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# Assessing and Predicting Medication Adherence and Diabetes Control Among African American Adults with Uncontrolled Diabetes

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## Abstract

Background/Objectives: Uncontrolled diabetes and associated comorbidities disproportionately affect African American (AA) adults. Medication adherence is key to diabetes control yet is often suboptimal, particularly among AA adults. This study examined associations between patient characteristics and adherence among AA adults with uncontrolled diabetes and compared two medication adherence instruments for predicting diabetes control. Methods: This cross-sectional analysis used baseline data from the Management of Diabetes in Everyday Life (MODEL) study, a clinical trial to improve diabetes self-care among AA adults with uncontrolled diabetes. Internal consistency of the 12-item Adherence to Medication Refills and Medications Scale for diabetes medications (ARMS-D) was evaluated by comparing its Cronbach $\alpha$ to the standardized Cronbach $\alpha$ calculated from MODEL data. Associations with variables were examined using correlations, *t*-tests, or ANOVA, as appropriate. Stepwise multiple regression identified predictors of diabetes control assessed by hemoglobin A1c (HbA1c). Results: Among 665 participants (mean age = 54 years, HbA1c = 10.24%; 67% female; 73% high health literacy), 75% reported perfect adherence on the Summary of Diabetes Self-Care Activities Medications Subscale (SDSCA-MS) versus 7.3% on ARMS-D. ARMS-D showed strong internal consistency ($\alpha = 0.81$). Lower adherence by ARMS-D was associated with younger age, higher social complexity, and depression (all $p \leq 0.001$). ARMS-D score, age, depression, and insulin, dipeptidyl peptidase 4 inhibitor, and sodium-glucose co-transporter 2 inhibitor use predicted baseline HbA1c. Conclusions: This study demonstrates that younger age, depression, and high social complexity are associated with lower medication adherence measured using the ARMS-D. Adherence gaps identified by ARMS-D may validly predict diabetes control and help guide interventions to improve diabetes care in AA adults with uncontrolled diabetes.

**Keywords:** medication adherence; type 2 diabetes; African American; ARMS-D

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## 1. Introduction

Diabetes affects 11.7% of African American (AA) adults, and approximately 50% of U.S. adults with diabetes have uncontrolled diabetes [1]. Uncontrolled diabetes and its comorbidities including obesity, hypertension, hyperlipidemia, chronic kidney disease,

and cardiovascular disease are more prevalent in AAs [2–5]. Diabetes treatment requires a multimodal approach that includes maximizing healthy nutrition and exercise patterns along with medication management.

However, medication adherence only averages 50% in developed countries like the United States for people with chronic diseases requiring daily medication [6]. The World Health Organization describes medication nonadherence as a worldwide problem with striking magnitude that worsens with the number of chronic diseases [6]. Compared to non-Hispanic Whites, AAs with diabetes are 12% less likely to take and overall less likely to refill their diabetes medication, even with equal access to medication [7,8]. Lower medication adherence leads to poorer glycemic control and higher risks of diabetes complications. AAs disproportionately suffer from diabetes-related microvascular and macrovascular complications, which are associated with increased morbidity, mortality, and health care expenditures [9–11]. Therefore, the racial disparity associated with medication adherence in AAs with diabetes widens the gap of adverse diabetes control, morbidity, and mortality.

The purposes of this study were to assess the demographic, social, and clinical characteristics associated with better medication adherence and diabetes control among AA adults with uncontrolled diabetes. In addition, we sought to assess the performance of two alternative medication adherence assessment tools, the Adherence to Medication Refills and Medications Scale to diabetes medications (ARMS-D) and the one-item Summary of Diabetes Self-Care Activities Medications Subscale (SDSCA-MS), in this population. Lastly, we sought to determine whether the ARMS-D or SDSCA-MS is more predictive of diabetes control.

## 2. Materials and Methods

### *2.1. Study Design and Population*

The cross-sectional study leveraged data from the Management of Diabetes in Everyday Life (MODEL) study, a large multi-site pragmatic clinical trial that tested three interventions for diabetes self-care improvement in AAs with uncontrolled diabetes (HbA1c > 8% extracted from electronic health record data within 6 months before clinical trial randomization) living in medically underserved areas in the Mid-South United States [12,13]. Data were collected from November 2016 through December 2020. The parent MODEL study was approved by the Institutional Review Boards of the University of Tennessee Health Science Center, Methodist Healthcare, and Regional One Health (ClinicalTrials.gov #NCT02957513). This ancillary analysis used only de-identified data from that study; the University of Tennessee Health Science Center IRB determined it does not constitute human subjects research and does not require separate ethical approval. The MODEL inclusion and exclusion criteria are listed in Table 1 [13].

