Even though Sweden has a well-developed welfare system and is often cited internationally as being one of the most equal countries in the world, general health follows a clear social gradient and social inequalities seem to increase over time (Rostila and Toivanen, 2012). Differences in general health may also depend on how social position is defined. The most common indicators for social classification are education, social class and income, which are strongly correlated, as education is usually of importance in order to find a

high-status and high-income job. Having said this, it is possible to find a well-paid job without extensive education, indicating that education is not the same as social position or income (Rostila and Toivanen, 2012). The social gradient varies during life, between genders, between countries and within geographical areas. The gradient differs during a person's life span, being steepest during childhood and in adulthood. The differences in general health are less marked during adolescence and in old age (Rostila and Toivanen, 2012).

Where a person lives has also been recognized to influence health (Diez Roux and Mair, 2010). In studies of neighborhood effects, it is assumed that people's behavior is influenced by the social interaction that occurs between residents in a certain area and that norms and behaviors are communicated with people in the immediate surroundings. Living in a neighborhood where few people have higher education or employment may reduce the residents' potential and expectations to get education and find work. Furthermore, the view on health, health habits and the ability to live a healthy life may be influenced by the social environment (Andersson et al., 2007; Diez Roux and Mair, 2010).

Single and composite deprivation indices for measurements of inequalities in public health and for resource allocation are used extensively in many countries (Jarman, 1983; Townsend, 1987; Pampalon et al., 2014; Hosseinpoor and Bergen, 2016); however, only a few composite deprivation indices are adapted to Nordic circumstances (Bajekal et al., 1996; Malmström et al., 1998; Meijer et al., 2013). In Sweden, for instance, the Care Need Index (CNI) has been useful as a basis for the distribution of resources to health care providers (Sundquist et al., 2003).

Areas for future policies for reducing health inequalities were identified in the late 1990s and more than half of the preventive approaches and recommendations are related directly or indirectly to oral health (Acheson et al., 1998). General health and oral health are inseparably connected and share several risk factors (Sheiham and Watt, 2000). Dental caries and periodontal disease are useful markers of general health and can reveal overall patterns of health inequalities (Heilmann et al., 2015).

1.2.2 Social inequalities and dental health

Since dental caries is a multifactorial disease, efforts have been made to identify individuals at risk of developing the disease (Hausen, 1997). Several assessment tools are available to dental clinicians (Twetman and Fontana, 2009; Hänsel Petersson et al., 2013; Twetman, 2016). Risk factors are described as "an aspect of personal behavior or lifestyle, environmental

exposure, inborn or inherited characteristic, which, on the basis of epidemiological evidence, is known to be associated with a health-related condition considered important to prevent" (MeSH, 2018). Risk determinant is described as a synonym of risk factor with the definition, "any aspect that may increase the chance of developing a disease" (Kirch, 2008). In epidemiology, risk has been defined as "the probability that an event will occur", and it also includes the event occurring within a specific period of time (Rothman, 2012).

As for general health, there is strong evidence of the associations between social inequalities and dental health, with worse dental health at the lower end of the socioeconomic ladder (Locker, 2000). An increasing amount of research evidence demonstrates how social, economic and environmental risk factors influence dental health inequalities (Burt, 2005; Sabbah et al., 2007; Marmot, 2011; Heilmann et al., 2015; Roncalli et al., 2015; Schwendicke et al., 2015).

Through the WHO Collaborating Center, an international multidisciplinary project provided a framework in the early 2000s for the development of explanatory models of inequalities in childhood caries. The project focused primarily on equity of oral health in young children, and inequalities related to social status, ethnicity group, geographic location and poor access to health care. The studies found obvious risk determinants for the impact on children's oral health in different ethnic and socioeconomic groups (Pine et al., 2004).

Children and adolescents with a migration background have been recognized as being at risk of dental caries, mainly related to their lower socioeconomic status compared with native-born children (Bankel et al., 2006; Christensen et al., 2010; Wigen and Wang, 2010). Other explanations of the high caries prevalence among immigrants relate to cultural differences. Attitudes and behaviors linked to dental care may differ between cultures. For example, children of immigrants may more often be given snacks and sweetened drinks between meals and dental attendance tends to be lower among children of immigrants than among children of native-born parents (Skeie et al., 2006b; Skeie et al, 2010). In Sweden, where dental care is free of charge for children and adolescents, immigrants do not attend dental appointments to the same extent as children with native-born parents (Socialstyrelsen, 2013). The lower dental care consumption is attributed to the fact that many immigrants come from countries without traditions similar to those in the Nordic countries, such as preventive dental care and regular examinations (Socialstyrelsen, 2013). Classification like "immigrant status" versus "non-immigrant status" is commonly used in studies (Jacobsson et al., 2011;

Stecksén-Blicks et al., 2014). Ethnic background has also been considered an important factor, depending on the person's country of origin. Differences in caries prevalence have been observed between different ethnic groups (Marcenes et al., 2013; Matsuo et al., 2015; van der Tas et al., 2016).

Low parental educational level is associated with caries experience (Cianetti et al., 2017; Sengupta et al., 2017). The mother's educational level, in particular, is of importance to children and adolescents. Highly educated mothers have been shown to influence their children's dental status positively (Christensen et al., 2010; Wigen et al., 2011; Schwendicke et al., 2015; van der Tas et al., 2017; Warren et al., 2017). This has been explained by individuals with higher education being more inclined to adopt health-promoting habits compared with individuals with lined to lower education. Like migrant status, children of mothers with a low educational level also attended dental clinics less often than children of highly educated mothers (Socialstyrelsen, 2013).

The increased risk of caries disease also applies to children in families with low income and unemployed parents (Christensen et al., 2010; Wigen et al., 2011). Children and adolescents from families with limited economic resources have exhibited a greater risk of dental caries experience (Ekbäck and Persson, 2012; Roncalli et al., 2016; Cianetti et al, 2017; Sengupta et al, 2017). The NBHW has reported that children of parents who receive financial benefits are at increased risk of dental caries compared with children of parents who are not recipients of benefits (Socialstyrelsen, 2013).

Previous caries experience is considered to be one of the strongest single risk predictors for continued disease development (Skeie et al., 2006a; SBU, 2007; Corrêa-Faria et al., 2016; Hänsel Petersson et al., 2016). There is strong evidence already during infancy that individuals with caries lesions continue to develop the disease (Wendt et al., 1991). A recent study (Hultquist and Bågesund, 2016) found that having caries at one year of age was associated with a more than six-fold increased risk of caries at three years of age. The association between the primary and the permanent dentition with regard to caries experience has been explored, and children from preschool age or younger with caries experience tend to develop decayed teeth later on in the primary dentition (Grindefjord et al., 1995; Wendt et al., 1999). The pattern with disease progress in the dentition has also been confirmed among preschool children who were followed to adolescence (Alm et al., 2007; Alm et al., 2012; Isaksson et al., 2013; Mejare et al., 2015; Hall-Scullin et al., 2017).

Region Västra Götaland uses a computer-based system for risk assessment in addition to assessing the risk of developing caries, the system also includes the risk of developing periodontal disease. The analysis is based on data on the patient's caries disease, anamnestic information, dietary habits, oral hygiene, periodontal status, fluoride use and salivary function. The risk assessment is based on the patient's dental, medical and social history, supplemented with a clinical examination, and serves as the basis for both therapy planning and suggestions for the examination recall interval (Folktandvården VGR, 2017).

1.3 Dental care for children and adolescents in Sweden

The first legal regulation on health and dental care in Sweden was introduced in 1663 and concerned permission to perform dental care. It was issued by the Collegium Medicum, today the NBHW. Most dentists at that time were travelling foreigners who stayed temporarily in Sweden. In the mid-1800s, a law on formal dental education was adopted (Lindblom, 2004; Ordell, 2012). During the latter part of the century, the awareness about public health increased in Sweden, like in many other countries at that time. In 1905, a private dentist in the town Köping established the first dental clinic providing dental care to schoolchildren. In the following years, several clinics financed by the municipalities were established. The dentistry profession put forward a proposal to carry out epidemiological studies of dental caries in schoolchildren. The results inspired a series of investigations that would later serve as the basis for the decision to establish the Public Dental Service (PDS) in 1938 (Lindblom, 2004).

However, the PDS was a costly affair for the taxpayers, and neither the government budget nor the availability of dentists sufficed to cover all individuals who needed treatment for decayed teeth. To explore what caused caries, the so-called *Vipeholm study* was initiated and the results, published in 1954, demonstrated the association between frequent carbohydrate intake and caries (Gustafsson, 1954; Gustafsson et al, 1954). These results were the beginning of a growing awareness of the need for preventive dental care.

It was later proposed that all citizens should be entitled to dental care on equal terms and the national dental insurance system was introduced in 1974 for all ages. At the same time, the county councils were given the mandatory task by the government to organize public dental care, free of charge, for all children and adolescents up to and including 19 years of age (Ordell, 2012). From 2017, the law stipulates that dental care should be free of charge for all children and adolescents up to and including 21 years of age, and this will be

expanded from 2019 to 23 years of age. This applies to both the PDS and to private dental care (SFS 1985:125). Some county councils provide free dental care for a few more years already today (Vårdgivarwebben VGR, 2018).

There are both public and private dental care providers in Sweden today. Dental care provision is controlled through political decisions by the government and the county councils. In general, the PDS carries out 95-98% of all dental care for children and young people, while private dental care provides most of the dental care for adults. However, there are large geographic differences regarding the proportion of children and adults treated by public and private dental care providers, respectively (Folktandvården Sverige, 2018).

1.3.1 Dental care in Region Västra Götaland

A goal has been established to provide all individuals entitled to free dental care, including all individuals attending private clinics in Region Västra Götaland (VGR), with high quality dental care on equal terms, including preventive care. Each individual should be examined regularly, based on individual needs and on the risk assessment performed by a licensed dental professional (Folktandvården VGR, 2017).

Region Västra Götaland is one of the most densely populated regions in the country, with roughly one-sixth of Sweden's total population. However, the population density varies considerably in the different parts of the region. In several municipalities, most of the inhabitants live in urban agglomerations and the proportion of residents living in urban areas has increased (Althoff, 2014).

There are a total of 49 municipalities in the VG region and all of them have at least one PDS clinic. Over the past decade, the trend has been for PDS clinics in the VGR to merge into larger units, leading to larger geographical catchment areas for individual clinics (Hassel Gustafsson and Östberg, 2017).

In addition to the clinical examinations and treatments performed by the dental health service, the VGR runs a population-based prevention program with both external and clinic-based activities. The prevention program includes individuals between 0–19 years of age and was introduced at the end of 2008 by the board of the PDS. The purpose of the program is to promote good oral health and to ensure similar guidelines and preventive efforts throughout the region. The program includes information to parents during the child's first year of life and school interventions by dental staff

about tobacco use, dietary habits and oral hygiene. Students in grade 6 to 9 are also treated with a fluoride varnish application by dental staff once or twice per semester (Bergström et al., 2016).

1.4 Registers in Sweden

1.4.1 History of national Swedish registers

The first registration of inhabitants in Sweden was established in the early 1600s, as a result of growing demand from the church and the Swedish government. A system was needed to distinguish between individuals for the levying of tax and the recruitment of soldiers. The clergy kept parish registers of the economy, keeping account of contributions and gifts that were associated with church ceremonies and regarding landownership. The content of the parish registers was expanded, and during the 1700s, some of the administration was transferred to the county governors. Presentation of population statistics began through the collection of statistical tables from the predecessor of today's Statistics Sweden (Andersson, 2006; SCB, 2017).

