Dyadic Associations between Body Mass Index, Stress and Type 2 Diabetes Complications

by

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Abstract

Type 2 diabetes (T2DM) can result in complications, including kidney problems or cardiovascular disease. Intrapersonal risk factors such as body mass index (BMI) and stress have been associated with increased odds of developing T2DM complications. However, little is known about interpersonal risk factors. The present study aimed to test associations among partner's BMI, partner's stress and T2DM complications development among married couples in which one partner has diabetes and if negative marital quality moderates these associations. Data ($n=274$) came from the Health and Retirement Study. BMI, stress, diabetes status and complications were self-reported at baseline (2006). Complications were assessed every two years from 2008-2016. Data were analyzed using logistic regression models. Unadjusted and adjusted models revealed no associations among partner BMI, partner stress, and incident T2DM complications, $p>0.05$. Furthermore, marital quality did not moderate these associations, $p>0.05$. Future research should consider other interpersonal risk factors onto intrapersonal health outcomes.

Keywords: type 2 diabetes, diabetes complications, dyads, stress, body mass index, negative marital quality

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Dyadic Associations between Body Mass Index, Stress and Type 2 Diabetes Complications

Over 430 million people worldwide are currently diagnosed with diabetes, with prevalence projected to increase to 730 million people by 2045 (International Diabetes Federation [IDF], 2019). Type 2 diabetes mellitus (T2DM) accounts for the majority of all diabetes cases across North America; over 90% of diabetes cases are T2DM (Center for Disease Control and Prevention [CDC], 2017; Public Health Agency of Canada [PHAC], 2017). T2DM is a chronic progressive disease, which can result in complications, including but not limited to: cardiovascular disease, nephropathy (i.e., kidney disease), stroke, neuropathy (i.e., nerve pain), eye damage (e.g., retinopathy), or death (Fonseca, 2009; Zhang et al., 2019). These complications increase the risk of hospitalization for amputations and kidney or heart failure (Diabetes Canada, 2019). Approximately 20-40% of people with diabetes develop kidney disease (Gheith et al., 2016) and 32.3% develop cardiovascular disease (Einarson et al., 2018). Moreover, the costs associated with T2DM and its complications increased to \$30 billion CAD in 2019 (Diabetes Canada, 2019).

The development of T2DM complications is associated with lifestyle factors, such as weight management (Janssen et al., 2004; Kramer et al., 2010), and psychological factors, such as stress, depressive symptoms, and anxiety (e.g., Paschalides et al., 2004; Smith et al., 2013; Tovilla-Zárate et al., 2012). However, many newly diagnosed patients with T2DM do not make the recommended lifestyle changes, thereby increasing their future risk of developing complications (American Diabetes Association [ADA], 2007; van Puffelen et al., 2015). Identifying risk factors for the development of T2DM complications can point to psychological processes that may be targeted in interventions that seek to reduce or delay the risk of complications, such as kidney or cardiovascular disease.

Intrapersonal risk factors for diabetes complications

Past research has primarily focused on intrapersonal risk factors for T2DM complications. Associations between one's own behaviours and mental health and one's own risk of diabetes complications have been extensively investigated (e.g., Tanaka et al., 2013; Wolde et al., 2018). For example, one's own smoking status, physical activity, diabetes distress, and depressive symptoms increase the risk of developing T2DM complications (ADA, 2004; Badawi et al., 2012; Maghbooli et al., 2014; Rodríguez-Segade et al., 2012; Simon et al., 2005; Snoek et al., 2011; Tanka et al., 2013; Waden et al., 2008; Wolde et al., 2018). One's own body mass index (BMI) and one's own stress have also been linked to the development of diabetes complications (Evans, 1985; Gray et al., 2015; Kaštelan et al., 2013).

Body mass index

BMI indicates the body mass of an individual while considering their height; a higher BMI indicates that an individual carries more body weight (Zierle-Ghosh & Jan, 2020). As an individual's BMI increases, so does one's weight status from underweight to obese¹. Obesity can exaggerate inflammatory responses and insulin sensitivity through metabolic pathways, which result in beta-cell dysfunction and insulin resistance (Al-Goblan et al., 2014). Beta-cell dysfunction and insulin resistance are critical to managing blood glucose levels, which, if unregulated, can result in an increased risk of T2DM complications (Al-Goblan et al., 2014; Keicolt-Glaser et al., 2010).

¹ Research has suggested that waist circumference is an alternative measure to BMI (e.g., Ashwell et al., 2011; Shah et al., 2009), however, the majority of intrapersonal research regarding T2DM complications has focused on BMI. Associations between waist circumference and health outcomes differ among ethnic groups (see Carroll et al., 2008; Zhu et al., 2005). Information about ethnicity was limited in the HRS, therefore waist circumference was not selected as a predictor.

BMI is a well-documented intrapersonal risk factor for T2DM complications, such as end-stage renal disease (Kovedy et al., 2017), and heart disease (Wilson et al., 2002). For example, in the Medicare Current Beneficiary Survey, higher BMI at baseline was associated with a greater likelihood of T2DM complications over 19 years, such as cardiovascular and kidney complications; individuals who were obese were at higher risk of complications compared to those who were overweight (Gray et al., 2015). Similarly, individuals with diabetes who had BMIs in the obese range were more likely to develop retinopathy compared to those with a BMI within the normal or overweight range (Kaštelan et al., 2013; Rooney et al., 2015). Additionally, individuals with T2DM and increased BMIs were more likely to develop neuropathy over three years compared to those with BMIs in the normal range (Dagliati et al., 2018). Some work suggests that the associations among BMI and T2DM complications follow a U-shaped pattern, such that having a BMI categorized as underweight also increases the risk of T2DM complications, such as poor glycemic control, neuropathy, and peripheral arterial disease (Curb et al., 1996; Xu et al., 2014; Zhang et al., 2019). Furthermore, a few studies have suggested gender differences in the association between BMI and T2DM complications, such that being overweight is a risk factor for T2DM complications for women but not men (Gray et al., 2015; Peters et al., 2015; Ritter et al., 2020).

Stress

Stressors are conditions or events that lead to distress, threatening an individual's wellbeing (Gunderson et al., 2011; Wheaton, 1999). Psychosocial stressors may be caused by interpersonal and intrapersonal events or conditions and affect one's mental or physical health. Links between one's own stress and diabetes outcomes (i.e., kidney problems, retinopathy,

neuropathy, cardiovascular disease and peripheral vascular disease) have been documented (see Dohrenwend & Dohrenwend, 1981; Evans, 1985; Lin & Ensel, 1989; Surwit et al., 1992).

T2DM can increase psychological stress (Kelly & Ismail, 2015). Psychological stress can influence the physiological associations among glucose intolerance and insulin resistance, which can lead to the development of complications (Siddiqui et al., 2015). Stress has direct and indirect influences on the body. Among those with T2DM, stress triggers the release of glucose into the bloodstream, which increases hyperglycemia, thereby increasing the likelihood of developing diabetic complications (Brindley & Rolland, 1989; Irvine et al., 1992; Morris et al., 2011; Surwit et al., 1984). The addition of stress management to the diabetes education program was associated with a “small but significant reduction of HbA1c” (Surwit et al., 2002, p.30), which is a marker of blood glucose control that is linked to the development of complications (ADA, 2010).

Stress may also indirectly lead to health consequences for people with T2DM. For example, stress can increase unhealthy behavioural responses, such as unhealthy eating or increased alcohol usage, which increase the risk of developing T2DM complications (Cox & Gonder-Fredrick, 1992). Moreover, psychological stress has been associated with decreased physical activity, which is linked to T2DM complications (Cox & Gonder-Frederick, 1992; Morris et al., 2011).

Interpersonal risk factors for diabetes complications

Although intrapersonal risk factors for T2DM complications, including one's own BMI and stress, have been studied, little is known about interpersonal risk factors for T2DM complications. However, multiple theories suggest that other people may influence the development of T2DM complications. Ecological systems theory (Bronfenbrenner, 1992) argues

that social context shapes social, cognitive, and biological development; an individual's development is influenced by their social environment, which includes immediate families in the microsystem. Ecological systems theory (Bronfenbrenner, 1992) has been expanded to socioecological theories, which further explain the dynamic interactions among personal factors (Walsh, 2003). These theories suggest that health behaviours and outcomes are shaped by those surrounding the individual due to the strong mutual and dynamic influences that individuals can have on one another (Kiecolt-Glaser et al., 2017; Monden, 2007).