**Table 1.** MODEL parent study inclusion and exclusion criteria.

| Inclusion Criteria | Exclusion Criteria |
| --- | --- |
| • Self-identified as African American<br>• Age $\geq$ 18 years<br>• Hemoglobin $A_{1c} \geq 8\%$<br>• One or more specified chronic co-morbidities (i.e., hypertension, hyperlipidemia, coronary artery disease, cardiac arrhythmia, stroke, congestive heart failure, chronic kidney disease, chronic obstructive pulmonary disease, arthritis, depression, cancer, and osteoporosis) | • Pregnancy<br>• Inability to understand study consent or communicate using English language<br>• Unstable psychiatric or neurological condition, dementia, severe head trauma, or brain tumor<br>• Recent severe depression<br>• Cognitive impairment<br>• Uncontrolled psychiatric behaviors that could be a danger to others<br>• Unwillingness or inability to participate in the study |

### 2.2. Medication Adherence Screening Instruments

Medication adherence was measured using two previously validated instruments: Adherence to Medication Refills and Medications Scale to diabetes medications (ARMS-D) [14] and the one-item Summary of Diabetes Self-Care Activities Medications Subscale (SDSCA-MS) [15].

The SDSCA-MS is a diabetes self-management assessment tool that includes self-report of nutrition, exercise, foot care, smoking, blood glucose testing, and medication adherence; therefore, the SDSCA-MS informed additional aspects of the data collection in the MODEL study [15]. However, for medication adherence, the 1-item SDSCA-MS asks, "On how many of the last seven days did you take your diabetes medication?" [14] Therefore, *higher scores* indicate *higher adherence* and are measured in days.

In contrast, the ARMS is a 12-item tool that includes an 8-item subscale of medication taking behaviors and 4-item subscale of medication refill behaviors [16]. ARMS-D is a revised version of the original ARMS tool that specifies diabetes medication in each question [16]. ARMS-D responses are measured on a 4-point rating scale: 1—"none of the time," 2—"some of the time," 3—"most of the time," 4—"all the time." ARMS was developed and validated in AA adults and patients with chronic diseases, including diabetes [14]. ARMS is also valid and reliable for use in patients with varying degrees of health literacy [14]. In contrast to SDSCA-MS, ARMS-D identifies specific barriers to adherence through patient self-report including forgetfulness when taking or refilling medication, purposeful skipping medication, running out of medication, missing medication when feeling better, sick, or out of carelessness, multiple dosing, and how often they plan ahead to refill medication. The ARMS-D total score ranges from most to least adherent of 12–48. Therefore, a *higher score* indicates *less adherence*. This medication adherence assessment tool is further divided into the 8-item medication taking subscale with a possible range of scores from most to least adherent of 8–32 and the 4-item medication refill subscale with a possible range of scores from most to least adherent of 4–16.

### 2.3. Baseline Characteristics and Variables of Interest

For this study, several baseline demographic characteristics were analyzed for their ability to predict baseline HbA1c and association with medication adherence (as measured by ARMS-D and SDSCA-MS) (Table 2). These characteristics include age (<60 years or $\geq$60 years), sex (male, female), marital status, level of education, location (urban, suburban), cell phone type (smartphone, non-smartphone), and social complexity. High social complexity was defined as a baseline positive screen for depression, anxiety, substance abuse, or housing insecurity utilizing the validated Patient Health Questionnaire (PHQ-9), Generalized Anxiety Disorder (GAD-7), National Institute on Drug Abuse (NIDA) Quick Screen, and Homeless Screening Clinical Reminder, respectively. Treating these four variables as a single binary social complexity variable limits the ability to determine which specific component most strongly influences the observed associations with medication adherence and glycemic control. Diabetes medications were divided into pharmacologic classes, which included metformin, insulin, sulfonylurea, sodium–glucose co-transporter 2 inhibitor (SGLT2i), dipeptidyl peptidase 4 inhibitor (DPP4i), thiazolidinedione (TZD), meglitinide, alpha glucosidase inhibitor, bile acid sequestrant, and glucagon-like peptide 1 receptor agonist (GLP-1a).

