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# Educational attainment in sociocentric networks associates with cardiac biomarkers in Korean elders

Ekaterina Baldina[1], Sung-Ha Lee[2], Yeong-Ran Park[3], Hyeon Chang Kim[4] & Yoosik Youm[5]✉

**The link between education and recovery from cardiovascular diseases is well-established, yet the relationship between the educational attainment of social network members and the development of these conditions remains underexplored. Cardiac biomarkers such as BNP, Troponin I, and NT-proBNP are early indicators of cardiovascular stress and subclinical damage. For instance, Troponin I is linked to myocardial infarction, while BNP and NT-proBNP are used to identify heart failure. This study examines the relationship between educational attainment of social network and cardiac biomarkers using data from the Korean Social Life, Health, and Aging Project (KSHAP), a longitudinal study of 709 adults aged 60–95 in a rural village, surveyed in 2011, 2016, and 2019. Fixed-effects models were employed to reduce unobserved heterogeneity by assessing within-individual changes. The educational attainment of rural older adults, who typically possess only basic education, showed no association with levels of cardiac biomarkers. However, compared to older adults with no college-educated friend, people with one college-educated friend-of-friend was linked to lower levels of BNP (β = − 0.26), Troponin I (β = − 0.81), and NT-proBNP (β = − 0.57). Social environments enriched with college-educated ties may offer cognitive or informational benefits that help prevent early cardiovascular damage.**

**Keywords** Cardiac biomarkers, Social networks, Education, Educational attainment of social network, Older adults, CVD

Individuals with more education and higher-level degrees tend to have better physical functioning[1], higher self-reported health[2], fewer medical conditions[3,4], a lower risk of mortality[5–7], and a reduced probability of subclinical cardiovascular disease compared to those with lower levels of education[8–11]. Higher levels of education are also associated with lower prevalence of coronary heart disease risk factors such as smoking, high blood pressure, overweight, elevated cholesterol levels, and a lower risk of cardiovascular mortality[8,12]. Older persons in the lowest educational and income groups had 41% and 50% higher risk, respectively, of subclinical cardiovascular disease[13]. Education may protect against CVDs by increasing the tendency for healthier behaviours and decisions related to health.

Social networks serve as important sources of informal education, emotional and instrumental support, and health-related information that influence cardiovascular health outcomes[14]. Friends can encourage healthier behaviors, improve decision-making, and promote early detection or treatment. When seeking various advice regarding cardiovascular disease (CVD), individuals often turn to friends before approaching medical professionals. For example, people with larger and more supportive social networks, on average, experience better recovery after cardiovascular disease[15], lower risk of stroke and CVD incidence[16], and reduced mortality from coronary heart disease[17]. Conversely, a lack of support, social isolation, being unmarried, or not having a confidant is associated with poorer prognosis and higher mortality following the incidence of coronary heart disease or other cardiac events[18]. The influence of highly educated network members may be particularly strong. Indeed, having highly educated friends can confer similar advantages to being highly educated oneself, as these individuals often provide accurate health information, model preventive behaviors, and facilitate access to health-related resources[19–21].

[1]Department of Sociology, Indiana University, Bloomington, USA. [2]Department of Psychology, Yonsei University, Seoul, Republic of Korea. [3]Division of Silver Industry, Kangnam University, Yongin, Gyeonggi, South Korea. [4]Department of Preventive Medicine, Yonsei University, Seoul, Republic of Korea. [5]Department of Sociology, Yonsei University, Seoul 03722, Republic of Korea. ✉email: yoosik@yonsei.ac.kr

However, little attention has been paid to the educational attainment of friends or social ties above and beyond the size of the supportive social networks. A few exceptions include three recent studies about the educational attainment of network members and health outcomes[19–21]. Hernandez et al. (2019) demonstrated that higher proportion of college-educated network members was associated with a higher probability of being vaccinated. Halpern-Manners et al. (2022) found that spousal education was beneficially related to one's health net of the individual's education. Brooks (2024) focused on pathways between social networks and health, showing that a higher average education level of network members was associated with self-rated good physical health. Furthermore, many studies have confirmed the relationships between social networks and the recovery from CVDs[18,22–26]. However, the evidence on the association of social networks with the incidence and development of cardiovascular disease is inconclusive at best[18].

Our study explores the educational attainment of social networks measured by the number of college-educated ties and examines its relationship with cardiovascular disease incidence-related biomarkers. We use three blood biomarkers to examine and define cardiac health: Brain Natriuretic Peptide (BNP), Troponin I, and N-Terminal -proBrain Natriuretic Peptide (NT-proBNP)[27]. Troponin I is a protein produced in cardiac muscle. Recent studies suggest the importance of Troponin I as a marker of chronic subclinical myocardial damage in asymptomatic populations with no history of cardiovascular disease[28]. BNP and NT-proBNP, markers of cardiac overload, are secreted when the myocardial wall experiences stress and are usually used to diagnose heart failure[29]. A handful of studies explored the relationships between levels of education and these cardiac biomarkers. One study reported that individuals with low educational attainment had a 36% higher chance of elevated Troponin I levels[30]. We provide further evidence of the relationships between cardiac biomarkers and the educational attainment of social networks.

