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Network science and oral health research

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Introduction

The complex relationships between networks of people and health outcomes have been of increasing interest in the health literature (1-4), but have received little attention in oral research. The present overview serves as a synopsis of the social network analysis (SNA) perspective, with an emphasis on how different types of SNA could be usefully applied to understanding oral health outcomes.

Social network analysis is a set of relational methods to identify connections between members of a system, or *network*. SNA is driven by characterizing the structure of the network and the interactions between its members – using systematic approaches grounded in both graphic imagery and computational models. SNA builds on the concept of network by ascribing to it precise mathematical features, so that it can be represented, analyzed, and modeled. SNA is distinctly separate from similar colloquial terms, which can be confusing as many of these terms appear directly exchangeable. SNA is not the same as the social network concept when the term is loosely applied to mean ‘social support’ (a perception or location in which a person is cared for, has assistance available from other people, and is part of a supportive group). Nor are networks a synonym with modern social media; however, both examples – the group of peers and acquaintances operating in the living environment of a person, or a network of persons socially connected through the Internet – are assemblies of *actors* and *relationships* that may be understood using network science methods and rationales.

Basic Assumptions about Networks

Health behavior researchers have turned to network science because there is a growing recognition that many of the perceptions, beliefs, and attitudes that drive health behavior are embedded in the social context of people’s lives (5-7), influencing different dimensions of such social environments – for an individual or entire communities (8). Researchers have often focused on individuals’ personal networks as these are most likely to influence behavior, whether by helping them to interpret health problems (9), by influencing the perception of social norms (10), by attempts to control or regulate behavior (11), or by a combination of types of social influence (12,13). At the same time, the structure of personal networks varies across many social characteristics, including socioeconomic status (SES)

(14-16); to the point that it has been argued that the relationship between SES and health may be a function of the structure and quality of social networks (17). E.g., SES and its association with health profiles in certain immigrant populations may be predicated on how migration can dramatically alter a person's social networks (18) or modulate risk-taking behavior (19).

For the present overview we will focus first on types of data that relate to social networks, then discuss how SNA studies can be designed to collect such data, the types of analysis that can be applied, and examples of oral health research questions that can be answered using SNA.

Social Network Analysis and Study Design

There are three types of network data from social and behavioral sciences that can usefully inform studies of oral health outcomes.

The first type includes what we term “network-inspired” data, which are studies that consider relationships between individuals but do not gather specific data about relationships. Studies may collect indirect measures of social relationships, such as what is often seen in social capital research (20). Questions that gather this sort of information should be broadly familiar to anyone involved in social survey research. What kind of community organizations do you belong to? Do you attend church? Do you have close relationships with neighbors? A prominent example of this type of work is the Bowling Alone study (21), which looked at American social life through the lens of declining civic participation.

A second, more specialized form of network study are *egocentric* studies. These are approaches that use information about *egos* (typically the person being interviewed or having data collected about them) and their relationships with other non-interviewed people that the *ego* names, the *alters*. E.g., Who do you talk to about important health matters in your life? Easier to derive from traditional social survey data, *egocentric* studies move beyond the proxies for network relationships used by network-inspired research; *egocentric* studies delve into specifics using a “generator” tactic to elicit information about *alters* (e.g., Who do you seek advice from when you have dental pain?). This type of approach has been used extensively (2,4,22-24) and recently in the prominent General Social Survey (25). *Egocentric* studies are characterized by actual information about real relationships but do not necessarily involve any additional contact with those *alters*. A wide variety of information can be gleaned from these studies – the number of *alters*, the composition of those networks (gender, education, health status, kin, non-kin), the stability of networks, and if collected, even *sociocentric* measures (which we will discuss below) from the perspective of the *ego*. The benefits of the *egocentric* approach are that it can accommodate a random sample design; both the collection and the analysis are accessible to researchers conducting social science research without massive additional preparation, and they have direct comparisons in many fields. The key aspect of these data is that they can be primarily used to answer questions about individuals and the association that their relationships might have

on them as individuals. They cannot be used, however, to answer questions about the broader social structure of a community, or questions about groups of people.