Similarly, interdependence theory, a social exchange theory, states that individuals, including family members, influence each other (Lewis et al., 2006). Interdependence theory takes into consideration the reciprocal nature of dyadic relationships and allows for the modelling of interdependence among dyad members (Garcia et al., 2015). As dyad members are dependent on one another, when analyzing data, researchers treat the dyad as one unit (Fitzpatrick et al., 2016, Kenny et al., 2006). Given that the dyad is the unit of analysis, interdependence theory distinguishes between actor and partner effects. Actor effects are associations between one's own risk factor and their own outcomes, such as associations between one's own BMI and one's own risk of developing T2DM complications (Bhupathiraju & Hu, 2016; Gray et al., 2015). In contrast, partner effects are associations between one's partner's risk factor and one's own outcome, such as associations between one's partner's BMI and one's own risk of developing T2DM (Burns et al., 2019, Garcia et al., 2015; Kenny et al., 2006).

Marriage is one of the most significant adult relationships (Robles et al., 2014). As such, these theories suggest that individuals within a married couple influence each other's health and development (Ellis et al., 2017; Kenny, 1999; Kenny & Cook, 2005). If applied to the context of

T2DM complications, these models suggest that spouses might influence the risk of T2DM complications.

Interpersonal health research

Although spousal influences on T2DM complications have not been examined, spousal influences (i.e., partner effects) on other health outcomes have been demonstrated. In the general population, actor and partner effects have been demonstrated in the contexts of diet (e.g. Markey & Markey, 2011) and physical activity (e.g. Baiocchi-Wagner & Talley, 2013). Actor and partner effects have also been examined in the context of disease. For example, emotional distress in cardiovascular patients with atrial fibrillation and their spouses were associated with their partner's perceived health, such that higher depressive symptoms in patients were associated with lower levels of vitality in spouses. In addition, spouses' depressive symptoms were associated with lower perceived physical health in patients (Dalteg et al., 2016). Further, dyadic associations between emotional wellbeing and physical wellbeing among patients with advanced cancers and their caregivers have been observed. Caregiver mental health was prospectively associated with emotional wellbeing among patients and patient self-efficacy was prospectively associated with caregiver physical health (Kershaw et al., 2015). Dyadic associations between disease-related pain and blood pressure have also been demonstrated in married couples (Monin et al., 2010). A similar pattern of results have also been observed in populations with advanced cancers, such as diet (e.g. Ellis et al., 2017), relationship mutuality (e.g. Kayser & Acquati, 2019), physical activity (e.g. Ellis et al., 2017) and cardiovascular outcomes in cardiovascular patients (e.g., Thomson et al., 2012).

Interpersonal research in the context of T2DM

Although actor and partner effects have not been tested in the context of T2DM complications, dyadic associations related to other facets of T2DM have been explored. For example, partner effects on the likelihood of developing T2DM have been demonstrated. A systematic review and meta-analysis concluded that spousal history of diabetes is associated with a 26% increase in T2DM risk without adjusting for BMI, and an 18% increase in risk after controlling for BMI (Leong et al., 2014). Dyadic associations between BMI and the likelihood of developing T2DM have also been observed; partners' BMI was associated with the likelihood of developing T2DM above and beyond one's own BMI (Burns, 2019). Nielsen et al. (2018) found similar associations between spousal waist circumference and risk of developing T2DM, though this association was moderated by sex. For men, the risk of T2DM incidence was greater when their wives' BMI was higher, despite controlling for their own BMI. However, for women, the risk of T2DM incidence was not associated with their partners' BMI, despite controlling for their own BMI (Nielsen et al., 2018).

Dyadic associations have also been investigated in couples in which one person has diabetes. In these contexts, the person with diabetes (PWD) is distinguished from their partner. Given that treatment for T2DM often involves lifestyle and behavioural changes, T2DM has been referred to as a family disease (Cradock et al., 2017; Franks et al., 2012; Tuomilehto et al., 2011). Many researchers have concluded that couples need to work together to identify health behaviours and adhere to recommended diabetes treatments to improve the overall quality of life (e.g., Beverly et al., 2008; Franks et al., 2012). Partners often provide diet support to the PWD, suggesting all partners provide diet support at least once a month, with nearly half providing daily diet support to the PWD (Franks et al., 2012). Moreover, among couples in which one member had T2DM, physical activity of the PWD was inversely associated with their partners'

BMI (Burns et al., 2019). However, partner physical activity was not associated with PWD's BMI (Burns et al., 2019). Iida et al (2013) examined daily symptoms, diabetes distress, and interaction quality among PWD and their partners. PWD's symptom severity was associated with decreased daily enjoyment and tension for PWDs and their partners, especially among PWD with increased diabetes duration. Furthermore, Franks et al (2010) examined diabetes distress and depressive symptoms experienced by PWDs and their partners, resulting in associations among partners' depressive symptoms for male PWD and their female partners only. In sum, past research has focused on predicting behaviour, wellbeing, or the development of T2DM. To our knowledge, no studies have applied a dyadic perspective to risk factors for diabetes complications.

The role of marital quality in health

Marital quality is a multi-dimensional construct that accounts for positive and negative aspects of the relationship. Marital quality is a key factor that defines life course contexts (Liu & Waite, 2014). A considerable amount of research has demonstrated that married couples, on average, have better mental and physical health compared to those who are unmarried (Robles et al., 2014). However, marital quality has implications for health because unhappy marriages can be sources of stress, which is linked to poor health outcomes (Birditt et al., 2014; Karney & Bradbury, 1995; Kiecolt-Glaser & Wilson, 2017).

A growing body of research suggests that marital conflict and criticism are associated with poor physiological functioning. For example, laboratory studies have revealed that women are more likely than men to experience psychological distress, as evidenced by through elevated endocrine, immune and cardiovascular responses, when discussing conflict with their partner (Kiecolt-Glaser et al., 1993; Kiecolt-Glaser et al., 1996; Kiecolt-Glaser et al., 1997; Kiecolt-

Glaser et al., 2001). Studies have also suggested that women experience elevated blood pressure and heart rate compared to men during marital conflict (Bloor et al., 2004; Smith et al., 2004). Increased conflict may arouse the hypothalamic-pituitary-adrenal (HPA) axis, therefore releasing increased cortisol levels, which has been linked to cardiovascular pathology (Ader et al., 1991; Wanic & Kulik, 2011). Moreover, perceived marital criticism has been linked to long-term depressive symptoms in community samples over a 5 and 10-year period; such that among those who perceived greater criticism, they were more likely to develop long-term depressive symptoms (Peterson-Post et al., 2014).

The dyadic biopsychosocial model of marriage and health, also known as the biopsychosocial model of marriage (Birditt et al., 2016), provides a multifaceted theory of understanding the effects of marriage on health. It is consistent with interdependence theory and socioecological systems theory by suggesting that individuals' health outcomes are influenced by their spouses. However, this model is distinct in that it further suggests that marital quality could influence dyadic health outcomes (see Figure 1). The model incorporates three frameworks: 1) the main effect model, which suggests that negative marital quality has a direct association with health, 2) the moderating effect model, which suggests that negative marital quality is influential when a dyad is under stress, and 3) the biopsychosocial model, which incorporates social and psychological factors that influence overall health (Birditt et al., 2016). The biopsychosocial model of marriage specifically proposes moderation, such that higher negative marital quality exacerbates the actor effect between stress and health.

Figure 1

The dyadic biopsychosocial model of marriage and health. An example of chronic stress (predictor) to blood pressure (outcome) moderated by negative marital quality.

Note. Figure from Birditt et al. (2016, p.776). The solid lines test direct effects of stress, dashed lines test direct effects of relationship quality, and dotted lines test the moderating role of negative relationship quality.

Consistent with this model, research has demonstrated that marital quality moderates associations between dyadic predictors and health outcomes. Through the National Social Life Health and Aging Project, associations between stress, marital quality, and blood pressure were examined (Birditt et al., 2014). High relationship quality acted as a buffer against the influence of stress on health, whereas poor relationship quality aggravated poor health (Birditt et al., 2014). In addition, marital quality moderated the association between income and blood pressure, such that supportive marital relationships were associated with lower diastolic blood pressure among

couples with lower incomes compared to couples with ambivalent marital quality (Cundiff et al., 2016). However, Birditt and colleagues (2014) did not find partner associations of partner relationship quality or stress on blood pressure, which was inconsistent with the dyadic biopsychosocial model of marriage and health.

Based on previous dyadic research and Birditt and colleagues' model (2016), it is expected that negative marital quality will moderate the relationship between T2DM predictors and complications among couples given one member has T2DM.