To pursue this, we use 8-year follow-up cohort data, including a sociocentric (global) social network of one entire village from the Korean Social Life, Health, and Aging Project (KSHAP)[31]. This sociocentric (global) network captures all individuals in the sample and their connections within the township, allowing us to observe both direct ties (friends) and indirect ties (friends-of-friends). Unlike egocentric networks limited to self-reported alters, this comprehensive structure enables us to assess the educational attainment of both immediate and more distal social ties in relation to cardiac biomarkers. Since our study comprises relatively healthy older adults, we have too few cases to analyze the incidence of CVD. Therefore, we focus on the incidence-related cardiac biomarkers instead. We hypothesize that securing highly educated friends helps older adults avoid or delay cardiac incidence.

## Methods

### Study design and participants

We used a part of the prospective cohort data obtained from the Korean Social Life, Health and Aging Project (KSHAP), which was collected across three waves: wave 1 (2011), wave 4 (2015–2016), and wave 5 (2018–2019)[31,32]. Response rates for the main interview were 94.7%, 96.5%, and 89.6% for Waves 1, 4, and 5, respectively. For the physical health examinations—which provided the biomarker data used in this study—the response rates were 85.7%, 77.8%, and 74.5%, respectively. Older adults (aged 60 years or older in 2011) and their spouses were eligible to participate in the face-to-face survey and clinical assessment.

Sociocentric (global) network data from an entire village were collected during the survey, and biomarkers were collected during the clinical examinations[31]. Sociocentric network data aim to capture the social ties of everybody in a given target population, not just the sample of the population of interest. Given that the lowest response rate was 89.6%, we are confident our data adequately captures the global social networks of the entire village. This sociocentric data enables us to examine the educational level of the social ties across varying social distances: in other words, we can probe the role of the educational level of friends, friends of friends, friends of friends of friends, and beyond.

Township K is a typical rural Korean village where farming is the primary industry. With the aid of the public officers of township K and a pilot study, 860 individuals aged 60 or older and their spouses were identified as the KSHAP population. The face-to-face survey was completed with 814 out of the 860 target residents during wave 1, with a response rate of 94.7%. The final analytic sample consists of 709 individuals after excluding those with missing covariates, respondents younger than 60 years old, those with diagnosed cardiovascular diseases, and those whose social network size equaled zero. Respondents were educated on the nature of the survey and written informed consent was obtained from all participants and/or their legal guardian(s) before survey completion. The institutional review board of Yonsei University approved this study, and all research was performed in accordance with relevant guidelines and regulations (YUIRB-2011-012-01 in 2011; 7001988-201806-HRBR-244-04 in 2015; 7001988-201812-HR-505-02 in 2018).

### Measures

*Cardiac biomarkers*

We used Troponin I, BNP, and NT-proBNP biomarkers collected during health assessments in 2011, 2015–2016, and 2018–2019. Blood samples were collected from the antecubital vein after an 8-hour fasting period. They were immediately stored in a -20 °C fridge until further analysis. The concentrations of Troponin I, BNP, and NT-proBNP were quantified using the Human Cardiovascular Disease (CVD) Magnetic Bead Panel I immunoassay kits (Merck Millipore, USA). The cardiac biomarkers were treated as continuous variables[29,33]. Extreme values (exceeding three standard deviations from the mean) are adjusted by winsorizing and log-transformed to reduce skewness.

*Social network survey*

A complete sociocentric (global) network was constructed using the Korean version of the Social Network Survey name generator, which is identical to the NSHAP instrument used in the United States[34]. The question was read as follows:

> From time to time, most individuals discuss things that are important to them with others. For example, these may include good or bad things that happen to you, problems you are having, or important concerns you may have. Looking back at the last 12 months, who are the individuals with whom you most often discussed things that were important to you?

In KSHAP, the social network includes the respondent's discussion network (up to five individuals), plus their spouse if applicable. Therefore, network size ranges from 0 to 6 if including the spouse, or 0 to 5 otherwise. Unlike NSHAP, KSHAP listed spouses on the network roster first, followed by up to five additional members[35]. For each discussion partner, detailed information was collected including name, gender, age, address (rhee level), relationship type and duration, cohabitation status, education level, frequency of contact, and emotional closeness.

*Constructing sociocentric network*

To construct the sociocentric network, KSHAP used information from respondents' egocentric network rosters—that is, the lists of people each respondent named as part of their social network. When the same individual was named by multiple respondents, we identified them as the same person if they matched on the following criteria: (1) at least two of the three Korean characters in their name, (2) gender, (3) age (within ± 5 years), and (4) residence in the same rhee (a small administrative unit). Using this approach, we assembled complete sociocentric networks for each wave of data collection (Waves 1, 4, and 5). Additional details on the matching procedure can be found in Youm et al. (2014) and Baek et al. (2023)[31,35]. Figure 1 presents the sociocentric network of the township. Node color represents BNP levels, with darker nodes indicating lower values. Node size reflects the number of college-educated individuals in each person's network. The smallest black nodes represent discussion partners who lived in Township K but did not participate in the survey.