1.4.2 Statistics Sweden

The world's oldest national population register is from Sweden, one of the two countries in the world, the other being Finland, that maintains coherent information about the population dating as far back as the 17th century. In 1858, Statistics Sweden (SCB) became an authority, and initially, their main task was to compile statistics on population, agriculture, municipal financing, banking and poverty (SCB, 2017). The personal identification number was established in 1947, initially a nine-digit number that later became a ten-digit number (Lunde et al., 1980). All individual-based registers in Sweden are based on personal identification numbers.

During last century, the number of registers was greatly expanded and the aggregated data are often accessible to the public via the Internet. Statistics Sweden is responsible for coordinating the system of official statistics submitted by almost thirty authorities. Only authorities may collect and report population statistics. The authority determines the variables and objects to be investigated and reported on. As one of the first statistics agencies in the world, the SCB has certified all its statistics in accordance with the International Standard for Market, Opinion and Social Surveys and follows the international guidelines. The SCB is governed by a board and also has an ethical committee (SCB, 2013).

There are a number of individual-based registers with information about the entire Swedish population, but also registers on businesses, properties and

geographic classifications. The SCB operates with an administrative division of Sweden, into, *i.a*. counties, municipalities, parishes, real estate and postal code areas. There is also a division of Sweden for statistical purposes, including, *i.a.,* metropolitan areas, type of municipality, localities, small areas and areas defined by coordinates (SCB, 2015) One of the most commonly used registers is The Population Register (RTB), a demographic register of all individuals in Sweden containing information such as date of birth, country of birth, civil status and gender (SCB, 2015).

1.4.3 Swedish registers in the health field

In the Middle Ages, health care and social welfare were integral parts of the monastic activity, until the monasteries were abolished in the 16th century through the Reformation process initiated by king Gustavus I (Gustavus Vasa). Efforts to bring together health care and social welfare again were made after more than 400 years, when the National Board of Health and Welfare (NBHW) was established in 1968. The NBHW is an authority regulated by the Government with responsibility for a wide range of social and health services. Their mission is to protect health, welfare and equal access to good care, and includes the social services, health care and disease control. The NBHW administers a number of registers in order to monitor and analyze trends in health care and social services social (Socialstyrelsen, 2017c).

The NBHW compiles reported statistics on disease, among other things, and evaluates knowledge within a number of areas, such as health care and patient safety. The NBHW is also a regulatory authority in its field of competence (Socialstyrelsen, 2018a). Within dentistry, the 21 county councils in Sweden report on the epidemiology of caries in children and adolescents entitled to free dental care to the NBHW for compilation. Additionally, the NBHW administers a dental health register on adults, based on reports from the national social insurance system (SOSFS 2008:13).

Besides the statutory registers there are today some hundred so-called “national quality registers” receiving financial support from the healthcare authorities and from the government. These registers were established by different health professions. Example of registers related to dental health are the National Quality Registry for Cleft Lip and Palate and the Swedish Quality Registry for caries and periodontal disease (SKaPa, 2017, Socialstyrelsen, 2018b).

1.5 The rationale for the thesis

Against this background, the improvement in dental health among children and adolescents has shown tendencies to stagnate and inequalities in dental health have been observed between groups. There is a need to obtain more knowledge and a better understanding of associated factors for the caries disease and to provide a basis for allocating dental care resources to reduce dental health differences among children and adolescents.

2 AIM

The overall aim of this thesis was to analyze the dental caries experience of children and adolescents and to explore the dental caries experience with respect to demographic and socioeconomic factors.

2.1 Specific aims

- To follow longitudinally and analyze the development of initial and manifest dental caries in the primary dentition among preschool children from 3 to 6 years of age in a Swedish county and to explore the caries disease according to its localization in the dentition (**Paper I**).

- To investigate the dental caries occurrence among Swedish children and adolescents, with special reference to age, gender and residence (**Paper II**).

- To explore possible associations between aggregated multiple socioeconomic factors and dental caries experience in Swedish children and adolescents (**Paper III**).

- To investigate the variability in dental caries experience in Swedish children and adolescents, at two different area levels (dental clinic and small areas) with respect to multiple individual socioeconomic factors (**Paper IV**).

3 MATERIAL AND METHODS

3.1 Designs

3.1.1 Paper I

The study was designed as a longitudinal prospective clinical study of a group of pre-school children. The children were consecutively included in the study in connection with their regular dental check-up at three years of age.

3.1.2 Papers II, III and IV

Papers II–IV were epidemiological register-based cross-sectional studies based on common data material. Data on 3 to 19-year-olds were derived from electronic dental records and from official statistics.

3.2 Participants and data collection

3.2.1 Paper I

A total of 300 guardians of children aged three years were asked to let their child participate in the study; one hundred children each from three PDS clinics in three cities in the Swedish Region of Västra Götaland (VGR), located in southern Sweden (**Table 1**). The clinics were chosen to represent different socioeconomic profiles: rural/industrial, suburban and administrative. The children were examined annually when they were 3, 4, 5 and 6 years old at dental clinics during the years 2003–2006.

Four dentists performed all the examinations at the three PDS clinics. A calibration session was held on two occasions for the dentists, in accordance with a similar Norwegian study (Skeie et al., 2005). The first calibration session was at baseline and the second in the middle of the study period. The calibration sessions were based on examinations of extracted teeth and on photographs of teeth. The exercise included that the four dentists also examined the same 10 children. The dentists then discussed their findings until consensus was reached, based on the diagnostic criteria. The same calibration program was implemented on the second occasion. The inter-examiner reliability from the first session was calculated using weighted Cohen's kappa with an average of 0.64.

Two dentists performed the examinations at one clinic and one dentist per clinic at the other two clinics. If necessary, extra visits were scheduled to train the children and getting them accustomed to dental examinations (Fällström and Nyberg, personal communication,). The caries diagnosis was based on visual inspection of dried teeth, probing, and radiographs when indicated and possible. During the whole study period, the total dropout rate was 10.3% (**Table 1**).

Table 1. Participants in Paper I according to age and dental clinic.

Age of the child	Dental clinic 1	Dental clinic 2	Dental clinic 3	Total
Invited	100	100	100	300
3 years (baseline)	90	87	94	271
4 years	87	84	91	262
5 years	85	83	82	250
6 years	84	79	80	243
Total dropout*	6 (6.7%)	8 (9.2%)	14 (14.9%)	28 (10.3%)

* from baseline

3.2.2 Papers II, III and IV

Epidemiological registrations of dental caries from all dental clinics treating 3 to 19-year-old children and adolescents, both in the PDS and in private dental care, in the Swedish Region of Västra Götaland, were included in the study base.

Data from electronic dental records were provided by the Regional Health Department, the responsible body for the Public Dental Service, as text files. Data from private dental care were merged with data from the PDS clinic in the area and the text files were entered using the SPSS software (Statistical Package for the Social Sciences).

The main year for collection of electronic records was 2009. Since the recall period was individual, the time period between the examinations could vary by up to 24 months. The data were therefore supplemented with recordings from 2008 and 2007, to obtain a final coverage of 97.3% of the total population in the studied ages in the VGR (**Table 2**). If an individual had more than one recording the most recent one was kept. Dentists or dental hygienists had performed the examinations and the recordings were retrieved from regular dental check-ups. Statistics Sweden (SCB) delivered the data on socioeconomic status (SES) for the individuals, their parents and the household. The SES data were based on the date December 31, 2008. This date was chosen to be in the middle of the period and because the majority of

individuals in the study base had recordings from examinations in 2009. The SCB retrieved the SES data via the individuals' personal identification numbers. The SCB then replaced the personal identification number with an identical serial number for both dental records and SES data. The two files were delivered by the SCB and merged into one file in the SPSS software.

Table 2. Number of participants in Papers II–IV

Year	**Number of individuals** (n)	**Proportion of the study population** (%)
2007	41,690	14
2008	96,262	32
2009	163,036	54
Total	300,988	100

3.3 Variables

3.3.1 Paper I

Initial and manifest dental caries lesions were recorded according to a five-grade system. Grade 1 and 2 constituted initial lesions and grade 3, 4 and 5 manifest lesions (**Figure 2**) (Espelid et al., 1990). Dental caries diagnoses were recorded in a specific protocol (**Figure 3**).

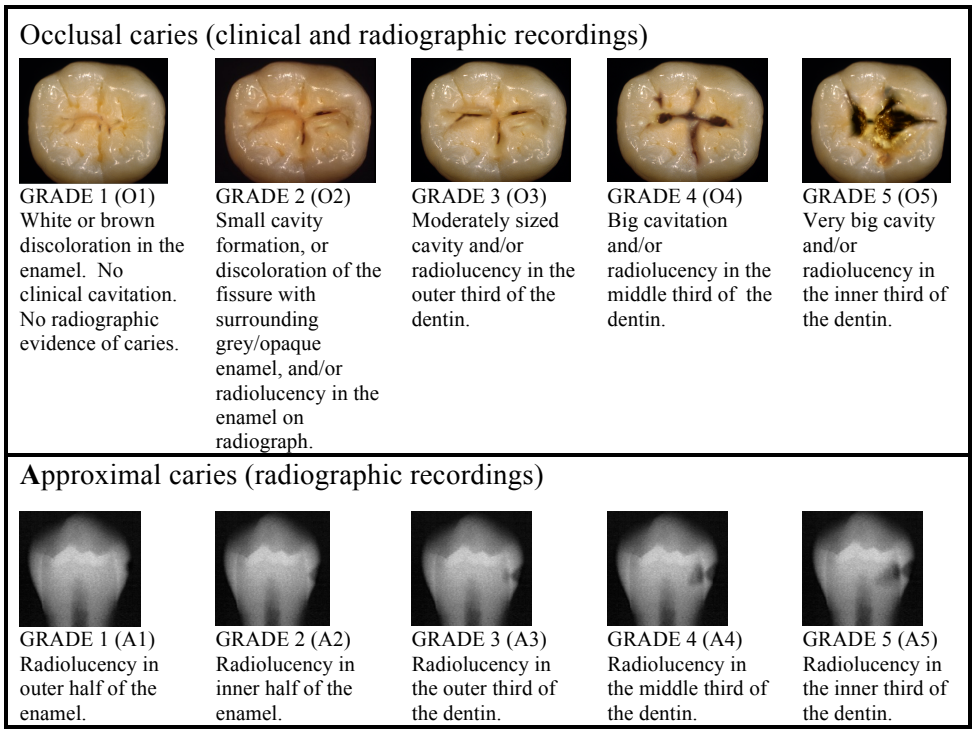
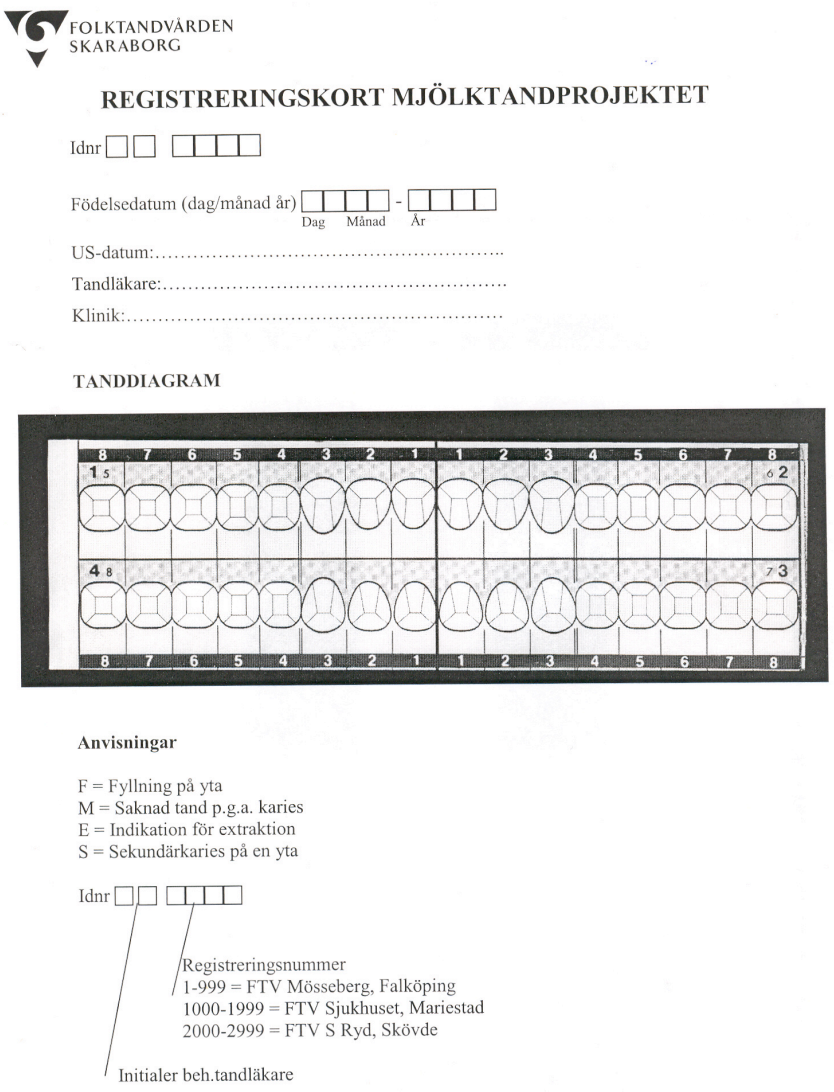