Theoretical perspectives

Three theoretical frameworks offer insights into interpersonal associations and health outcomes. First, the socioecological approach emphasizes that individuals are influenced by their microsystem which includes their immediate family members (Bronfenbrenner, 1992). Second, interdependence theory states that individuals are influenced by each other and takes into consideration the reciprocal nature of dyadic relationships and allows for the modelling of interdependence among dyad members (Garcia et al., 2015; Lewis et al., 2006). Finally, the dyadic biopsychosocial model of marriage and health specifies how marital quality influences health outcomes (Birditt et al., 2016). Together, these three theories will provide as theoretical foundations for the proposed research.

The present study

Although many intrapersonal risk factors for T2DM complications, such as BMI and stress, have been identified, interpersonal risk factors for the development of T2DM complications have not been investigated. This thesis aims to fill this gap in the literature by examining intrapersonal associations between stress, BMI, and the development of T2DM complications. Drawing on the interdependence theory and the dyadic biopsychosocial model of

marriage, the following research questions (see Figure 2) pertaining to BMI will be examined: 1) Is the PWD's BMI associated with their own odds of developing T2DM complications? (i.e., actor effect), 2) Is partner's BMI associated with the PWD's odds of developing T2DM complications, above and beyond the PWD's own BMI? (i.e., partner effect), 3) Is the PWD's negative marital quality associated with their own odds of developing T2DM complications? 4) Is the partner's negative marital quality associated with the PWD's odds of developing T2DM complications? 5) Does PWD negative marital quality moderate the association between partner's BMI and the PWD's odds of developing T2DM complications?

Figure 2

Proposed model of BMI as an interpersonal predictor and negative marital quality as a moderator.

It is hypothesized that the PWD's BMI at baseline will be positively associated with their odds of developing T2DM complications over the next ten years (actor effects) and that

partner's BMI at baseline will be positively associated with the PWD's odds of developing T2DM complications (partner effects). It is hypothesized that PWD negative marital quality will be positively associated with their own odds of developing T2DM complications and that partner's negative marital quality will be positively associated with the PWD's odds of developing T2DM complications. Negative marital quality is hypothesized to moderate the association between partner BMI and the odds of the PWD developing T2DM complications, such that the association between partner BMI and T2DM complications will be stronger when marital quality is low compared to high.

Similarly, the following research questions related to stress will be examined (see Figure 3): 1) Is the PWD's stress associated with their own odds of developing T2DM complications? (i.e., actor effect), 2) Is a partner's stress associated with the PWD's odds of developing T2DM complications, above and beyond the PWD's own stress? (i.e., partner effect), 3) Is the PWD's marital quality associated with their own odds of developing T2DM complications? 4) Is the partner's marital quality associated with the PWD's odds of developing T2DM complications? 5) Does PWD marital quality moderate the association between partner's stress and the PWD's odds of developing T2DM complications?

Figure 3

Proposed model of stress as an interpersonal predictor and negative marital quality as a moderator.

It is hypothesized that the PWD's stress at baseline will be positively associated with their odds of developing T2DM complications over the next ten years (actor effects) and that partner's stress at baseline will be positively associated with the PWD's odds of developing T2DM complications (partner effects). It is hypothesized that PWD marital quality will be positively associated with their own odds of developing T2DM complications and that partner's marital quality will be positively associated with the PWD's odds of developing T2DM complications. Marital quality is hypothesized to moderate the association between partner stress and the odds of the PWD developing T2DM complications, such that the association between partner stress and T2DM complications will be stronger when marital quality is low compared to high.

Methods

Data source and participants

Data was obtained from the Health and Retirement Study (HRS). The HRS is sponsored by the National Institute on Aging (grant number NIA U01AG009740) and is conducted by the University of Michigan. The HRS is a national longitudinal panel study that surveys a representative sample of approximately 37,000 participants in 23,000 households in the United States (Sonnega & Smith, 2015). The HRS is a multidisciplinary dataset containing economic, psychosocial, cognitive, and biological information (Sonnega & Smith, 2015). All HRS respondents have provided written consent, and the HRS protocol has been approved by the University of Michigan Institutional Review Board.

The HRS has been collecting data since 1992 via telephone or face-to-face interviews with data collection occurring every two years. New participants are added routinely to maintain the target sample size of roughly 18,000-23,000 participants, with new participant screening efforts in 2004 and 2010 (Sonnega et al., 2014; Sonnega & Smith, 2015). A brief household screening interview is conducted to determine eligibility. Participants aged 50 years and older and their spouses, if applicable, are invited to participate in the study.

In addition to the core biennial data collection, enhanced face-to-face (EFTF) interviews, which include a battery of objective biomeasures (e.g., height, weight) and self-administered psychosocial questionnaires, were introduced in 2006 (Birditt et al., 2016; Sonnega et al., 2014). One random half of the households completed the EFTF measures in 2006, whereas the remaining half of the participants completed EFTF interviews in 2008 (Sonnega & Smith, 2015). Participants completed EFTF interviews every four years (Sonnega et al., 2014).

The present study treated 2006 as the baseline because stress was only measured in 2006. Follow-up data came from data collection which occurred in 2008, 2010, 2012, 2014 and 2016, with a total follow-up time of ten years. The inclusion criteria for this present study include that both dyad members participated in the HRS at baseline and follow-up. Additionally, only one member of a couple must have diabetes at baseline. The PWD must not have the target complications (i.e., kidney problems, cardiovascular disease) at baseline. Moreover, dyad members had to complete the BMI and stress measures. Further, participants must stay married during follow-up, and the partner must not develop diabetes during follow-up.

Measures

Diabetes Status

At baseline, T2DM status was assessed via self-report with the item “Has a doctor ever told you that you have diabetes or high blood sugar?” (HRS, 2006, 2008, 2010, 2012, 2014, 2016). The person with diabetes responded at baseline (2006), whereas the partner’s diabetes status was tested at every wave (2006, 2008, 2010, 2012, 2014, 2016).

BMI

BMI was provided at baseline using subjective BMI during the EFTF interviews. BMI was examined categorically and continuously. Individuals with a BMI of less than 25.00 were classified as not overweight/obese. Those with a BMI greater than or equal to 25.00 but less than 30.00 were classified as overweight, and those with a BMI greater than or equal to 30.00 were classified as obese (CDC, 2020).

Chronic Stress

Stress was assessed at baseline via self-report. Participants were asked to indicate whether they were enduring a series of eight “current and ongoing” stressful situations lasting

twelve months or longer. The situations were: intrapersonal health, interpersonal physical or emotional health, alcohol or drug use in a family member(s), work, finances, housing, close relationships, and caregiving (Sonnega & Smith, 2015). Responses were made on a 4-point scale (1 = no, didn't happen, 2 = yes, but not upsetting; 3 = yes, somewhat upsetting; 4 = yes, very upsetting) (HRS 2006; Mooney et al., 2018). Stress scores were averaged across all items.

T2DM Complications

Diabetes complications (i.e., kidney problems, cardiovascular disease), were self-reported at baseline and follow-up waves. Participants were asked, “Has your diabetes caused you to have trouble with your kidneys or protein in your urine?” (yes, no) and “Has a doctor ever told you that you had a heart attack, coronary heart disease, angina, congestive heart failure, or other heart problems?” (yes, no) (HRS, 2006, 2008, 2010, 2012, 2014, 2016). Participants who respond affirmatively to at least one of these items will be classified as having T2DM complications. T2DM complications will be treated dichotomously (0 = no complications, 1 = cardiovascular disease and/or kidney disease).

Negative Marital quality

At baseline, participants self-reported current negative marital quality with the spousal subscale of the Perceived Social Support of the Participant and Lifestyle Questionnaire (PLQ). Four questions evaluated respondents' perceptions of spouses' negative qualities: (a) ‘How often do they make too many demands on you?’, (b) ‘How much do they criticize you?’, (c) ‘How much do they let you down when you are counting on them?’ and (d) ‘How much do they get on your nerves?’ (Birditt et al., 2016; Smith et al., 2017). Responses were made on a 4-point Likert scale (1 = a lot, 2 = some, 3 = a little, 4 = at not all). All responses were reverse-coded. An index of negative behaviours were created by averaging the scores (Smith et al., 2013). If more

than two items were missing, the final score was considered missing (Smith et al., 2013).

Negative marital quality scores were analyzed continuously, such that increased negative support scores indicate poor relationship quality. Alpha reliability information across negative behaviours have been determined in 2006; the reliability is 0.78 for negative behaviours (Smith et al., 2017).

