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DIABETIC
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The Impact Of Socioeconomic Factors And Treatment Adherence On Diabetes Complications: A Multi-Model PLS-SEM Analysis In Saudi Arabia

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Abstract

Background: The management of diabetes mellitus and its complications presents a significant healthcare challenge in Saudi Arabia, particularly given the complex interplay between socioeconomic factors and treatment outcomes. While previous studies have examined clinical aspects of diabetes management, the relationship between social determinants, treatment adherence, and health outcomes remains understudied in the Saudi context.

Objective: This study employs Partial Least Squares Structural Equation Modeling (PLS-SEM) to analyze the complex relationships between socioeconomic factors, treatment adherence, and diabetes complications among patients in Al-Ahsa Governorate, Saudi Arabia. Through three progressive models, we examine how demographic characteristics and treatment compliance influence health outcomes.

Methods: We conducted a cross-sectional study (n=X) using a comprehensive survey instrument. Three PLS-SEM models were developed: (1) a basic model examining direct effects of demographics and treatment adherence on complications, (2) a mediation model incorporating treatment adherence as a mediator, and (3) a comprehensive model including complications severity as an additional construct. The models were evaluated using standard fit indices, path coefficients, and comparative metrics.

Results: Demographic factors showed significant direct effects on complications (β=-0.273, $p<0.05$) and treatment adherence (β=0.397, $p<0.05$). Treatment adherence demonstrated a substantial negative relationship with complications (β=-0.401, $p<0.05$). Model comparison revealed that the basic model provided the best fit (BIC=-119.040, Akaike weight=0.960). Notably, socioeconomic factors significantly influenced complications severity (β=-0.407, $p<0.001$) in the comprehensive model.

Conclusions: Our findings reveal significant associations between socioeconomic factors, treatment adherence, and diabetes complications in Saudi Arabia. The multi-model approach demonstrates that while demographic characteristics directly influence health outcomes, treatment adherence plays a crucial mediating role. These results suggest the need for targeted interventions that consider both social determinants and clinical factors in diabetes management.

Keywords: Diabetes Mellitus; PLS-SEM; Treatment Adherence; Socioeconomic Factors; Health Outcomes; Saudi Arabia; Structural Equation Modeling; Multi-Model Analysis.

1. Introduction

Diabetes mellitus (DM) remains one of the most significant global health challenges of the 21st century, affecting approximately 537 million adults worldwide, with projections suggesting this number could reach 783 million by 2045(International Diabetes Federation [IDF], 2023). The evolution of diabetes treatment, from traditional herbal remedies to modern pharmaceutical interventions, reflects humanity's ongoing struggle to manage this complex metabolic disorder. While insulin therapy has emerged as a cornerstone of diabetes management, successful treatment outcomes depend on a complex interplay of medical, social, and economic factors that extend far beyond clinical interventions alone.

In Saudi Arabia, particularly in the Al-Ahsa province, the prevalence of diabetes has reached alarming levels, with recent estimates suggesting that 18.3% of the adult population is affected (Al-Rubeaan et al., 2021; Saudi Ministry of Health [MOH], 2023). This high prevalence, coupled with unique sociocultural characteristics and economic dynamics, creates a distinctive environment for studying diabetes management. The region's rapid socioeconomic transformation, changing dietary patterns, and evolving healthcare infrastructure present both challenges and opportunities for understanding the multifaceted nature of diabetes care. Despite advances in medical treatment and increased healthcare accessibility, diabetes management outcomes in Al-Ahsa remain suboptimal, with previous research primarily focusing on clinical aspects while leaving gaps in our understanding of how socioeconomic factors and treatment adherence patterns influence health outcomes.

Our study aims to address these knowledge gaps by evaluating the relationship between socioeconomic determinants and diabetes-related health outcomes, analyzing how variations in insulin administration practices and treatment adherence affect complication rates, and developing a comprehensive model that captures the interactions between social, economic, and clinical factors in diabetes management. Through this investigation, we address two primary research questions: how do socioeconomic determinants influence diabetes prevalence and associated complications in the Al-Ahsa population, and what is the relationship between insulin administration practices, treatment adherence, and health outcomes among diabetes patients?