Figure 2. Clinical and radiographic recordings of occlusal and approximal caries grade 1 to 5 (with permission from Espelid, 2017).



FOLKTANDVÅRDEN
SKARABORG

REGISTRERINGSKORT MJÖLKTANDPROJEKTET

Idnr ☐☐ ☐☐☐☐

Födelsedatum (dag/månad år) ☐☐☐☐ - ☐☐☐☐
Dag Månad År

US-datum:.....

Tandläkare:.....

Klinik:.....

TANDDIAGRAM

8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8

8 7 6 5 4 3 2 1 1 2 3 4 5 6 7 8

Anvisningar

F = Fyllning på yta
M = Saknad tand p.g.a. karies
E = Indikation för extraktion
S = Sekundärkaries på en yta

Idnr ☐☐ ☐☐☐☐

Registreringsnummer
1-999 = FTV Mösseberg, Falköping
1000-1999 = FTV Sjukhuset, Mariestad
2000-2999 = FTV S Ryd, Skövde

Initialer beh.tandläkare

Figure 3. Registration-protocol for dental caries diagnoses and fillings for Paper I.

3.3.2 Papers II, III and IV

The DMFT system was used (Klein and Knutson, 1938). The indices used for the primary dentition and the permanent dentition are shown in **Table 3**. Only manifest lesions in both dentitions were recorded.

Table 3. Dental caries variables used in studies II–IV.

Dental caries index	Variable name	Age
deft	decayed filled teeth	3–9
DT	Decayed Teeth	7–19
DFT	Decayed Filled Teeth	7–19
DSa	Decayed Surface approximally	7–19
DFSa	Decayed Filled Surface approximally	7–19

Variables delivered by the SCB concerning gender, residential community, SAMS areas, country of birth, migration background, the household's disposable income, parental education and parental occupation described the demographic and socioeconomic status of the individuals (**Table 4**). The SAMS areas are illustrated in **Figure 4**.

Table 4. Registers, demographic- and SES variables for studies II–IV provided by Statistics Sweden.

Register	Variable name	Study
The Total Population Register	Gender[1]	II, III, IV
	Country of birth[1]	III, IV
	Migration background[1]	III, IV
Register of Households' Housing and Finances	Disposable income[2]	III, IV
	Social welfare allowance[2]	III, IV
	Housing allowance[2]	III, IV
The Longitudinal Integration Database for Health Insurance and Labor Market Studies	Residential community[1]	II
	SAMS area[1]	IV
	Educational level[3]	III, IV
	Employment days[3]	III, IV
	Occupation[3]	III, IV

[1] Individual level. [2] Family level. [3] Parental level (mother and father, respectively).

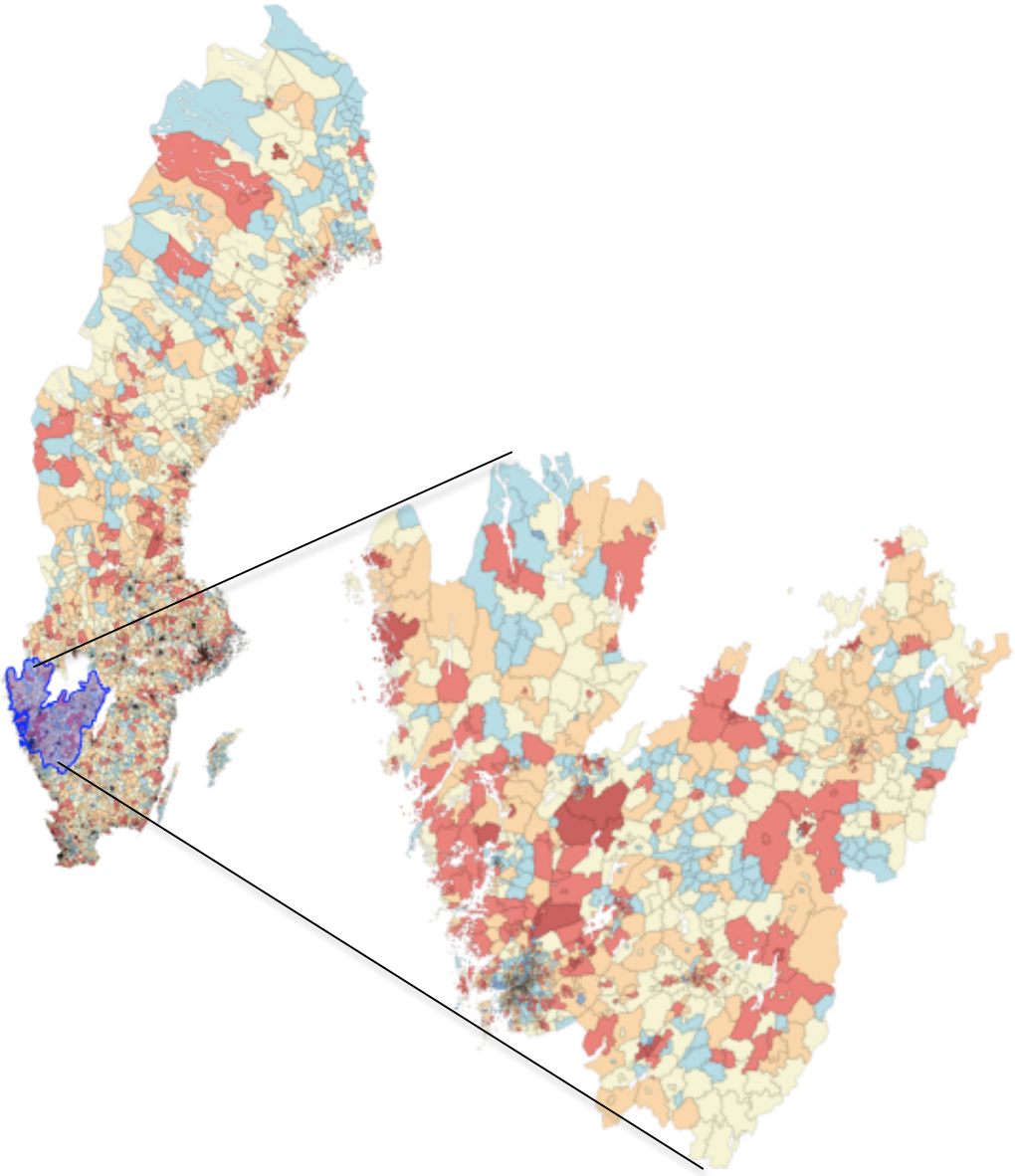


Figure 4. SAMS areas in Sweden and in Region Västra Götaland, respectively (with permission from SCB).

3.4 Data analysis

The statistical methods used in the papers are presented in **Table 6**.

3.4.1 Paper I

The data were registered in the Epi info software, version 6.04d (CDC, 2001), and the statistical analyses were made using the SPSS, version 19.0 (SPSS., 2011). The MedCalc Software version 12.4.0 was used to calculate Cohen's kappa for inter-rater reliability between the examiners (MedCalc, 2012). Descriptive statistics for the study group included mean values, frequency value distributions and standard deviations (SD). Analyses were made both at tooth and surface level. The tooth level was categorized into three groups, *incisors and canines, first molars* and *second molars* (**Figure 5**). The dentition as a whole was analyzed. As an overall initial test, Friedman's test was performed to explore differences in caries occurrence during the study period. The Chi-square test was performed to analyze differences in caries prevalence between genders. Wilcoxon's non-parametric, two-related-samples test was used to analyze the annual caries increment, and logistic regression was applied to explore the predictive power of the caries outcome between baseline and the end of the study period.

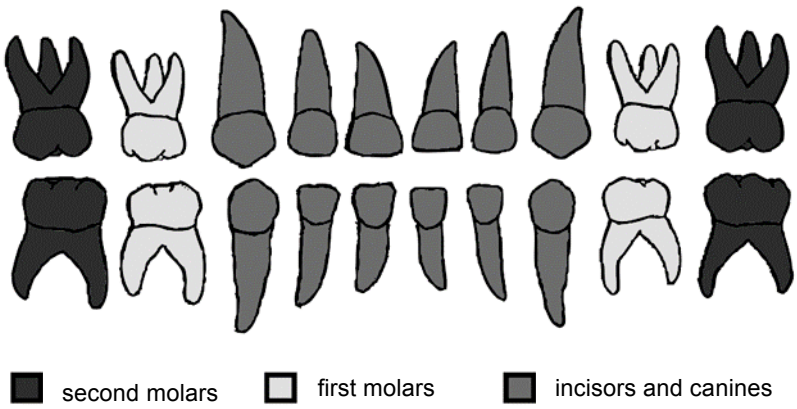


Figure 5. Primary dentition grouped in "incisors and canines", "first molars" and "second molars"

3.4.2 Paper II

All analyses in **Papers II–IV** were performed using the SPSS, version 22 (SPSS, 2013).