Covariates

Covariates for both dyad members included age, ethnicity, years of education as a proxy of socioeconomic status, and marriage duration (years). Covariates for the PWD included the number of self-reported comorbidities [sum of current cancer, chronic pulmonary disease (chronic bronchitis or emphysema), arthritis (arthritis or rheumatism), migraines, hypertension, stroke, memory-related disease] (Stenholm et al., 2014), diabetes duration (years), and insulin use (yes, no). Covariates have been chosen as they have been linked to BMI, stress, and T2DM complications (see Birditt et al., 2014; Birditt et al., 2016; Cusick et al., 2005; Franks et al., 2012; Simon et al., 2005).

Statistical Analyses

Statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS), version 27.0 for MAC (IBM Corporation, 2020).

All variables were checked for accuracy of data entry, missing values, and normality. Descriptive statistics, including means, standard deviations, and correlations for all variables were computed. The PWD is the only person in the dyad who can develop T2DM complications (i.e., the outcome). Therefore, this analysis plan cannot include the traditional Actor-Partner Interdependence Model (APIM) presented by Kashy and Kenny (1999) because the APIM requires both members of the dyad to be able to experience the outcome. Accordingly, data will

be analyzed with logistic regression models with PWD's T2DM complications as the sole outcome variable.

Moderation was tested using the PROCESS macro for SPSS (Hayes, 2013). Moderation analyses are used when one is interested in testing whether the magnitude of a variable's association on some outcome variable of interest depends on a third variable (Hayes, 2013). For the BMI model, the outcome variable was PWD T2DM complications with the predictor variables: PWD BMI, partner BMI, partner marital quality, PWD marital quality and PWD marital quality X PWD BMI. For the categorical BMI model, BMI was coded using indicator coding, with not overweight/obese as the reference term. For the stress model, the outcome variable was the PWD T2DM complications with the predictor variables: PWD stress, partner stress, partner marital quality, PWD marital quality and PWD marital quality X PWD stress, see the statistical model (Figure X). This model represented in statistical form is:

$$\text{Log} \left[\frac{Y}{(1 - Y)} \right] = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + b_4M_1 + b_5X_1M_1$$

In the statistical form, $\text{Log} [Y/(1-Y)]$ is the outcome variable (T2DM complications), b_0 represents the intercept and b_{1-5} represent the slopes for each predictor. X_1, X_2, X_3 are the predictor variables (PWD predictor, partner predictor, partner marital quality respectively), M_1 is the moderator (PWD marital quality) and X_1M_1 is the interaction term (PWD predictor X PWD marital quality).

Figure 4

Statistical model of moderation analysis.

Note. X1 and X2 predictors are interchangeable depending on BMI or stress model.

Results

Attrition Bias

To explore possible attrition biases, a series of independent t-tests and chi-square analyses were performed between participants who met all eligibility criteria, hereinafter referred to as ‘analyzed’ ($n = 274$) compared to participants who met all eligibility criteria with the exemption of providing follow-up information, referred to as ‘lost to follow-up’ ($n = 214$) (see Table 1). There were statistically significant differences in age between PWD lost to follow up ($M = 68.220$, $SD = 9.148$) and analyzed PWD ($M = 65.927$, $SD = 8.995$), $t(486) = 2.773$, $p < 0.001$, $d = 0.253$. Further, differences were also present amongst their partners’ age, $t(486) = 3.975$, $p < 0.001$, $d = 0.363$. Moreover, analyzed PWDs were more likely to be male, ($\chi^2(1) = 17.241$, $p < 0.001$) and have increased number of comorbidities at baseline, ($t(486) = 2.931$, $p = 0.004$). Notably, partners lost to follow-up were more likely to have increased stress scores ($M = 1.562$, $SD = 0.477$) compared to analyzed partners ($M = 1.450$, $SD = 0.411$), $t(441) = -2.641$, $p = 0.009$, $d = 0.254$. Furthermore, BMI significantly differed among partners lost to follow-up ($M = 30.317$, $SD = 6.917$) compared to analyzed partners ($M = 27.807$, $SD = 4.927$), $t(471) = 4.606$, $p < 0.001$, $d = 0.427$.

Figure 5

Participants analyzed ($n = 274$).

Note. MQ = marital quality.

Table 1

Participant characteristics and attrition analyses.

	Analyzed (<i>n</i> = 274)		Lost to Follow- up (<i>n</i> = 214)		Test of difference	<i>p</i> -value	Effect Size
	<i>M</i> (<i>SD</i>)	% (<i>n</i>)	<i>M</i> (<i>SD</i>)	% (<i>n</i>)			
PWD Age (years)	65.927 (8.995)		68.220 (9.148)		$t(486) = 2.773$	0.006	0.253
Partner Age	65.035 (8.919)		68.508 (10.344)		$t(486) = 3.975$	<0.001	0.363
PWD Gender					$\chi^2(1) = 17.241$	<0.001	
Male		59.124 (162)		40.187 (86)			
Female		40.976 (112)		59.813 (128)			
PWD Ethnicity					$\chi^2(2) = 7.228$	0.027	-
White or Caucasian		85.766 (235) ^a		76.636 (164) ^a			
Black or African American		9.854 (27) ^b		17.757 (38) ^b			
Other		4.380 (12)		5.607 (12)			
Partner Ethnicity					$\chi^2(2) = 7.361$	0.025	-
White or Caucasian		84.672 (232) ^a		77.570 (166) ^a			
Black or African American		9.854 (27) ^b		18.224 (39) ^b			
Other		5.474 (15)		4.206 (9)			
PWD Education	12.770 (3.245)		12.170 (3.230)		$t(458.759) = -2.038$	0.042	-0.186
Partner Education	12.682 (2.956)		12.084 (3.185)		$t(440.467) = -2.125$	0.034	-0.196

			39.029 (16.150)	$t(478) = -1.841$	0.066	0.169
Marriage Duration	36.457 (14.397)					
PWD Negative Marital Quality	2.072 (0.661)		2.129 (0.714)	$t(486) = -0.914$	0.361	0.083
Partner Negative Marital Quality	2.058 (0.650)		2.123 (0.648)	$t(445) = -1.054$	0.292	0.101
PWD Stress	1.503 (0.417)		1.565 (0.477)	$t(475) = -1.505$	0.133	0.139
Partner Stress	1.450 (0.411)		1.562 (0.477)	$t(441) = -2.641$	0.009	0.254
Diabetes Duration	8.574 (8.026)		8.953 (9.958)	$t(483) = -0.465$	0.642	0.043
Insulin use (yes)		14.2 (39)	16.4 (35)	$\chi^2(1) = 0.420$	0.517	0.527
PWD BMI	30.594 (5.881)		30.629 (6.377)	$t(475) = -0.062$	0.95	0.006
PWD BMI				$\chi^2(2) = 2.111$	0.348	-
Not Overweight/Obese		14.552 (39)	18.182 (38)			
Overweight		37.687 (101)	32.057 (67)			
Obese		47.761 (128)	49.761 (104)			
Partner BMI	27.807 (4.927)		30.317 (6.917)	$t(471) = 4.606$	<0.001	0.427
Partner BMI				$\chi^2(2) = 16.933$	<0.001	-
Not Overweight/Obese		25.843 (69)	20.388 (42)			
Overweight		44.943 (120) ^a	32.039 (66) ^a			
Obese		29.213 (78) ^b	47.572 (98) ^b			
Comorbidities	1.496 (0.977)		1.743 (0.847)	$t(486) = 2.931$	0.004	0.267
Complications		41.606 (114)				

Note. Adjusted standardized residuals indicated that values with the same superscript are significantly different, $p < 0.05$. Effect size

is Cohen's d for t -tests and Fisher's Exact Test for chi-square analyses with 2 categories.

Participant characteristics

The final sample included 274 dyads. Over the 10-year follow-up, 114 (41.606%) PWDs reported developing T2DM complications (i.e., kidney disease or cardiovascular disease). Among these 274 couples, PWDs were, on average, 65.927 years old ($SD = 8.970$), had been married for 36.457 years ($SD = 14.643$), had 12.770 ($SD = 3.245$) years of education and had 1.496 ($SD = 0.977$) comorbidities at baseline. The majority of the PWDs identified as White (85.77 %). On average, partners were 65.035 years old ($SD = 8.909$) and had 12.682 ($SD = 2.956$) years of education. The majority of partners identified as White (84.766%).

At baseline, PWDs had a self-reported average BMI of 30.594 ($SD = 5.881$), an average stress score of 1.503 ($SD = 0.417$), and an average negative marital quality score of 2.072 ($SD = 0.661$). At baseline, 47.761% of PWDs were categorized as obese. At baseline partners had a self-reported average BMI of 27.807 ($SD = 4.927$), an average stress score of 1.450 ($SD = 0.411$) and an average negative marital quality score of 2.058 ($SD = 0.650$). At baseline, 43.943% of partners were categorized as overweight. Participant characteristics are presented in Table 1.