*Educational attainement of social networks*

We measured the educational attainment of social networks by counting the number of individuals with a college degree or higher among respondents' direct and indirect social ties.

Direct ties were defined as individuals named by respondents in response to name-generator questions during structured interviews. For each named alter, respondents reported detailed characteristics, including gender, age, relationship type, cohabitation status, and level of education. Education responses included: no education, informal education (soedang or hanhak), elementary school, middle school, high school, professional college, bachelor's degree, and graduate degree. Direct ties were coded as college-educated if they had completed a bachelor's degree or higher.

Indirect ties (friends of friends or second-degree ties) were identified using sociocentric (global) network data, which allowed us to observe the connections between alters. These individuals were not named by respondents directly but were connected to their named alters within the same village. We constructed measures of college-educated indirect ties using this sociocentric network data.

Variability is shown in Table S5: 7.5% of observations had one or more directly connected college-educated friends, and 12.8% had one or more college-educated friends of friends. Due to this distribution, we used a binary measure for direct ties and a categorical measure for second-degree ties in our analyses.

To avoid conflating the absence of social ties with the absence of college-educated ties, we excluded respondents who reported no ties. Sensitivity analyses that included these individuals yielded substantively similar results (Table S4).

Given prior evidence that geographically proximate and emotionally close ties are especially influential for health, we restricted our primary analyses to village-based networks—i.e., ties who resided in the same Township. Analyses of educational attainment among ties residing outside the Township did not show significant associations with cardiac biomarkers (Table S7).

We also examined the distinct associations of the educational attainment of friends of distance up to 4 and examine if they show a statistically significant relationship with cardiac biomarkers in our prospective data (Table S3).

*Respondent's educational attainment*

Respondents reported their educational attainment during each wave of the survey. Response options included: no formal education, informal education (soedang or hanhak), elementary school, middle school, high school, professional college, bachelor's degree, and graduate degree. Because education levels are unlikely to change in late adulthood, we used baseline reports to minimize recall error and inconsistency across waves. Respondent education was coded as a binary variable: 1 if they completed high school or higher, and 0 otherwise. We did not use college education as the threshold because only 3.1% had completed college.

*Covariates*

We controlled for potential the sociodemographic and health-related variables confounders. Sociodemographic covariates included annual household income and marital status (coded as 1 for living with a spouse, 0 otherwise). Income was coded as 1 for household earning approximately $10,000 or more per year, and 0 otherwise.

Health variables included comorbidity, cognitive functioning, physical health, smoking (1 for ever smoked, 0 otherwise), and hypertension diagnosis (1 for ever diagnosed, 0 otherwise). Comorbidity was defined as the