Description of the population was presented with mean values, confidence intervals and frequencies. The ANOVA test was used to explore initially if there were any overall differences between the sub-groups (gender, age group and residential community). Age was categorized into age groups, 3–6 and 7–9 years for the primary dentition, and 7–9, 11–12, 13–15, 16–17 and 18–19 years for the permanent dentition. Residential community was classified on the basis of structural parameters in accordance with a national system used by the Swedish Association of Local Authorities and Regions (SKL, 2014) into *rural, urban* and *metropolitan* areas **(Paper II)**. ANOVA is a variance analysis used to compare mean values for more than two groups and tests the hypothesis that all mean values are equal and all mean values are tested at the same time. The variance analysis compares the variation within groups with the variation between groups (Altman, 1999). If the ANOVA test gives a significant result, the null hypothesis can be rejected. A commonly used level is 95%, meaning that there is 95% confidence that a least one of the mean values differs from the others in a way that is not dependent on chance. It is not possible, based on the analysis of variance, to determine which of the group means that differ. For this reason, a so-called "post-hoc" analysis was performed to explore which groups' mean values were statistically different from each other. Bonferroni adjustments were made when the null hypothesis was rejected. This is done to reduce the risk of obtaining false-positive results (type I error) when multiple pair-wise tests are performed on a single set of data. Generalized linear regression models with Poisson distribution for the caries variables were used (rate ratios, RR) to analyze the caries occurrence between the sub-groups, Poisson distribution was applied as the caries outcome was assumed to occur independently. In addition, logistic regression analyses were made with dichotomized caries variables as the outcome. Fisher's exact test was also used for dichotomous variables to compare percentage distributions.

Dental caries was analyzed, handled as a continuous variable, and as dichotomized variables. The dental caries indices were dichotomized into no caries (0) or caries (1). Analyses with alternative dichotomizations were carried out, allowing 0-1/0-2/0-3 decayed teeth/lesions in the reference category (0) versus ≥2/≥3/≥4, (1) (**Papers II–IV**).

3.4.3 Paper III

Descriptive frequencies for the study group were calculated. To handle missing SES variables, multiple imputation was performed for missing SES values. These were taken from estimates of the distribution of the known variables (Donders et al., 2006). This was done to reduce the risk of distortion that may occur due to missing data, and to make it possible to perform all the analyses. All SES variables were included as predictors in the imputation model. Ten separate imputation sets with estimated values (imputation 1–10) were calculated. After the imputation, the SES variables were dichotomized and are presented in **Table 5**. The classification of migration background followed the guidelines from the SCB, consistent with those of the United Nations and Eurostat (SCB, 2013). Disposable income was dichotomized into families with an income above the lowest quintile versus the lowest quintile (Vyas and Kumaranayake, 2006). Educational level was categorized according to compulsory schooling, into > 9 years (0)/ ≤ 9 years (1). Principal component analysis (PCA) was carried out to explore the interaction of the dichotomized SES variables. The scores from the first factor from the PCA were used as an SES index variable in the following analyses. The full model in the PCA contained all the dichotomized SES variables. Reduced models, where variables with item loadings < 0.5 were omitted, were also tested. The scores from the first factor were saved and dichotomized into 'above the lowest quintile' (< 20% coded as 0) versus 'the lowest quintile' (≤ 20% coded as 1), and used as the independent variable in logistic regression (Vyas and Kumaranayake, 2006). Logistic regression models with the variable from the PCA were used to explore binary outcomes. All analyses were made on both the original data and the imputed data.

*Table 5. Dichotomization (0/1) of the SES variables for **Papers III** and **IV**.*

SES variable	**0**	**1**
Country of birth	Born in Sweden	Born abroad
Migration background	Native background Born in Sweden with two native Swedish parents or born in Sweden with one native Swedish and one foreign-born parent	Foreign background Foreign-born or born in Sweden having two foreign-born parents
Disposable income	Above the lowest quintile (> 20%)	The lowest quintile (≤ 20%)
Social welfare allowance	No	Yes
Housing allowances	No	Yes
Educational level*	> 9 years	≤ 9 years
Employment status*	No unemployment days	Unemployment days ≥ 1
Occupation*	Worked all year	Worked occasionally or not at all during the year

** Mother and father, respectively. All data extracted 2008-12-31.*

3.4.4 Paper IV

Descriptive analyses were made using the SPSS. All other analyses were performed in the Statistical Analysis System (SAS, 2017). The SES index (constructed from PCA, **Paper III**) was used as the independent variable, categorized into the 1st to 5th deciles as the reference category and the 6th to 10th deciles as separate categories. Two-level multilevel regression models were used to investigate whether there was variability in dental caries experience between dental clinic areas and between SAMS areas, respectively, and to which extent the variability could be explained by age, gender and the individual SES (Merlo et al., 2005; Hayes, 2006; Ene et al., 2014). Five models were fitted separately to the two different area types (dental clinic and SAMS). Model 1 analyzed the probability of individuals attending a typical dental clinic or within a typical SAMS area of having caries experience (empty model). In Model 2, adjustment was made for age. In Model 3, gender was added to age, with females as the reference, and in Model 4, adjustment for age and gender was added as an interaction term, all as fixed- effects. In Model 5, the categorized SES index was added as a fixed effect. To explore the variability for dental caries experience at the dental clinic level and the SAMS level, the ICC was computed for the five models. The five models were tested consecutively for goodness-of-fit for deviance in likelihood ratios.

Table 6. Methods for statistical analyses in studies I–IV.

Study	Statistical methods
I Clinic-based data	Descriptive statistics, Cohen's kappa, Friedman's test, chi-square analyses, Wilcoxon non-parametric test; two-related-samples test
II Register-based data	Descriptive statistics, ANOVA, Generalized Linear Regression Model, Logistic regression, Fisher's Exact Test
III Register-based data	Descriptive statistics, multiple imputation, Principal Component Analysis, Logistic Regression
IV Register-based data	Descriptive statistics, Multilevel Regression Model, Intra Cluster Correlation

3.5 Ethical considerations

3.5.1 Paper I

All guardians of the participating children signed a written informed consent form. They were also informed about the purpose of the study, the possibility to leave at any point of time without giving a reason, and that this would not affect their children's future dental care. Linguistic help was offered when needed. The study was approved by the Regional Ethical Review Board in Gothenburg (No. O199-02).

3.5.2 Papers II, III and IV

In register studies, the individual cannot choose to refrain from participating as the data are already recorded, which may be regarded as an ethical dilemma. It is of utmost importance to handle the data so that individuals cannot be identified, and this was taken into account. Due to the large number of individuals in the study material, it was not possible to obtain written informed consent.

The Regional Ethical Review Board in Gothenburg approved the study (No. 507-10). The SCB also conducted an internal confidentiality and scrutiny process regarding the socioeconomic information. The SCB removed the personal identification number and replaced it with a serial number before delivering the socioeconomic data, to ensure that the researcher had no access to individual SES data.

4 RESULTS

4.1 Dental caries experience

In the clinical study (**Paper I**), the caries increment among the youngest children (3-6 years) showed statistically significant associations from three to six years of age for both initial and manifest caries in the dentition as a whole. Among three-year-old children, almost one child in four had initial caries and one in eight had manifest caries (8.9%). At six years of age, only half of the children were free from dental caries (**Table 7**). The primary second molar was the most affected tooth during all the years studied, both at tooth level and at surface level. When the children were six years old, the greatest proportion of manifest caries at tooth level was seen in the first primary molars, and at surface level on the approximal surfaces. The pattern was inconsistent between years (**Table 7**) (**Paper I**).

In the register-based studies **(Papers II–IV),** the total manifest caries experience, expressed as the mean (SD) in the primary (3–6 years) and permanent (7–19 years) dentition in the study group as a whole, was low overall (**Table 8**). The proportion of children and adolescents free from manifest caries were consistently lower at higher ages in all studied indices (**Paper II**). Among 18–19-year-olds, the proportion of adolescents free from manifest dental caries was 32% and without approximal lesions about 65%. The distribution of the dental caries experience was highly skewed in all ages; *i.e.*, the disease burden was substantial among those with caries (**Paper II**). In **Paper II,** the caries mean was analyzed in age groups, both for the total group and separately for those with caries. Among the 3–6-year-olds, the mean deft value in the total group was 0.49 (95%, CI 0.48–0.51), and in the group with caries it was 3.09 (95%, CI 3.04–3.14). The skewness was most marked for the DT and the DSa indices (**Figure 6**), but statistically significant for all studied indices (**Figure 7**) (**Paper II**).

Table 7. Proportions (%) of children with initial and manifest caries at tooth and surface level at 3, 4, 5 and 6 years of age. P-value between 3 and 6 years of age at individual level for caries increment (**Paper I**).*

	3 yrs. (%)	**4 yrs.** (%)	**5 yrs.** (%)	**6 yrs.** (%)	**p-value*** 3→6 years
Initial caries					
Incisors and canines	9.2	9.5	12.8	12.8	0.172
First molars	9.2	12.2	12.8	21.4	< 0.001
Second molars	16.2	29.0	33.6	32.5	< 0.001
Buccal	10.0	14.1	20.0	18.9	< 0.001
Lingual	4.1	5.3	6.4	7.8	0.043
Occlusal first molars	7.0	7.3	6.4	9.5	0.106
Occlusal second molars	13.7	24.8	28.0	28.0	0.001
Approximal	2.6	5.0	8.0	17.3	< 0.001
Total dentition	24.7	34.7	36.8	42.8	< 0.001
Manifest caries					
Incisors and canines	4.8	7.3	8.0	8.6	0.003
First molars	4.4	6.1	10.4	13.2	0.002
Second molars	4.8	12.6	14.4	12.8	< 0.001
Buccal	3.7	4.2	3.2	3.7	0.550
Lingual	1.8	1.5	4.0	3.3	0.221
Occlusal first molars	4.8	5.0	4.0	2.9	0.312
Occlusal second molars	5.2	11.8	11.6	9.1	0.072
Approximal	4.1	7.3	12.4	18.1	< 0.001
Total dentition	8.9	18.0	21.2	23.5	< 0.001
Initial and manifest caries	27.3	38.1	42.0	49.4	< 0.001

Table 8. Manifest caries experience in the total study group (**Paper II–IV**).*

Dental caries index	**Dental caries**		
	(%)	(mean)	(SD)
deft	16.0	0.49	(1.57)
DT	16.9	0.30	(0.90)
DSa	7.0	0.13	(0.61)
DFT	44.9	1.33	(2.23)
DFSa	19.1	0.47	(1.47)

* n = 300,988

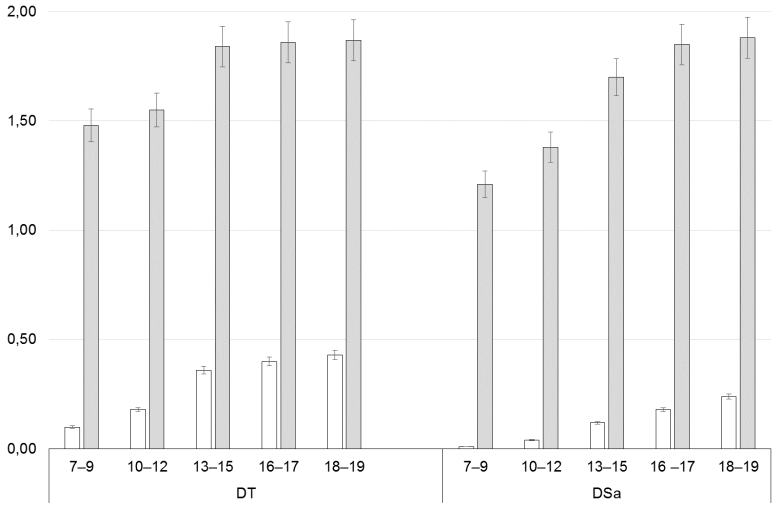


Figure 6. Mean values and 95 % confidence intervals for the DT and DSa indices in age groups, in the total group (plain bars) and in the group with caries (grey bars).