Based on existing literature and preliminary observations, we propose several key hypotheses. First, we posit that adverse socioeconomic conditions correlate with higher diabetes prevalence, increased complication risks, and lower treatment adherence rates. Second, we hypothesize that treatment non-compliance, including irregular insulin administration, inconsistent medical follow-up, and poor adherence to prescribed regimens, is associated with higher rates of diabetes-related complications. Additionally, we propose that the relationship between socioeconomic factors and health outcomes is mediated by treatment adherence patterns, access to healthcare resources, and health literacy levels.

To test these hypotheses, we employ Partial Least Squares Structural Equation Modeling (PLS-SEM), a sophisticated analytical approach that allows us to model complex relationships between multiple variables, account for both direct and indirect effects, handle non-normal data distributions, and incorporate both formative and reflective constructs. This methodological approach enables a comprehensive examination of the intricate relationships between socioeconomic factors, treatment adherence, and health outcomes.

The significance of this research lies in its potential to provide empirical evidence of the relationship between socioeconomic factors and diabetes outcomes, identify key mediating factors in diabetes management, develop a comprehensive model for understanding diabetes care in Saudi Arabia, and inform evidence-based interventions and policy recommendations. Through rigorous analysis and comprehensive modeling, we aim to contribute meaningful insights that can inform both clinical practice and public health policy.

The remainder of this paper presents a comprehensive review of relevant literature, details our methodology and analytical approach, presents the study results, discusses the findings and their implications, and concludes with recommendations for future research and practice. Through this investigation, we endeavour to deepen understanding of the multifaceted factors shaping diabetes management and inform targeted interventions to improve health outcomes for individuals contending with this pervasive condition in the Saudi Arabian context.

2. Literature review

The impact of social and health environments on diabetes patients is a multifaceted area of study, encompassing various factors that influence outcomes and management strategies. Hill-Briggs et al. (2020) emphasize the intricate relationship between social determinants of health (SDOH) and diabetes outcomes, particularly in vulnerable populations within the U.S. Their findings underscore the critical need to consider socioeconomic status, neighborhood conditions, and access to healthcare in managing diabetes effectively. Aligning with this perspective, Qi et al. (2021) delve into the relationship between social support, self-management behavior, and quality of life in elderly patients with type 2 diabetes mellitus (T2DM). Their study highlights the significant impact of social support and self-management strategies on enhancing the well-being of elderly T2DM patients.

Safari-Alighiarloo et al. (2023) contribute to the understanding of diabetes complications by identifying potential metabolic biomarkers for critical limb ischemia (CLI) in people with T2DM. While their focus is on physiological markers related to vascular complications, their findings complement studies investigating psychosocial and behavioral aspects of diabetes management. Additionally, Okamoto et al. (2023) shed light on the complex interplay between metabolic factors and mental health conditions in individuals with T2DM and major depressive disorder (MDD). By analyzing serum metabolomics patterns, they provide insights into potential pathways underlying the comorbidity of these conditions.

Ehsan et al. (2023) explore the use of surface-enhanced Raman spectroscopy (SERS) to characterize blood serum samples of T2DM patients, offering potential biomarkers for early diagnosis. Their findings suggest promising avenues for improving early diabetes detection and screening, which aligns to enhance diabetes management. Furthermore, Dendup et al. (2017) provide insights into the environmental determinants of T2DM, highlighting the importance of factors such as walkability, air pollution, and food environments. Understanding these environmental influences is crucial for informing public health policies aimed at preventing and managing diabetes.

Pinhal et al. (2022) conducted a longitudinal study examining the impact of diabetes on functional decline over time. Their findings underscore the complex interaction between diabetes and various aspects of functioning, including physical, psychological, and social dimensions. This holistic understanding of diabetes-related functional decline complements research focusing on the psychosocial aspects of diabetes management.

Ergasheva (2024) assesses the awareness level of the socially important effects of diabetes among patients with T2DM. By evaluating the accessibility of diabetic-friendly food products, the study sheds light on the societal impact of diabetes and the importance of preventive measures. Similarly, El-Radad et al. (2023) examine the relationship between diabetes self-care activities, social support, and glycemic control in primary healthcare settings. Their findings emphasize the role of social support in diabetes management and highlight avenues for improving patient outcomes through enhanced support systems.

