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Title: Investigating societal determinants of oral health – opportunities and challenges in multilevel studies

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Abstract:

The high prevalence of oral diseases and the persistent nature of socioeconomic inequalities in oral health outcomes across societies presents a significant challenge for public health globally. A debate exists in epidemiology on the merits of investigating population variations in health and its determinants over studying individual health and its individual risk factors. The choice of analytical unit for health outcomes at the population level has policy implications and consequences for the causal understanding of population-level variations in health/disease. There is a lack of discussion in oral epidemiology on the relevance of studying population variations in oral health. Evidence on the role of societal factors in shaping variations in oral health at both the individual-level, and the population-level, is also mounting. Multilevel studies are increasingly applied in social epidemiology to address hypotheses generated at different levels of social organization, but the opportunities offered by multilevel approaches are less applied for studying determinants of oral health at the societal level. Multilevel studies are complex as they aim to examine hypotheses generated at multiple levels of social organization and require attention to a range of theoretical and methodological aspects from the stage of design to analysis and interpretation. This discussion paper aims to highlight the value in studying population variations in oral health. It discusses the opportunities provided by multilevel approaches to study societal determinants of oral health. Finally, it reviews the key methodological aspects related to operationalizing multilevel studies of societal determinants of oral health.

Introduction

Oral diseases affect half of the global population.[1] Untreated dental caries remains as the most prevalent non-communicable disease world-wide,[1] despite some success in reducing childhood dental caries in high-income countries during the latter part of the twentieth century.[2] Persistent socioeconomic inequalities in oral health outcomes within and between societies are also highlighted.[3] Collectively, the two issues reflect limited or inadequate policy responses at both global and local levels. High levels of disease and inequalities in oral health persist because current prevention methods that are based mainly on the biomedical approach and focus on changing individual behaviour. These approaches tend to result in only short terms improvements for certain patients but do not address the underlying causes of diseases.[3, 4] Evidence-based actions at the population level are necessary to reduce the enormous burden of oral diseases and counter the persistent socioeconomic inequalities in oral health outcomes.

Majority of oral epidemiologic studies investigate only individual variations in oral health and its individual determinants notwithstanding the current challenges in population oral health.[1, 3] Studies that examine individual-variations in oral health within populations and its determinants tend to examine biologic/behavioral effects.[5-7] The underlying biomedical and individual-based approach of such epidemiological investigations is a key limitation as they do not address the underlying causes of diseases. Individual-based approaches neglect population variations in oral health and its societal risks. Alternatively, studies of population variations in health are fundamental if the goal is to ascertain the determinants of population health.[5] These investigations are directed to study population-level variations in oral health and its determinants, also called as ecologic effects.[6] Studies of population variations in oral health are also critical to understanding systematic differences due to which oral health inequalities mirror the social inequalities present within societies. A timely discussion of the theoretical rationale for investigating population variations in oral health is essential in the light of current challenges.

Multilevel studies are progressively applied in the discipline of social epidemiology and in oral health.[8] The foundation of a multilevel approach lies in the inexorable dependency of individual's health on the surrounding social and physical environment. Social contexts and their characteristics are integral determinants of variations in health outcomes both within populations and between populations. Societal patterns of oral diseases represent the biological consequences of living and working conditions differentially afforded to social groups as a product of economic and political priorities of societies.[3, 9-11] These priorities vary across different levels of administrative and political boundaries ranging from global and national, to small areas like neighbourhoods, local areas, municipalities, performing a fundamental role in the distribution and access to oral health promoting/risks factors. Multilevel studies pay equal attention to both intimate and ultimate causes of health without discounting that individual health and its individual risk factors do not function in isolation.[9] Hence, the opportunities and challenges offered in multilevel approaches for a better understanding of the role of societal determinants of oral health need to be highlighted.