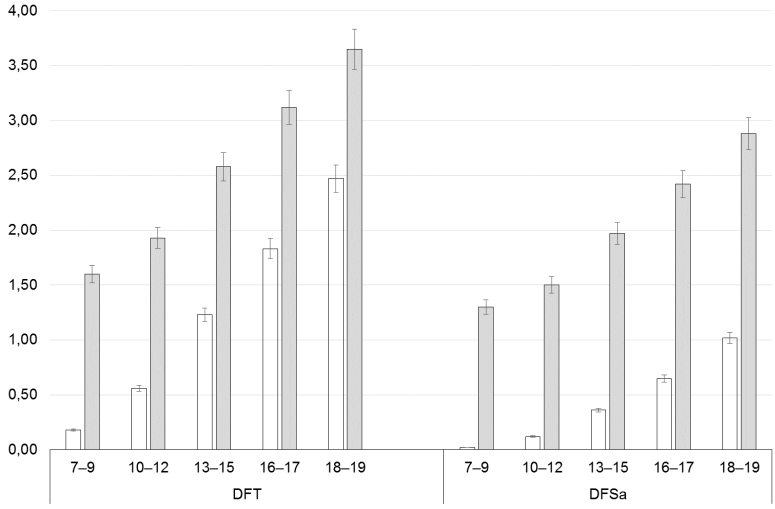


Figure 7. Mean values and 95 % confidence intervals for the DFT and DFSa indices in age groups, in the total group (plain bars) and in the group with caries (grey bars).

4.2 Gender and caries

In **Papers II–IV**, possible associations between gender and dental caries experience were explored. A consistent pattern for the primary dentition was revealed in **Paper II**, with young boys being at a higher risk of dental caries than young girls. For the permanent dentition, a gender gradient was disclosed; adolescent males were at a higher risk of dental caries experience than their female counterparts, while the reverse pattern was seen the before adolescence (**Table 9**).

In **Paper III,** associations between dental caries and SES were analyzed with logistic regressions analyses. Adjustments for gender and age strengthened the associations for dental caries experience overall and this was most pronounced among the youngest children (deft index) (**Paper III**). In **Paper IV,** the associations between gender and caries experience were confirmed. Boys were at a higher risk than girls of dental caries experience when adjustments for age were made for the DFSa, DT and DSa indices, and at a lower risk when age adjustment was made for the DFT index. Using dichotomized caries indices strengthened the associations (**Paper IV**). Also, in **Paper I**, the only significant association between gender and caries was observed among the 4 -year-olds; girls were at a higher risk of dental caries compared with boys of the same age.

Table 9. Rate ratios (RR) with confidence intervals (95% CI) of caries indices (deft, DFT, DSa, DT and DSa) between genders (ref. boys), separately by age group by means of generalized linear modeling in full models. Dependent variables: continuous caries indices.

	Girls	
	RR	CI
deft		
3–6 yrs.	0.93	0.90–0.95
DFT		
7–9 yrs.	1.19	1.13–1.25
10–12 yrs.	1.12	1.09–1.15
13–15 yrs.	1.05	1.02–1.07
16–17 yrs.	1.01	0.99–1.03
18–19 yrs.	0.98	0.97–0.99
DFSa		
7–9 yrs.	0.97	0.83–1.13
10–12 yrs.	0.96	0.91–1.02
13–15 yrs.	0.98	0.95–1.01
16–17 yrs.	0.93	0.90–0.95
18–19 yrs.	0.90	0.88–0.91
DT		
7–9 yrs.	1.10	1.03–1.17
10–12 yrs.	1.12	1.07–1.17
13–15 yrs.	0.94	0.90–0.97
16–17 yrs.	0.84	0.81–0.87
18–19 yrs.	0.83	0.81–0.85
DSa		
7– 9yrs.	1.01	0.81–1.25
10–12 yrs.	1.07	0.97–1.17
13–15 yrs.	0.94	0.88–0.99
16–17 yrs.	0.80	0.76–0.84
18–19 yrs.	0.78	0.75–0.80

deft = decayed filled teeth (primary dentition)
DFT = Decayed Filled Teeth
DFSa = Decayed Filled Surfaces approximally
DT = Decayed Teeth
DSa = Decayed Surfaces approximally

4.3 Socioeconomy and dental caries

The SES characteristics of the study population in **Papers III–IV** are presented in **Table 10**. In **Table 11,** single SES factors associated with dental caries experience are presented (**Paper III**). For example, the strongest association with a caries experience was observed for the variables *social welfare allowance* and *migration background*, both for children 3-6 years of age (deft index). In the permanent dentition, the variables *social welfare allowance* and *migration background* had the strongest associations with caries experience in all studied indices (DT, DSa, DFT and DFSa). *Family disposable income* and *father's education* were two of the variables with weaker associations with a caries experience (**Paper III**). Using an alternative dichotomization of the caries indices, allowing up to three decayed teeth in the reference category, strengthened the associations throughout.

In **Paper III,** the single SES variables were studied separately and in a combined index. All separate SES variables were included in a PCA. The scores from the item loadings in the PCA from the first factor were similar in the original and the imputed data. The scores from the first factor were saved and categorized into the quintile with the lowest SES score versus the four quintiles with higher SES scores. The dichotomized index was used in logistic regressions and as an explanatory variable. The SES index was significantly associated with dental caries experience in all caries indices, with the strongest ORs among the youngest children in the primary dentition. For 3–6-year-old children, the risk of dental caries was about three times higher for those with an unfavorable SES compared with children from privileged families (OR 3.26; 95% CI 3.09–3.43, deft). Adjustments for age and gender strengthened the association (**Paper III**).

In **Paper IV,** the SES index from **Paper III** was used as an independent variable, categorized into deciles. The reference category for the SES index was the 1st to the 5th deciles, as the distribution of the SES index was skewed with roughly half of the individuals representing the least deprived category. For deciles 6 to 8, the associations with dental caries were quite similar, and the strongest associations were observed from the 9th to the 10th decile (most deprived), compared with the least deprived (1st to 5th deciles), after adjustments for age and gender. The pattern was similar for all caries indices, with the largest differences in OR among the youngest children (deft index) between the 9th and the 10th decile. Also, the strongest associations between SES and dental caries were observed among the youngest children. The association with caries was five times higher for the most deprived children

(10^{th} decile), compared with children in the reference category (1^{st} to 5^{th} deciles) (deft index) (**Paper IV**).

*Table 10. SES characteristics with proportions (%) of the study population (**Papers III & IV**).*

Socioeconomic status	**%**
Country of birth: abroad	7.2
Migration background: foreign*	17.4
Family disposable income below €24,550	20.0
Social welfare allowance	6.7
Housing allowance	14.0
Educational level ≤ 9 yrs. mother	11.4
Educational level ≤ 9 yrs. father	14.6
Unemployment days ≥ 1, mother	8.8
Unemployment days ≥ 1, father	6.1
No gainful occupation, mother	16.9
No gainful occupation, father	9.2

*Foreign-born or born in Sweden with two foreign-born parents.
Missing data for individual and family; 0–<1%, mother 7.7–8.6%, father 20.5–21.1%

Table 11. Associations in original data between single socioeconomic variables and dental caries. OR and 95% CI adjusted for age and gender.

	deft*		DT		DSa		DFT		DFSa	
Independent variable	OR	CI	OR	CI	OR	CI	OR	CI	OR	CI
Country of birth	3.31	3.04–3.61	2.32	2.25–2.40	2.76	2.64–2.89	1.95	1.89–2.02	2.11	2.04–2.18
Migration background	4.77	4.53–5.01	2.54	2.47–2.60	3.20	3.09–3.31	2.32	2.26–2.38	2.44	2.38–2.51
Family disposable income	2.55	2.42–2.68	1.59	1.55–1.63	1.66	1.60–1.72	1.38	1.35–1.41	1.33	1.30–1.37
Social welfare allowance	5.16	4.80–5.54	2.78	2.68–2.88	3.13	2.98–3.27	2.41	2.32–2.50	2.26	2.18–2.35
Housing allowance	3.60	3.41–3.80	2.15	2.09–2.21	2.51	2.42–2.61	1.93	1.89–1.99	1.92	1.86–1.97
Education mother	3.30	3.10–3.51	2.17	2.10–2.24	2.48	2.37–2.59	2.08	2.02–2.14	2.05	1.98–2.11
Education father	2.30	2.15–2.45	1.57	1.52–1.62	1.64	1.56–1.72	1.53	1.49–1.58	1.46	1.42–1.51
Unemployment days mother	1.90	1.78–2.02	1.69	1.63–1.76	1.85	1.75–1.96	1.52	1.47–1.58	1.51	1.45–1.57
Unemployment days father	2.64	2.44–2.85	1.94	1.85–2.03	2.13	1.99–2.28	1.74	1.66–1.81	1.74	1.65–1.83
Gainful occupation mother	3.13	2.98–3.29	2.20	2.13–2.26	2.54	2.45–2.65	1.84	1.79–1.89	1.90	1.84–1.95
Gainful occupation father	3.54	3.29–3.80	2.17	2.09–2.25	2.45	2.32–2.57	1.90	1.83–1.96	1.90	1.83–1.98

* 3–6 years † 7–19 years. deft:decayed extracted filled teeth, DT:Decayed Teeth, DSa:Decayed Surfaces approximally, DFSa:Decayed Filled Surface approximally.
All caries indices dichotomized ≥1 lesion vs no lesions.
Country of birth: born abroad vs born in Sweden. Migration background: foreign background vs native background. Family disposable income: lowest quintile vs above lowest quintile. Social welfare allowance: yes vs no. Housing allowance: yes vs no. Education mother: ≤9 yrs (compulsory schooling) vs >9 years. Education father: ≤9 yrs (compulsory schooling) vs >9 years. Unemployment days mother, number of days during the year: ≥1 days vs no days. Unemployment days father, number of days during the year: ≥1 days vs no days. Gainful occupation mother: not working at all during the year vs worked all year. Gainful occupation father: not working at all during the year vs worked all year.

4.4 Areas and caries

In **Paper II,** associations between residential areas in the VGR and caries experience were explored. Children and adolescents living in urban and metropolitan areas had a higher risk of dental caries, both in the primary and the permanent dentition, than their counterparts living in rural areas. The associations with dental caries experience were up to more than twice as high as for children living in metropolitan areas, compared with children living in rural areas (**Paper II**). Using an alternative dichotomization of caries, allowing up to two decayed teeth/lesions in the reference category, strengthened the outcomes throughout.

Paper IV had a multilevel approach to explore the variability in dental caries in dental clinic areas and in SAMS areas. The ranges in dental caries mean values (min.-max.) for all studied indices are presented in **Table 12**. The ranges were wider in SAMS areas than in dental clinic areas, with the widest range for the deft index (**Table 12**).

*Table 12. Ranges (min.-max.) in dental caries mean (SD) at dental clinical level and at SAMS area level (**Paper IV**).*

	Dental clinic areas	**SAMS areas ***
Dental caries index	**Dental caries** mean (SD) $_{min}$ – mean (SD) $_{max}$	**Dental caries** mean (SD) $_{min}$ – mean (SD) $_{max}$
deft	0.09 (0.50)–1.31 (2.63)	0.00 (0.00)–3.08 (3.64)
DT	0.10 (0.50)–0.87 (1.69)	0.00 (0.00)–1.37 (2.08)
DSa	0.03 (0.20)–0.37 (1.17)	0.00 (0.00)–0.91 (2.15)
DFT	0.42 (1.11)–3.08 (3.53)	0.29 (0.59)–4.02 (4.86)
DFSa	0.20 (0.63)–1.06 (2.44)	0.03 (0.18)–2.24 (4.17)

* SAMS areas with < 30 individuals not included (391 areas, n = 4727)

The distribution of the individual SES variables in **Paper IV** in dental clinic areas and in SAMS areas is shown in **Table 13**. There was wide variation in the proportion of individuals with unfavorable SES in single variables in the SAMS areas. For all variables, there were SAMS areas without any low-scoring individuals; the corresponding findings for dental clinic areas only applied to two of the variables. The variable *family disposable income below € 24,550* had a similar maximum proportion in dental clinic areas and SAMS areas. The maximum proportion was notably higher for all other variables in the SAMS areas (**Paper IV**).

