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Original Article

Social Relationships and Risk of Type 2 Diabetes Among Postmenopausal Women

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Abstract

Objectives: We examined whether social relationship variables (social support, social strain, social network size, and stressful life events) were associated with risk of developing type 2 diabetes among postmenopausal women.
Method: 139,924 postmenopausal women aged 50–79 years without prevalent diabetes at baseline were followed for a mean of 14 years. 19,240 women developed diabetes. Multivariable Cox proportional hazard models tested associations between social relationship variables and diabetes incidence after consideration of demographics, depressive symptoms, and lifestyle behaviors. We also examined moderating effects of obesity and race/ethnicity, and we tested whether social variable associations were mediated by lifestyle or depressive symptoms.
Results: Compared with the lowest quartile, women in the highest social support quartile had lower risk of diabetes after adjusting for demographic factors, health behaviors, and depressive symptoms (hazard ratio [HR] = 0.93, 95% confidence interval [CI] = 0.89–0.97). Social strain (HR = 1.09, 95% CI = 1.04–1.13) and stressful life events (HR = 1.10, 95% CI = 1.05–1.15) were associated with higher diabetes risks. The association between diabetes and social strain was stronger among African American women. Social relationship variables had direct relationships to diabetes, as well as indirect effects partially mediated by lifestyle and depressive symptoms.
Discussion: Social support, social strain, and stressful life events were associated with diabetes risk among postmenopausal women independently of demographic factors and health behaviors. In addition to healthy behaviors such as diet and physical activity, healthy social relationships among older women may be important in the prevention of diabetes.

Keywords: Diabetes, Social relationships, Women

Type 2 diabetes is a major global public health problem. A recent estimate indicates that 500 million people had type 2 diabetes globally in 2018 (Kaiser, Zhang, & Van der Pluijm, 2018). Type 2 diabetes is usually adult-onset and accounts for 90% of diabetes cases (International Diabetes Federation, 2015). In the United States, more than 30 million people of all ages, or 9.4% of the population, currently have diabetes (Koplitz, Jacob, Sulprizio, Myllyvirta, & Reid, 2017). The percentage of adults with diabetes increases with age, reaching a high of 25.2% among those aged 65 years or older (Koplitz et al., 2017).

Consequences of type 2 diabetes (diabetes hereafter) are serious and include blindness, kidney failure, heart attack, stroke, lower limb amputation, and death (WHO, 2018). Major risk factors for diabetes include older age, overweight or obesity, family history of diabetes, race/ethnicity, history of gestational diabetes, impaired glucose tolerance, smoking, and physical inactivity (CDC, 2011). Additionally, as described in the following paragraphs, there is evidence that psychosocial variables may influence risk of diabetes.

Although diabetes prevalence rates for men and women are similar, research that focuses on postmenopausal women in the examination of relationships between interpersonal social variables and diabetes risk is appropriate for at least three reasons. One is the fact that incidence of diabetes peaks at ages 45–64 years (CDC, 2017), corresponding to the age range when women in the current study were recruited for participation. Women with diabetes have a higher risk than men of a number of diabetes-related complications including heart disease, blindness, kidney disease, and depression, highlighting the importance of prevention (CDC, 2018). It is therefore important to understand conditions that may lead to diabetes among older women. A second reason is that interpersonal relationships are related to health behaviors differently for men and women in ways that may influence diabetes risk. Women, for example, generally receive less social support for engaging in physical activity than men (Edwards & Sackett, 2016), and may be at greater risk for poor health behaviors under conditions of low social support (Kim, McEwen, Kieffer, Herman, & Piette, 2008). Third, the qualities of social relationships among older women are different than for other age and sex groups. Older people may encounter difficulties with social connections due to cognitive or physical declines (O'Rourke, Collins, & Sidani, 2018). Older women specifically may have larger social networks than older men (Cornwell, 2011). For a variety of reasons, understanding how social relationships may influence diabetes risks among older women is an important endeavor.

The social-ecological model provides a framework for representing possible social contributions to diabetes incidence (Barrera, Toobert, Angell, Glasgow, & Mackinnon, 2006; Hill et al., 2013; Whittemore, Melkus, & Grey, 2004). The model depicts how multiple levels of influence—individual, interpersonal, organizational, community, and policy—contribute to an ultimate outcome of interest. This model has been previously applied to diabetes prevention (Hill et al., 2013; Whittemore et al., 2004). For the current study, the most relevant piece of the model is the interpersonal influence level, which describes how an individual's friends, family, and other social contacts might alter an important health outcome. The social-ecological perspective often focuses on how influences from home, work, school, or community environments affect health states through individual behavioral mediators (CDC, 2011; Hill et al., 2013). The perspective in this approach has been that social variables might either increase food consumption or decrease energy expenditure that lead to increases in obesity and diabetes risk. It has been observed, for example, that obesity will spread within social circles over time as individuals reinforce each other's obesity-related behaviors (Christakis & Fowler, 2007). Barrera and colleagues (2006) emphasized how social-ecological resources can contribute to improvements in healthful lifestyles for women with type 2 diabetes.