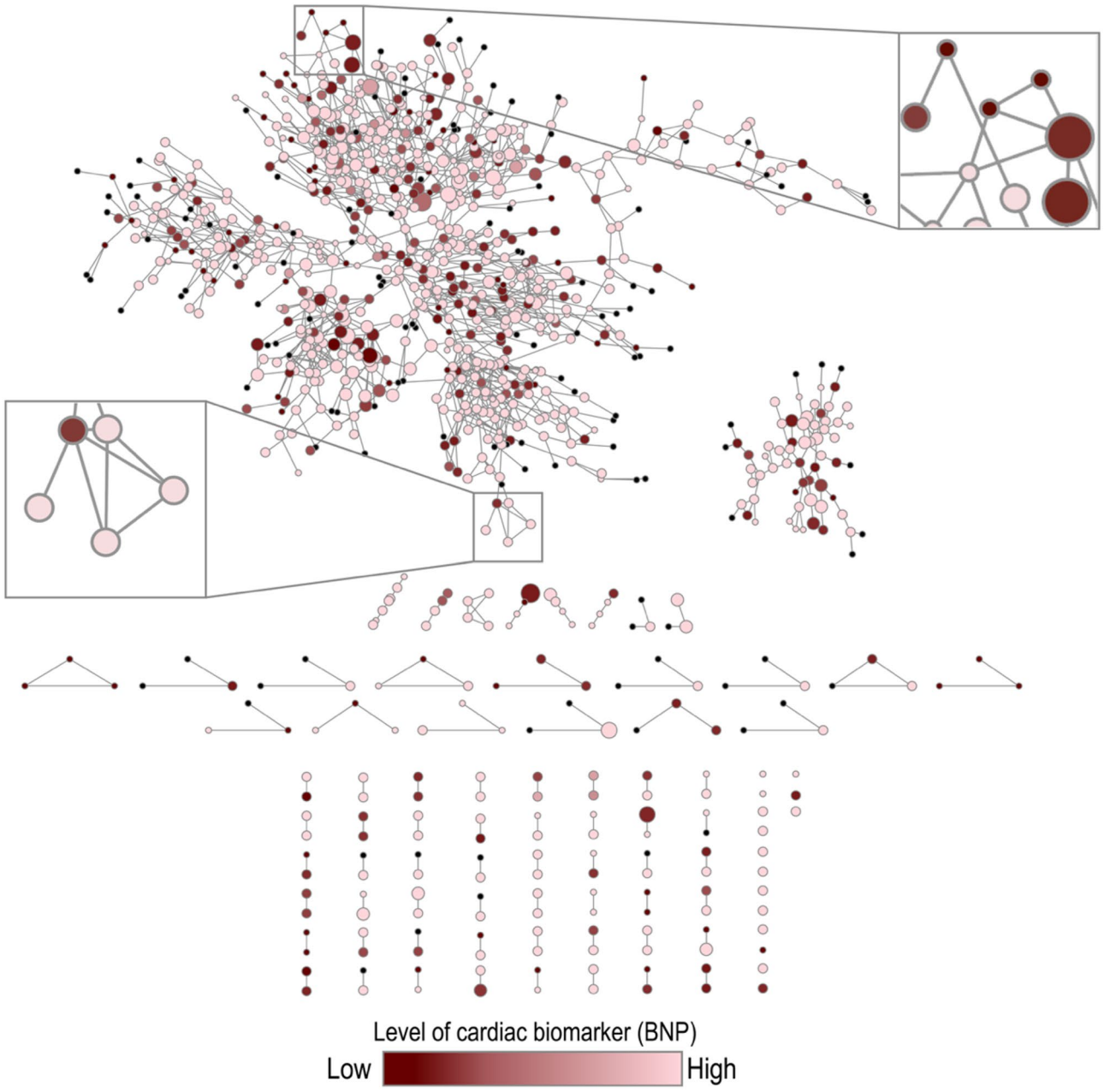


**Fig. 1**. The socio-centric (complete) social network of Township K at the baseline $n = 1{,}009$). The color of the nodes represents the magnitude of each participant's educational attainment of social network. The size of nodes represents the amount of BNP (smaller size → lower levels). The smallest black nodes represent discussion confidants living in Township K but did not participate in the survey.

number of diagnoses out of the following illnesses for each participant: diabetes, cancer, angina, cataracts, and osteoporosis. Cognitive function was assessed using the Korean version of the Mini-Mental State Examination for Dementia Screening (K-MMSE)[47], with scores ranging from 0 to 30—higher values reflecting a better cognitive health status. Physical health statuses are assessed using the six-item physical component summary (PCS) from the SF-12 using standard methods.

We excluded participants who had been diagnosed with stroke, acute myocardial infarction (AMI), coronary heart disease (CHD), or angina over the study years to reduce potential reverse causation. We also excluded participants those with no social ties ($n = 6$). Sensitivity analyses including these cases yielded similar results (Table S4).

## Statistical analysis

We used person-year fixed-effects regression models to examine within-individual changes in cardiac biomarkers as a function of educational attainment of social network and other covariates. This approach allows

us to account for unobserved heterogeneity – difference in individual characteristics that are stable over time but not observed in our data (e.g. genetics, personalities, early-life conditions). This way, we control for these time-invariant confounders by reducing potential endogeneity and omitted variable bias[36].

The Hausman test is conducted for all models to assess whether random-effects models are more acceptable. This test evaluates whether an explanatory variable is correlated with the error term, which signals the presense of endogeneity and violates assumptions of random-effects model[37]. In each case, the test indicates that unobserved heterogeneity is not randomly distributed, and therefore, the use of fixed-effect model is recommended.

We also perform several sensitivity analyses to check the robustness of our findings, which are available in supplemental material and briefly summarized in the results section. All analyses were conducted using Stata 18.0 (StataCorp LP, College Station, TX, USA).

## Results

The mean age at the baseline was 71.70 years (SD 7.28 years). About 57.8% of participants were women, 74.8% lived with a spouse, and 14.8% had an education equal to and higher than high school (Table 1). 62.2% of respondents reported having an annual income of less than $10,000. Around 6.9% of respondents reported having at least one college-educated social network member, and 11.4% reported having one or more college-