Testing hypotheses at multiple levels of social organization using multilevel studies, although very useful, are complex.[12] These complexities arise due to the mutual interactions and interdependencies between individual-level and societal-level factors related to health. Methodological experts in epidemiology, particularly social epidemiologists, have highlighted some challenges (relevant groups/levels, lag times, fallacies, confounding among others) in the light of general health outcomes.[12-15] Oral health conditions provide unique opportunities to study social inequalities in health.[16] The aetiological factors for two commonly prevalent oral diseases (dental caries and periodontal disease) include a complex mix of biological, environmental, and social influences.[16] Many high-income countries continue to exclude dental health-care from their universal health coverage policies leaving the responsibility on individuals to cover and manage dental expenses.[17] Collectively, social determinants across different levels of social organization may systematically determine the magnitude of oral health inequalities both within and between societies. Consequently, general health and oral health conditions often differ in strength and the type of their relationship with social determinants when examined simultaneously within the same context.[18, 19] For example, social inequalities in oral health were found to be more pronounced than those in general health in Canada.[18] A stronger association between income inequality and dentition status (presence of teeth) than between income inequality and self-rated health was reported in Japan.[19] Accordingly, multilevel studies on societal determinants of oral conditions can benefit from attention to theoretical and methodological considerations, some of which may uniquely apply to oral conditions.

In the light of the public health challenges presented in oral health at the population level, this paper aims to:

i) present theoretical and pragmatic reasons to consider re-balancing the weight of studies on individual-level variations in oral health towards studies on population-level variations in oral health,

ii) discuss the contribution of multilevel studies to generate valuable evidence on societal determinants of oral health and understanding population variations in oral health, and,

iii) review methodological aspects relevant to the application of multilevel studies in oral health.

The case for more studies on population variations in oral health and its determinants

Geoffrey Rose's seminal work in 'The Strategies of Preventive Medicine' stressed the distinction between the risks for individual variations in health, and, the risks for population variations in health.[20] Rose's theorem' or the 'prevention paradox' states that "a large number of people exposed to a small risk may generate more cases than a small number exposed to a high risk". Therefore, when everyone is exposed to the risk within a population, it is not possible to measure the effect of the exposure without reference to a population that has a different level of exposure. Building on this, Rose established that the determinants of variations in health between populations differ from the determinants of variations in health within the population.[20] This is a key argument for studying population variations in health and its determinants. Differences in the magnitude of the influence of determinants of caries rates among children within and between Australia and Vietnam is one example of operationalization of Rose's theorem in oral epidemiology.[2] The study reported that while individual social position was relevant for individual risk, country-level economic development and social inequality were more relevant for population risk.[2]

Another epidemiologist, McMichael[21] raised a relevant question that further underscores a key argument for conceptualizing and studying health outcomes at a population level that is relevant to oral health:

"Are we, merely distinguishing between upstream social contexts and their downstream proximate manifestations? Or is there a category of risk factor that, in some collective way, influences the health of the population at large via processes that have no direct downstream manifestation?"

Evidence summarised below from the oral health literature reinforces the need to pursue this line of enquiry.

Growing evidence on the independent contribution of contexts in shaping oral health: A systematic review,[22] and a scoping review,[23] have separately confirmed poor oral health outcomes to be associated with less favourable contextual socioeconomic variables (high area-level social inequality, high area-level deprivation, low social capital, and, low access to dental healthcare). Socioeconomic inequalities in oral health outcomes according to contexts are expressed spatially based on the variations in area-level social, political, and economic characteristics. Therefore, population-level variations in oral health outcomes can finely capture the population-level impact of contextual societal disadvantage.

Population variations in oral health reveal underlying societal determinants: Investigating patterns of variation in oral health between populations is important in its own right. The observed population-level variations are important to understand the significance of specific contexts for oral health outcomes.[24] Otherwise, similar individuals may have differences in their health dependent on where they live because of differing cultural, economic, political, geographic, climatic and historical contexts.[25] The more homogenous the oral health of individuals within a population, the higher the probability that determinants of oral health are directly related to the contextual environment or the population characteristics. Interventions in this case needs to be directed to contexts rather than individuals.[26] From an equity perspective, population-variations in health outcomes, that are systematic, socially produced and unfair, are highly relevant.[27] These inequities result from systematic differences in exposure to health risks and protective factors as well as to treatment services, based on social position.[28] Therefore, the observation of population variations in oral health between societies reflects the need to understand the differences in characteristics of these societies.