Less investigated is the possibility that interpersonal variables may affect diabetes risk directly via biological pathways. A number of possible biological mechanisms linking interpersonal variables to diabetes risk have been suggested (Fernandez-Real et al., 2002; Hackett & Steptoe, 2016; Kamba et al., 2016; Yang, Schorpp, & Harris, 2014). In the current study, we will test the hypothesis that interpersonal social experiences have direct associations with diabetes risk independent of behavioral mediators.

In this study, we represent interpersonal social relationships by social support, social network size, stressful life events, and social strain. The choice of these four concepts is partly a practical consideration, as our data from the Women's Health Initiative includes established measures of all of these, but they are all representations of interpersonal experiences that are consistent with the social-ecological model, and for which some prior research may be called upon to inform our study questions. Evidence suggests that social support influences the risk of diabetes. Indicators of social support such as low emotional support in women (Norberg et al., 2007), living alone in men (Meisinger, Kandler, & Ladwig, 2009) or women (Lidfeldt, Nerbrand, Samsioe, & Agardh, 2005), or not having a partner (Strodl & Kenardy, 2006) have been associated with a higher risk of diabetes. Poor structural social support has been associated with diabetes risk in men, but not women (Altevers et al., 2016). Another study reported that a measure of social integration assessing the number and quality of social connections was related to a lower risk of diabetes in women, but to a higher risk in men (Hilding, Shen, & Ostenson, 2015). Social strain addresses the negative aspects of social relationships such as friends or family who are critical or demanding; social strain has not been studied as a risk for diabetes, although one study reported that social strain was associated with higher risk of obesity (Yang et al., 2016).

Sample sizes in previous studies have often been relatively small. Studies have sometimes focused on younger women (Hilding et al., 2015; Norberg et al., 2007), while data on postmenopausal women have been scarce. One study (Hilding et al., 2015) found that the association between social integration and diabetes for women became nonsignificant when considering multiple covariates. Another study (Lidfeldt et al., 2005) found that the relationship between diabetes and living alone for women could be largely attributed to behaviors such as smoking and diet.

Chronic stress exposure has also been implicated as a risk factor for diabetes. To date, the majority of research has focused on the relationship between work stress and diabetes incidence (Heraclides, Chandola, Witte, & Brunner, 2009; Kivimaki et al., 2015; Norberg et al., 2007). Few studies have investigated major stressful life events and diabetes risk and findings are inconsistent. One cross-sectional study reported a positive association between stressful life events and prevalence of undiagnosed diabetes (Mooy, de Vries, Grootenhuis, Bouter, & Heine, 2000). Two other studies [one case–control study (Rasouli et al., 2017) and another a prospective study (Kumari, Head, & Marmot, 2004)] reported weak or no association.

In sum, although prior research has suggested that social relationships may contribute to diabetes incidence, results have been inconsistent, and little research on postmenopausal women has been reported. Furthermore, whether social relationship variables may have direct effects on diabetes, or whether effects are mediated through behaviors, is unclear. The aim of the current study was to test hypotheses that social support, social networks, social strain, and stressful life events will be associated with incident diabetes among older women. In particular, we test a feature of the social-ecological model to examine whether interpersonal influences may affect diabetes directly, or through behavioral mediators including poor diet, physical inactivity, smoking, or high alcohol consumption. We focus on postmenopausal women, an at-risk population that has not been adequately studied in previous research.

Method

Study Population

We used data from the Women's Health Initiative (WHI), a large prospective cohort study designed to address the major causes of morbidity and mortality in postmenopausal women. Details of the scientific rationale, eligibility requirements, and baseline characteristics of WHI participants have been published elsewhere (Hays et al., 2003; Langer et al., 2003). Briefly, a total of 161,808 women aged 50–79 were recruited from 40 clinical centers throughout the United States between September 1, 1993 and December 31, 1998. The WHI includes both clinical trial (CT) and observational study (OS) components. Participants in the OS included 93,676 women who were screened for the CT but were ineligible or unwilling to participate, or were recruited through a direct invitation for the OS. The study was approved by Institutional Review Boards at all 40 clinical centers and at the coordinating center. All participants in WHI gave written informed consent. Both WHI CT and OS data are used in this study. Women were followed annually for an average of 14 years after baseline.

We excluded 12,655 women who had a history of cancer (except nonmelanoma skin cancer) at baseline; 636 who joined but provided no follow-up information; and 8,593 women with prevalent diabetes at baseline. Consistently with other WHI studies, we excluded women with cancer because a cancer diagnosis will often prompt changes in lifestyle that could influence study variables. We included 139,924 women in analyses (Figure 1).

Exposures

Social support, social network size, social strain, and stressful life events were based on measures developed for the WHI from 28 items as described below, collected at baseline questionnaire.