**Table 2.** Baseline demographic characteristics.

| Characteristic | (n = 665) n (%) |
|---|---|
| Age (years)—mean (standard deviation) | 54.2 (11.5) |
| Age | |
| <60 years | 435 (65.41) |
| ≥60 years | 230 (34.59) |
| Gender | |
| Female | 446 (67.07) |
| Male | 219 (32.93) |
| Health Literacy | |
| Low health literacy | 179 (26.92) |
| High health literacy | 486 (73.08) |
| Social Complexity | |
| Low social complexity | 406 (61.05) |
| High social complexity | 259 (38.95) |
| Education (Highest Completed) | |
| Grade 6–8 | 6 (0.9) |
| Grade 9–12 | 120 (18.05) |
| High school diploma/GED | 177 (26.62) |
| Some college | 170 (25.56) |
| Associate degree | 67 (10.08) |
| Bachelor's degree | 75 (11.28) |
| Graduate degree | 44 (6.62) |
| Other [a] | 7 (1.05) |
| Marital Status | |
| Single/Never married | 254 (38.20) |
| Married | 194 (29.17) |
| Divorced | 112 (16.84) |
| Widowed | 56 (8.42) |
| Separated | 46 (6.92) |
| Cohabitating | 2 (0.30) |
| Other | 1 (0.15) |
| Location | |
| Urban | 559 (84.06) |
| Rural | 106 (15.94) |
| Phone Type | |
| Cellphone | 112 (16.87) |
| Smartphone | 552 (83.13) |
| Comorbidities | |
| Number of Comorbidities | |
| 1 Comorbidity | 89 (13.38) |
| 2 Comorbidities | 178 (26.77) |
| 3 Comorbidities | 176 (26.47) |
| 4 Comorbidities | 113 (16.99) |
| 5 Comorbidities | 57 (8.57) |
| 6 Comorbidities | 33 (4.96) |
| 7 Comorbidities | 13 (1.95) |
| 8 Comorbidities | 3 (0.45) |
| 9 Comorbidities | 3 (0.45) |

**Table 2.** *Cont.*

| Characteristic | (n = 665) n (%) |
|---|---|
| Comorbidities | |
| Hypertension | 606 (91.13) |
| Hyperlipidemia | 508 (76.39) |
| Arthritis | 368 (40.30) |
| Depression | 161 (24.21) |
| Asthma | 100 (15.04) |
| Stroke | 73 (10.98) |
| Congestive heart failure | 72 (10.83) |
| Chronic kidney disease | 70 (10.53) |
| Arrhythmia | 53 (7.97) |
| Coronary artery disease | 48 (7.22) |
| COPD | 35 (5.26) |
| Cancer | 33 (4.96) |
| Osteoporosis | 23 (3.46) |
| Medication Categories | |
| Oral Diabetes Medications [b] | |
| Metformin | 445 (66.92) |
| Sulfonylurea | 218 (32.78) |
| Dipeptidyl peptidase 4 inhibitor (DPP-4i) | 125 (18.80) |
| Sodium–glucose transport protein 2 inhibitor (SGLT2i) | 51 (7.67) |
| Thiazolidinedione (TZD) | 22 (3.31) |
| Meglitinide | 5 (0.75) |
| Alpha glucosidase inhibitor | 3 (0.45) |
| Bile acid sequestrant | 1 (0.15) |
| Injectable Diabetes Medications | |
| Glucagon-like peptide 1 (GLP-1) receptor agonist [b] | 85 (12.78) |
| Insulin | 372 (55.94) |
| Number of Diabetes Medication Categories Per Patient | |
| 0 | 28 (4.21) |
| 1 | 198 (29.77) |
| 2 | 240 (36.09) |
| 3 | 152 (22.86) |
| 4 | 42 (6.32) |
| 5 | 5 (0.75) |
| Hemoglobin A1c (%) | |
| Mean | 10.24 ± 1.9 |
| Median | 9.7 (8.7, 11.4) [c] |
| ARMS-D—Mean | |
| Total score | 18.48 ± 4.79 |
| 8-item medication taking subscale | 11.51 ± 3.29 |
| 4-item medication refill subscale | 7.14 ± 1.61 |
| SDSCA-MS: "On how many of the last seven days did you take your diabetes medication?" (Maximum score = 7) | |
| Mean | 6.34 ± 1.46 |
| Median | 7 (7, 7) [c] |

ARMS-D, Adherence to Medication Refills and Medications Scale for Diabetes medications; SDSCA-MS, Summary of Diabetes Self-Care Activities Medications Subscale; [a] Vocational/trade school or technical college. [b] No participant on a dopamine agonist. Oral GLP1 agonist not available in oral formulation at time of study. [c] Reported as median (25th percentile, 75th percentile).

### *2.4. Statistical Analyses*

All statistical analyses were performed using SAS statistical software, Version 9.4 (SAS Institute Inc., Cary, NC, USA), except multiple regression, which was performed in R version 4.4.2. Descriptive statistics were used to summarize the baseline characteristics of the study population. Associations between baseline characteristics and SDSCA-MS, ARMS-D total score, subscales, or HbA1c were assessed using Pearson product-moment, point-biserial, or biserial correlation coefficients, as appropriate. For continuous variables compared with dichotomous variables, *t*-tests were performed. Education was analyzed by individual categories using least-squares means. Marital status was evaluated both categorically (least-squares means) and dichotomously (with a partner vs. without a partner) using *t*-tests.

Medications were grouped by pharmacologic category, and t-tests were used to examine associations with SDSCA-MS, ARMS-D total score, medication-taking and refill subscales, and HbA1c. The number of diabetes medication categories was also analyzed. Comorbidities were assessed individually using *t*-tests, and the total number of co-morbidities was examined using correlation coefficients.