Socio-political and multilevel nature of oral health determinants: Individual-level risk factors for most prevalent oral conditions include high sugar consumption, tobacco use, lack of access to fluoride, high levels of stress, lack of oral hygiene and favorable pattern of dental visiting.[29-31] The distribution of these individual-level determinants both within and between societies can be influenced by societal determinants and policy decisions at multiple geographic and administrative levels. Variations in presence and intensity of policy implementation can also exist between the geographic and administrative levels. Key policy determinants that impact distribution of individual-level behavioural risk factors include federal, state and local level decisions on community water fluoridation;[32] health care arrangements including provision and financing; tobacco control policies including ratification of Framework Convention of Tobacco Control (FCTC) at the national level to its compliance at different sub-national geographic and administrative levels;[33] trade arrangements/agreements and marketing regulations impacting food demand and supply;[34] and availability of local physical and social environments that improve social cohesion and physical activity.[35] Studying population variations in oral health can allow comparisons between societies and provide key insights about existing policies and the impact on population oral health of different political and administrative arrangements. Cross-national studies comparing countries with different policies, for example regarding taxation of sugar foods/beverages or their dental care systems, can contribute significantly in assessing the potential impact of upstream interventions on oral health. Additionally, natural experiments at the societal level that compare population oral health can serve as a useful tool. Natural experiments applied in oral health context from Brazil and Japan have improved the current understanding of the effectiveness of water fluoridation in reducing dental caries among adults, and the impact of socioeconomic disadvantage on tooth loss. [36, 37]

Explanatory potential of individual-level studies for population oral health: Most epidemiological studies report measures of individual relative risk (odds ratio (OR), risk ratio (RR) rather than the population attributable risk (PAR).[38] PAR describes how much of the condition within the population can be attributed to a particular risk factor, while the risk ratio (RR) informs the change in risk of an outcome among exposed individuals compared to unexposed individuals. Even with larger and statistically significant levels of RR, the PAR can be smaller and insignificant from a public health perspective, if the exposure is not widespread.[38] Alternatively, a low RR can accompany a high PAR when an exposure occurs frequently in the population. The study by Do [2] on the differences between caries rates among Vietnamese and Australian children found an RR of 1.24 for dental caries among Vietnamese children who did not start brushing with toothpaste before three years of age. The RR for Australian children was similar with a value of 1.27. However, the Population Attributable Fraction (PAF - the proportion of the disease in the population attributable to a factor of interest) for Vietnamese children by introducing brushing with toothpaste before the age of three years was 18% compared to only 3% for Australian children for the prevention of caries. Lack of reporting of PAR along with measures of association in studies of individual-level outcomes limits the knowledge of the preventive capacity of interventions for population oral health.

Individual-level risk factors for oral diseases often do not vary enough within populations to permit quantification of their probability to increase risk at an individual level.[39-41] This issue further limits the value of individual-level studies in generating evidence for population-level prevention, even when PAR is reported. For instance, the WHO recommends that free sugars intake should be restricted to less than 10% of total energy. A conditional recommendation for further health benefits particularly with regard to dental caries includes restriction to less than 5% of total energy. [42] This recommendation is exceeded in most countries. A review of data on sugar intake from national surveys from Australia, Denmark, Ireland, Norway and US showed that at a population level none of these countries met the recommendation of 5% limit.[43] Furthermore, evidence from Australia demonstrates the prevalence of exceeding the recommendations is high (52% for the 10% recommendation and 89% for the 5% recommendation).[42] Therefore, there may not be enough variation in the exposure within a population to the effects on dental caries to be determined. Ecological studies, which study between-population, rather than within-population variation in caries according to sugar availability, report larger variations in caries status according to sugar availability when compared to individual-level studies.[44] In cases where the individual risk factors do not vary within populations, evidence on population variations in oral health are likely to be more informative in making public health decisions.