Walker et al. (2023) address the global inequity in diabetes care, emphasizing the disproportionate burden faced by marginalized communities. By outlining best practice approaches to achieve equity in diabetes outcomes, the study provides valuable insights for shaping inclusive diabetes management strategies. Additionally, Lin and Yin (2022) explore the relationship between exposure to endocrine-disrupting chemicals (EDCs) and the development of T2DM. Their findings underscore the importance of environmental factors in diabetes risk, highlighting the need for regulatory action to mitigate exposure to EDCs.

Păunică et al. (2022) investigate the bidirectional relationship between periodontal disease and diabetes mellitus, emphasizing the interdependence of these conditions. By discussing therapeutic approaches and the importance of collaborative efforts, the study offers valuable insights for improving diabetes and periodontal disease management. Jafari et al. (2023) examine the impact of diabetes health literacy (DHL) and health locus of control (HLOC) on the quality of life among patients with T2DM. Their findings emphasize the significance of enhancing DHL and fostering positive HLOC beliefs to improve self-care behaviors and overall quality of life.

Lastly, Petersen (2024) investigates the utilization of mobile applications for physical activity among diabetic patients in South Africa. By identifying age-related differences in factors influencing app usage, the study provides insights for designing tailored interventions to improve diabetes management across diverse demographics. Similarly, Lv et al. (2024) contribute to enhancing plant photosynthesis assessment through their study on the quantitative analysis of chlorophyll in Catalpa bungei leaves. Though not directly related to diabetes management, their research underscores the broader applications of spectral reflectance in vegetation analysis, highlighting potential avenues for interdisciplinary collaboration and knowledge exchange.

In summary, the reviewed studies collectively contribute to our understanding of the multifaceted nature of diabetes management, spanning social, environmental, and physiological domains. These insights offer valuable implications for shaping holistic approaches to diabetes care, emphasizing the importance of addressing social determinants, leveraging technological advancements, and fostering interdisciplinary collaboration to improve patient outcomes and reduce disparities in diabetes care.

3. Study Design and Data Collection

3.1 Study Design and Sample Characteristics

This cross-sectional study was conducted in Al-Ahsa Governorate, Saudi Arabia, using a structured survey to collect data from diabetes patients. The sample demonstrated diverse demographic characteristics, with most respondents being female (59.3%), Saudi nationals (96.3%), married (53.3%), and having attained secondary education (24.9%). Regarding employment status, a notable portion were not working (32.5%) or students (24.1%).

3.2 Clinical Characteristics and Treatment Methods

The clinical profile of participants revealed that most patients were diagnosed with type 2 diabetes (41.2%) and had been living with the condition for more than 10 years (42.5%). Treatment patterns showed a strong preference for insulin pens (91.3%), with self-administration being the predominant practice (82.9%). Patient monitoring data indicated that:

- Regular follow-up with doctors occurred every 3 months for 46.2% of respondents
- Hemoglobin A1c levels at last measurement showed a considerable proportion in the 7-8% range (47.0%)

3.3 Complications and Side Effects

Diabetes-related complications were documented among participants, with varying prevalence rates:

- Systemic Complications:
  - High blood pressure (8.1%)
  - Retinopathy (6.3%)
  - Neuropathy (1.6%)
- Injection Site Issues:
  - Redness (17.6%)
  - Swelling (17.6%)
  - Lump formation (9.2%)

These findings highlight the range of treatment practices and complications experienced by diabetes patients in Al-Ahsa, suggesting the need for targeted interventions and improved management strategies.