Stepwise bidirectional multiple linear regression was used to identify predictors of baseline HbA1c, ARMS-D score, and SDSCA-MS. Candidate predictors for each stepwise model were selected based on significant univariate association with that specific outcome and clinical relevance; all candidates were entered simultaneously with no imposed order of entry, and the bidirectional procedure used AIC as the selection criterion to determine inclusion in the final model. Stepwise selection is acknowledged to be data-driven and may produce results that are unstable across samples; hence, the findings should be interpreted as hypothesis-generating rather than confirmatory. Pearson correlation coefficients were used to examine the association between the ARMS-D total score and the SDSCA-MS. To compare the predictive utility of ARMS-D versus SDSCA-MS for HbA1c, previously reported Cronbach's $\alpha$ values of the 12-item ARMS-D total ($\alpha = 0.86$), medication-taking subscale ($\alpha = 0.84$), and medication-refill subscale ($\alpha = 0.71$), as well as SDSCA-MS, were compared to standardized Cronbach's $\alpha$ values calculated from the MODEL study's baseline ARMS-D scores. Cronbach's $\alpha > 0.70$ was considered indicative of good internal reliability.

## 3. Results

### *3.1. Study Population Demographics*

The sample included 665 AA adults with uncontrolled diabetes (mean HbA1c of 10.24%). The demographic variables and results are listed in Table 2. The average age was 54.2 years, with 65% under 60 years old, 67% female, 81% with a high school education/GED or higher, and 73% with high health literacy. The most frequent diabetes medication categories included metformin (66.92%), insulin (55.94%), and sulfonylureas (32.78%). DPP4i, GLP-1a, and SGLT2i were less frequent. Patients were most frequently on two diabetes medication categories (36.09%), with 4.21% on no diabetes medication.

### *3.2. Performance of Alternative Instruments for Assessing Medication Adherence*

The 12-item ARMS-D demonstrated good internal consistency, with a total standardized Cronbach's alpha of 0.81, 0.81 for the medication-taking subscale, and 0.18 for the medication-refill subscale. The SDSCA-MS assessed adherence with a single question, with an average of 6.34 out of 7 days, and 501 participants (75%) reporting perfect adherence in the previous week. In contrast, the mean ARMS-D scores were 18.48 (total), 11.51 (medication-taking subscale), and 7.14 (medication-refill subscale), with only 3.9% of

participants achieving perfect adherence (ARMS-D total score = 12). The ARMS-D scores were moderately and inversely correlated with the SDSCA-MS scores (r = −0.37, $p < 0.001$).

### *3.3. Predictors of Baseline Medication Adherence and Diabetes Control*

In univariate analyses, older age (>60) was associated with lower ARMS-D total score ($p < 0.001$), ARMS-D medication taking ($p < 0.001$) and refill subscales ($p = 0.004$), higher SDSCA-MS score ($p < 0.001$), and poorer diabetes control as assessed by HbA1c ($p < 0.001$). (Table 3). Social complexity was associated with ARMS-D total, medication taking and refill subscales, and SDSCA-MS (all $p < 0.001$), indicating those with higher social complexity were more likely to have worse scores. However, social complexity was not related to HbA1c. Individuals with diagnosis of depression had a significantly higher ARMS-D total score ($p = 0.001$), medication taking subscale score ($p = 0.003$), and HbA1c ($p = 0.005$) and a lower SDSCA-MS score ($p = 0.027$) compared to scores in individuals without depression.

Additionally, individuals with a diagnosis of coronary artery disease had higher medication refill subscale scores versus those without coronary artery disease ($p = 0.041$), but there was no significant difference in the total ARMS-D, medication taking subscale, SDSCA-MS scores, or HbA1c. Participants with chronic obstructive pulmonary disease had lower SDSCA-MS scores compared to those without COPD ($p = 0.021$). There were no other co-morbidities (from Table 2) significantly related to the ARMS-D or SDSCA-MS scores or HbA1c.

Specifically for associations between medication class and HbA1c, individuals with prescriptions for SGLT2i ($p < 0.001$), DPP4i ($p = 0.013$), thiazolidinediones ($p = 0.007$), and sulfonylureas ($p = 0.011$) had lower HbA1c measurements. Conversely, individuals with prescriptions for insulin had higher HbA1c ($p < 0.001$). Neither the number of co-morbidities nor the number of medications were associated with the ARMS-D or SDSCA-MS scores or HbA1c.

Multivariate modeling identified social complexity, older age, and prescriptions for DPP4i and sulfonylureas as strong predictors of medication adherence as assessed by ARMS-D (Table 4). Similarly, social complexity, older age, prescriptions for insulin and DPP4i, and diagnosis of depression were identified as predictors of medication adherence as assessed by SDSCA-MS (Table 5).

Multivariate modeling identified a prescription for insulin, DPP4i, and SGLT2i, ARMS-D score, and older age, as strong predictors of the baseline HbA1c. SDSCA-MS was not found to be a predictor of HbA1c even in models excluding ARMS-D ($p = 0.861$). Thiazolidinedione and sulfonylurea use did not improve the model and were therefore excluded from the final regression model (Table 6).