| Variables | | Zero college-educated friends ($n=660$) | | | One and more college educated friends ($n=49$) | | | Total ($n=709$) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean (SD)/ % (N) | Min | Max | Mean (SD)/ % (N) | Min | Max | Mean (SD)/ % (N) | Min | Max |
| R's educational level | Middle school and lower | 87.3% (576) | | | 57.1% (28) | | | 85.2% (604) | | |
| | High school and higher | 12.7% (84) | | | 42.9% (21) | | | 14.8% (105) | | |
| Number of college-educated social ties of distance one (friends) | | - | | | 1.08 (0.34) | 1.00 | 3.00 | 0.07 (0.29) | 0.00 | 3.00 |
| Zero college educated friends | | 100.0% (660) | | | - | | | 93.1% (660) | | |
| One and more college educated friend | | - | | | 100% (49) | | | 6.9% (49) | | |
| Number of college-educated social ties of distance two (friends of friends) | | 0.12 (0.38) | 0.00 | 3.00 | 0.27 (0.57) | 0.00 | 2.00 | 0.13 (0.40) | 0.00 | 3.00 |
| Zero college educated friends | | 89.2% (589) | | | 79.6% (39) | | | 88.6% (628) | | |
| One college educated friend | | 9.2% (61) | | | 14.3% (7) | | | 9.6% (68) | | |
| Two and more college educated friends | | 1.6% (10) | | | 6.1% (3) | | | 1.8% (13) | | |
| Network size | | 3.17 (1.27) | 1.00 | 6.00 | 4.04 (1.32) | 1.00 | 6.00 | 3.23 (1.30) | 1.00 | 6.00 |
| BNP (pg/mL)[a] | | 32.92 (18.98) | 0.94 | 196.48 | 33.49 (17.41) | 10.28 | 93.56 | 32.95 (18.87) | 0.94 | 196.48 |
| Troponin I (pg/mL)[a] | | 279.68 (459.40) | 0.01 | 1721.74 | 204.08 (436.94) | 1.13 | 1721.74 | 275.13 (458.06) | 0.01 | 1721.74 |
| NT-proBNP (pg/mL)[a] | | 36.82 (63.28) | 0.07 | 258.55 | 34.57 (59.02) | 0.14 | 258.55 | 36.69 (62.98) | 0.07 | 258.55 |
| Sex | Male | 40.9% (270) | | | 59.2% (29) | | | 42.2% (299) | | |
| | Female | 59.1% (390) | | | 40.8% (20) | | | 57.8% (410) | | |
| Age | | 71.96 (7.27) | 60.00 | 96.00 | 68.18 (6.53) | 60.00 | 93.00 | 71.70 (7.28) | 60.00 | 96.00 |
| Marital status | Not married | 26.2% (173) | | | 12.2% (6) | | | 25.2% (179) | | |
| | Married | 73.8% (487) | | | 87.8% (43) | | | 74.8% (530) | | |
| Income | <$10,000 | 62.3% (411) | | | 53.1% (26) | | | 62.2% (441) | | |
| | ≥$10,000 | 37.7% (249) | | | 46.9% (23) | | | 37.8% (268) | | |
| Smoking | Never smoked | 70.2% (463) | | | 57.1% (28) | | | 69.3% (491) | | |
| | Past and current smoker | 29.8% (197) | | | 42.9% (21) | | | 30.7% (218) | | |
| Physical Health | | 45.97 (9.00) | 14.61 | 63.97 | 50.79 (8.05) | 28.09 | 60.07 | 46.30 (9.01) | 14.61 | 63.97 |
| Cognitive Health | | 23.74 (4.87) | 0.00 | 30.00 | 26.18 (5.16) | 0.00 | 30.00 | 23.91 (4.92) | 0.00 | 30.00 |
| Comorbidity | | 2.62 (0.80) | 0.00 | 5.00 | 2.39 (0.67) | 2.00 | 4.00 | 2.61 (0.79) | 0.00 | 5.00 |
| Hypertension diagnosis | Yes | 47.9% (316) | | | 32.7% (16) | | | 46.8% (332) | | |
| | No | 52.1% (344) | | | 67.3% (33) | | | 53.2% (377) | | |

**Table 1**. Descriptive characteristics of the Korean social life, health, and aging study sample at the baseline ($n=709$). [a]Extreme values in biomarkers (exceeding three standard deviations from the mean) are adjusted by winsorizing, a method of replacing extreme values with values equal three standard deviations.

educated friends of friends. The average number of college-educated network members was 0.08 (SD = 0.30) for friends and 0.13 (SD = 0.41) for friends of their friends (friends of social distance two).

At the baseline, participants had average levels of BNP equalled 32.95 pg/ml (SD = 18.87), Troponin I equalled 275.13 pg/ml (SD = 458.06), and NT-proBNP equalled 36.69 pg/ml (SD = 62.98). We used widely accepted thresholds for each biomarker to assess the proportion of high-risk participants in our study[38–40]. We found that only twelve respondents have a BNP level higher than the normal range ( > = 100 pg/ml), and 21.2% of respondents have a Troponin I level higher than the normal range ( > = 400 pg/ml). However, nobody has an NT-proBNP level higher than the normal range ( > = 900 pg/ml among 50 ~ 75 years respondents and > = 1800 pg/ml among 75 years and higher respondents). The observational nature of the data from healthy older adults who could comply with the face-to-face surveys and clinical assessment protocols may explain the relatively low prevalence of high-risk CVD sample participants.

First, we examined the association between educational attainment of social network and cardiac biomarkers. We fitted five analytical models to examine potential confounding effects of household income and marital status, which could bias the association between social networks and cardiac health. Across all five models we did not observe consistent or statistically significant associations between having at least one college-educated directly connected friend and levels of cardiac biomarkers (with the exception of NT-proBNP). For example, in the fully adjusted model (Model 5), the association between having a college-educated friend and BNP was not statistically significant ($\beta = -0.16$, $p = 0.143$) and marginally significant for Troponin I ($\beta = -0.57$, $p = 0.095$). All coefficients were negative, meaning that an increase in the number of college-educated friends was associated with a decrease in the levels of cardiac biomarkers.

Further, we examined the relationships between educational attainment of friends at social distance up to two and biomarker levels (Table 2 Model 2–5; see full results in Tables S11-S13). We found similar negative relationships and robust, consistent coefficients for all biomarkers. These associations held across different operationalizations (binary, one friend-of-friend, and two or more; see Table S14) and model specifications. For example, in the fully adjusted model (Model 5), having one college educated friend was associated with lower levels of BNP ($\beta = -0.26$, 95% CI: −0.41 to −0.10, $p = 0.001$), Troponin I ($\beta = -0.81$, 95% CI: −1.28 to −0.34, $p = 0.001$), and NT-proBNP ($\beta = -0.57$, 95% CI: −1.06 to −0.09, $p = 0.020$). Similar but stronger effects were observed for having two or more college-educated friends-of-friends.