Social Support

Women provided information regarding how often each of nine different types of support were available to them (Sherbourne & Stewart, 1991). Responses were scored on a 5-point Likert scale (from 1 = *none of the time* to 5 = *all of the time*) and summed for a total scale score from 9 to 45.

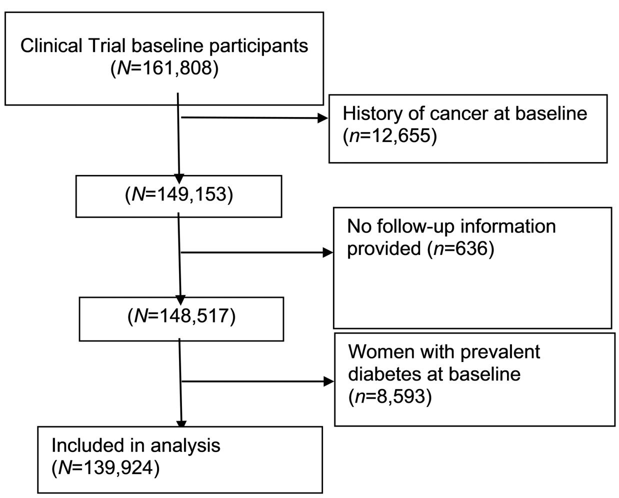

Figure 1. Flow diagram of participants included in the analysis.

A higher score indicates greater social support. Examples of social support include having someone to give good advice, having someone to have a good time with, and having someone to share private worries or fears.

Social Network

In the WHI, information on intimate spouse/partner, club ties, religious ties, and number of living first-degree relatives were collected. We constructed the same composite measure developed by Kroenke and colleagues (2013) in the WHI. Scores on the index ranged from 0 to 5 with 1 point each for marital status (married/in an intimate relationship vs not), club ties (yes vs no), religious ties (yes vs no), and 0–2 points based on tertiles of ties to supportive relatives (0 points for < 4 ties, 1 point for 5–7 ties, and 2 points for more than 7 ties.) The variable is a measure of social network size.

Social strain

Negative support/social strain is a construct that measures the negative aspects of social relations. The WHI measure contained four items selected from the original 7-item scale devised by Antonucci, Kahn, and Akiyama (1989). The responses were summed for possible ranges from 4 to 20. Higher scores on this measure indicated greater social strain. Examples of social strain questions included, "Of the number of people who are important to you, how many … get on your nerves?" and "how many … ask too much of you?"

Stressful Life Events

Eleven items were used to assess stressful life events, each scored 0–3 (Ruberman, Weinblatt, Goldberg, & Chaudhary, 1984). The responses were summed for a possible range of 0–33 where a higher score indicates greater number and severity of upsetting events. Examples of life events include the death of a partner or spouse, having major problems with money, or having major conflicts with children or grandchildren.

Outcome

The primary outcome was incidence of diabetes during the 14-year follow-up. This was defined by self-report of a new diagnosis of diabetes treated with insulin or oral drugs. Self-reported diabetes in the WHI has been found to be reliable and valid; about 78% of women who self-reported diabetes had a diabetes medication in the inventory (Margolis et al., 2008), and a validation study of medical record reviews confirmed 92% of self-reported prevalent diabetes and 82% of self-reported incident diabetes, while finding evidence for diabetes in only 5% of women who did not report diabetes (Jackson et al., 2013).

Covariates

We considered potential confounders at baseline including age in continuous years; race/ethnicity (American Indian or Alaska Native, Asian or Pacific Islander, Black or African American, Hispanic/Latina, non-Hispanic white, and other); level of education (high school or less, some college/technical training, college or some postcollege, and master or higher); family history of diabetes (no, yes); body mass index (BMI) (continuous) based on measured weight; healthy eating index (HEI)-2005 score; physical activity (<5, 5–<10, 10–<20, 20–<30, 30+ metabolic equivalent [METs]/week); smoking (never, former, current); alcohol intake (nondrinker, past drinker, current and <7 drinks/week, current and ≥7 drinks/week); depression (none, mild, or moderate); and different study cohorts (participation in OS or CTs, and different treatment assignments for all three CTs). Depression scores were computed from the Center for Epidemiological Studies depression scale (CES-D, short form); scores range from 0 to 1 with a higher score indicating a greater likelihood of depression. Depression was included as a covariate because of evidence that it is associated with diabetes risk (Moulton, Pickup, & Ismail, 2015). Cutoff values of .06 and .009 were used to indicate levels of depression severity (Burnam, Wells, Leake, & Landsverk, 1988). Total HEI-2005 score was a measure of diet quality that assesses conformance to the 2005 dietary guidelines for Americans. Physical activity (PA) was determined by asking participants how often they were currently participating in different types of PA (mild, moderate, and strenuous or very hard exercise) and the frequency (from never to ≥5 days/week) and duration (<20 min, 20–39 min, 40–59 min, and ≥1 hr) of each exercise session; these activities were converted to METs.

