SPECIAL ARTICLE

The Spread of Obesity in a Large Social Network over 32 Years

Nicholas A. Christakis, M.D., Ph.D., M.P.H., and James H. Fowler, Ph.D.

ABSTRACT

BACKGROUND
The prevalence of obesity has increased substantially over the past 30 years. We performed a quantitative analysis of the nature and extent of the person-to-person spread of obesity as a possible factor contributing to the obesity epidemic.

METHODS
We evaluated a densely interconnected social network of 12,067 people assessed repeatedly from 1971 to 2003 as part of the Framingham Heart Study. The body-mass index was available for all subjects. We used longitudinal statistical models to examine whether weight gain in one person was associated with weight gain in his or her friends, siblings, spouse, and neighbors.

RESULTS
Discernible clusters of obese persons (body-mass index [the weight in kilograms divided by the square of the height in meters], ≥30) were present in the network at all time points, and the clusters extended to three degrees of separation. These clusters did not appear to be solely attributable to the selective formation of social ties among obese persons. A person's chances of becoming obese increased by 57% (95% confidence interval [CI], 6 to 123) if he or she had a friend who became obese in a given interval. Among pairs of adult siblings, if one sibling became obese, the chance that the other would become obese increased by 40% (95% CI, 21 to 60). If one spouse became obese, the likelihood that the other spouse would become obese increased by 37% (95% CI, 7 to 73). These effects were not seen among neighbors in the immediate geographic location. Persons of the same sex had relatively greater influence on each other than those of the opposite sex. The spread of smoking cessation did not account for the spread of obesity in the network.

CONCLUSIONS
Network phenomena appear to be relevant to the biologic and behavioral trait of obesity, and obesity appears to spread through social ties. These findings have implications for clinical and public health interventions.

From the Department of Health Care Policy, Harvard Medical School, Boston (N.A.C.); the Department of Medicine, Mt. Auburn Hospital, Cambridge, MA (N.A.C.); the Department of Sociology, Harvard University, Cambridge, MA (N.A.C.); and the Department of Political Science, University of California, San Diego, San Diego (J.H.F.). Address reprint requests to Dr. Christakis at the Department of Health Care Policy, Harvard Medical School, 180 Longwood Ave., Boston, MA 02115, or at christakis@hcp.med.harvard.edu.

N Engl J Med 2007;357:370-9.

The prevalence of obesity has increased from 23% to 31% over the recent past in the United States, and 66% of adults are overweight.[1,2] Proposed explanations for the obesity epidemic include societal changes that promote both inactivity and food consumption.[3] The fact that the increase in obesity during this period cannot be explained by genetics[4,5] and has occurred among all socioeconomic groups[1] provides support for a broad set of social and environmental explanations. Since diverse phenomena can spread within social networks,[6-10] we conducted a study to determine whether obesity might also spread from person to person, possibly contributing to the epidemic, and if so, how the spread might occur.

Whereas obesity has been stigmatized in the past, attitudes may be changing.[11,12] To the extent that obesity is a product of voluntary choices or behaviors, the fact that people are embedded in social networks and are influenced by the evident appearance and behaviors of those around them suggests that weight gain in one person might influence weight gain in others. Having obese social contacts might change a person's tolerance for being obese or might influence his or her adoption of specific behaviors (e.g., smoking, eating, and exercising). In addition to such strictly social mechanisms, it is plausible that physiological imitation might occur; areas of the brain that correspond to actions such as eating food may be stimulated if these actions are observed in others.[13] Even infectious causes of obesity are conceivable.[14,15]

We evaluated a network of 12,067 people who underwent repeated measurements over a period of 32 years. We examined several aspects of the spread of obesity, including the existence of clusters of obese persons within the network, the association between one person's weight gain and weight gain among his or her social contacts, the dependence of this association on the nature of the social ties (e.g., ties between friends of different kinds, siblings, spouses, and neighbors), and the influence of sex, smoking behavior, and geographic distance between the domiciles of persons in the social network.