Table 13. Socioeconomic characteristics of the study population in the total group of children and adolescents in dental clinic areas and in SAMS (Small Areas for Market Statistics) in Västra Götaland Region, Sweden.

	Dental clinic area	**SAMS area**[1]
Socioeconomic status	Proportion (%) min – max	Proportion (%) min – max
Country of birth: abroad	1.7–20.8	0–39.0
Migration background: foreign[2]	1.7–72.9	0–90.0
Family disposable income below €24,550[3]	6.0–50.0	0–51.0
Social welfare allowance	0.1–39.9	0–67.7
Housing allowance	1.9–47.8	0–84.6
Educational level ≤ 9 yrs., mother	2.3–40.0	0–60.3
Educational level ≤ 9 yrs., father	3.6–32.1	0–54.3
Unemployment days ≥ 1, mother	2.8–20.3	0–24.2
Unemployment days ≥ 1, father	0–29.2	0–35.4
No gainful occupation, mother	6.1–63.4	0–86.6
No gainful occupation, father	0–40.1	0–68.3

[1] SAMS areas with < 30 individuals not included (391 areas, n = 4727)

[2] Foreign-born or born in Sweden with two foreign-born parents

3 Lowest quintile of income in the total group

Missing data for: individual and family 0 – < 1%, mother 7.7–8.6%, father 20.5–21.1%

In **Paper IV,** the ICC (intra cluster correlation) was computed to estimate the variability in dental caries experience in dental clinic areas and in SAMS areas. The variability was low overall for all the studied indices, but stronger at the smaller SAMS areas than at the larger dental clinic areas (**Table 14)**. The ICC increased in all indices from Model 2 to Model 4 when age, gender and an interaction of age and gender were stepwise included in the three models, compared with the empty model, both at the dental clinic level and at the SAMS level. In Model 5, the SES was included, and the low ICC indicated a small variability in dental caries experience within the neighborhood area, which was explained by differences between the areas; *i.e.,* the individuals in the area were similar when the SES was included, and the ICC somewhat higher at the lower SAMS level, particularly for the youngest children (deft) (**Paper IV**). Using an alternative dichotomization of caries indices, allowing up to two decayed teeth/lesions in the reference category, strengthened the outcomes throughout.

Table 14. Variability for dental caries experience in dental clinic areas and in SAMS areas in Region Västra Götaland, Sweden.

	Dental clinic areas					SAMS areas				
	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**
ICC[1] / ICC_{adj} [2]										
deft[3]	0.0674	0.0736	0.0736	0.0736	0.0342	0.1070	0.1202	0.1203	0.1203	0.0435
DT[4]	0.0499	0.0535	0.0535	0.0536	0.0417	0.0621	0.0657	0.0658	0.0659	0.0423
DFT[5]	0.0297	0.0454	0.0454	0.0454	0.0354	0.0370	0.0548	0.0548	0.0548	0.0398

[1] ICC: Intra Cluster Correlation, amount of variability in dental caries accounted for by clinic/SAMS.
[2] ICCadj: ICC adjusted from Model 2 for age; Model 3 for gender; Model 4 for age*gender; Model 5 for SES-index.
[3] deft (decayed filled teeth, 3-6 yrs.)
[4] DT (Decayed Teeth, 7-19 yrs.)
[5] DFT (Decayed Filled Teeth, 7-19 yrs.)

5 DISCUSSION

The main findings in this thesis were the high skewness of the disease burden of dental caries in all ages and the high risk of disease progression among preschool children with an early caries experience. Gender differences in dental caries were revealed, with teenage females having less caries experience than teenage males, while the pattern was reverse before the teens. Socioeconomic factors showed significant associations with the dental caries experience, particularly among preschool children. Living in a rural area entailed a lower risk of caries experience than living in an urban or a metropolitan area. Small geographical areas explained more of the variance in caries experience compared with larger areas.

5.1 Methodological considerations

The studies in this thesis are based on material from two populations. It is likely that the children from the first population (**Paper I**) were included in the second population (**Papers II-IV**), as both populations were from the VGR during the studied period. However, a certain proportion of the children and adolescents had probably moved in or out of the region.

5.1.1 The clinical study

The longitudinal design of the clinical study (**Paper I**) made it possible to follow young individuals from baseline over three years, and such studies are rare in dentistry (Hultquist and Bågesund, 2016; Lim et al., 2015; Skeie et al., 2008; Winter et al., 2015). A strength of the study was the high participation rate and the low dropout rate throughout the study period. A reason for the high participation rate may be the combination of examinations with planned, regular check-ups; thus, no extra visits were needed. The time of examination was standardized and performed in connection with the child's birthday, with a margin of ± 2 months. For ethical reasons, it was not possible to explore the characteristics of the children who left the study, except for the inclusion criteria, which were age, gender and clinic; however, the dropout rate could be considered to be limited (Higgins et al., 2011). A possible limitation might be that the children's co-operation at the examination was dependent on their level of maturity, which may have led to underdiagnosis of the caries. However, special efforts were made to accustom the young children to dental care (Fällström and Nyberg, personal communication).

An advantage was that a small number of experienced dentists performed all the examinations. They were carefully calibrated both before the start of the study and in the middle of the study period. The calibration sessions were held in accordance with a calibration program used in similar international studies (Espelid et al., 1990; Pine et al., 2004). The inter-rater reliability from the first calibration occasion was moderate. It would have been desirable to calculate it for the second session as well, and this also applies to intra-examiner reliability. A manual check also showed the consistency between the registration-protocols and the input data to be good.

The examinations in **Paper I** comprised a visual examination, tactile exploration, air-drying and radiographs for caries detection. The five-grade diagnosis system used included recordings of both initial and manifest lesions. Initial lesions are of importance for exploring caries increment (Jacobsen et al., 2016; Reddy et al, 2017). The national compilations in Sweden only survey manifest caries, which fails to give a total picture of the caries experience of the population (Socialstyrelsen, 2010, 2017a). Still, there are other, more detailed systems for diagnosing dental caries, such as the ICDAS (International Caries Detection and Assessment System) and the CAST (Caries Assessment and Treatment instrument) systems (Frencken et al., 2013; Pitts, 2004.) Both systems cover ranges of dental caries, from sound teeth to caries lesion progression in the enamel and dentine and into the pulp. In addition, there are other technological assessment tools for detecting caries lesions, for instance, laser fluorescence and fiber optic trans-illumination, which could increase the possibility of detecting caries lesions (Zandona and Zero, 2006; Bussaneli et al., 2015; Sasazawa et al., 2015; Zaidi et al., 2016). Still, Zandona et al. (2006) stated that "no single caries detection method can be used on all surfaces under all circumstances", and which is the best index for epidemiological surveys depends on the purpose of the survey and the target population (Twetman, 2015; Melgar et al., 2016).

Caries lesions develop differently depending on their localization, both with regard to the tooth position in the mouth and the tooth surface (Mejàre, 2008). Thus, we divided the dentition into three groups, "*incisors and cuspids*", "*first molars*", and "*second molars*", and for the surface levels: buccal, lingual, occlusal and approximal, in addition to analyses of the dentition as a whole. The categorization made it possible to explore the caries disease pattern. However, no distinction was made between the upper and the lower jaw, which could be seen as a shortcoming. Later studies confirm that particular attention should be paid to the primary molars (Weusmann et al., 2015; Tickotsky et al., 2017).

It would have been desirable to perform a power calculation before the study started. The sample size was governed to some extent by the fact that there were no more children born in the age group at the selected dental clinics, which were chosen to be representative of the desired socioeconomic profiles. In addition, it would have been difficult to estimate the occurrence of initial caries in children as the basis for a power calculation, as there were few and, rather old relevant Swedish studies in the field (Wendt et al., 1991; Wendt et al., 1992; Holst et al., 1999). There may have been studies from other countries on which to base the power calculation, but it would have been difficult to compare these with Swedish conditions. In small sample sizes, there is a possible risk of incorrectly retaining a false null hypothesis, a type II error, leading to underestimation of the association with the studied outcome (Altman, 1999). Instead, Friedman's test was conducted initially to explore whether there were any overall differences in caries prevalence between the years in the material. This is a suitable method for investigating differences between groups in repeated measurements and in skewed data.

The data in the clinical study were collected a fairly long time ago (2004-2006), implying that the figures on caries prevalence may be somewhat outdated. However, the main focus was the longitudinal follow-up at the individual level and the caries development over time in the dentition. This is probably less dependent on the time of data collection.

5.1.2 The register studies

The study base for **Papers II-IV** basically constituted a census of the regional population in the studied ages (SCB, 2014). The vast majority of Swedish children and adolescents visit the dental health service regularly for checkups and their dental health is recorded, providing good access to epidemiological data. In Sweden, the county councils are responsible for ensuring that all children and adolescents are examined regularly by a dentist or a dental hygienist, either by the PDS or a private dental care provider. The data in the studies were retrieved from electronic dental records registered at regular dental visits. By retrieving data from three years, based on the recall intervals, the degree of coverage was high. Most likely, the system with care providers reporting epidemiological data as a basis for remuneration also contributed to the high coverage. Children not included in the registers may be recently have moved to the region from another county and had already been examined during the period. It is also possible that children visiting the dental clinic for other treatment may have been examined but not registered. Moreover, children who suffered from dental fear or dental neglect may never come to the clinic and those individuals may have had worse dental

health, leading to underestimation of the caries disease in the studies of the thesis (Wigen et al., 2009). However, the dental clinics make efforts to reach such children and, hopefully, this was a minor problem.

A drawback was that only manifest caries recordings were available for **Papers II–IV**. Since only manifest caries has been reported to the NBHW, it is not possible to take advantage of the initial registrations made at the dental clinics. A classic threshold for dental caries in epidemiological studies is the clinically detectable lesion in the dentine; *i.e.*, manifest caries lesions (Pitts, 2001). As mentioned before, there are other diagnoses, management systems and indices for the surveillance of dental caries, which take into account whether a caries lesion is progressive or not, and which have a more comprehensive scale for grading lesions (Nyvad et al., 1999; Pitts and Ekstrand, 2013; Skeie and Klock, 2014; Ismail, 2015b). Therefore, the choice of diagnosis system should be carefully considered. However, the existing contents in the dental registers that is, manifest caries was used. Thus, the disease burden demanding dental treatment/fillings is mirrored, which is interesting from a societal perspective. In **Papers II–IV**, in addition to the dichotomization into "caries-free" and "having caries", an alternative dichotomization of the caries indices explored the dental caries outcome and allowed up to three decayed teeth/surfaces in the "healthy" reference group, as an approach to explore the possibility that dental caries was misclassified due to fissure sealants or hypomineralization (Fejerskov et al., 2015).