Statistical Analysis

Means and proportions of baseline demographic and behavioral characteristics were calculated and compared across the four social variables. Chi-square tests were used to evaluate differences for categorical covariates. For continuous variables, ANOVAs were used. Bivariate Pearson correlations were calculated among the four social variables.

Cox proportional hazards regression models were used to evaluate the relationships (hazard ratios and 95% confidence intervals) between quartiles of social support, social network size, social strain, stressful life events, and diabetes incidence. Missing data were included in the regression models as separate categories. In addition to analyzing by quartiles, we also treated each of the four social variables as continuous to check the stability of findings. Participants were followed until date of diabetes report, death, loss to follow-up, or the end of the follow-up period (February 2017), whichever came first.

In the multivariate-adjusted models, potential confounders included the variables listed above. However, we evaluated several progressive models. The first model included age, race/ethnicity, education, and family history of diabetes (Model 1); the second model additionally included major modifiable lifestyle factors (BMI, dietary quality, physical activity, smoking and alcohol consumption) (Model 2); and the final model further considered adjusting for depression (Model 3). Based on mediation analysis principles (Baron & Kenny, 1986; Tavakoli & Heiney, 2013), we assessed whether associations between social variables and diabetes risk were explained by behavioral factors by comparing results between Models 1 and 2 to determine whether social variables remain significant at comparable statistical levels after addition of behavioral variables (Tavakoli & Heiney, 2013). Analyses were conducted using SAS software version 9.4.

We further tested mediation effects by using a SAS software macro for causal mediation analysis with survival data (Valeri & VanderWeele, 2015). This analysis estimates natural direct and natural indirect effects between an exposure, a mediator, and an outcome with control for covariates. Indirect effects indicate that part of an exposure effect between social variables and diabetes which arises by affecting a set of intermediate behavioral variables, and direct effects operate directly without intermediating variables; direct plus indirect effects equals the total effect. We tested each significant social variable from Model 3 in association with each mediator (depressive symptoms, BMI, physical activity, diet, smoking, and alcohol consumption), to assess the proportion of association between the exposure and the outcome that was mediated, and to test for the significance of both indirect and direct effects.

We performed two stratification analyses by BMI and race\ethnicity. One was performed by BMI normal weight ($BMI < 25$), overweight (BMI = 25–<30) and obese ($BMI \geq 30$) categories. The second was performed among the three largest race groups in the study (Hispanic/Latina, African American and non-Hispanic white).

Finally, based on observed results, we conducted an additional post hoc analysis of the association between social network size and diabetes stratified by caregiving status, since previous work in the WHI (Kroenke et al., 2012) showed that larger networks, counter to expectation, were related to higher breast cancer mortality in women providing caregiving. Caregivers were identified from the WHI based on an item asking if the participant was "helping at least one sick, limited, or frail family member or friend on a regular basis."

Results

By the end of follow-up, there were 19,240 incident cases of diabetes, representing 13.8% of the sample. Table 1 presents a descriptive summary of the study variables by levels of social support. Women in the lowest, relative to the highest, quartile of social support were more likely to be older, Black/African American or Hispanic/Latina, less educated, current smokers, to have a greater family history of diabetes, higher BMI, lower physical activity, lower diet quality, and higher levels of depression.

Bivariate Pearson correlations among the social variables were significant and in expected directions, but were not high enough to raise concerns about collinearity (average $r = |.14|$, ranging from $r = -.26$ to .25), suggesting that the four social measures could be treated as distinct exposure variables.

Table 2 includes results from the Cox proportional hazards regression models. The quartile scores for the social variables are indicated in the first column. Model 1 shows significant trends across three of the four social variables: risk of incident diabetes was lower among those with more social support (HR = 0.83, 95% CI = 0.79–0.86 for highest quartile). Risk of incident diabetes was higher among those with greater social strain (HR = 1.21, 95% CI = 1.17–1.26), and greater number of stressful life events (HR = 1.24, 95% CI = 1.19–1.29). For social network size, the second and fourth quartiles showed significantly lower risk for diabetes compared with the referent, but the trend was not significant. Model 2 tested the possible mediating effects of modifiable health behaviors, including BMI, smoking, alcohol intake, physical activity, and diet quality. The associations in Model 2 remained largely unaffected for social support (HR = 0.91, 95% CI = 0.87–0.94), social strain (HR = 1.11, 95% CI = 1.07–1.15), and stressful life events (HR = 1.13, 95% CI = 1.09–1.18). The association with social network size was not significant.

In Model 3, the association between stressful life events (HR = 1.10, 95% CI = 1.05–1.15), social strain (HR = 1.09, 95% CI = 1.04–1.13), and lower social support (HR = 0.93, 95% CI = 0.89–0.97) remained highly significant (*p*-trend < .0001 for all associations). Although the social network index variable was not significantly associated with diabetes, being married was related to lower diabetes risk (HR = 0.95, 95% CI = 0.92–0.98; Supplementary Table 1).