A third type, and the most complicated form of SNA from both data collection and analysis standpoints, are *sociocentric* studies. These are sometimes referred to as research on *whole* or *complete* networks. They focus on a complete population of interest, not a sample. In a traditional survey context, it would mean asking each population member about each other population member (with a roster, or with a “free recall” version, allowing members to name others). This type of study involves taking an entire *bounded* community and either asking about or observing relationships between all individual members. The boundary of a community is a definition of which actors belong to it (and which do not): e.g., a neighborhood, a workplace, a professional association, or a community defined by nationality of origin. This is simultaneously the most complicated and the more limited form of data collection because it entails considerable data collection burden. Also, there cannot be an assumption of independence of cases as in other randomly-sampled survey research, because all individuals could be connected to one another (indeed it is these relationships that we hope to find). Missing data pose a large problem in this type of study precisely because individuals are expected to be connected to one another, and survey response and quality are of utmost importance. Because cases collected are implicitly understood as dependent upon one another, analytic approaches are specific to the data, affecting greatly by graph theory and specific *sociocentric* techniques (2,4,26,27). Examples can be seen in the seminal SNA textbook by Wasserman & Faust (27), but are probably better known in current health studies from the Christakis and Fowler studies (1,28,29) that constructed network data from the Framingham Heart Study. They evaluated the impact of social relationships on health-related behaviors and states like smoking and obesity, and psychological outcomes such as happiness and loneliness.

SNA uses discipline-specific terminology. In *sociocentric* studies, individuals are referred to as *actors*, *nodes*, or *vertexes*, which are connected through relationships called *edges*, *arcs*, or *ties*. Figure 1 illustrates these terms using a small sub-network from our TalaSurvey study (NIDCR DE022096) for Ego 218. In this case, the ego – who is not shown in this figure – was asked how all of the nine individuals that she had named as people she spoke to about important or health matters knew one another. The names of the *actors* (pseudonyms used), are listed on each circular *node*. In Figure 1, the existence of a *tie* between *actors* is indicated by a *line* between them. *Ties*, sometimes called *edges*, simply indicate that there is a relationship (such as being married). The term *arcs* can indicate that there is *direction* to the *tie* (e.g., a community health worker disseminating health information to a group of lay people). Questions can then be asked not just about the individual and how prominent or important that *node* is in the population (a feature called *centrality*, illustrated in Figure 1 by the varying size of *nodes* as determined by their *weighted degree*) or how often such *ties* are sought (such as with high school peer popularity and friendships, which connote a feature conceptualized as *prestige*), but also about how groups of people interact. Such interactions may be defined both exogenously through attributes such as race or gender, and endogenously through observed patterns of social relationships. In addition, questions can be asked about the whole network. For instance, what its *density* is (how many *ties* in fact exist

out of all possible *ties*) and what structure the entire community network has. There are many different approaches to conducting *sociocentric* SNA, and within this category, there can be many different types of data. As with other research paradigms, the design can be cross-sectional or longitudinal. Relations can be conceived as *binary* or *dichotomous* (two people are friends or are not but such *tie* has no strength associated with it), *undirected* (two persons are simply observed to be connected, such as in Figure 1), or *directed* (a relationship that can be received from one actor to another but there is not an assumed two-way correspondence, as in one person reporting the friendship but the other not doing so). They can also be *valued* or *weighted*: e.g., instead of just being friends (yes/no), the friendship is *valued* by being scored as having strength of 10 on a scale of 1 to 10. In Figure 1, there are three difference possible tie values. The thinnest line represents individuals who know one another, but are “not very close.” The middle width indicates that two individuals are reported to be “somewhat close.” The thickest line indicates that two individuals are “very close.” An absence of any line indicates that the two individuals reportedly did not know one another. Such visual distinctions applied to make a comprehensible *sociogram* do follow SNA conventions, but are generally flexible for researchers. However, for mathematical and statistical analysis, each data type mentioned above has separate analysis approaches developed for it. Another prevalent form of data collection is for *affiliation* data, in which relationships about two individuals are not measured by their directly reported or observed relationship between each other but are instead proxied by shared membership or participation in a group or event. E.g., two scholars may be affiliated only through papers they have co-authored together, but they may not be affiliated by being faculty in the same university.