Informing strategies for prevention for oral diseases: During the second half of the 19th and first half of 20th century, there was a shift in epidemiology away from studying societal causes of diseases and a move towards the individual and microbial causes.[45, 46] and is identified as an epistemological revolution in understanding the causes of diseases.[46] Different approaches to disease causality have important political and medical implications as they mean a different locus of responsibility for prevention of diseases. A causal focus on microbial factors confers responsibility of prevention to health professionals, individual behaviours or lifestyle factors implies a personal responsibility for disease control, while a socio-environmental causal model places responsibility on authorities and general society for the prevention of disease and reduction of exposure.[47] Prevention strategies for non-communicable diseases including oral diseases often suffer from a similar individually-focussed approach by promoting change in individual risk-factors. The population-based strategy, the high-risk strategy, and the directed population strategy are the three types of strategies applied towards prevention of oral diseases and promoting oral health. The population-based strategy for prevention starts with the recognition that the occurrence of common diseases and exposures reflects the behavior and circumstances of society as a whole.[41] Alternatively, the high-risk strategy targets individuals identified as having an elevated risk of some adverse health outcome.[41] The directed population strategy is a version of the population strategy but it is directed more towards vulnerable groups based on their social circumstances rather than elevated levels of risk.[48, 49] The studies on the causes of individual variations in oral diseases generate evidence that may provide limited support to whole population approach for prevention. For instance, Holst and colleagues have reported that the occurrence of a carious lesion in individuals and the occurrence of caries in populations have different causal candidates and patterns. This exemplifies the distinction between the causes of cases and the causes of incidence in a population.[50, 51] Individual-level approaches have remained as the dominant paradigm in understanding the production and prevention of oral diseases.[4, 52] This approach is consistent with the ‘high-risk strategy’[20] and has evolved from both the biomedical nature of dentistry and an individual ‘risk factor’ focus from clinical oral epidemiology.[4] The limitation of a ‘high-risk strategy’ in reducing variations in population levels of oral health is well established within the literature.[4, 53] This approach does not acknowledge the growing understanding of the multilevel nature of health determinants[9] and societal determinants in shaping the distribution of oral health.[4, 54, 55] Therefore, dominance of individual based approaches shifts attention from underlying societal determinants of health and encourages individual responsibility to maintain oral health rather improving environments to promote oral health.[56]

Advancing the multilevel study approach

An ecological design within epidemiology seeks to understand how contexts affect the health of groups through selection, distribution, interaction, adaption and other responses.[57] Multilevel studies investigate both groups and individuals as the unit of analysis. It allows the simultaneous investigation of between-group and within-group variability in individual-level outcomes.[12] Therefore, multilevel studies can be applied to examine the associations between group level and individual level variables with individual-level outcomes. Additionally, it can be applied to examine between-group and within-group variability and the contributions of group-level and individual-level variables to variability at both levels -population variations in health and its determinants.[58]

A key advantage of multilevel study is its potential to address confounding generated from variables at alternate levels of social organizations when simultaneously analyzing variables at two or more levels of social organization, multilevel studies allow addressing. This advantage of multilevel studies has been widely exploited in studies of area-level income inequality and health outcomes.[59] Early ecological studies on area-level income inequality and population health using single-level regression models have been criticized in the past. It is debated that the observed associations between area-level income inequality and average health status at the population level in ecological studies were due to the effect of individual income on individual health (compositional effect) rather than a true effect of income inequality.[60] Multilevel studies offer the opportunity to separate the contextual effect of income inequality on individual health from the compositional effect of individual income by allowing to adjust for individual income within the same regression.[59] However, ecological studies analyzed population risk according to area-level income inequality, while the multilevel studies assessed individual risk according to area-level income inequality.[61] The population-level aspect of health outcome in multilevel studies is studied through investigating the share of individual-level variation in health outcomes that exist at the population level through decomposition of variance. [61]

Methodological experts argue that multilevel modelling has not been used to its potential to answer questions on population-level variations in health status and its determinants in the field of social epidemiology.[24, 61-65] Studies have mostly focussed on average associations between individual and societal determinants, and health outcomes, ignoring a thorough analysis of heterogeneity around average associations examined through the variance estimates obtained from multilevel studies.[61] The variance component informs to what extent individuals within a group are correlated with one another in relation to health. The extent of clustering has value in the context of ideas about considering interventions on places instead of people.[26] One application of this logic is identified in a study where multilevel modelling is utilized to identify appropriate geographic levels for policy intervention.[66] Geographic levels at which the observed variations in outcomes are larger, there may be greater potential for policy intervention to have an impact on the outcomes of interest, compared with targeting policy at levels with relatively smaller variations.[66] Multilevel studies also provide a suite of measures based on average association between societal exposures and individual health outcomes (OR, RR), and measures of variation in individual health (variance) and its decomposition at the population level (variance partition coefficients (VPCs), intra-class correlation coefficient (ICC) for continuous outcomes and median odds ratio (MOR) for binary outcomes), that can be applied to understand societal causes of population variations in oral health. Two additional measures: 80% Interval Odds Ratio (IOR) and Proportion of Odds Ratio in Opposite Direction (POOR), can be quantified by combining regression coefficients obtained from averaged associations between societal determinants and individual oral health and the variance attributed to the contextual level. The two measures estimate the heterogeneity in the associations between societal exposures and individual health outcomes among contexts/population groups.[61] Measures of variation in individual health and its decomposition are critical for inferences on population-level variations in health. In addition to ICC, measures of discriminatory accuracy such as Area Under Curve (AUC) can be applied to understand the independent contribution of societal context in general, and of specific societal exposure, in determining oral health outcomes. [61] Collectively, these measures can be exploited to provide a thorough and realistic assessment of the relationship between societal determinants and oral health within the same dataset.