METHODS

SOURCE DATA

The Framingham Heart Study was initiated in 1948, when 5209 people were enrolled in the original cohort.[16] The Framingham Offspring Study began in 1971, when most of the children of members of the original cohort and their spouses were enrolled in the offspring cohort.[17] There has been almost no loss to follow-up other than death in this cohort of 5124 people; only 10 people left the study. In 2002, the third-generation cohort, consisting of 4095 children of the offspring cohort, was initiated. All participants undergo physical examinations (including measurements of height and weight) and complete written questionnaires at regular intervals.

NETWORK ASCERTAINMENT

For our study, we used the offspring cohort as the source of 5124 key subjects, or "egos," as they are called in social-network analysis. Any persons to whom the egos are linked — in any of the Framingham Heart Study cohorts — can, however, serve as "alters." Overall, 12,067 living egos and alters were connected at some point during the study period (1971 to 2003).

To create the network data set, we entered information about the offspring cohort into a computer. This information was derived from archived, handwritten administrative tracking sheets that had been used since 1971 to identify people close

Glossary

Ego: The person whose behavior is being analyzed.

Alter: A person connected to the ego who may influence the behavior of the ego.

Node: An object that may or may not be connected to other objects in a network. In this study, nodes represent people in the Framingham Heart Study cohorts.

Tie: A connection between two nodes that can be either one-way (directed) or two-way (bilateral). In this study, all family ties (e.g., between siblings and parents) as well as marital ties are bilateral, but friendship ties are directional since a subject may identify someone as a friend who does not necessarily identify that person as a friend in return.

Degree of separation: The social distance between two people as measured by the smallest number of intermediaries between an ego and other members of the network. For a given ego, alters are degree 1, since they are directly connected to the ego. Nodes that are connected to the alters but not to the ego are degree 2 (alters' alters). Nodes that are connected to the alters' alters but not to the ego are degree 3, and so on.

Homophily: The tendency for people to choose relationships with people who have similar attributes.

Induction: The spread of a behavior or trait from one person to another.

Cluster: A group of nodes, each of which is connected to at least one other node in the group.

Connected component: Part of a social network in which all persons have a social tie to at least one other person and no person is connected to a member of any other component of the network.