**Table 3.** Univariate associations of baseline characteristics with ARMS-D total, ARMS-D subscales, SDSCA-MS, and hemoglobin A1c.

| Variable | ARMS-D Total | *p*-Value | ARMS-D Medication Taking Subscale | *p*-Value | ARMS-D Medication Refill Subscale | *p*-Value | SDSCA-MS | *p*-Value | HbA1c (%) | *p*-Value |
|---|---|---|---|---|---|---|---|---|---|---|
| Age ≥ 60 years | 17.544 ± 3.977 | **<0.001** | 10.835 ± 2.704 | **<0.001** | 6.883 ± 1.445 | **0.004** | 6.580 ± 1.161 | **<0.001** | 9.886 ± 1.804 | **<0.001** |
| Age < 60 years | 18.970 ± 5.109 | | 11.860 ± 3.516 | | 7.278 ± 1.676 | | 6.207 ± 1.587 | | 10.421 ± 1.932 | |
| High Social Complexity | 20.440 ± 5.350 | **<0.001** | 12.819 ± 3.776 | **<0.001** | 7.571 ± 1.725 | **<0.001** | 6.517 ± 1.600 | **<0.001** | 10.370 ± 1.983 | 0.150 |
| Low Social Complexity | 17.224 ± 3.924 | | 10.668 ± 2.623 | | 6.867 ± 1.470 | | 6.054 ± 1.340 | | 10.151 ± 1.850 | |
| CAD | 18.833 ± 5.737 | 0.653 | 12.146 ± 1.662 | 0.424 | 7.438 ± 4.126 | **0.041** | 6.125 ± 1.770 | 0.389 | 10.233 ± 2.041 | 0.990 |
| No CAD | 18.449 ± 4.716 | | 11.653 ± 1.687 | | 6.916 ± 3.374 | | 6.353 ± 1.437 | | 10.237 ± 1.894 | |
| COPD | 18.743 ± 4.017 | 0.717 | 11.886 ± 1.648 | 0.720 | 6.600 ± 3.306 | 0.201 | 5.486 ± 2.174 | **0.021** | 9.800 ± 1.656 | 0.120 |
| No COPD | 18.462 ± 4.835 | | 11.678 ± 1.690 | | 6.973 ± 3.442 | | 6.384 ± 1.401 | | 10.261 ± 1.914 | |
| Depression | 19.578 ± 5.030 | **0.001** | 12.404 ± 3.418 | **0.003** | 7.335 ± 1.569 | 0.122 | 6.087 ± 1.708 | **0.027** | 10.626 ± 2.068 | **0.005** |
| No Depression | 18.125 ± 4.666 | | 11.460 ± 3.223 | | 7.079 ± 1.619 | | 6.416 ± 1.369 | | 10.111 ± 1.834 | |
| SGLT2i | 18.275 ± 4.996 | 0.764 | 11.373 ± 3.499 | 0.651 | 7.196 ± 1.686 | 0.519 | 6.569 ± 0.900 | 0.076 | 9.508 ± 1.350 | **<0.001** |
| No SGLT2i | 18.494 ± 4.780 | | 11.516 ± 3.277 | | 7.137 ± 1.605 | | 6.317 ± 1.500 | | 10.296 ± 1.932 | |
| DDP4i | 17.456 ± 4.400 | **0.005** | 10.824 ± 3.008 | **0.011** | 7.104 ± 1.534 | 0.497 | 6.643 ± 0.934 | **<0.001** | 9.874 ± 1.734 | **0.013** |
| No DDP4i | 18.713 ± 4.853 | | 11.663 ± 3.337 | | 7.150 ± 1.628 | | 6.265 ± 1.554 | | 10.320 ± 1.934 | |
| Insulin | 18.570 ± 4.620 | 0.576 | 11.651 ± 3.161 | 0.74 | 7.094 ± 1.516 | **0.016** | 6.446 ± 1.301 | **0.034** | 10.603 ± 1.978 | **<0.001** |
| No Insulin | 18.358 ± 5.010 | | 11.321 ± 3.448 | | 6.776 ± 1.723 | | 6.197 ± 1.638 | | 9.769 ± 1.699 | |
| TZD | 17.546 ± 3.997 | 0.281 | 10.864 ± 2.765 | 0.487 | 6.955 ± 1.430 | 0.228 | 6.682 ± 0.839 | 0.069 | 9.396 ± 1.331 | **0.007** |
| No TZD | 18.509 ± 4.818 | | 11.527 ± 3.308 | | 7.148 ± 1.616 | | 6.325 ± 1.479 | | 10.265 ± 1.915 | |
| Sulfonylurea | 18.674 ± 5.082 | 0.472 | 11.578 ± 3.484 | 0.748 | 6.986 ± 1.705 | 0.145 | 6.381 ± 1.390 | 0.576 | 9.983 ± 1.709 | **0.011** |
| No Sulfonylurea | 18.380 ± 4.649 | | 11.470 ± 3.198 | | 7.217 ± 1.558 | | 6.315 ± 1.499 | | 10.359 ± 1.983 | |