It should also be noted that social network data can be collected through observational means instead of through surveys or asking individuals directly about their relationships. This is the basis for many studies that look at social media interactions, but can also be applied to small group observation, such as patients seeking dental care in a community clinic.

Examples of Research Applications

SNA is not based on a single, unified theory. It is a perspective of how *ties* tell stories that may accrue different types and wealth of evidence about health and disease phenomena, compared to individual level characteristics. The assumption is that social *actors* (persons, organizations, clans, and so on) shape their lives through sharing information, experiences, and other forms of interaction. Such dynamic exchanges vary over time, and even feed on prior interactions to shape subsequent exchanges – strong or weak in nature, positive or negative in their outcomes. While many of the applications have involved social and behavioral processes with human *actors*, it is theoretically reasonable to think of organizations delivering clinical services in health systems, or microorganisms in biofilms, as members of networks. Once categorized in those roles it is then feasible to place the interactions within their networks (based on their relations and attributes) under scrutiny using SNA.

SNA applied to social and behavioral aspects of health differs radically from other approaches often used in oral health research; in particular because the foci of analysis are not on observations pertaining to independent cases, nor on explanatory variables. E.g., SNA could incorporate the norms prevailing about food items, oral health behaviors, and dental care utilization within a network. Collection of socio-demographic variables from members, and variables depicting those norms, may be undertaken using surveys, qualitative tools, direct observation, or records. Collection of the characteristics of the network and its structure would be amenable to indirect observations but it is commonly addressed through completion of a survey to determine the relations between *egos* and *alters* (depicting who knows whom, and the interactions between them). Under this approach, each *ego* would be asked to nominate the people they talk with about health-related matters (name-generator questions), including questions about the *alters* nominated such as the sources of support, the frequency of contact, and the *direction* of health communications (e.g., whether it be giving and/or receiving of advice). Besides the name-generator questions, *egos* may be assisted in thinking about who they interact with by supplying a roster of network members.

The description of the network is the first analytic task. This description may be supplemented by socio-demographic variables from members, and (using the example above) the variables depicting their norms about food, oral health behaviors, and dental care utilization. Describing the network usually includes network size, composition, and frequency of contact (30). These are obtained through summing the number of, or computing the proportion of, each *actor's* network *ties*. It is possible to add features of interest, such as the percent of *nodes* who are men or women, the length of time they have lived in a location, their age, a categorization of the sources of dental care they use, and other variables. But to better understand the *respondents'* networks themselves, an $N \times N$ matrix is constructed using network analysis software to represent all network *ties*. N is the number of actors in a network – traditionally a network would be represented in a matrix that is N rows deep and N columns wide. Matrices thus attained allow mapping whether or not two *actors* mentioned each other (e.g., as a significant support to help each other remain in a tobacco cessation program) through a *sociogram*: a graphic representation of network relationships, comprised of *nodes* and *ties*. Through the matrices it is also feasible to create measures to describe each *node's* social character as a provider/receptor of health knowledge or health advice within the community network (specifically, measures of *centrality*, *betweenness*, *prestige* and *rank*, and belonging to *subgroups* or to *affiliation* networks). Building on the sophisticated information depicting the *ties* across *nodes* in the network it would also be possible to ascertain whether experience of oral health problems or adherence to schedules of professional dental care are influenced by the experiences of network members at a *distance* of 2 and 3 – i.e., *nodes* that are removed from the index *node* by one or two *nodes* of separation. In practical terms, being able to accurately measure and model spatially how characteristics disseminate throughout a network opens attractive applications to gauge the effect of interventions: e.g., whether a health promotion intervention reaches members at a *distance* of 2 or 3 (or more) of the individual member receiving the formal instruction, or how permanent are changes in health behaviors within a network when supported through motivational interviewing training of a few *hubs*. The term *hub* connotes an important *actor*, surrounded by connections to many other *actors*,

disproportionately more connected or popular than the rest. A *hub* is characterized by high *centrality*; this general term can be measured in many ways – such as the number of *ties* an *actor* has (*degree centrality*), the number of other *actors* so positioned they can be efficiently reached by that one *actor* (*closeness*), or the number of connections between other *actors* that an *actor* exists on (*betweenness*).