Assumption testing for logistic regression models

Assumptions were tested for the entire sample ($n = 274$). The first assumption of logistic regression models is that the outcome variable must be dichotomous. As the outcome variable was coded as 0 (no complications) and 1 (1+ complications), the first assumption was met. The second assumption is that the predictor variables must be on a continuous or nominal scale. For the BMI models, BMI was coded as continuous and nominal. Additionally, for the stress model, average stress scores were on a continuous scale. The third assumption for logistic regression models is the independence of observations. Fourth, all nominal predictor variables should be mutually exclusive and exhaustive; such that, participants cannot be categorized as having

complications and not having complications. Further, all covariates met this assumption. The fourth assumption requires a minimum 15 cases/predictor variable; the data met this requirement as the predictor variables had minimum of 36 cases. The fifth assumption requires a linear relationship between the continuous independent variable and the logit transformation of the dependent variable. Linearity of continuous variables were assessed with the Box-Tidwell (1962) procedure. A Bonferroni correction was applied, resulting in statistical significance being indicated when $p < 0.00625$ (Tabachnick & Fidell, 2014). Based on these analyses, all continuous independent variables were found to be linear ($p > 0.00625$), therefore, all independent variables are linearly related to the logit of the dependent variable. The sixth assumption is that the data does not have evidence of multicollinearity. Multicollinearity detection was inspected through correlation coefficients and tolerance. Tolerance was assessed using variance inflation factor (VIF) values approach. For this approach, linear regression models were implemented. Suggestions for the VIF approach is that the values must be below 10.00 (Myers, 1990 as cited in Fields, 2009); the analyses suggested that the VIF values for the predictor values were between 1.032-1.181. Finally, the last assumption is that no outliers are present in the data; results suggest that there were no standardized residuals with a value greater than 1 SD, therefore all datapoints were retained.

Bivariate Correlations

Bivariate correlations assessed the relationships among PWD and partner characteristics. Complications were not correlated with PWD BMI, partner BMI, PWD stress, $p > 0.05$. PWD BMI and partner BMI were positively correlated, $r = 0.123$, $p < 0.05$. PWD stress and partner stress were also positively correlated, $r = 0.348$, $p < 0.01$. Bivariate correlations are presented in Table 2.

Table 2

Bivariate correlations among BMI, stress, relationship quality, incident complications, and covariates.

	1.	2.	3	4.	5.	6.	7.	8.	9.	10.	11	12	13	14
1. PWD BMI	-													
2. Partner BMI	0.123*	-												
3. PWD Stress	0.100	-0.059	-											
4. Partner Stress	0.125	0.136*	0.348**	-										
5. PWD MQ	-0.082	-0.043	0.266**	0.030	-									
6. Partner MQ	0.030	-0.047	0.167*	0.324**	0.295**	-								
7. Diabetes Duration	-0.018	-0.028	0.018	0.072	-0.069*	0.021	-							
8. Insulin Use	0.089	0.126*	0.006	0.121	0.003	0.017	0.349**	-						
9. Comorbidities	0.056	0.009	-0.088	0.039	-0.028	0.050	-0.066	0.018	-					
10. Complications	-0.001	-0.060	0.041	-0.010	-0.016	0.077	0.227	-0.005	0.087	-				
11. PWD Age	-0.329**	-0.021	-0.240**	-0.112	-0.047	0.001	0.098	-0.044	0.282**	0.102	-			
12. Partner Age	-0.241**	-0.084	-0.174**	-0.125	-0.035	-0.011	0.024	-0.018	0.273**	0.065	0.815**	-		
13. PWD Education	0.012	-0.033	-0.086	-0.021	-0.071	-0.222*	-0.219	-0.055	0.014	-0.070	-0.145*	-0.126*	-	
14. Partner Education	-0.022	-0.043	-0.207**	0.030	-0.089	-0.131*	-0.027	-0.094	0.018	-0.095	0.029	-0.024	0.512**	-
15. Marriage Duration	-0.168**	-0.038	-0.193**	-0.140*	0.018	0.022	0.070	-0.050	0.220**	0.116	0.525**	0.581**	-0.030	-0.007

Note. MQ = marital quality, PWD = person with diabetes, BMI = body mass index

*. Correlation is significant at the 0.05 level (2-tailed)

**. Correlation is significant at the 0.01 level (2-tailed)

BMI model

Interpersonal associations between BMI and incident T2DM complications included 245 dyads, as only 245 dyads provided self-reported BMI at baseline. For both the continuous and categorical BMI models, dyads who provided self-reported BMI were included in the BMI model. Over the 10-year follow-up, 102 (41.633%) PWDs reported developing T2DM complications (i.e., kidney disease or cardiovascular disease). At baseline, PWDs, on average, were 65.71 years old ($SD = 9.101$), had been married for 37.052 years ($SD = 14.299$), had 12.85 ($SD = 3.185$) years of education and had 1.502 ($SD = 0.994$) comorbidities at baseline. The majority of the sample identified as White (85.714 %). At baseline, PWDs had a self-reported average BMI of 30.646 ($SD = 6.024$), were categorized as obese (47.347%), and had an average negative marital quality score of 2.067 ($SD = 0.665$). Further, PWDs, on average had a stress score of 1.471 ($SD = 0.379$). At baseline, partners, on average, were 64.771 years old ($SD = 9.078$) and had 12.824 ($SD = 2.861$) years of education. Partners had a self-reported average BMI of 27.773 ($SD = 4.928$) and were categorized as overweight (44.898%). Partners reported an average stress score of 1.453 ($SD = 0.416$) and an average negative marital quality score of 2.063 ($SD = 0.645$). Participant characteristics are presented in Table 3.

Table 3Participant demographic and health-related characteristics at baseline for the BMI model ($n = 245$).

	Person with Diabetes $n = 245$			Partner $n = 245$		
	$M (SD)$	% (n)	Range	$M (SD)$	% (n)	Range
Age (at baseline)	65.714 (9.101)		41-91	64.771 (9.078)		42-91
Gender						
Male		60.816 (149)			39.184 (96)	
Female		39.184 (96)			60.816 (149)	
Ethnicity						
White or Caucasian		85.714 (210)			84.082 (206)	
Black or African American		9.796 (24)			10.204 (25)	
Other		4.450 (11)			5.714 (14)	
Education (years)	12.848 (3.185)		0-17	12.824 (2.861)		0-17
Marriage Duration (at baseline)	37.052 (14.299)		0.50-70.50	36.805 (14.563)		0.60-70.50
Negative Marital Quality	2.067 (0.665)		1-4	2.063 (0.645)		1-4
Stress	1.471 (0.379)		1-2.75	1.453 (0.416)		1-2.71
Diabetes Duration (at baseline)	8.551 (7.804)		0-44			
Insulin use (yes)		13.061 (32)				
Body Mass Index (continuous)	30.646 (6.024)		20-64.6	27.773 (4.928)		15.2-50.10

Body Mass Index			
Not overweight/obese	14.694 (36)		26.122 (64)
Overweight	37.959 (93)		44.898 (110)
Obese	47.347 (116)		29.980 (71)
Comorbidities	1.502 (0.994)	0-4	
Complications (yes)	41.633 (102)		

Stress model

Tests of the interpersonal associations between stress and T2DM complications included 249 of the 274 dyads as they provided both PWD and partner stress. For both the stress model, dyads who provided average stress scores were included in the stress model. Over the 10-year follow-up, 102 (40.964%) PWDs reported developing T2DM complications (i.e., kidney disease or cardiovascular disease). At baseline, PWDs, on average, were 65.578 years old ($SD = 9.102$), had been married for 36.967 years ($SD = 14.488$), had 12.775 ($SD = 3.201$) years of education and had 1.494 ($SD = 0.963$) comorbidities at baseline. The majority of the sample identified as White (85.944%). At baseline, PWDs had a self-reported average BMI of 30.687 ($SD = 6.041$) and were categorized as obese (48.148 %). At baseline, PWDs reported an average negative marital quality score of 2.058 ($SD = 0.669$) and an average stress score of 1.491 ($SD = 0.403$). At baseline, partners, on average, were 64.751 years old ($SD = 9.069$) and had 12.815 ($SD = 2.804$) years of education. Partners had a self-reported average of BMI of 27.807 ($SD = 4.957$) and were categorized as overweight (44.628%). Partners reported an average stress score of 1.444 ($SD = 0.403$) and an average negative marital quality score of 2.044 ($SD = 0.640$). Participant characteristics are presented in Table 4.