ARMS-D, Adherence to Medication Refills and Medications Scale for Diabetes medications; HbA1c, hemoglobin A1c; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; DDP4i, dipeptidyl peptidase 4 inhibitor; SDSCA-MS, Summary of Diabetes Self-Care Activities Medications Subscale; SGLT2i, sodium–glucose transport protein 2 inhibitor; TZD, thiazolidinedione. Higher ARMS-D score indicates worse adherence. Lower SDSCA-MS score indicates worse adherence. Bolded values indicate statistically significant results ($\alpha < 0.05$).

**Table 4.** Multivariate associations of baseline characteristics with ARMS-D.

| | Simple Regression Coefficient ± Standard Error | Correlation Coefficient [b] | *p*-Value | Partial Regression Coefficient ± Standard Error | *p*-Value |
|---|---|---|---|---|---|
| Social Complexity | 3.229 ± 0.361 | 0.327 | <0.001 | 3.042 ± 0.362 | <0.001 |
| Older Age | −1.431 ± 0.388 | −0.142 | <0.001 | −1.149 ± 0.372 | 0.002 |
| Prescription for DPP4i | −1.260 ± 0.474 | −0.103 | 0.008 | −0.963 ± 0.450 | 0.033 |
| Prescription for Sulfonylureas [a] | 0.291 ± 0.397 | 0.029 | 0.463 | 0.587 ± 0.377 | 0.120 |
| Diagnosis of Depression | 1.469 ± 0.432 | 0.130 | <0.001 | | |

ARMS-D, Adherence to Medication Refills and Medications Scale for Diabetes medications; DDP4i, dipeptidyl peptidase 4 inhibitor; SDSCA-MS, Summary of Diabetes Self-Care Activities Medications Subscale. [a] Simple regression results were not significant, but prescription for sulfonylureas remained in the step-wise regression model; [b] Pearson product-moment, point-biserial, and biserial correlation coefficients are reported as appropriate based on variable type; all are mathematically equivalent and computed identically to the Pearson correlation coefficient.

**Table 5.** Multivariate associations of baseline characteristics with SDSCA-MS.

| | Simple Regression Coefficient [a] ± Standard Error | Correlation Coefficient [b] | *p*-Value | Partial Regression Coefficient ± Standard Error | *p*-Value |
|---|---|---|---|---|---|
| Social Complexity | −0.463 ± 0.115 | −0.155 | <0.001 | −0.365 ± 0.119 | 0.002 |
| Older Age | 0.373 ± 0.118 | 0.121 | <0.001 | 0.322 ± 0.118 | 0.007 |
| Prescription for Insulin | 0.249 ± 0.114 | 0.085 | 0.029 | 0.312 ± 0.112 | 0.006 |
| Prescription for DPP4i | 0.378 ± 0.144 | 0.101 | 0.009 | 0.366 ± 0.143 | 0.010 |
| Diagnosis of Depression | −0.329 ± 0.132 | −0.096 | 0.013 | −0.179 ± 0.136 | 0.189 |

DDP4i, dipeptidyl peptidase 4 inhibitor; SDSCA-MS, Summary of Diabetes Self-Care Activities Medications Subscale. [a] For simple regression results, only significant *p*-values ($p < 0.05$) are reported. [b] Pearson product-moment, point-biserial, and biserial correlation coefficients are reported as appropriate based on variable type; all are mathematically equivalent and computed identically to the Pearson correlation coefficient.

**Table 6.** Multivariate associations of baseline characteristics with hemoglobin A1c.

| | Simple Regression Coefficient [a] ± Standard Error | Correlation Coefficient [b] | *p*-Value | Partial Regression Coefficient ± Standard Error | *p*-Value |
|---|---|---|---|---|---|
| Prescription for Insulin | 0.833 ± 0.145 | 0.218 | <0.001 | 0.75 ± 0.143 | <0.001 |
| ARMS-D | 0.062 ± 0.015 | 0.156 | <0.001 | 0.049 ± 0.315 | 0.001 |
| Prescription for SGLT2i | −0.79 ± 0.276 | −0.110 | 0.004 | −0.67 ± 0.266 | 0.012 |
| Older Age | −0.53 ± 0.154 | −0.134 | 0.001 | −0.37 ± 0.151 | 0.015 |
| Diagnosis of Depression | 0.51 ± 0.171 | 0.116 | 0.003 | 0.298 ± 0.168 | 0.076 |
| Prescription for DPP4i | −0.45 ± 0.188 | −0.092 | 0.018 | −0.26 ± 0.182 | 0.149 |
| Prescription for Sulfonylureas | −0.38 ± 0.157 | −0.093 | 0.016 | | |
| Prescription for Thiazolidinediones | −0.87 ± 0.412 | −0.082 | 0.035 | | |

ARMS-D, Adherence to Medication Refills and Medications Scale for Diabetes medications; DDP4i, dipeptidyl peptidase 4 inhibitor; SGLT2i, sodium–glucose transport protein 2 inhibitor. [a] For simple regression results, only significant *p*-values ($p < 0.05$) are reported. [b] Pearson product-moment, point-biserial, and biserial correlation coefficients are reported as appropriate based on variable type; all are mathematically equivalent and computed identically to the Pearson correlation coefficient.