An advantage of the studies was the access to socioeconomic information about individuals collected from official registers. Many other studies have used self-reporting by parents or children (Declerck et al., 2008; Oliveira et al., 2008; Cianetti et al., 2017). Individuals may perceive personal information to be too sensitive to disclose and there may also be memory bias. The task of Statistics Sweden, to provide independent statistics on different aspects of society, is regulated by law (SFS 2001:99), and the SCB works actively to ensure that statistics have content validity, which involves using improved methods and instruments for measurement (SCB, 2012). Missing data are always a concern, as this may cause a risk of biased estimates of the associations investigated in the study. In **Paper III**, the missing values in the socioeconomic variables were replaced using multiple imputation. The method is increasingly advocated in research and the technique makes it possible to impute values predicted by the scores of the individual's other known variables (Donders et al., 2006). The missing data mainly related to the fathers' variables, assuming there were absent fathers. In the imputation model, all SES variables – not only the missing variables – were included as predictors, and ten new data sets were created. The model

was thus comprehensive, with all the SES variables included, as the purpose was to avoid bias in the data. However, the analyses made of the imputed datasets in both **Paper III** and **Paper IV** revealed results similar to those of the analyses of the original data, which may be interpreted as the original data serving their purpose well despite some missing values in the SES data.

The categorization into age groups in **Paper II** made it possible to compare the caries experience at different age stages. The youngest children (3–6 yrs.) constituted one group for exploration of the primary dentition. The other ages (7–19 yrs.) were categorized into groups with fairly similar proportions, except for the oldest group (18–19 years), which included a slightly larger number of individuals. This can be explained by dental care providers attempting to perform the last free examination before the period expired. That was also the reason for using generalized linear regression, as this method takes data with skewed distribution into account.

Since the SES variables were chosen to give as broad a picture as possible of the individuals, principal component analysis (PCA) was chosen to explore the pattern of the variables in **Paper III**, and was an attempt to reduce the number of variables to a small set that still contains most of the information. The individual SES variables were dichotomized in order to achieve uniform variables, as PCA can only be applied to numerical data. The PCA assumes the variables to be correlated to some extent and facilitates further statistical analysis by using the scores from the first saved component from the analysis (Vyas and Kumaranayake, 2006). Despite some factor loadings in the PCA being comparatively low (<0.5), all variables were deemed relevant for the association with the dental caries experience and were kept in the model. This also supports the reasoning that scores in indices with multiple variables should be more stable than those of single variables (Bajekal et al., 1996). The scores from the PCA constituted the index used for further analyses in **Paper IV**.

In **Paper II,** the municipalities were classified in accordance with the system applied by the Swedish Associations of Local Authorities and Regions (SKL, 2014) into *metropolitan, urban* and *rural* areas, on the basis of population, industry, agriculture, commuting patterns and tourism. The national classification used made it possible to explore the distribution of the dental caries experience in the region in subdivisions. The geographical SAMS division used for the multilevel analyses in **Paper IV** made it possible to examine the variability in dental caries experience at a low level. The use of geographic divisions can help monitor and identify disadvantaged areas (Hosseinpoor and Bergen, 2016; Holmèn et al., 2018). We identified some

areas with few subjects in our database, which could possibly be explained by population movement from these areas, or the areas having few young inhabitants. Also, individuals who moved to the VG region and were examined during 2009 kept their SAMS code from their previous area of residence. The SCB is planning updates of the system under a new designation (SCB, 2018). A benefit of this update will be that the new boundaries will coincide with the municipal boundaries. However, according to our results, the main and important point is to perform statistical analyses of dental caries at a low level, where the populations are probably more homogenous than at higher levels.

In summary, we used already existing registers for the epidemiological studies. Such information is fairly readily available and the studies are thus relatively inexpensive. In our studies, individual-based data were used, both for the dental caries experience and the SES variables. Still, caution must be observed when the results are interpreted and conclusions must be drawn at group level, as these cannot be equated with conditions at the individual level, that is, the ecological fallacy (Sedgwick, 2015).

5.2 On the results

5.2.1 Dental caries experience

The dental health of Swedish children and adolescents has improved dramatically in Sweden since the middle of the last century. Thus, the caries disease has often been regarded as a minor societal problem. However, despite the fact that dental care has been free of charge, our results indicate that the disease distribution is highly skewed and constitutes a significant problem for the affected group.

As shown in **Paper I**, initial caries constituted a large proportion of the disease in the primary dentition. At three years of age, every fourth child had initial caries, which turned out to be a significant risk predictor for further caries development. This is in line with earlier studies (SBU, 2007; Mejàre et al., 2014). Recent studies found that the progression rate in the primary dentition is more rapid than previously thought (Tickotsky et al., 2017). The progression rate from initial and/or moderate carious lesions to severe lesions was up to 20 times higher than the development of a severe lesion from a sound surface (Ismail et al., 2015b). In the light of our results, it is of utmost importance for oral health planning and preventive caries therapy to pay attention to initial caries lesions and to record and report enamel caries.

Caries occurrence is usually presented for the dentition as a whole (WHO, 2018). Our results in **Paper I** revealed an interesting pattern in manifest caries development. When the teeth were divided into tooth groups ("*incisors and canines", "first molars"* and *"second molars"*), all groups showed significant manifest caries increment during the study period, while only the approximal surfaces, but not other surfaces, displayed a significant increment in manifest caries. Corresponding results were found in Denmark and Poland, where the caries lesions were primarily located on the occlusal and approximal surfaces of the primary molars (Bruzda-Zwiech et al., 2015; Norrisgaard et al., 2016). However, the surfaces most exposed to increases in initial caries were the buccal surfaces. This could be explained as it may be easier to discover an initial lesion on a buccal surface than on an approximal surface. Another study found that individuals with caries in the primary dentition had a higher DMFT mean in their permanent dentition than individuals who developed caries in their permanent dentition but were free from caries in the primary dentition (Hall-Scullin et al., 2017). Furthermore, both initial and manifest caries in the second primary molar are positively associated with having caries in the first permanent molar (Mejàre and Stenlund, 2000; Mejàre et al., 2001). Even though the second molar usually erupts as the last of the primary teeth, it is the tooth often affected by caries. To sum up, the findings in this thesis, as well as in other studies, show the need for prevention activities for the primary dentition.

For monitoring the possible skewness of the caries distribution in populations, the WHO recommends use of the Significant Caries Index (SiC) (Bratthall, 2000). The SiC is calculated as the mean of the DMFT index for the one third of the population with the highest caries score. In Sweden, the NBHW presents the SiC for 12-year-olds, in accordance with the WHO recommendations, and in 2016 the SiC was 2.07 at national level, corresponding figure in 2010 was 2.35 (Socialstyrelsen, 2010, 2017a). In this thesis, the caries distribution was highly skewed at all ages **(Paper II)**, meaning that a large proportion of the children and adolescents had no manifest caries experience. The small group of children with caries was less than one third in most ages. The sensitivity of the SiC may no longer capture disparities in dental caries experience in populations with a caries prevalence as low as that in Sweden today. According to the findings in this thesis, a smaller proportion, for instance 25% or 20%, may be better for this purpose, in a setting with low caries prevalence.

The register studies in the thesis (**Papers II–IV)** were based on cross-sectional surveys and no conclusions can be drawn regarding caries increment. However, age *per se* was associated throughout with the dental caries

experience. Similar trends have been observed in other countries (Bernabé and Sheiham, 2014). Although the majority of the children and adolescents in the studies had most likely been dentally examined on a regular basis, the caries prevalence and "incidence" were higher at higher ages; or, the other way around, the proportion of individuals without dental caries experience was consistently lower for all studied indices in older age groups. For the 18–19-year-olds, only one third remained free from manifest caries (**Paper II**). The NBHW has estimated that about 75% of the fillings performed in adult dental care are made on previously carious or filled teeth (Socialstyrelsen, 2015; Cederlund et al., 2016) The proportion of older adolescents with dental caries experience is therefore an important indicator of future dental care needs (Socialstyrelsen, 2016). By maintaining healthy teeth during childhood and adolescence, lowered dental care costs could be expected for both individuals and society.

5.2.2 Gender

According to the national reports from the NBHW, there is no difference in caries prevalence between boys and girls. The only observation made by the NBHW was that 12-year-old girls had a slightly higher caries mean than boys, 0.71 and 0.67, respectively (Socialstyrelsen, 2017a). In our studies, the gender pattern in relation to dental caries experience was consistent throughout (**Papers II & IV**), with females having a higher risk of dental caries than boys before the teens, and a reverse pattern during the teenage years. In **Paper II**, the results showed a clear trend towards girls having a significantly lower risk of caries experience during adolescence than boys of the same age. This was especially distinct for the indices containing approximal lesions (DSa, DFSa). This trend regarding differences between genders was an interesting finding, as other studies have reported a higher caries prevalence for females than for males, regardless of age (Lukacs, 2011; Hall-Scullin et al., 2017). Gender differences have also been observed among children in general health-care settings. A recent review in pediatrics observed gender differences both for several diseases and for side-effects after treatments (Piccini et al., 2018). A possible explanation for the gender differences in dental caries experience may be related to oral hygiene habits. In a Swedish sample of young people, boys had a higher prevalence of plaque and gingivitis but also less positive attitudes and behavior towards oral health than girls (Ericsson et al., 2009; Eriksson et al., 2012). Another explanation of the gender differences may be that female adolescents have been found to be more concerned with body image and weight control than males (Östberg et al., 2002), and consider their intake of carbohydrates to be too high (Östberg et al., 1999). The adoption of such concerns may differ between

genders during the socialization process. In this process, the child gradually becomes aware and acquires knowledge, norms, attitudes, behavioral patterns and skills that fit into the culture where he or she grows up. Roles that currently prevail in society are transferred to individuals. The literature suggests that the role expectations and the demands to follow the adult norms are greater for girls than for boys (Ruble et al., 1993; Bjerrum Nielsen H, 1994; Ruble et al., 2007).

5.2.3 Socioeconomy

In addition to biological factors, socioeconomic factors have been recognized as determinants of dental health. Whether measured in terms of education, occupational status, income or economic standard, the more socio-economically favored are healthier, on average, than those with less resources (Schwendicke et al., 2015). Education is important for entering the labor market, and is equally important for the ability to remain in the labor market. Without secondary education there is a risk of unemployment. These individuals also have a higher risk of more unemployment periods. Education and work experience are the two most important factors in order to find employment. Conversely, without these two characteristics, it is difficult to enter the labor market (SKL, 2015). There are more people without work among people born abroad than among people born in Sweden. Also, the foreign-born population in Sweden has varying levels of education. How long a person has lived in Sweden affects the chances of finding a job. Employment rates increase over time in Sweden for the whole population, but differ greatly, depending, among other things, on the level of education and the reason why a person has immigrated. Refugee immigrants, for example, have a significantly lower employment rate than many other groups, but their employment rate also increases over time in Sweden (OECD, 2018). Economic standard is largely due to the household income and the household dependency. Those having secondary or upper secondary education are more likely to have greater economic assets than those with only compulsory education (Folkhälsomyndigheten, 2017).

In the register-based studies of the thesis (**Papers III & IV**), several individual-based socioeconomic variables were explored and all turned out to be strongly associated with the dental caries experience of the subjects. Roughly, the variables could be grouped into individual characteristics, economic assets for the families and parent-associated variables.

The variables linked to the young person her/himself were those representing place of birth. Country of birth was the individual's own country of birth, and

migration background referred to the parents' country of origin. Migration background was more strongly associated than country of birth with a caries experience, indicating that the parents' origin is of importance for the child's dental health. However, the group of immigrants is heterogeneous with differences in lifestyle, depending, among other things, on the country of origin (Kawamura et al., 2000; Remington Abramson and Moran, 2014). For this reason, it is important for dental professionals to have a good understanding and knowledge of different cultures, in order to provide good dental care.