Table 4Participant demographic and health-related characteristics at baseline for the stress model ($n = 249$).

	Person with Diabetes $n = 249$			Partner $n = 249$		
	$M (SD)$	% (n)	Range	$M (SD)$	% (n)	Range
Age (at baseline)	65.578 (9.102)		41-91	64.751 (9.069)		42-91
Gender						
Male		59.840 (149)			40.160 (100)	
Female		40.160 (100)			59.840 (149)	
Ethnicity						
White or Caucasian		85.944 (214)			84.739 (211)	
Black or African American		10.040 (25)			10.441 (26)	
Other		4.016 (10)			4.819 (12)	
Education (years)	12.775 (3.201)		0-17	12.815 (2.804)		0-17
Marriage Duration (at baseline)	36.967 (14.488)		0.50-70.050	36.779 (14.742)		0.60-70.50
Negative Marital Quality	2.058 (0.669)		1-4	2.044 (0.640)		1-4
Stress	1.491 (0.403)		1-2.75	1.444 (0.403)		1-2.71
Diabetes Duration (at baseline)	8.494 (7.730)		0-44			
Insulin use (yes)		14.056 (35)				
Body Mass Index (continuous)	30.687 (6.041)		20-64.6	27.807 (4.957)		15.20-50.10

Body Mass Index			
Not overweight/obese	14.814 (36)		25.620 (62)
Overweight	37.037 (90)		44.628 (108)
Obese	48.148 (117)		29.752 (72)
Comorbidities	1.494 (0.963)	0-4	
Complications (yes)	40.964 (102)		

Inferential Statistics

Results of the unadjusted and adjusted models are presented in Figures 6-8. Unadjusted and adjusted models produced similar patterns of results (Figures 6-8), therefore results from the adjusted model are detailed below.

BMI Model

Continuous BMI Model. Similar to the unadjusted model, after adjusting for covariates, neither significant actor nor partner effects were observed. One's own (i.e., PWD) BMI was not associated with one's own odds of developing T2DM complications ($OR = 0.936$, $SE = 0.073$, $p = 0.365$). Partner BMI was not associated with PWD's odds of developing T2DM complications ($OR = 0.968$, $SE = 0.029$, $p = 0.265$). PWD's negative marital quality was not associated with their own odds of developing T2DM ($OR = 0.271$, $SE = 1.126$, $p = 0.246$). Partner's negative marital quality was not associated with PWD's odds of developing T2DM complications ($OR = 1.112$, $SE = 0.235$, $p = 0.650$). PWDs' BMI did not interact with PWDs' negative marital quality to predict odds of developing T2DM complications ($OR = 1.039$, $SE = 0.036$, $p = 0.289$). As the interaction term was not statistically significant, the interaction term was not probed. The continuous BMI model pathways are presented in Figure 6.

Figure 6

The continuous BMI model ($n = 245$) testing interpersonal associations among BMI and T2DM complications. Dashed lines represent paths that were modeled, but were not significant, $p > 0.05$.

Note. Covariates were included in this model but are not displayed.

Categorical BMI Model. Similar to the unadjusted model, after adjusting for covariates, neither significant actor nor partner effects were observed. For PWDs categorized as overweight, being overweight was not associated with their odds of developing T2DM complications relative to PWDs who were not overweight/obese ($OR = 0.373$, $SE = 1.380$, $p = 0.474$). For PWDs categorized as obese, being obese was not associated with their own odds of developing T2DM complications compared to PWDs who were not overweight/obese ($OR = 0.653$, $SE = 0.973$, $p = 0.661$). For partners categorized as overweight, their BMI was not associated with the PWD's odds of developing T2DM complications compared to partners who were not overweight/obese ($OR = 1.794$, $SE = 0.382$, $p = 0.126$). For partners categorized as obese, their BMI was not associated with the PWD's odds of developing T2DM complications compared to partners who were not overweight/obese ($OR = 1.666$, $SE = 0.348$, $p = 0.143$). The PWD's negative marital quality was not associated with their own odds of developing T2DM complications ($OR = 0.798$, $SE = 0.303$, $p = 0.456$). Partners' negative marital quality was not associated with the PWD's odds of developing T2DM complications ($OR = 1.077$, $SE = 0.236$, $p = 0.752$). PWD BMI categorized as overweight did not interact with PWD negative marital quality to predict the odds of developing T2DM complications ($OR = 1.306$, $SE = 0.618$, $p = 0.666$). Further, PWD BMI categorized as obese did not interact with PWDs negative marital quality to predict odds of developing T2DM complications ($OR = 1.165$, $SE = 0.452$, $p = 0.735$). As the interaction term was not statistically significant, the interaction term was not probed. The categorical BMI model pathways are presented in Figure 7.

Figure 7

The categorical BMI model ($n = 245$) testing interpersonal associations among BMI and T2DM complications. Dashed lines represent paths that were modeled, but were not significant, $p > 0.05$.

Note. Covariates were included in this model but are not displayed.

Stress Model

Similar to the unadjusted model, after adjusting for covariates, neither significant actor nor partner effects were observed. One's own (i.e., PWD) stress was not associated with one's own odds of developing T2DM complications ($OR = 1.285$, $SE = 1.204$, $p = 0.835$). Partner stress was not associated with the PWD's odds of developing T2DM complications ($OR = 1.108$, $SE = 0.385$, $p = 0.995$). The PWD's negative marital quality was not associated with their own odds of developing T2DM ($OR = -0.244$, $SE = 0.794$, $p = 0.759$). Partners' negative marital quality was not associated with their own odds of developing T2DM complications ($OR = 0.210$, $SE = 0.229$, $p = 0.359$). PWD stress did not interact with PWDs negative marital quality to predict odds of developing T2DM complications ($OR = 0.005$, $SE = 0.063$, $p = 0.942$). As the interaction term was not statistically significant, the interaction term was not probed. The stress model pathways are presented in Figure 8.

Figure 8

The stress model ($n = 249$) testing dyadic associations among stress and T2DM complications.

Dashed lines represent paths that were modeled, but were not significant, $p > 0.05$.

Note. Covariates were included in this model but are not displayed.

Discussion

The purpose of the present study was to test interpersonal associations between BMI, stress and the development of T2DM complications. Contrary to the proposed hypotheses, PWDs' BMI and stress were not associated with their own odds of developing T2DM complications. Similarly, partner BMI or stress were not associated with PWDs' odds of developing T2DM complications. For both PWDs and partners, negative marital quality was not associated with the PWDs' odds of developing T2DM complications and negative marital quality did not interact with PWDs' BMI or stress to predict the odds of developing T2DM complications.

BMI

In the present study, PWDs' BMI, whether examined continuously or categorically, was not associated with increased odds of developing T2DM. However, previous investigations have demonstrated intrapersonal associations between BMI and the development of T2DM complications (Kovedy et al., 2017; Wilson et al., 2002). For example, Gray and colleagues (2015) investigated associations among self-reported categorical BMI and T2DM complications. Over a 19-year period, among individuals with T2DM ($n = 4532$), those with increased BMIs at baseline displayed increased risk of T2DM complications (i.e., cardiovascular, cerebrovascular, renal, ocular) (Gray et al., 2015). As individuals' BMI increased from overweight to obese, the risk of complications increased; this pattern of results was more prominent for men, compared to women (Gray et al., 2015). Similar to the present study, Gray and colleagues (2015), examined BMI categorically which included collapsing BMI categories. However, Gray and colleagues (2015) further expanded on the overweight and obese BMI categories. In the present study, we were unable to do this as our sample sizes were small ($n = 245$), which would have led to small samples in each BMI category. Polemiti et al (2020) also found an association between one's

own BMI and T2DM complications with a median follow-up of 10.8 years. However, Polemiti et al (2020) investigated stroke, neuropathy and retinopathy in addition to kidney disease and cardiovascular disease and Gray et al (2015) examined fourteen different T2DM complications (i.e., coronary artery disease, myocardial infarction, occlusion, stenosis, stroke, transient ischemic attack, cerebrovascular carotid bruit, proteinuria, renal failure, diabetes muscular edema, retinopathy, ulcers and gangrene), whereas the present study investigated two T2DM complications in a 10-year follow-up. If the present study had included additional T2DM complications, there may have been increased opportunities for the outcome variable to be present as more participants would be categorized as experiencing T2DM complications during the follow-up period. Therefore, perhaps the lack of associations observed in the present study are a result of minimal T2DM complications.