## 4. Discussion

This study found that, when assessing medication adherence, the ARMS-D questionnaire was more clinically useful and accurate than the SDSCA-MS to measure barriers to adherence and identified these barriers to adherence. Additionally, the ARMS-D total and medication taking subscale were predictive for HbA1c, where the SDSCA-MS was not. When the ARMS-D score is high, indicating poorer adherence, this study found the HbA1c was also higher. The ARMS-D has also been specifically validated in AA participants, suggesting better generalizability than the SDSCA-MS [15].

Even though SDSCA-MS and ARMS-D both aim to measure medication adherence, and they were moderately correlated, the high adherence reported in the previous week by the SDSCA-MS (75% with perfect 7 out of 7 days adherence) differs significantly from the ARMS-D (3.9% perfect adherence). These results may be influenced by an aspect of the MODEL study design. Because of the two-week run-in period to demonstrate responsiveness to texts and voice messages, it is possible that during the week prior to their scheduled enrollment appointment, these participants took their medications as prescribed but had been largely noncompliant previously. Just the action of contacting the patient could serve as a reminder to take their medication.

Aligned with this study's findings, the ARMS-D has previously demonstrated superior sensitivity for measuring medication adherence compared to the SDSCA-MA (79% ARMS-D versus 27% SDSCA-MA) [16]. The ARMS-D questionnaire also enlightens clinicians on specific issues of adherence (i.e., dosing frequency, forgetting, skipping, or missing medication in illness, feeling better, or carelessness). Once specific barriers are identified, clinicians can work on strategies to address them.

### *4.1. Predictive Characteristics of Medication Adherence and HbA1c*

In this sample, younger age, high social complexity, and diagnosis of depression were generally associated with lower medication adherence. Additionally, individuals who were younger, had depression, or used insulin had a higher HbA1c. Depression has been previously associated with poorer medication adherence for multiple chronic diseases including diabetes, which these results support [17]. Asthma was the only condition associated with less medication refill adherence. It is possible this is related to the cost of inhalers or fewer refills for patients who have types of intermittent asthma and do not necessarily require daily medication or regular refills. Insulin was inversely associated with HbA1c, meaning those on insulin had a significantly higher HbA1c. The ability to titrate or personalize dosing with insulin makes this a surprising finding. However, it cannot be concluded whether these were patients new to insulin because of their elevated HbA1c, or whether they were on insulin but still have an elevated HbA1c. If individuals were on multiple injections of insulin per day, where more frequent dosing is associated with lower adherence [18], this might also explain the inverse association of insulin and HbA1c.

The ARMS-D total score, age, depression, and use of insulin, DPP4i, and SGLT2i are independently predictive of HbA1c, and by looking at them together, a larger proportion of variability can be explained in patients with uncontrolled T2D (HbA1c > 8%). This is a prediction model that can assist clinicians to identify possible characteristics of patients that can predict worse HbA1c and barriers to adherence. This clinical prediction model could be generalizable to those outside of the MODEL study because younger age, presence of depression, and use of insulin, DPP4i, or SGLT2i are commonly seen in clinical practice.

### *4.2. Comparison of MODEL Participants to Real World Data*

The MODEL results differ compared to previous studies on medication adherence. Previous studies have found that patients are more likely to be adherent to diabetes

medications if they are older, male, married, living in a region other than the South, have fewer numbers of antidiabetic medications, and have more chronic diseases [19–23]. In contrast, the MODEL participants were from the South and predominantly younger, female, and single. Therefore, in this study, higher medication nonadherence would be expected, which *was* found when using the ARMS-D and not with the SDSCA-MS. The previous data and this study support using the ARMS-D for better accuracy compared to the SDSCA-MS.