To put numbers in perspective, we calculated the average predicted cardiac biomarkers values for respondents with zero, one, and two or more college-educated friends of friends (Table S10). For reference, the BNP values greater than 100 pg/ml are considered critical and used to diagnose heart failure[39]. While our sample averages fell well below that threshold, the difference remained notable: respondents with zero college-educated network members had an average BNP level of 29.99 pg/ml, compared to 18.41 pg/ml among those with three such connections—a 40% decrease. This suggests that even modest variation in the educational attainment of social ties may meaningfully shape subclinical markers of cardiovascular health. Regarding Troponin I, while levels above 400 pg/ml are typically used to diagnose myocardial infarction, values exceeding 40 pg/ml have been identified as elevated in some clinical contexts and may indicate low-level cardiac stress or injury[40]. In our sample, individuals with zero college-educated friends-of-friends had an average predicted Troponin I level of 48.67 pg/ml.

Some covariates could potentially be mediators rather than confounders, such as annual household income and marital status. To evaluate this possibility we presented analyses that use different model specifications: Model 1 included only the educational attainment of directly connected social network members; Model 2 added the educational attainment of indirectly connected (distance two) network members; Model 3 was adjusted for age, household income, and marital status; Model 4 was adjusted for cognitive health, physical health, comorbidities, hypertension status, and smoking status; and Model 5 was the fully adjusted model, incorporating all covariates including network size. This modeling strategy enabled a direct evaluation of whether potential mediators—particularly household income and marital status—accounted for observed associations between educational attainment of social network and health.

Across all biomarkers and model specifications, the association between having college-educated friends-of-friends and lower levels of cardiac biomarkers remained statistically significant and directionally consistent. For example, the association between having two or more college-educated friends-of-friends and NT-proBNP levels ranged from $\beta = -1.67$ to −1.41 across Models 2 to 5, with all p-values < 0.05.

A similar pattern was observed for BNP and Troponin I. Notably, for NT-proBNP and Troponin I, the inclusion of household income and marital status (in Model 3) attenuated the coefficients for social network education by 11–37% when compared to Model 2. This suggests that these sociodemographic variables may act as partial mediators—a finding that is theoretically plausible, as changes in socioeconomic status and marital status (e.g., spousal loss) often lead to changes in social networks, particularly in later life[41,42].

We further examined whether an increase in social distance remained associated with cardiac biomarkers. Previous studies have confirmed that interpersonal similarities and diffusion effects operate only up to a social distance of four. This has been observed in loneliness[43], obesity[44], smoking[45], and depression[46]. To assess this, we calculated the educational attainment of social networks at distances of three and four and conducted analyses to determine the extent to which social distance was associated with cardiac biomarkers (Table S3). We found that educational attainment at distance three was significantly associated with BNP and Troponin I, but not with NT-proBNP. However, the effect sizes were smaller compared to those observed at shorter distances, indicating a diminished influence from third-degree ties. At a distance of four, associations with all biomarkers became statistically insignificant. These findings suggest that although individuals may have more college-educated network members at greater distances, it is likely impractical to receive meaningful health-related support or influence from ties as socially distant as friends of friends' friends.

| | Model 1 | | | Model 2 | | | Model 3 | | | Model 4 | | | Model 5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | β | 95% CI | p-value | β | 95% CI | p-value | β | 95% CI | p-value | β | 95% CI | p-value | β | 95% CI | p-value |
| | Log(BNP) | | | | | | | | | | | | | | |
| One and more college-educated friends (binary) | -0.12 | -0.35,0.10 | 0.282 | -0.14 | -0.36,0.09 | 0.233 | -0.17 | -0.39,0.05 | 0.128 | -0.17 | -0.39,0.05 | 0.127 | -0.16 | -0.38,0.06 | 0.143 |
| One college-educated friends of distance two (friends of friends) | | | | -0.27 | -0.43,-0.11 | 0.001 | -0.27 | -0.42,-0.11 | 0.001 | -0.28 | -0.44,-0.13 | 0.000 | -0.26 | -0.41,-0.10 | 0.001 |
| Two and more college-educated friends of distance two (friends of friends) | | | | -0.37 | -0.73,-0.02 | 0.039 | -0.48 | -0.82,-0.13 | 0.007 | -0.50 | -0.85,-0.16 | 0.005 | -0.49 | -0.83,-0.14 | 0.006 |
| | Log(Troponin I) | | | | | | | | | | | | | | |
| One and more college-educated friends (binary) | -0.63 | -1.30,0.05 | 0.068 | -0.69 | -1.36,-0.02 | 0.043 | -0.62 | -1.29,0.04 | 0.067 | -0.68 | -1.35,-0.01 | 0.048 | -0.57 | -1.23,0.10 | 0.095 |
| One college-educated friends of distance two (friends of friends) | | | | -0.99 | -1.45,-0.52 | 0.000 | -0.88 | -1.35,-0.42 | 0.000 | -0.97 | -1.44,-0.50 | 0.000 | -0.81 | -1.28,-0.34 | 0.001 |
| Two and more college-educated friends of distance two (friends of friends) | | | | -1.48 | -2.57,-0.40 | 0.007 | -1.35 | -2.43,-0.28 | 0.014 | -1.48 | -2.57,-0.39 | 0.008 | -1.26 | -2.34,-0.18 | 0.022 |
| | Log(NT-proBNP) | | | | | | | | | | | | | | |
| One and more college-educated friends (binary) | -0.93 | -1.61,-0.25 | 0.008 | -1.01 | -1.69,-0.34 | 0.003 | -0.90 | -1.57,-0.24 | 0.008 | -0.94 | -1.61,-0.26 | 0.007 | -0.88 | -1.55,-0.21 | 0.011 |
| One college-educated friends of distance two (friends of friends) | | | | -0.74 | -1.22,-0.26 | 0.003 | -0.61 | -1.08,-0.14 | 0.012 | -0.68 | -1.16,-0.21 | 0.005 | -0.57 | -1.06,-0.09 | 0.020 |
| Two and more college-educated friends of distance two (friends of friends) | | | | -1.67 | -2.74,-0.60 | 0.002 | -1.42 | -2.47,-0.36 | 0.009 | -1.47 | -2.54,-0.40 | 0.007 | -1.41 | -2.48,-0.34 | 0.010 |