Globally, approximately 20 - 40% of PWDs develop kidney disease (Gheith et al., 2016) and 32.3% develop cardiovascular disease (Einarson et al., 2018), however, in the present study, 14.964% of PWDs developed kidney disease and 30.292% developed cardiovascular disease. Therefore, the proportion of PWDs who developed cardiovascular disease in the present study is similar to the proportion observed in the previous literature, though the proportion of PWDs who developed kidney disease in the present study was smaller than that observed in the previous literature. The HRS population may explain this discrepancy. For example, perhaps there are differences between the HRS and global population regarding socioeconomic status, exercise facilities and healthy food options and therefore the HRS population cannot be generalized to the overall global population. Moreover, possibly, there are differences regarding access to healthcare providers, and this increased access may result in reduced T2DM complications.

Although this study cannot speak to the specific mechanisms for developing T2DM complications, alternative intrapersonal risk factors apart from BMI have been identified, such as glycemic control (De Block et al., 2005; Maghbooli et al., 2014) or hypertension (Afroz et al., 2019). Alternatively, physical activity (Afroz et al., 2019; Dirani et al., 2014; White et al., 2011) is associated with T2DM complications. Physical activity is defined as any bodily movement produced by skeletal muscles that requires energy expenditure; physical activity encompasses exercises, sports, physical activities as a result of occupation, leisure and active transport (Caspersen et al., 1985). Engaging in physical activity improves glucose control and facilitates weight loss (Sigal et al., 2018). Furthermore, engaging in physical activity plays a role in delaying or preventing developing of T2DM by improving insulin sensitivity and producing these changes throughout the body, which in turn impacts the development of T2DM complications (Sigal et al., 2004). Moreover, engaging in physical activity improves responses to induce, reduces blood pressure and cholesterol levels which are all risk factors to T2DM complications development (Sigal et al., 2004; Sigal et al., 2018). Both macro- and micro-vascular complications have been associated with physical inactivity in PWDs (Afroz et al., 2019; Dirani et al., 2014; White et al., 2011). Further, physical activity and BMI are related (Ball et al., 2001; Cameron et al., 2017), suggesting that physical activity plays a large role on one's BMI. Moreover, physical activity drives the associations among BMI and T2DM complications, such that, engaging physical activity is a protective factor against incident T2DM complications (Colberg et al., 2010; Long & Dagogo-Jack, 2011; Magalhães et al., 2008). Therefore, partner effects may have been identified if physical activity was tested as an intrapersonal risk factor.

The current results also suggest that there is no association between partner BMI and the development of T2DM complications. Although there interpersonal associations were not present, the present study found differences between PWDs' and partners' BMIs; however both the PWDs' and partners' BMIs were correlated, $r = 0.123, p < 0.05$. The attrition bias analyses indicated that partner BMI among those lost to follow-up ($M = 30.317, SD = 6.917$) differed from that of those analyzed ($M = 27.807, SD = 4.927$). Those lost to follow-up were more likely to be categorized as obese compared to those who were analyzed. Furthermore, the range of BMIs also differed as those lost to follow-up had a range of 14.50-56.40 compared to those analyzed, which had a range of 15.20-50.10. Therefore, due to the relatively restricted range of BMIs observed in the analyzed sample, the associations among partner BMI and incident complications may not have been present as dyads with partners with greater BMIs dropped out of the present study. This loss of participants may partially explain the lack of associations between partner BMI and PWDs' T2DM complications development.

Although actor and partner effects have not been tested in the context of T2DM complications, dyadic associations related to developing T2DM have been explored. Dyadic associations among BMI and the development of T2DM demonstrated both actor and partner effects (Burns, 2019; Nielsen et al., 2018). Nielsen et al. (2018) found associations among men's T2DM development increased as their partner's obesity level, after adjusting for their own obesity. However, these associations were not present for women and their T2DM development (Nielsen et al., 2018). A similar pattern of associations were found for actor and partner cholesterol levels (Nielsen et al., 2018). Similarly, Burns (2019) found that one's partner's BMI at baseline was positively associated with one's own odds of developing T2DM, above and beyond their own BMI (Burns, 2019). In Burns (2019), on average participants had a BMI of

28.85 ($SD = 5.34$) and were classified as overweight (40.0%) followed by obese (35.9%).

Therefore, it is unclear why partner associations were not present, as the current study had similar sample characteristics. Potentially, interpersonal BMI is a strong predictor of incident T2DM diagnosis, as opposed to T2DM complications. This may be due to many behaviours and care that are experienced among people who have been diagnosed with T2DM, but not those who are at risk of developing T2DM. For example, managing a diagnosis of T2DM generally involves taking prescribed medication (Smith, 2009) and routine contact with their healthcare team, such as doctors, pharmacists, endocrinologists or registered dietitians (Grossman, 2011). Perhaps frequent healthcare and taking medication to manage T2DM has such a strong influence on the development of complications that the influence of partner BMI on incident T2DM complications diminishes compared to incident T2DM diagnosis. Further, when PWDs are diagnosed with T2DM, often medical management including oral medication or insulin, diet are introduced (Ley et al., 2014). Perhaps the combination of medical management and healthcare access that can accompany living with T2DM stifles the influences of partner BMI on diabetes outcomes among individuals who are diagnosed with diabetes.

Stress

In the present study, PWD's stress was not associated with increased odds of developing T2DM. Previous investigations of intrapersonal chronic stress and the development of T2DM complications (i.e., nephropathy, cardiovascular disease) have been demonstrated (e.g., Dohrenwend & Dohrenwend, 1981; Evans, 1985; Lin & Ensel, 1989; Surwit et al., 1992). Past literature has found associations among stress and the development of T2DM. For example, Brindley and Rolland (1989) demonstrated associations between increased stress and atherosclerosis, which is a T2DM complication. As an individual's stress increases, there are

increased stress hormones, including cortisol, in the bloodstream, which aggravate metabolic changes in T2DM and alter ones' insulin response (Brindley & Rolland, 1989). Moreover, stress can also indirectly lead to health consequences for PWDs through health behaviours and characteristics, such as a sedentary lifestyle (Brindley & Rolland, 1989), or lack of physical activity (Cox & Gonder-Frederick, 1992; Morris et al., 2011). In the present study, PWDs' average stress were relatively low ($M = 1.491$, $SD = 0.403$, possible range: 1 to 4) compared to previous studies which demonstrated higher stress scores; for example, Surwit et al (2002) demonstrated that among PWDs their average stress score was 23.98 ($SD = 9.67$) on the Perceived Stress Scale (14-items), which has a range from 0-56. In the present study, average stress levels were relatively low, therefore, there may have been a floor effect for stress. Floor effects skew the distributions of scores, thus making it difficult to differentiate among individuals (Lim et al., 2015). Further, floor effects can increase bias (Šimkovic & Träuble, 2019). Due to the presence of a possible floor effect, it may be difficult to differentiate amongst individuals. The lack of associations may be due to the little variability seen, therefore it may be difficult to demonstrate associations among stress and increased odds of developing T2DM complications as the stress scores are skewed.

Previous literature has also demonstrated alternative psychological risk factors for incident T2DM complications such as diabetes distress. *Diabetes distress* refers to an emotional state that PWDs experience stress, burn out, fear or guilt that arise from the disease and self-management demands (Kreider, 2017). In a community sample, up to 45% of PWDs may suffer from diabetes distress (Fisher et al., 2012). Fisher and colleagues (2010) demonstrated that diabetes distress has associations with glycemic control, such that the increased diabetes distress is associated with a significant increase in glycemic control in PWDs. Further, diabetes distress

is also associated with decreased self-management behaviours (i.e., diet, physical activity) (Fisher et al., 2012; Kreider, 2017), which ultimately increases the risk of developing T2DM complications (Tanaka et al., 2013).

An additional possible cause for the lack of associations among stress and incident T2DM complications could stem from the HRS chronic stress measure. The chronic stress measure used in the current study had participants reflect on stressors lasting over 12 months in a wide range of domains, such as intrapersonal health and work. If an individual was extremely stressed in only one of eight domains but did not experience stress in the remaining domains, this would be reflected as a low average stress score, despite an individual experiencing chronic stress in one facet of their life. Therefore, perhaps a more sensitive measure of global, perceived stress would have been more appropriate and sensitive to the PWDs' stress.