Predominantly, multilevel studies on societal determinants of oral health are of two kinds. Some studies have simultaneously examined the role of multiple societal determinants (Human Development, access to fluoridated tap water, oral health coverage, and income inequality) and oral health outcome/s consistent with a more exploratory approach using the social determinant framework.[67-69] Others have tested specific associations between one societal determinant (for example area-level income inequality, neighbourhood deprivation)[19, 70-73] and oral health outcome/s consistent with a causal approach. The dominance of probabilistic risk factor epidemiology has limited the use of multi-level models to examine between-group and within-group variability through quantification of variance and its decomposition at different levels of social organizations.[64, 65] The understanding of the social determinants oral health can substantially benefit from the application of multilevel models by examining between-group variability in individual-level oral health outcomes as a method to study population-level variations in oral health.

Methodological aspects relevant to application of multilevel approaches within oral health

Methodological considerations related to multilevel studies relevant to oral health are collated from the general health literature and discussed below under logical headings. Wherever possible, published or hypothetical examples from oral health are used to illustrate their relevance.

Types of cross-level associations and arising fallacies

The simultaneous assessment of associations between societal and individual factors and individual health outcomes in multilevel studies has led to investigations of three main different types of associations.[15] A societal exposure can potentially impact oral health at an individual level through direct cross-level association, indirect cross-level association, and cross-level effect modification. A direct cross-level association occurs when a societal factor has a direct impact on the individual oral health outcome. For example, a person living in an area with community water fluoridation (exposed to fluoride) has lower risk of dental caries, than a person in non-fluoridated area.[32] Indirect cross-level association occurs when a societal factor results in a change in individual-level exposure, which consequently, increases or decreases risk of disease at an individual level. For instance, the presence of school policies on the availability of sugar-sweetened beverages (SSBs) can discourage individual consumption of during the day, therefore, reduce the risk of dental caries.[74] Finally, cross-level effect modification occurs when a societal factor modifies the association between an individual level factor and individual health outcome. Some evidence exists to suggest that the associations between individual social position and oral health vary according to the welfare typology,[75, 76] in line with the cross-level effect modification. Clarity on these pathways when generating hypothesis is critical as the findings have consequences of the choice of policy intervention points for improving oral health.

Several fallacies are produced in a situation when the hypothesis generated in both conventional ecological studies and multilevel studies are not theoretically aligned with the potential mechanisms of how societal factors can impact oral health. These fallacies are called ecological, atomistic, sociologistic, and psychologistic, and are widely discussed in general health literature.[15, 77] Each of these fallacies are described along with a suitable published or hypothetical example in Table 1.

Ecological variables: classification and constructs

Ecological variables represent group-level properties, including societal factors, which are relevant to oral health. Depending on their measurement or the construct they aim to capture, ecological variables have been classified in several ways within the literature. Classification of ecological variables reveals its degree and nature of dependency on individual-level factors. For instance, ecological variables can be integral or derived.[12] Integral ecological variables are only group characteristics, and cannot be measured at an individual level, for example community water fluoridation and air pollution. Conversely, derived ecological variables present as a mathematical summary of individual characteristics within a group,[12] for example percentage of children with sugar consumption above the World Health Organization recommendation, or area-level mean income. However, derived ecological variables may or may not have their individual-level analogue. While area-level mean income has an individual income as its individual equivalent, area-level income inequality is solely a group property and does not have an individual equivalent.