**Table 2**. Estimated effects ($\beta$) and 95% confidence intervals (CI) from fixed-effects models showing an association between cardiac biomarkers and educational attainment of social network. Model 1 includes only the educational attainment of directly connected social network members. Model 2 adds the educational attainment of indirectly connected (distance-two) network members. Model 3 adjusts for demographics such as age, household income, and marital status. Model 4 adjusts for health and health behaviors such as cognitive health, physical health, comorbidities, hypertension status, and smoking status. Model 5 is the fully adjusted model, incorporating all covariates and adding network size.

We separately analyzed the association between respondents's baseline education and cardiac biomarkers (Table S9). We estimated random-effects models using baseline educational attainment and tested multiple coding strategies (e.g., binary, categorical). These analyses revealed the absence of significant associations between respondents' own education and any of the cardiac biomarkers.

### Sensitivity analyses

To strengthen confidence in our findings, we conducted a series of sensitivity analyses. First, in our main models, the educational attainment of the social network measure was based only on network members residing within Township K. However, many older adults in this village had relatives and children living outside the township. Therefore, we repeated the analyses using the educational attainment of network members residing outside of Township K (Table S7). We did not find statistically significant results for distance one (directly connected friends) or distance two (friends of friends). The association between highly educated social ties and better cardiac health appears to be significant only when those friends were in close geographic proximity in our sample.

Second, we tested an alternative operationalization of social network educational attainment by examining whether the number of network members with at least a high school education was associated with cardiac biomarkers. This measure allowed us to assess whether lower thresholds of educational attainment might similarly influence cardiovascular health. As shown in Table S5, 43.5% of respondents had at least one friend-of-friend with a high school diploma or higher—offering greater variation than our original college-based measure. However, we found no significant associations between this high school-based measure and cardiac biomarkers (see Tables S6 and S8 for both in-village and out-of-village measures).

Third, the educational attainment of the social network may have been associated with cardiac biomarkers through (1) information flow or (2) better access to financial resources. Although we could not examine the first pathway directly, we attempted to rule out the possibility that the association with education could be explained away by higher income, given that the two indicators are highly correlated. Highly educated friends may also have higher incomes, which could provide better access to health services. We measured the economic level of the social network as the number of individuals whose annual income exceeded 10 million won. We chose this cutoff because 60% of our sample reported that their income was less than or equal to 10 million won. We found no evidence that the economic level of the social network was associated with cardiac biomarkers (Table S1). Interestingly, respondents' own income was associated with biomarkers in an unexpected direction: higher income was linked to higher biomarker levels. We suspect this income variable may be prone to measurement error. Around 14% of respondents refused to report their income, which may introduce bias. In addition, some participants were surveyed in a senior center in the presence of others, which may have influenced their willingness to report income accurately.

Finally, we explored whether physical proximity to neighborhood facilities (e.g., hospitals, emergency care, public services) could have confounded the relationship between social network education and cardiac biomarkers. It is plausible that individuals with more college-educated friends may live closer to better-resourced neighborhoods. Given that Township K is a rural area with highly variable access to public transportation and services, we used geolocation data to calculate the average distance between respondents' homes and nearby facilities (e.g., police station, health center, clinics, banks, supermarkets). Because neither people nor facilities moved during the study period, we could not fit fixed-effects models and instead used random-effects models. We found a significant association between facility proximity and BNP but not for Troponin I or NT-proBNP (Table S2). Importantly, we also found no correlation between having college-educated friends and access to facilities.