### *4.3. White-Coat Adherence*

While the SDSCA-MS is a simple one-question tool, its clinical usefulness for medication adherence is limited. Clinically, this tool lacks any information beyond the number of days in the past week the patient took their medication. The SDSCA-MS limits the patient's recall of medication adherence to the previous seven days, which leaves the opportunity for "white-coat adherence." This concept is where medication adherence is markedly increased the days preceding and following a health care encounter [24,25]. While medication adherence is increased the week before the office visit, three days prior to the visit is most affected [26]. Therefore, restricting the recall of self-reported medication adherence to the week before the health care encounter leads to much lower sensitivity of medication adherence in the SDSCA-MS compared to the ARMS-D. Furthermore, white coat adherence would potentially affect medication adherence and not the change in HbA1c, since the HbA1c is a 3-month average measure of glycemia. However, because both tools share the same seven-day recall window, white-coat adherence alone cannot fully explain why scores differed so dramatically between the two measures. The difference in the number of items is also important. As a single-item measure, the SDSCA-MS is less reliable than the 12-item ARMS-D. Additionally, the directness of the SDSCA-MS question may increase susceptibility to social desirability bias, where patients feel pressure to report perfect adherence when asked one straightforward question. The ARMS-D assesses a broader range of behaviors and barriers, including running out of medication, changing doses, and delays in refilling prescriptions due to cost. This wider scope and less direct framing may reduce social desirability bias and better capture the true burden of nonadherence, which may also explain the greater predictive utility of the ARMS-D for HbA1c.

A better understanding is needed of factors of nonadherence and of clinician characteristics that affect adherence through medication choice and regimen. Surprisingly, although all patients had uncontrolled diabetes, 70.07% of patients were on two or fewer medication categories for diabetes. These patients have high health literacy and higher education than expected for this study population location [12], which was focused on medically underserved areas. This creates questions of why the patients are not on more diabetes medication if they are adherent (which is questionable, as described previously), yet their HbA1c is still elevated. With most patients on insulin, yet with uncontrolled diabetes, adherence specifically to insulin dosing (whether fixed or titration dosing) would be beneficial to explore. Other avenues to consider are clinician characteristics of medication choice. Is there an association of clinician education or type of clinician, assumptions of clinicians, age, gender, area of town, or types of insurance accepted, and categories or number of medications prescribed? Furthermore, sulfonylureas are known to be inexpensive but carry many risks (e.g., hypoglycemia, weight gain, limited efficacy over time, and questionable increase in cardiovascular risk). Many of these concerns are substantially reduced with other antidiabetic medication options (e.g., metformin, DDP4i, SGLT2i, and GLP-1a). Therefore, exploration into associations among provider, insurance, and patient factors with medication adherence could help improve understanding and create interventions to improve this disparity.

### *4.4. Limitations*

The findings of this study may have limited generalizability outside of this specific patient population of people who are AA adults living in medically underserved areas with uncontrolled diabetes in the Mid-South United States. Additionally, measuring medication adherence through self-report screening tools may be less accurate than objective or observational sensors. Furthermore, while the ARMS-D identifies barriers in adherence that can be addressed in the clinic setting, it does not assess other pertinent factors to adherence such as cost, pharmacy, insurance or office issues (e.g., prior authorization, delay of clinician sending prescription, or pharmacy having to order medication), or transportation. These data were also collected from 2016 to 2019, and earlier in the study, SGLT2is were not as routinely used, weekly GLP1a was newly approved, and an oral GLP-1a was not available. This ancillary study's cross-sectional design and measurement of HbA1c prior to assessment of medication adherence limits causal conclusions.

The medication-refill subscale of the ARMS-D demonstrated poor internal consistency in this sample ($\alpha = 0.18$), which is notably lower than the $\alpha = 0.71$ reported in the original validation study. This study sample was well-educated with high health literacy. It is plausible that the participants did not have significant barriers to medication refills, which may have resulted in uniformly high refill adherence with little variance across participants. This pattern may have reduced the Cronbach's $\alpha$, and findings from the medication-refill subscale should be interpreted with caution.

## 5. Conclusions

Racial disparities in diabetes prevalence, control, complications, and commonly associated co-morbidities in AA adults exist and are compounded by poorer medication adherence. While medication adherence impacts an individual's health, clinician and healthcare system factors also exist that impact adherence. The accurate measurement and identification of barriers to medication adherence allows for individualized treatment plans to increase adherence. Careful attention should be given to individuals with depression, younger age, high social complexity, and using insulin, as this study found these characteristics to be associated with lower adherence. Clinicians should use the ARMS-D over SDSCA-MS to measure adherence.

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## Abbreviations

The following abbreviations are used in this manuscript:

| | |
|---|---|
| AA | African American |
| ARMS-D | Adherence to Medication Refills and Medications Scale for Diabetes medications |
| CAD | Coronary artery disease |
| COPD | Chronic obstructive pulmonary disease |
| DDP4i | Dipeptidyl peptidase 4 inhibitor |
| GAD-7 | Generalized Anxiety Disorder |
| GLP-1a | Glucagon-like peptide 1 receptor agonist |
| HbA1c | Hemoglobin A1c |
| MODEL | Management of Diabetes in Everyday Life |
| NIDA | National Institute on Drug Abuse |
| PHQ-9 | Patient Health Questionnaire |
| SDSCA-MS | Summary of Diabetes Self-Care Activities Medications Subscale |
| SGLT2i | Sodium–glucose transport protein 2 inhibitor |
| TZD | Thiazolidinedione |

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