Based on the constructs they capture; ecological variables can be categorized as:

i. aggregate/ contextual/ analytical,
ii. contagion,
iii. environmental,
iv. structural, and
v. global/ integral.

The description of these categories of ecological variables along with suitable examples is presented in Table 2. Clarifying the constructs that the ecological variable of interest aims to capture has implications on measurement issues and analytical approaches. For instance, global variables such as legislations and policies are likely to have a more diffused effect among populations rather than leading to an instant biological or bio-behavioural impact on ‘high-risk’ individuals. In such cases ecologic inferences about effects on group rates or population-level variations may be more relevant than individual risks.[40]

Meaningful population groups, scale, and unique characteristics

Specifying meaningful boundaries and identifying groups of interest for the ecological unit of interest is core to any multilevel study.[14, 78] Despite the use of ‘population’ across many disciplines analysing population data—for example, epidemiology, demography, sociology, ecology, population biology and population genetics, statistics, and biostatistics, it is rarely defined, except in abstract statistical terms.[79] Various criteria can be applied to define population groups of interest. For instance, the boundaries of a ‘neighbourhood’ can be defined based on historical or geographic criteria, the perception of the residents or the administrative boundaries used for policy delivery. Moreover, 'neighbourhood', 'community', and 'area' are often used loosely within the health literature to identify an individual's immediate residential environment, and the three terms are not explicitly defined or distinguished.[80] The population-level effectiveness of public policies such as community water fluoridation in reducing dental caries are more consistent with administratively defined boundaries, compared to interventions to improve opportunities for social interactions. Creating opportunities for social interaction in a community is likely dependent on what an individual perceives as the boundary for a community rather than the administratively defined limits. Recently, it was highlighted that a "residential" effect fallacy bias exists in most studies of neighbourhood and health studies that ignorantly capture non-residential environment effects, leading to overestimation of residential intervention effects.[81] These non-residential environment effects may be due to schools or workplaces depending on the health outcome, population density, and individual mobility.[8, 81]

The selection of spatial scale for testing associations between ecological factors and health outcomes is both an important theoretical and methodological aspect. First, the societal processes that produce health may vary by geographic scale.[82] Second, group-level characteristics do not occur randomly and are based on the social and political context that influence these characteristics. The spatial scale of assessment has been used consistently as one of the most important explanations for the lack of association income inequality and general health outcomes at a sub-national and/or small area level. [83] Studies have examined associations between income inequality and health outcome at different levels of aggregation within the same country and found significant variations.[84] The lack of association at a smaller level of geographic aggregation and the presence at the larger is attributed to the inability of income inequality as an exposure to reflect the social stratification within a society at a small area level. [83] Medical geographers have also recognized the 'modifiable areal unit problem (MAUP)' and 'uncertain geographic context problem (UGCoP)' that need to be considered when selecting the relevant spatial scale. [85-88] MAUP relates to the fact that societal exposures vary based on the definition of the geographic scale selected as well as zonation areas even when one scale is selected.[85] Consequently, there is a possibility of spatial misclassification of exposure, and the likelihood of a spurious association between area-level factors and oral health outcome. [85, 86] Consistent with MAUP, exposure misclassification based on the selection of neighbourhood definition has been empirically shown for the exposure of youths' access to tobacco retailers in a study.[85] UGCoP identifies two sources of contextual uncertainty. These sources include spatial configuration of geographically defined contexts and the timing and duration of exposure to those contexts.[87, 88] However, the role of spatial aggregation and individual mobility has not been dealt in multilevel studies of oral health.