Economic assets have previously been associated with dental caries experience (Socialstyrelsen, 2013) and this is in line with the findings in the thesis. The economy of the household was reflected by three register variables: *disposable income, social welfare allowance* and *housing allowance.* The *disposable income* is a "composite" variable consisting of all available income after tax, with all potential allowances included, such as child allowance and sickness benefit. In Sweden, the social security system aims to provide an opportunity for people to have a decent standard of living (Socialstyrelsen, 2012). Therefore, disposable income is probably not a single good marker to identify the economically disadvantaged. On the other hand, in other countries without the social security system that Sweden has established, income may be a good variable for identifying less affluent families, but this probably varies a great deal between countries, depending on how income is defined. The strongest association with dental caries with regard to economic assets was found between allowances and dental health. *Social welfare allowance* was more strongly associated with dental caries than *housing allowance*. One reason for the difference may be that the economic criteria for obtaining a housing allowance are less stringent than those for social welfare. Applying for social welfare may also be regarded as intruding more upon a person's integrity than applying for a housing allowance, and social welfare may therefore be a stronger measure of social and economic vulnerability (Musterd and Andersson, 2005).

The parent-associated variables completed the socioeconomic picture and an interesting gender pattern was revealed. The *mother's education* was significantly more strongly associated with all caries indices compared with the *father's education*, as noted in several earlier studies (van der Tas et al., 2017; Warren et al., 2017). This was also the reason for retaining the variable *mother's education* in the PCA, despite the comparatively low loading (< 0.5) (**Paper III**). On the contrary, the number of father's *unemployment days* had a stronger association with dental health than the mother's days of unemployment. One possible explanation may be that men are generally

better paid than women, and the father's unemployment will therefore more likely result in a lower family income (SCB, 2016). Lastly, an inconsistent pattern of *gainful occupation* between parents was seen in relation to the dental caries experience. Whether it is the mother or the father who is unemployed, the family can be characterized by concerns about the future/economy, which may result in giving less priority to everyday routines, such as taking care of one's teeth. It may also be more common in families where there is unemployment not to afford nutritious food; for example, fruit instead of sweets and milk instead of soda (Darmon and Drewnowski, 2008; Han and Powell, 2013; Livsmedelsverket, 2016).

All the SES variables used were likely correlated to some extent. Foreign background often entails a poorer chance of finding employment, even if the person is highly educated (OECD, 2018). Likewise, people with a Swedish background and low educational level are often at greater risk of unemployment (SKL, 2015). Unemployment may also lead to a strained economy and need for allowances. Thus, socioeconomic status is an interaction of many factors, as mentioned above; however, indices combining variables are rarely studied or used in dentistry (Havard et al., 2008; Ha et al., 2016; Östberg et al., 2017a). The associations between single SES variables and dental caries shown in **Paper III** justified the approach to use a multiple SES index to explore the multifactorial caries disease. Single SES factors may change more quickly and may be inappropriate and unreliable for the allocation of resources. Composite indices are considered more stable over time than single indicators (Bajekal et al., 1996). Composite area-based indices for exploring oral health outcomes were advocated by Locker (2000) already two decades ago. Based on our findings, this approach still seems to be relevant. The multiple SES index had strong associations with the dental caries experience, and could be deemed a relevant marker of social disparities. Still, it is important to bear in mind that an unfavorable socioeconomic status is not directly linked to poor dental health.

5.2.4 The parental role through the child's developmental stages

Parents have a profound influence on their children's dental health, both through their own dental habits and through their attitudes and behavior in relation to dental care (Skaret et al., 2008; André Kramer, 2009; De Castilho et al., 2013; Östberg 2017b). This indirectly affects their ability to maintain good dental health in their child. In this thesis, the strongest association between SES and the dental caries experience was observed among the most dependent individuals; that is, the preschool children in **Papers III & IV**.

The 'Convention on the rights of the child', adopted by the UNICEF, states that the child's parents or guardians have the main responsibility to care for the child and to act in the best interest of the child (UNICEF, 2018).

The parental role is not always uncomplicated and may be conflict-laden when the child is going through different development phases. When the child is around three years old, it usually goes through a period of defiance. Minor conflicts with the parents may take place as often as every three minutes, and major conflicts up to three to four times per hour. "I can do it myself", is a common expression, applied to tasks such as dressing and brushing the teeth. Children aged four to five years are usually quite happy and content, but then become more emotional around six years of age. Around nine years of age, children begin to prepare for leaving childhood, for instance, by spending time away from home on their own, and friends become more important. The period from ten to twelve years is also called the latency stage. The child is still both physically and emotionally more a child than an adult, but is training to become an adult. The term "tweenie", derived from the words "teen" and "between", is sometimes used (Tetzchner, 2005; Hwang and Nilsson, 2011). The development through these phases affects the everyday life of both the child and the parents, and also the child's dental health through dietary and oral hygiene habits.

Parents may have their own concerns, as mentioned above, such as worries about the economy and/or unemployment. Such situations may result in giving less priority to the child's dental health. The parent's ability to obtain, understand and use dental care information in order to make appropriate decisions, and to follow instructions for preventive action for the child; that is, health literacy, is important (Ringsberg, 2014).

When entering adolescence, the child becomes less dependent on the parents' care and the relationship between children and parents may change as the child becomes more capable of managing her/himself. Peers often take over as role models regarding attitudes, beliefs and behavior during this period, when both emotional and social development occurs (Wrangsjö, 2004; Broberg et al., 2006). In many ways, adolescence is about becoming independent and creating an own identity, but the ability to consider the long-term consequences of one's own actions is not fully developed in the early part of this period (Wrangsjö, 2004). Some examples could be the ability to understand the importance of healthy oral habits or the potentially negative effects of unfavorable oral habits on dental health. On average, the process of maturity starts two years earlier for girls than for boys, which could mean that girls become more aware of their dental health earlier than boys. The

finding in **Paper II** that the female adolescents had better dental health than boys of the same age may be an indicator of this. Dental professionals have an important function to fulfill in identifying children and families that may need additional support from dentistry in order to achieve, but also to maintain, good dental health in the children and adolescents. The supportive action by dental professionals should therefore be customized to target both the individual and the parents, especially with regard to the youngest children and their parents.

5.2.5 Setting and areas

The studies were carried out in the largest region in Sweden, the Västra Götaland Region, which can be said to resemble a "miniature Sweden", with both rural and urban areas and both sparsely and densely populated areas. In **Paper I**, the clinics were chosen to represent different socioeconomic profiles; however, no clinic was located in a metropolitan area. Had this been the case, even greater caries increments may have been found. This assumption is based on the results from **Paper II**, where a distinct pattern was found, with a higher risk of caries in children and adolescents living in metropolitan areas compared with rural and urban areas. Almost ten years have passed since the data in **Paper I** were gathered, and society has changed for instance, throuhg increased immigration in recent years. The caries experience may be greater today than what we found, due to greater exposure and access to stores, cafés and fast food outlets with longer opening hours. This is probably more common in metropolitan and urban areas than in rural areas and may contribute to unhealthier dietary habits including more sweetened products (Chow, 2009).

The results in **Paper II** regarding caries experience in relation to context – rural, urban and metropolitan – warranted further, more detailed, studies. For this reason, in **Paper IV**, we explored the dental caries experience in relation to dental clinic areas and SAMS areas, respectively. The caries mean value ranges at both dental clinic areas and SAMS areas differed considerably, especially for the deft and DFT indices. These findings indicate large variations in the need for treatment. Dental clinics have been merged into fewer, larger units in the region in recent years and this probably contributes to leveling out the caries outcome at clinic level in epidemiological compilations (Hassel Gustafsson and Östberg, 2017). The proportions of unfavorable SES variables were higher in SAMS areas than in dental clinic areas, indicating that socioeconomic disparities in society become more visible in smaller areas compared with larger areas. Thus, smaller areas, such

as SAMS areas, are preferable in order to identify areas that need tailored prevention activities.

In **Paper IV,** the associations between SES and dental caries were explored in relation to the child's dental clinic area and SAMS area. The distribution of the SES scores was skewed. Roughly half of the individuals had the lowest SES index scores, meaning the least deprived, and constituted the reference group. The most deprived children (10^{th} decile) had significantly stronger associations with dental caries experience than individuals in the 9^{th} decile, both for dental clinic areas and SAMS areas. This indicates a strong social gradient among those who are the most socially disadvantaged, and those who need the most support. The findings in **Paper IV** were concordant with studies from Germany in preschool children and from Brazil in adolescents, which identified neighborhood areas as the explanation of poor dental health, and this was associated with less favorable sociodemographic characteristics (Santiago et al., 2014; Meyer et al., 2016). There is a social gradient within countries worldwide. Sweden is considered to be one of the most equal societies globally. Wilkinsson & Picket (2009) reviewed and concluded in their book '*The spirit level'* that "more equal societies almost always do better". The authors describe large differences and inequalities in many areas, such as health and social problems, within and between countries. Based on the results in **Paper IV**, dental caries appears to be an important marker of inequality among children and adolescents in Sweden that can be linked to geographical areas. This suggests that the neighborhood area should be taken into account when allocating resources to the dental health service and when targeting interventions at a low level.

To summarize, this thesis uses clinical and register-based data to explore aspects of demography and socioeconomic status, in an attempt to explore the dental caries experience in children and adolescents. We had no data regarding risk factors such as oral health behavior, or on dietary habits. Preventive action in dentistry has most likely been performed for individuals at risk of dental caries disease. Still, the preventive programs in dentistry may need to be evaluated and adapted, both to the individuals with caries and to those who remain caries-free.

6 CONCLUSION

In conclusion, inequalities in dental caries experience among children and adolescents in Region Västra Götaland were found, with a skewed distribution, within age groups, between genders, between residential areas and in relation to individual socioeconomic status. The findings may serve as a basis for allocating resources in dentistry with the goal/ambition to reach greater equity of dental health.

6.1 Specific conclusions in Papers I-IV

- Preschool children with an early caries experience were at greater risk of developing caries lesions over time. Initial caries constituted a large proportion of the caries lesions and the primary second molar carried the largest disease burden (**Paper I**). The caries experience was highly skewed in all ages (**Papers II–IV**).

- The proportion of children without manifest caries was consistently lower at higher ages. Females showed a higher risk of caries experience compared with males before adolescence, with a reverse pattern during adolescence, when males had a higher risk of caries experience than females (**Paper II**).

- Living in a rural area involved a lower risk of caries than living in an urban or metropolitan area. Small geographical areas had less variability in dental caries experience than larger areas (**Papers II & IV**).

- Individual multiple socioeconomic status was strongly associated with dental caries experience, particularly among preschool children (**Papers III & IV**).

7 FUTURE PERSPECTIVES

The findings in this thesis revealed a highly skewed pattern of dental caries experience in children and adolescents with strong associations with demography and socioeconomic status. This knowledge calls for action when planning further research and future dental care.

- New indices, other than the DMFT system, for epidemiological registration of oral health should be tested and evaluated;

- Qualitative studies with both young people and parents would provide more profound knowledge of the influencing factors on children's and adolescents' oral health;

- Longitudinal studies of oral health in children and adolescents are needed;

- Allocation of dental care resources should take into account the socioeconomic profiles in the population at an appropriate and low level;

- Oral health promotion and prevention programs for children and adolescents need to consider the age and gender of the target group.

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