Table 2 also shows that the results were unchanged when the four social variables were treated as continuous rather than categorical. Diabetes incidence was associated with lower social support, more stressful life events, and higher social strain, but was not associated with social network size.

Table 3 provides a summary of the mediation effects for the three significant social exposure variables (social support, social strain, and life events). For each exposure, each of the six mediators was analyzed for natural direct and natural indirect effects, and for proportion of exposure–outcome variance that was mediated. Across all tests, results indicated that the natural indirect effects were significant, indicating that a portion of the association between social variables and diabetes outcome was mediated. The proportion of the exposure–outcome relationship that was mediated varied from 2% to 37%. The highest mediation proportions across social variables were for BMI and depression. However, across all tests, the natural direct (i.e., unmediated) effects for each social variable remained significant.

Table 1. Baseline Characteristics of Participants by Social Support in Quartile

	Q1 (9–31)		Q2 (32–37)		Q3 (38–42)		Q4 (43–45)	
Characteristic	*N*	Mean (*SD*) or %	*N*	Mean (*SD*) or %	*N*	Mean (*SD*) or %	*N*	Mean (*SD*) or %
Age (mean years)	33,298	63.6 (7.4)	36,228	62.8 (7.2)	32,304	62.9 (7.1)	34,515	62.7 (7.1)
Age at screening								
50–59	10,757	32.3	12,874	35.5	11,064	34.2	12,000	34.8
60–69	14,399	43.2	16,020	44.1	14,731	45.6	15,871	46.0
70–79	8,142	24.5	7,394	20.4	6,509	20.1	6,644	19.2
Ethnicity								
American Indian or Alaskan Native	164	0.5	127	0.3	114	0.4	108	0.3
Asian or Pacific Islander	860	2.6	1,028	2.8	822	2.5	794	2.3
Black or African American	3,227	9.7	3,068	8.5	2,573	8.0	2,136	6.2
Hispanic/Latino	1,795	5.4	1,168	3.2	1,033	3.2	1,059	3.1
White (not of Hispanic origin)	26,691	80.2	30,398	83.8	27,390	84.8	29,995	86.9
Other	561	1.7	499	1.4	372	1.2	423	1.2
Education								
Missing	265	0.8	268	0.7	217	0.7	238	0.7
HS diploma or less	7,727	23.2	7,344	20.2	6,967	21.6	7,371	21.4
Some college/technical training	12,993	39.0	13,632	37.6	11,988	37.1	12,499	36.2
College graduate or some postcollage	6,939	20.8	8,381	23.1	7,359	22.8	8,296	24.0
Master degree or higher	5,374	16.1	6,663	18.4	5,773	17.9	6,111	17.7
Body mass index (kg/m^2)	32,981	28.2 (6.0)	35,990	27.7 (5.8)	32,044	27.6 (5.7)	34,212	27.3 (5.5)
Physical activity (MET-hr/week)	31,752	11.2 (13.1)	34,607	12.5 (13.5)	30,650	12.9 (13.7)	32,754	14.0 (14.7)
Healthy eating index (HEI)-2005 score	33,223	66.0 (11.2)	36,219	67.3 (10.6)	32,259	67.6 (10.6)	34,447	68.0 (10.5)
Smoking status								
Missing	462	1.4	403	1.1	325	1.0	337	1.0
Never smoked	15,942	47.9	18,050	49.7	16,669	51.6	18,374	53.2
Past smoker	13,890	41.7	15,357	42.3	13,292	41.1	13,974	40.5
Current smoker	3,004	9.0	2,478	6.8	2,018	6.2	1,830	5.3
Alcohol intake								
Missing	274	0.8	228	0.6	169	0.5	194	0.6
Nondrinker	3,515	10.6	3,481	9.6	3,350	10.4	3,848	11.1
Past drinker	6,791	20.4	6,055	16.7	5,241	16.2	5,212	15.1
<1 drink per month	4,507	13.5	4,556	12.6	3,888	12.0	3,951	11.4
<1 drink per week	7,035	21.1	7,743	21.3	6,812	21.1	6,681	19.4
1–<7 drinks per week	7,781	23.4	9,911	27.3	8,822	27.3	9,788	28.4
7+ drinks per week	3,395	10.2	4,314	11.9	4,022	12.5	4,841	14.0
Relative had adult diabetes								
Missing	2,163	6.5	1,748	4.8	1,422	4.4	1,275	3.7
No	20,699	62.2	23,440	64.6	20,990	65.0	23,206	67.2
Yes	10,436	31.3	11,100	30.6	9,892	30.6	10,034	29.1
Depressive symptoms								
Missing	1,062	3.2	796	2.2	613	1.9	599	1.7
None	19,524	58.6	26,591	73.3	25,632	79.3	29,099	84.3
Mild	5,788	17.4	5,409	14.9	4,000	12.4	3,399	9.8
Moderate	6,924	20.8	3,492	9.6	2,059	6.4	1,418	4.1

The direction of the effects was consistent with social strain and life events increasing the risks of both mediators and outcomes, and social support decreasing those risks.