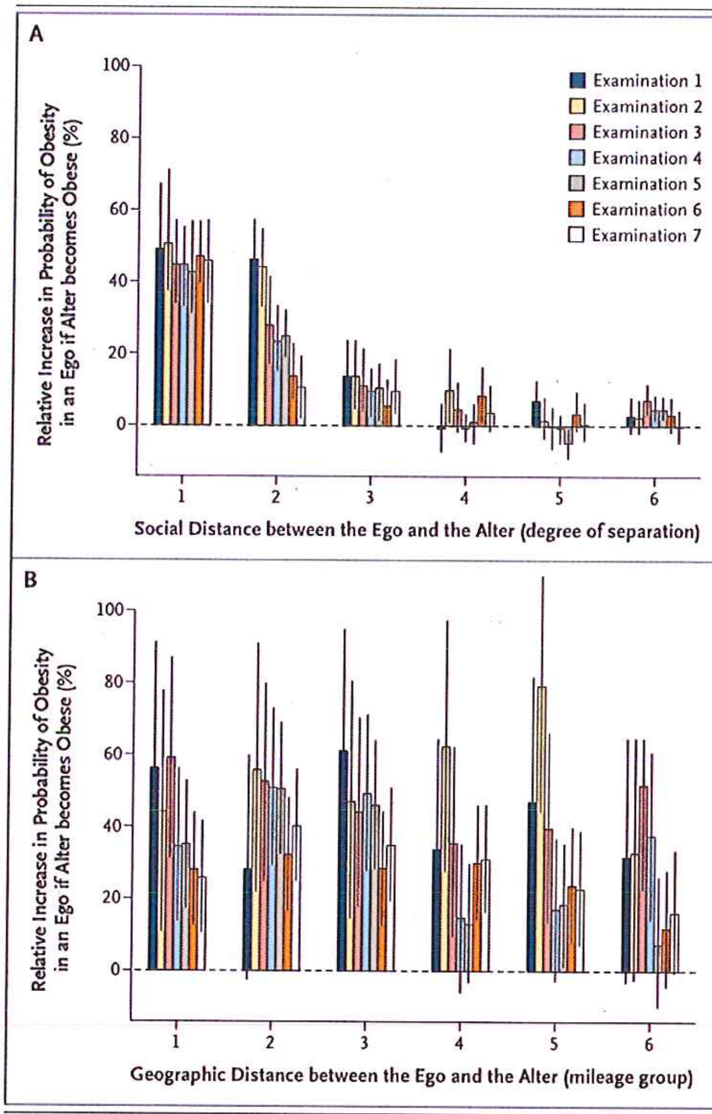

Figure 3. Effect of Social and Geographic Distance from Obese Alters on the Probability of an Ego's Obesity in the Social Network of the Framingham Heart Study.

Panel A shows the mean effect of an ego's social proximity to an obese alter; this effect is derived by comparing the conditional probability of obesity in the observed network with the probability of obesity in identical networks (with topology preserved) in which the same number of obese persons is randomly distributed. The social distance between the alter and the ego is represented by degrees of separation (1 denotes one degree of separation from the ego, 2 denotes two degrees of separation from the ego, and so forth). The examination took place at seven time points. Panel B shows the mean effect of an ego's geographic proximity to an obese alter. We ranked all geographic distances (derived from geocoding) between the homes of directly connected egos and alters (i.e., those pairs at one degree of separation) and created six groups of equal size. This figure shows the effects observed for the six mileage groups (based on their average distance): 1 denotes 0 miles (i.e., closest to the alter's home), 2 denotes 0.26 mile, 3 denotes 1.5 miles, 4 denotes 3.4 miles, 5 denotes 9.3 miles, and 6 denotes 471 miles (i.e., farthest from the alter's home). There is no trend in geographic distance. I bars for both panels show 95% confidence intervals based on 1000 simulations. To convert miles to kilometers, multiply by 1.6.

poraneous obesity (changing from 0 to 1), using 1000 randomly drawn sets of estimates from the coefficient covariance matrix and assuming mean values for all other variables.[29] All tests were two-tailed. The sensitivity of the results was assessed with multiple additional analyses (see the Supplementary Appendix).

RESULTS

Figure 1 depicts the largest connected subcomponent of the social network in the year 2000. This network is sufficiently dense to obscure much of the underlying structure, although regions of the network with clusters of obese or nonobese persons can be seen. Figure 2 illustrates the spread of obesity between adjoining nodes in a part of the network over time. A video (available with the full text of this article at www.nejm.org) depicts the evolution of the largest component of the network and shows the progress of the obesity epidemic over the 32-year study period.

Figure 3A characterizes clusters within the entire network more formally. To quantify these clusters, we compared the whole observed network with simulated networks with the same network topology and the same overall prevalence of obesity as the observed network, but with the incidence of obesity randomly distributed among the nodes (in what we call "random body-mass–index networks"). If clustering is occurring, then the probability that an alter will be obese, given that an ego is known to be obese, should be higher in the observed network than in the random body-mass–index networks. What we call the "reach" of the clusters is the point, in terms of an alter's degree of separation from any given ego, at which the probability of an alter's obesity is no longer related to whether the ego is obese. In all of the examinations (from 1971 through 2003), the risk of obesity among alters who were connected to an obese ego (at one degree of separation) was about 45% higher in the observed network than in a random network. The

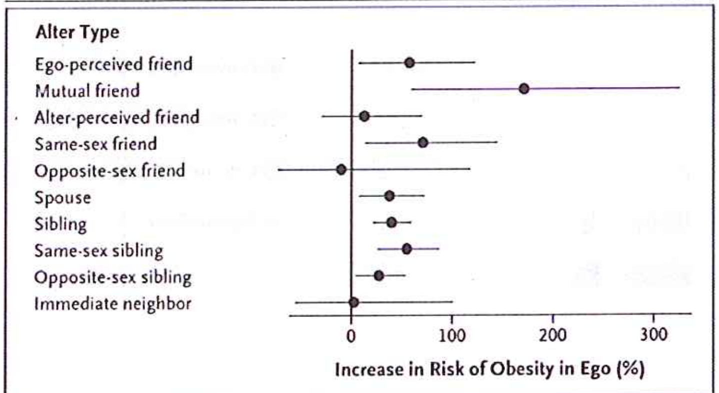

Figure 4. Probability That an Ego Will Become Obese According to the Type of Relationship with an Alter Who May Become Obese in Several Subgroups of the Social Network of the Framingham Heart Study.