Explicit definitions of ecological factors are crucial when generating hypothesis on societal determinants of health. This applies also to the clarity on levels (societal or individual) at which ecological factors are measured. The level of measurement has consequences on theoretical pathways through which they impact oral health outcomes. Differences in definitions of concepts might exist according to levels. For instance, there is a lack of consensus on the meaning and definition of social capital.[89] Lack of clarity on the definition makes the operationalization of social capital in epidemiological investigations challenging. Social capital is a contextual construct– a societal property. However, social capital is often measured at a societal level through deriving aggregates of individuals' perceptions of reciprocity, trust, and, engagements in civic activities. Social interactions among residents are rarely captured at the contextual level.[90] Individual perceptions of contextual social capital may potentially vary within the same context. Therefore, relying on aggregated measures of social capital that are unadjusted for individual-level variations in perceptions can lead to potential misclassification. This complexity in the measurement of social capital reflects the need for the explicit meaning of ecological measures at the contextual level. Additionally, recognizing the diversity of multiple mediating pathways (social capital or neo-material factors) for each and every oral health outcome and, at both individual and population levels can be helpful in a better understanding of causal relations and potential interventions.[23] While social capital explained the association between income inequality and self-rated health in Japanese adults, it did not explain their dentition status.[19]

Most multilevel studies are a secondary analysis of already collected data. Consequently, researchers may be forced to use imperfect proxies for measuring group level constructs. This provides limited information and can further make inferences drawn from such analysis inaccurate.[8] Caution is required particularly in identifying appropriate population groups, spatial scales and differentiating between the unique properties of ecological factors in interest.

Role of lag times

Failure to recognize and account for lag time between an ecological exposure and individual health outcome is a form of misclassification bias. The role of lag times between exposure and outcome has been paid less attention than other challenges in multilevel studies.[15] Usually, multilevel studies are conducted using cross-sectional data where the distinction between current and past exposures cannot be made. Societal factors are not likely to have an instantaneous effect on individual health, and therefore establishing appropriate lag period between the exposure and specific oral health outcome is necessary particularly when the exposure is not stable over time.[15] The lack of association between a societal exposure and an oral health outcome due to the inappropriate definition of lag times can be misleading as associations may be present when appropriate lag times are considered. Therefore, assessment of lag time is critical before dismissing the evidence on the impact of societal determinants on oral health based on findings where the exposure is non-stable and exposure and outcome are measured simultaneously.

Current challenges and limitations with multilevel statistical modelling

Multilevel models are still evolving. Issues such as appropriate sample size, methods for selecting and reporting appropriate measures of interest, and the reporting of diagnostic tests within multilevel studies are yet to be resolved.[14] Model diagnostics are also seldom reported within studies.[14] Assumptions of multilevel modelling regarding the hierarchical units being independent of each other are also rarely met. A lack of reporting of measures of variation in individual health and its decomposition is also identified within the literature.[65]

A more conceptual issue relevant to oral health needs further examination in the application of multilevel models in studying population variations in oral health. Compared to general health outcomes like mortality and health that are captured widely in census data and registration data, for oral health information data is obtained from oral health surveys that are not designed with a primary purpose to make inferences at smaller geographies, and are underpowered for this purpose. This limits the examination of average associations between an area-level societal determinant (area-level income inequality, area-level deprivation) and population oral health (rates of dental caries, rates of oral cancer) at small area level in multilevel studies. This restricts the assessment of theoretical pathways proposed to explain population-level variations in health/disease rates according to societal determinant when applied to explaining individual-level variations in oral health/disease. Some of the mediating pathways operate more strongly at an environmental level (legislation, policies, social capital, access to health services) while others at the individual level (stress, health behaviour, utilization of health services). Therefore, theoretical pathways need to be proposed and defended based on the level at which each oral health outcome is analysed. Potential differences in strengths of associations at the population level (population risk), and at the individual level (individual risk), may also demand separate prevention strategies and policy responses.[91] The extent to which studying population variations in oral health in multilevel studies through analysing variance share at population level informs these two policy-relevant issues needs further assessment.

Power and sample size calculations for multilevel hypotheses are complex as power depends both on a number of groups as well as the number of individuals per group.[13] Calculation of sample size in multilevel studies is dependent on the level at which inferences are to be made. When these are at the group level, there should be a sufficient number of groups rather than individuals. But, when the inference is to be made at the individual level, then both sufficient number of groups and individuals are required. Often multilevel studies are challenged due to the small size of groups. Simulation studies have shown that multilevel models with large numbers of groups (more than 459 groups) even with smaller group sizes remain stable, and neither fixed or random components are affected due to group sizes.[92] Since most multilevel studies on societal determinants of oral health use secondary data, Monte Carlo simulation of the model should be applied to estimation post-hoc power and for sample size calculation.[93] Most multilevel studies analyse cross-sectional data where the temporal sequence between exposure and outcomes cannot be established. Multilevel studies on longitudinal datasets can help resolve this issue as temporal sequence between the societal exposure and oral health outcomes can be established. However, multilevel statistical modelling is mainly applied in longitudinal data to manage data imbalances due to loss to follow up, rather than to examine associations between societal determinants and oral health outcomes.