Associations were similar regardless of overweight or obesity status (results not shown). We found no evidence of effect modification by overweight/obesity in tests of interactions.

We also found little difference in diabetes risk by race/ethnicity in analyses of social network size, stressful life events, or social support (Supplementary Table 2). There were no significant differences between Hispanic and non-Hispanic white women on any of the four social measures. However, the association between social strain and diabetes risk was more pronounced in African American

Table 2. Association (HR and 95% CI) Between Social Support, Social Strain, Stressful Life Events, Social Network and Diabetes Risk

		Model 1 (demographics and basic covariates)[a]	Model 2 (Model 1 plus behavioral covariates)[b]	Model 3 (Model 2 plus depressive symptoms)[c]
Social variable	Cases	HR (95% CI)	HR (95% CI)	HR (95% CI)
Social support				
1 (9–31)	4,838	Reference	Reference	Reference
2 (32–37)	5,095	0.91 (0.88–0.95)	0.96 (0.93–1.004)	0.98 (0.94–1.02)
3 (38–42)	4,326	0.85 (0.82–0.89)	0.91 (0.87–0.94)	0.93 (0.89–0.97)
4 (43–45)	4,463	0.83 (0.79–0.86)	0.91 (0.87–0.94)	0.93 (0.89–0.97)
p-trend		<.0001	<.0001	<.0001
In continuous		0.990 (0.989–0.992)	0.995 (0.993–0.997)	0.996 (0.994–0.998)
Social strain				
1 (4)	4,893	Reference	Reference	Reference
2 (5)	2,373	1.03 (0.98–1.08)	1.02 (0.97–1.07)	1.02 (0.97–1.07)
3 (6–7)	5,092	1.08 (1.04–1.13)	1.05 (1.01–1.09)	1.04 (0.996–1.08)
4 (8–20)	6,411	1.21 (1.17–1.26)	1.11 (1.07–1.15)	1.09 (1.04–1.13)
p-trend		<.0001	<.0001	<.0001
In continuous		1.037 (1.030–1.047)	1.020 (1.014–1.025)	1.016 (1.010–1.022)
Stressful life events				
1 (0)	3,490	Reference	Reference	Reference
2 (1–2)	4,763	1.08 (1.03–1.13)	1.05 (1.01–1.10)	1.05 (0.005–1.10)
3 (3–4)	4,569	1.12 (1.07–1.17)	1.07 (1.03–1.12)	1.06 (1.01–1.11)
4 (5–33)	5,988	1.24 (1.19–1.29)	1.13 (1.09–1.18)	1.10 (1.05–1.15)
p-trend		<.0001	<.0001	<.0001
In continuous		1.027 (1.022–1.031)	1.016 (1.011–1.020)	1.012 (1.007–1.017)
Social network				
1 (0–1)	3,120	Reference	Reference	Reference
2 (2)	4,877	0.95 (0.91–0.99)	0.96 (0.92–1.01)	0.97 (0.92–1.01)
3 (3)	5,866	0.97 (0.93–1.01)	0.99 (0.94–1.03)	0.99 (0.95–1.04)
4 (4–5)	5,377	0.95 (0.91–0.99)	0.97 (0.93–1.02)	0.98 (0.94–1.03)
p-trend		.16	.52	.84
In continuous		0.987 (0.975–0.998)	0.991 (0.979–1.003)	0.994 (0.982–1.006)

[a]Model 1 adjusts for age at enrollment (in continuous), race/ethnicity (American Indian or Alaska Native, Asian or Pacific Islander, Black or African American, Hispanic/Latino, non-Hispanic white, and other), education (high school or less, some college/technical training, college or some postcollege, and master or higher), family history of diabetes (no, yes), and different study cohorts (participation in OS or CTs, and different treatment assignments for all three CTs).
[b]Model 2 further adjusts for BMI (in continuous), smoking (never, former, current), alcohol intake (nondrinker, past drinker, current and <7 drinks/week, current and ≥7 drinks/week), physical activity (<5, 5–<10, 10–<20, 20–<30, 30+ metabolic equivalent [METs]/week), and quality of diet (quartile).
[c]Model 3 further adjusts for depressive symptoms (none, mild, and moderate).

women than in non-Hispanic white women. Also, being married was protective among non-Hispanic white women (HR = 0.93, 95% CI = 0.90–0.96), but there was no significant association in African American women.

Results from the post hoc analysis of caregivers showed that larger social network size was positively related to diabetes among caregivers in this study (HR = 1.07, 95% CI = 1.01–1.13, *p*-trend = .04, *p*-interaction = .03).