The closeness of friendship is relevant to the spread of obesity. Persons in closer, mutual friendships have more of an effect on each other than persons in other types of friendships. The dependent variable in each model is the obesity of the ego. Independent variables include a time-lagged measurement of the ego's obesity; the obesity of the alter; a time-lagged measurement of the alter's obesity; the ego's age, sex, and level of education; and indicator variables (fixed effects) for each examination. Full models and equations are available in the Supplementary Appendix. Mean effect sizes and 95% confidence intervals were calculated by simulating the first difference in the contemporaneous obesity of the alter (changing from 0 to 1) with the use of 1000 randomly drawn sets of estimates from the coefficient covariance matrix and with all other variables held at their mean values.

risk of obesity was also about 20% higher for alters' alters (at two degrees of separation) and about 10% higher for alters' alters' alters (at three degrees of separation). By the fourth degree of separation, there was no excess relationship between an ego's obesity and the alter's obesity. Hence, the reach of the obesity clusters was three degrees.

Figure 3B indicates that the effect of geographic distance is different from the effect of social distance. Whereas increasing social distance appeared to decrease the effect of an alter on an ego, increasing geographic distance did not. The obesity of the most geographically distant alters correlated as strongly with an ego's obesity as did the obesity of the geographically closest alters. These results suggest that social distance plays a stronger role than geographic distance in the spread of behaviors or norms associated with obesity.

We evaluated the extent of interpersonal association in obesity with the use of regression analysis. Our models account for homophily by including a time-lagged measurement of the alter's obesity. We evaluated the possible role of unobserved contemporaneous events by separately analyzing models of subgroups of the data involving various ego–alter pairings. Figure 4 summarizes the associations.

If an ego stated that an alter was his or her friend, the ego's chances of becoming obese appeared to increase by 57% (95% confidence interval [CI], 6 to 123) if the alter became obese. However, the type of friendship appeared to be important. Between mutual friends, the ego's risk of obesity increased by 171% (95% CI, 59 to 326) if an alter became obese. In contrast, there was no statistically meaningful relationship when the friendship was perceived by the alter but not the ego ($P=0.70$). Thus, influence in friendship ties appeared to be directional.

The sex of the ego and alter also appeared to be important. When the sample was restricted to same-sex friendships (87% of the total), the probability of obesity in an ego increased by 71% (95% CI, 13 to 145) if the alter became obese. For friends of the opposite sex, however, there was no significant association ($P=0.64$). Among friends of the same sex, a man had a 100% (95% CI, 26 to 197) increase in the chance of becoming obese if his male friend became obese, whereas the female-to-female spread of obesity was not significant (38% increased chance; 95% CI, −39 to 161).

Among pairs of adult siblings, one sibling's chance of becoming obese increased by 40% (95% CI, 21 to 60) if the other sibling became obese. This phenomenon appeared to be more marked among siblings of the same sex (55%; 95% CI, 26 to 88) than among siblings of the opposite sex (27%; 95% CI, 3 to 54), although the difference was not significant ($P=0.16$). Among brothers, an ego's chance of becoming obese increased by 44% (95% CI, 6 to 91) if his alter became obese, and among sisters, an ego's chance of becoming obese increased by 67% (95% CI, 27 to 114) if her alter became obese. Obesity in a sibling of the opposite sex did not affect the chance that the other sibling would become obese.

Among married couples, when an alter became obese, the spouse was 37% more likely (95% CI, 7 to 73) to become obese. Husbands and wives appeared to affect each other similarly (44% and 37%, respectively). Finally, we observed no effect on the risk that an ego would become obese if an immediate neighbor became obese.