The current study results also suggest that there is no association between partner stress and incident T2DM complications. From an interpersonal lens, dyadic associations between stress and health outcomes have been demonstrated. For example, Birditt et al (2014) investigated associations between marital quality, stress and blood pressure. Birditt and colleagues (2014) found interactions among partner demands and stress onto actor blood pressure. However, among those with high stress, there were no associations with poor health, despite having associations for participants with lower stress. Further, Birditt et al (2016) found that greater partner stress was associated with increased actor waist circumference. In the Birditt et al (2016) study, partners' average perceived stress was 1.41 ($SD = 0.02$) (Birditt et al., 2016), which is similar to the present study ($M = 1.444$, $SD = 0.403$), therefore, the range of stress scores did not explain the inconsistent results experienced in the present study. As Birditt et al (2016) demonstrated, partners' stress is associated with the actors' poor blood pressure, however, this

association does not appear to hold for the development of T2DM complications. It is possible that partner stress is associated with blood pressure because blood pressure is able to fluctuate (Parati et al., 2013), whereas T2DM complications are less malleable, such that one's blood pressure is often continuously measured and T2DM complication are relatively more stable.

Furthermore, when investigating the attrition biases analyses, partners lost to follow-up ($M = 1.562$, $SD = 0.477$) had significantly higher average stress scores compared to those analyzed, $t(441) = 4.606$, $p = 0.009$, $d = 0.254$. Therefore, it is possible that those who experienced more stress were unlikely to participate in a voluntary study, thus influencing the samples' average stress scores, which threatens the internal and external validity of this current study (Miller & Wright, 1995). Alternative to chronic stress, diabetes stress is also a dyadic risk factor. Franks et al (2010) found that both actor and partners' diabetes-related distress was associated with actors' depressive symptoms, however, no partner associations were present. Dyadic diabetes distress is an area that warrents further investigation as a risk factor due to the inconsistencies in the literature.

Negative marital quality

The present study found that the PWDs' negative marital quality did not moderate the association between BMI or stress with one's own odds of developing T2DM complications. To our current knowledge, previous studies have not investigated if negative marital quality moderates the association between BMI, stress and T2DM complications development. However, actor negative marital quality has been demonstrated to have significant health outcomes. Prior research has shown that poor marital quality is associated with markers of inflammation (i.e., interleukin 6) (Uchino et al., 2013; Whisman & Sbarra, 2012), which has been known to increase the risk of developing T2DM complications. Further, when marital quality declines, dyads may

be at increased risk for developing T2DM complications as declining marital quality has associations with decreased positive health behaviours (Burke et al., 2012). Moreover, the presence of T2DM in one dyad member may promote worsening marital quality (Whisman et al., 2014), which may lead to worsening health over-time thereby increasing the risk of poor health outcomes. Bennett-Britton et al (2017) examined associations among marital quality and cardiovascular risk factors in a 6-year longitudinal study in men. Among men with improved marital quality, associations with BMI were present, such that having increased marital quality was a protective factor for an increasing BMI (Bennett-Britton et al., 2017). Furthermore, among men with poor marital quality, blood pressure increased as negative relationship quality increased (Bennett-Britton et al., 2017). However, Bennett-Britton and colleagues (2017) measured marital quality at two timepoints using the 12-item ‘care’ subscale of the Intimate Bond Measure (IBM) (Wilhelm & Parker, 1988) and categorized the scores from least caring to most caring. Possibly by utilizing the IBM, they were able to capture more facets of marital quality, as the current study did not utilize all dimensions of marital quality (i.e., understands my problems and worries, shows their appreciation of me). In contrast, the negative marital quality measure utilized in the present study was broad and did not include specific dimensions of one’s marital quality. Therefore, future investigations should consider using a validated measure of negative marital quality to understand its associations onto incident T2DM complications.

Additionally, partners’ negative marital quality was not associated with the PWDs’ odds of developing T2DM complications. Whisman et al (2014) examined marital quality and incident T2DM diagnosis using the HRS. Whisman and colleagues (2014) examined positive and negative dimensions of marital quality, however, they did not include one item of the negative marital quality scale, “How much do they get on your nerves?” (HRS, 2006). Similar to the

present study, Whisman and colleagues (2014) created the negative marital quality score by calculating the means of each items, with higher scores reflecting increased negative marital quality. Among participants in the Whisman et al (2014) study, women's negative marital quality scores were 2.03 ($SD = 0.70$), where as men's negative marital quality scores were 1.88 ($SD = 0.62$). For men who viewed their partners as critical, demanding and undependable, they were more likely to develop T2DM, whereas men who had positive marital quality were less likely to develop T2DM (Whisman et al., 2014). A similar pattern of results was not found in women (Whisman et al., 2014). In the present study, negative marital quality also ranged from 1-4; the PWDs ($M = 2.07$, $SD = 0.661$) and partners ($M = 2.06$, $SD = 0.650$) had positively correlated scores, $r = 0.295$, $p < 0.01$, demonstrating the concordance of negative marital quality. Furthermore, there were no differences amongst those lost to follow-up and those analyzed in negative marital quality scores for the PWDs and partners, $p < 0.05$. In addition to the dyadic biopsychosocial model, the systemic-transaction model has also been applied to understanding dyadic relationships and health outcomes.

The systemic-transaction model views stressors as dyadic because the stressors either concern the dyad directly (i.e., affects both members) or indirectly, when the stressor affects one partner and 'spills over' to the other (Rottenman et al., 2015). Aside from negative marital quality, dyadic coping could play a role in health outcomes such as T2DM complications development. Dyadic coping explains behaviours that the dyad engages in when coping with a stressor, such as a disease (Regan et al., 2014). Similar to marital quality, dyadic coping can also be positive or negative, which refers to the responses a partner provides (Regan et al., 2014). Rottmann et al (2015) found associations among negative dyadic coping and increased depressive symptoms in dyads which one member has breast cancer. Therefore, possibly

investigating negative dyadic coping as a predictor and as an interaction term may capture the dyads' coping behaviours to the disease.

Strengths and limitations

This study has several strengths. First, studies investigating T2DM complications have been from an intrapersonal approach. The present study collected data from both dyad members instead of relying on one member reporting their partners' stress, BMI or marital quality. Additional strengths include: 10-year longitudinal design and accounting for covariates.

Despite these aforementioned strengths, a few limitations must be considered. First, data were collected every two years and it was not possible to pinpoint when participants were diagnosed with complications. Second, limited diabetes information was provided. For example, there was limited T2DM complications available and no information regarding diabetes type or severity. Potential issues emerge as we were unable to control for additional confounders of T2DM complications. Moreover, kidney disease complications were no longer included in the HRS dataset after 2012, therefore limiting the number of T2DM complications that were investigated. Additionally, the stress questionnaire was not implemented in 2008, thus we were unable to include 2008 as a baseline for this study, ultimately reducing our sample size. Perhaps by including an additional baseline in this study, the sample size would have potentially doubled and the participants' characteristics would be more representative of the population. A G*Power analysis suggested that for a small-medium effect, 395 dyads are needed, therefore this study was underpowered. Third, the stress and poor marital quality items were included in the 'take home' portion of the HRS, therefore the majority of the participants ($n = 1452$) who met the original criteria to be included in this study, failed to complete the take home questionnaires ultimately reducing our sample size. Fourth, the timelines for participants to reflect were unclear,

specifically for negative marital quality and stress. Participants may have recall bias, a systematic error that occurs when participants do not remember previous events or experiences accurately (Althubaiti, 2016). Fifth, we utilized self-reported BMI, which may elicit the social desirability bias as participants may ‘fake good’ (Zerbe & Paulhus, 1987); as well, individuals often provide lower BMIs (Elgar & Stewart, 2008). Sixth, some evidence suggests limitations with BMI as a predictor, as BMI may not be the most well-rounded predictor (see Bogin & Varela-Silva, 2012 for review). Seventh, the stress measure utilized in the HRS has not been validated. Furthermore, it has the anchor to ask participants to reflect on a situation that has been ongoing for over 12 months (HRS, 2006). Alternative stress measures such as the Perceived Stress Scale (Cohen et al., 1983) asks its users to reflect during the last month and focuses on stress broadly (e.g., in the last month, how often have you felt nervous and stressed?) as opposed to one domain (e.g., work, housing) an individual may experience stress in. Eighth, the negative marital quality measure did not include other characteristics of poor marital quality such as faithfulness, or marital regret. Finally, T2DM status and complications were self-reported which may have lead to errors in potentially missing participants.

Future directions and conclusion

The purpose of this study was to elucidate interpersonal risk factors for incident T2DM complications. However, dyadic BMI and stress did not associate with PWDs’ T2DM complications development. Despite the null findings of this study, future research is encouraged to examine interpersonal influences on T2DM complications, such as physical activity or diabetes distress. Moreover, future research should consider examining BMI and stress in a single model. T2DM is a family disease (Franks et al., 2012) and therefore should be studied from a socioecological, interdependence and dyadic biopsychosocial model approaches. Future studies

should consider a more sensitive outcome variable, such as glycemic control in PWDs as a proxy of incident T2DM complications.

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