Discussion

This article endeavored to examine whether social relationships were associated with diabetes incidence, and whether associations were direct or were mediated via behavioral indicators. The social-ecological model would predict such associations but would focus primarily on their mediated, rather than direct, effects. The results indicated that postmenopausal women with lower social support, greater social strain, and a greater number of stressful live events had higher risk of incident diabetes over a 14-year follow-up period. The effects for social strain and stressful life events appeared to be most pronounced in the highest quartiles. A mediation analysis indicated that associations between social variables and diabetes were partially mediated through lifestyle and depressive symptoms, but that direct associations between social variables and diabetes remained significant.

These findings are relevant to patient-centered care because they demonstrate that poor interpersonal relationships may contribute to the development of diabetes. Consistent with the social-ecological model, the results show that social variables are important for patients and health care

Table 3. Mediation Analysis Results for Social Strain, Social Support and Life Events, Comparing Highest Quartile to Lowest Quartile

Mediation variable	Estimate	95% CI lower limit	95% CI upper limit	*p* Value	Proportion mediated
Social strain					
BMI as continuous variable					0.371
Nature direct effect (NDE)	1.09	1.05	1.13	<.0001	
Nature indirect effect (NIE)	1.05	1.04	1.05	<.0001	
Physical activity as continuous variable					0.046
NDE	1.09	1.04	1.13	<.0001	
NIE	1.01	1.01	1.01	<.0001	
Diet as continuous variable					0.036
NDE	1.09	1.04	1.13	<.0001	
NIE	1.01	1.00	1.01	.01	
Smoking (current vs others)					0.029
NDE	1.09	1.05	1.14	<.0001	
NIE	1.00	1.00	1.01	.0002	
Depression (moderate vs others)					0.142
NDE	1.10	1.05	1.14	<.0001	
NIE	1.01	1.01	1.02	.0006	
Alcohol (highest vs others)					0.028
NDE	1.09	1.04	1.13	<.0001	
NIE	1.00	1.00	1.01	<.0001	
Social support					
BMI as continuous variable					0.185
NDE	0.92	0.88	0.96	<.0001	
NIE	0.98	0.97	0.98	<.0001	
Physical activity as continuous variable					0.102
NDE	0.92	0.88	0.96	.0002	
NIE	0.99	0.99	0.99	<.0001	
Diet as continuous variable					0.043
NDE	0.97	0.96	0.99	<.0001	
NIE	0.99	0.99	0.99	<.0001	
Smoking (current vs others)					0.062
NDE	0.92	0.88	0.96	.0001	
NIE	0.99	0.99	0.99	.0003	
Depression (moderate vs others)					0.267
NDE	0.92	0.88	0.97	.002	
NIE	0.97	0.95	0.99	.02	
Alcohol (highest vs others)					0.063
NDE	0.92	0.88	0.96	.0002	
NIE	0.99	0.99	0.99	.0003	
Life events					
BMI as continuous variable					0.330
NDE	1.10	1.05	1.16	<.0001	
NIE	1.05	1.04	1.05	<.0001	
Physical activity as continuous variable					0.023
NDE	1.10	1.05	1.15	<.0001	
NIE	1.00	1.00	1.00	.006	
Diet as continuous variable					0.039
NDE	1.10	1.05	1.15	<.0001	
NIE	1.00	1.00	1.01	.001	
Smoking (current vs others)					0.034
NDE	1.10	1.05	1.16	<.0001	
NIE	1.00	1.00	1.01	.0001	
Depression (moderate vs others)					0.131
NDE	1.12	1.07	1.17	<.0001	
NIE	1.02	1.00	1.03	.007	
Alcohol (highest vs others)					0.024
NDE	1.10	1.05	1.15	<.0001	
NIE	1.00	1.00	1.00	.004	

providers to consider in efforts to prevent diabetes (CDC, 2011; Hill et al., 2013). However, the current results offer an extension of the model by showing that interpersonal variables may have direct effects on diabetes risks above the effects they have through behavioral sequelae. These direct social effects may act through biological mechanisms. For example, negative life events, social strain, and stress related to feelings of low social support may affect the development of diabetes through inflammation or glucose dysregulation (Hackett & Steptoe, 2016). Increased stress associated with poor social support may influence insulin production through increased glucocorticoids (Kamba et al., 2016). A prospective study of middle-aged adults found that social strain was associated with higher inflammatory biomarker levels, while social support was linked to modestly lower levels (Yang et al., 2014). Psychological stress leading to cortisol production may promote inflammatory responses, which in turn may promote insulin resistance and increase diabetes risk (Fernandez-Real et al., 2002).

Results of the mediation analysis indicated that social relationships had their strongest mediating effects through BMI and depression. This suggests that poor social relationships may increase risk for depressive symptoms, which in turn increases diabetes risk through the effects of depression on health behaviors or biological mechanisms. Poor social relationships may also increase risk for health behaviors leading to unhealthy BMI levels.