## Discussion

The primary objective of this study was to examine the association between the educational attainment of social ties among older adults and their cardiac biomarkers. Our findings reveal that (1) participants' own educational level was not associated with cardiac biomarkers; (2) an increase in the number of college-educated individuals within one's social network was consistently linked to a statistically significant decrease in cardiac biomarkers; and (3) the increase in educational attainment of social networks was consistently associated decrease in levels of cardiac biomarkers only up to a social distance of two—that is, the educational level of friends of friends (social distance of two). The educational attainment of social networks demonstrated a robust association with cardiac biomarkers. As the number of college-educated individuals in one's social discussion network increases, levels of cardiac biomarkers decrease. Access to more individuals with tertiary education may enhance health information access, improve health literacy and numeracy, and provide an advantage in obtaining health-related information through social networks over time[47,48].

Our findings underscore the role of education within social networks as a critical mechanism for disseminating health-related knowledge, consistent with prior research on health information transmission through network resources[19,49]. For instance, studies have shown that greater educational attainment among social network members correlates with increased medical help-seeking, resource diversity, and financial support during the COVID-19 pandemic[50,51]. Similarly, we found that the health of our sample respondents was associated with the number of college-educated individuals in their social networks. Beyond information, these educated network members may exert health-related influences and pressures, encouraging adjustments in beliefs, attitudes, or behaviors.

Additional analyses revealed no association between the number of college-educated network members residing outside the village and cardiac biomarkers, suggesting that resource proximity significantly shapes health-related benefits. This may stem from distant network members providing less timely or contextually relevant information and influence. For instance, respondents' children in urban areas may lack insight into

rural health challenges, such as farming's physical demands, health-related lifestyles, or limited healthcare access. Moreover, physical distance could reduce communication frequency and timely resource exchange, despite the perceived importance of these ties. This finding refines existing theories by highlighting the spatial and contextual factors influencing educational benefits, indicating that mechanisms from prior research vary with the geographic and social proximity of network ties.

Prior literature has established that an individual's educational attainment contributes to cardiac health[30,52–56]. However, our study revealed no such association within this specific population, potentially due to the relatively homogeneous low educational background of the study population. First, residents of traditional Korean rural townships have, on average, very low educational attainment with minimal variation. Therefore, the effect of an individual's education may be difficult to detect. In fact, only 3.1% of participants in the KSHAP sample had a college degree, and just 14.8% completed high school. This limited variation reduces statistical power and makes it difficult to detect associations in models estimating within-person change. Second, college-educated respondents were distinct from the rest of the sample demographically and socially. They were more likely to have fewer years of residence in the Township K (10.33 years compared to 50.14 years) and a lower portion of local friends (44% compared to 75%), suggesting weaker embeddedness in the local social networks. In contrast, respondents who were both well-integrated into the village and successfully recruited college-educated individuals as friends may benefit easily from network-based educational spillovers. This may explain why the educational attainment of one's social network, which is more dynamic and socially embedded, shows stronger associations with cardiovascular biomarkers than respondents' own education. Finally, although this study utilizes sociocentric data from KSHAP, allowing us to examine the educational attainment of participants' social ties and their association with cardiac biomarkers, this very strength also limits the generalizability of our findings beyond the context of remote rural villages.

Despite the limitations regarding generalizability, our findings offer valuable insights and implications for the early prevention of cardiac diseases among older adults in remote rural areas. Due to the observational nature of the study and potential selection of healthy individuals into the sample, none of the respondents demonstrated clinically critical levels of cardiac biomarkers that would require immediate medical attention. However, we observed that having college-educated friends of friends—as opposed to having none—was associated with a 40% lower level of BNP, a 44% lower level of NT-proBNP, and a 71% lower level of Troponin I. Although these biomarkers remain within subclinical differences, such differences may reflect meaningful variation in cardiovascular stress.

Our results suggest that a low educational attainment within one's social network can be considered a significant risk factor for the development of cardiac diseases. The study provides a foundation for early screening of individuals with disadvantaged educational attainment within one's social network and highlights the importance of targeted interventions to prevent the progression of cardiovascular conditions. Notably, our findings indicate a powerful social network effect. Having no college-educated friends-of-friends was associated with a 79% increase ($\beta = 0.58$ or Geometric Mean Ratio (GMR) = $\exp(0.58) = 1.79$; $1.79 - 1 = 0.79$) in NT-proBNP levels compared to having one. To put this in perspective, Wassberg et al. reported that high psychosocial burden level is associated with with a more moderate 21% increase in the same biomarker (GMR = 1.21)[33]. While our observational design prevents causal claims, this striking comparison highlights the potential importance of a social network's educational attainment in cardiovascular risk.

## Data availability

All data files are available from the figshare database (https://doi.org/10.6084/m9.figshare.29910170.v2).

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## Author contributions

E.B. contributed to conceptualization, formal analysis, writing—original draft, and writing—review & editing.S.L. contributed to writing—original draft and writing—review & editing.Y.P. contributed to funding acquisition and writing—review & editing.H.C.K. contributed to funding acquisition and writing—review & editing.Y.Y. contributed to conceptualization, funding acquisition, writing—original draft, and writing—review & editing.

## Declarations

## Competing interests

The authors declare no competing interests.

## Additional information

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**Correspondence** and requests for materials should be addressed to Y.Y.

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