Corollary and Opportunities for Research

This brief overview of SNA illustrated some of the basic postulates and the underlying rationale of a large set of analytic methods hitherto poorly used in oral health research. We were able to identify only three citations of network science applications in an oral health context (search terms *network science AND dental*) (31-33). Although by no means an exhaustive literature search and potentially confounded by various connotations of the terms social network or social support, sparse SNA reports suggest there is ample opportunity to expand the utilization of SNA in oral health research. Even though the emphasis of the present overview was about human behavior and implications for oral health, it is evident the considerable scope for SNA applications at both macro and micro levels of research – e.g., organizational systems or pathophysiology mechanisms. One of the more recent and all-encompassing perspectives for SNA in health applications, the Network-Episode Model (3), describes the theoretical possibilities of factors interacting across highly diverse layers, from/to the higher levels of societal domains to/from the more basic building blocks (from community networks to organizational networks, to personal networks and its manifestations in an illness career, to organs and systems, and to the cell/tissue level). Started with a focus on how individuals first recognize, then respond to disease onset, and how they come to utilize health care services, the Network-Episode Model has provided new insights into the patterns and pathways to care, adherence to treatment, and the outcomes of health care. Great many applications for SNA are readily apparent in the field of dental public health and population-based oral health research – starting with the more basic questions. First, how important are relationships for oral health? Itself an empirical question, other fields of health research suggest that relationships could in fact be important; while their features remain to be characterized, there is considerable research potential to understand how those relationships and interactions fluctuate in light of individual or network attributes. Also, what are the norms governing the relationships between health care providers and consumers? Most of the accounts have so far been rather directional and prescriptive, from the value system of health care providers gauging what consumers do or fail to do to support their oral function and health. This is in fact another way of asking what are the mechanisms for relationships to affect health – in positive or negative ways? And, in a more distant horizon, how interventions to improve health can take relational realities into account? Perhaps most importantly, can those relational realities be used as a building block in interventions? And how?

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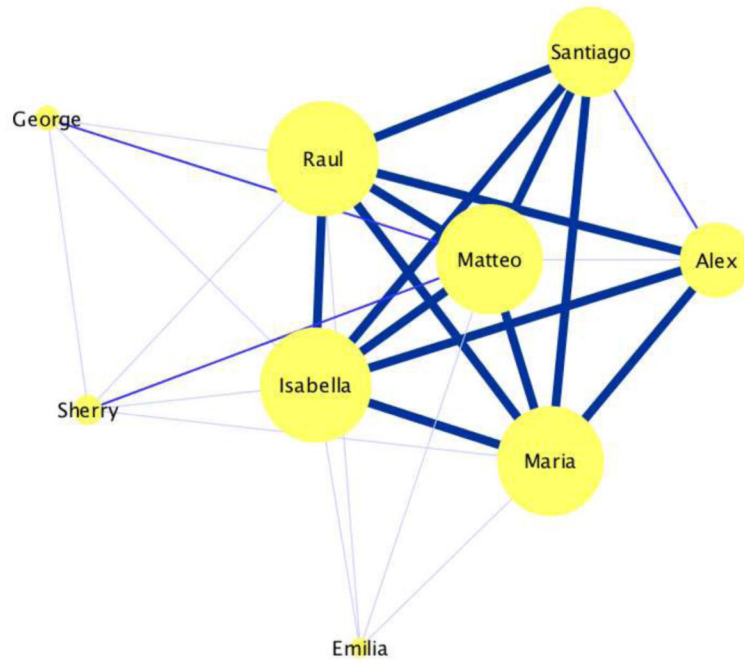


Figure 1.
Sample Sociogram of Sociocentric Network Derived from Ego 218 of the TalaSurvey Study.