Although social network size overall was not significantly associated with diabetes risk, one component of the social network measure, being married, was associated with reduced diabetes risk among postmenopausal women. This finding may reflect previous observations that women who live alone (Lidfeldt et al., 2005) or do not have a partner (Strodl & Kenardy, 2006) are at higher risk of diabetes. Being married may confer social, emotional, behavioral, or economic advantages that help protect older women against diabetes.

Social strain conferred greater diabetes risk in African American women compared with non-Hispanic white women. A previous WHI study found that African American women had higher levels of social strain than white women, and that social strain was related to incident coronary heart disease and stroke (Kershaw et al., 2014), but did not report interactions by race, and similar analyses for diabetes have not been reported previously. Some investigations have been conducted of the health effects of racism or discrimination. These findings suggest that racism or discrimination experienced by African Americans may lead to higher levels of social strain and contribute to higher inflammation and diabetes risk (Bacon et al., 2017).

The association of social network size and diabetes was weak in the initial model and became nonsignificant after adjusting for health behaviors suggesting that health behaviors may fully mediate the association. However, results from a post hoc analysis showed that women who had caregiver responsibilities had higher diabetes risk in association with larger social networks. This finding, consistent with previous WHI work, suggests that social obligations can have both positive and negative effects on health.

Our findings are largely consistent with those previous studies that have shown associations between social relationship variables and diabetes risk (Mooy et al., 2000; Norberg et al., 2007). In addition to diabetes incidence, social support has also been shown to be important to diabetes prevalence (Gallo et al., 2015) and to diabetes treatment adherence (Miller & Dimatteo, 2013). Our study extends previous research by examining a larger set of social variables than has typically been considered within a single study, by testing for mediation effects that help to illuminate how social variables may influence diabetes, and by focusing on an at-risk population, older women, who have not received much attention in studies of diabetes incidence. Consistent with the social-ecological model, our study suggests that diabetes incidence may be influenced by social and familial relationships, but extends the model by showing that social relationships may exert effects through both direct and mediated paths, which has not been directly recognized within the model.

Strengths of the study include the large sample size collected from women living in regions across the country, the long follow-up period, and collection of comprehensive data on numerous variables of interest. Limitations included self-reported diabetes, diet, smoking, and physical activity. Self-reported diabetes has been found to be valid in the WHI based on previous studies (Jackson et al., 2013; Margolis et al., 2008), but under-diagnosis of diabetes remains possible. Baseline glucose as a measure of prediabetes or glucose intolerance was not assessed. Risk variables were assessed only at baseline and it is possible that there were changes in these conditions before development of diabetes, although to the extent that error was nondifferential (e.g., social support may increase or decrease) this would tend to bias results toward the null. However, if other risk variables increase over time (e.g., BMI increases) the influence of these risk variables may be underestimated. We have suggested that social variables may have direct effects on diabetes through biological mechanisms, but we did not measure these mechanisms directly and follow-up studies of this possibility would be useful. Another limitation concerns the measure of social network size, which was limited to a count variable and did not assess the closeness of relationships or the frequency of contacts. Social networks can potentially have both positive and negative aspects which were not well discriminated here. There are limits to the mediation analysis, which allow for consideration of only one exposure and mediator at a time (although covariates are included), and is restricted to measures of exposure that are either continuous or dichotomous. Finally, results are specific to postmenopausal women and may not generalize to other populations.

In conclusion, better social support, fewer stressful life events, and less social strain were all associated with lower risks of incident diabetes among postmenopausal women. These relationships were only partially accounted for by health behaviors or depressive symptoms, and direct effects remained significant after mediation analysis. The association between diabetes risk and social strain was most pronounced in African American women. Prevention of diabetes in older women requires attention to maintenance of healthy behaviors such as engaging in physical activity and eating a proper diet. However, preventive efforts may also be aided by promotion of healthy communities that foster healthy social environments. Clinicians should furthermore be aware that social relationships may have powerful influences on the development of diabetes among older women. Future studies may investigate the mechanisms by which social relationships alter physiological variables in ways that reduce diabetes risk. Additionally, prevention programs may consider including assessments of social support or social strain, and interventions targeted to at-risk persons (e.g., people with pre-diabetes) may test whether social support intervention components, perhaps in combination with lifestyle intervention components, reduce diabetes risk. A possible approach to interventions may be to incorporate how social activities are mediated through leisure activities among older women (e.g., social gatherings, friendships, or religious groups) which in turn may influence healthy behaviors (Chang, Wray, & Lin, 2014).

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series B: Psychological Sciences and Social Sciences* online.

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M. Hendryx planned the study, contributed to analysis, and wrote the article. W. Nicholson, J. E. Manson, C. H. Kroenke, J. Lee, J. C. Weitlauf, L. Garcia, J. M. Jonasson, and J. Wactawski-Wende all contributed to study conceptualization and manuscript revisions. J. Luo conducted the data analysis and contributed to study planning and writing.

Conflict of Interest

None reported.

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