Final remarks

The challenges currently posed in population oral health highlight the need for more population focussed research and the use of ecological studies in the field or dental public health. The value in studying population-variations in oral health and its determinants has a rationale embedded in theory and is fundamental for policy assistance. This will likely contribute towards a better understanding of how exposures that affect all individuals in a population contribute to their oral health. There is a need for balancing the weight of individual-level studies with studies of population variations and societal determinants, not to replace the individual-level studies, but to complement them.

Ecological studies offer an opportunity to study average associations between societal determinants and population-level variations in oral health, but cannot account for potential confounding introduced by factors from alternate levels of social organization.[6] Multilevel studies using individual and societal data collectively, overcome this limitation by simultaneously examining multiple hypotheses generated at different levels of social organization. Using multilevel models to quantify the share of individual-level variation in oral health outcomes that exist at a societal level, the contribution of societal and individual determinants on this share of variance, allows the investigation of population-level variations in oral health and its determinants.[61]

Multilevel studies of societal determinants of oral health require careful attention from the stage of conceptualization to design, analysis and reporting, as highlighted in this paper. These features are not unique to such studies and form the basis of any scientific enquiry. In addition to multilevel methods, studies on societal determinants of oral health can deal with inherent complexity by exploring methodological approaches from other disciplines such as social and political sciences including qualitative methods. Finally, studies with explicit theoretical bases[23] that draw on the strengths of multilevel modelling can provide a more enhanced understanding of societal determinants of oral health, and consequently lead to robust evidence for relevant policy solutions.

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Table 1. Description of fallacies along with suitable examples from oral health

Fallacy	Reason	Description	Example
Ecological	Construct and measurement issues	Associations at ecological level are used to make inferences on the association at an individual level due to absence of data at an individual level. The more heterogeneous the population, the higher is the fallacy	Association between water fluoridation and skeletal fractures[94]: Supportive evidence for the association came largely from ecological studies comparing rates of fracture between fluoridated and non-fluoridated communities. However, well designed studies that measured individual exposure to water fluoridation/fluoride intake and controlled for different confounders could not find an association between dentally optimal doses of fluoride and fracture. This indicates a case when ecological level associations were not held true at the individual level.
Atomistic	Construct and measurement issues	Associations at individual level are used to make inferences on the association at an ecological level due to absence of data at a population level. This fallacy ignores the fact that societal factors and population has independent characteristics	Individual income may be negatively associated with tooth loss and it is inferred that mean income of an area is associated positively with population rate of tooth loss. However, the mean income may not be associated or positively associated with population rate of tooth loss.
Sociologistic	Ignorance of variables from	This fallacy is a consequence of ignoring the role of individual level factors in group level	Effects of fluoride intake on population-level differences in dental caries is determined by testing correlations between

	individual level	associations	community-level water fluoridation and community levels of dental caries. Interpreting that community water fluoridation reduces every residents' risk of dental caries within such studies can be prone to sociologistic fallacy as certain sub-groups may have preferences of bottled water over tap water.
Psychologistic	Ignorance of variables from population level	This fallacy is a result of ignoring the role of ecological level factors in individual level associations	Ignoring the fact that water fluoridation is an environmental factor, and its presence may modify the association between fluoride intake and dental caries at the individual level.

Table 2. Description of different categories of ecological variables according to their classification and examples

Category	Description	Example
Aggregate/contextual/analytical	Aggregate summary measure of individual characteristics in a group (similar to derived variables)	Area-level mean income
Contagion	Aggregates of individual outcomes	Prevalence of dental caries and tooth loss rates of a group

Environmental	Physical characteristics with individual analogue	Environmental measure: Residential access to water fluoridation Individual analogue: Consuming fluoridated tap water
Structural	Patterns of relationship between individuals of a group	Social capital, social cohesion, social inequality as a product of power relations
Global	Attributes belonging to groups and not reduced to individuals	Legislations and policies