4. Statistical Analysis (PLS Method)

4.1 Model 1: Baseline Structural Model

The first model examines the relationships between demographic factors, treatment methods, and diabetes complications using Partial Least Squares (PLS) regression. This model incorporates three latent variables:

Table 1: Model 1 Variables and Indicators

Latent Variable	Description	Indicators
Demographic Structure (D)	Patient demographic characteristics	• Gender (X1) • Age (X2) • Marital status (X5) • Employment status (X6)
Treatment Adherence and Follow-up (T)	Treatment methods and compliance measures	• Medication use (X9) • Insulin type (X10) • Insulin administration (X11) • Doctor follow-up frequency (X12) • Blood sugar monitoring frequency (X16) • Previous specialist sessions (X19) • Adherence to guidance (X20)
Complications and Side Effects (E)	Health outcomes and complications	• Diabetes type (X7) • Duration since diagnosis (X8) • HbA1c level (X13) • Hospitalization history (X14) • Hypoglycemia occurrence (X17) • Complications presence (X18) • Injection site issues (X26)

The model is represented in the figure 1:

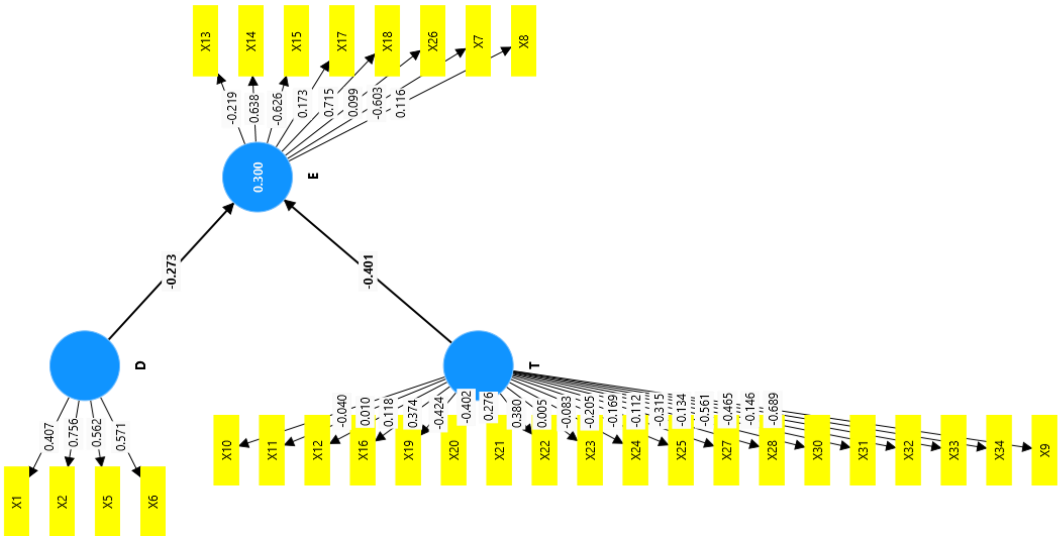

Figure 1: Model 1 representation

4.2 Model 1 Results and Analysis

- **Key Findings**

The investigation of relationships between demographic structure (D), treatment adherence (T), and complications (E) revealed significant patterns in diabetes management outcomes. Our analysis demonstrated that both demographic factors and treatment adherence have negative relationships with complications, suggesting that favorable demographic conditions and better treatment adherence are associated with fewer complications.

- **uantitative Results**

Table 1: Correlation Matrix

Variable	D	E	T
D	1	-0.392	0.296
E	-0.392	1	-0.482

Variable	D	E	T
T	0.296	-0.482	1

Table 2: Effect Sizes (f-square)

Path	Value
D → E	0.097
T → E	0.209

Table 3: Reliability and Validity Measures

Variable	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
D	0.413	0.416	0.668	0.345
E	-0.657	0.567	0.014	0.222
T	0.328	0.539	0.281	0.103

Table 4: Model Fit Indices

Metric	Saturated model	Estimated model
SRMR	0.094	0.094
d_ULS	4.387	4.387
d_G	1.009	1.009
Chi-square	1828.044	1828.044
NFI	0.132	0.132

- **Key Results**

Path Coefficients:

D → E: -0.273 (negative relationship)

T → E: -0.401 (negative relationship)

Model Explanatory Power:

Adjusted R-square: 0.296 (30% variance explained)

Validity Concerns:

D: Moderate internal consistency

E: Poor reliability (α = -0.657)

T: Moderate consistency with lower convergent validity

The model reveals important relationships between variables but suggests needed improvements in measurement reliability, particularly for complications and side effects (E). While providing valuable insights into diabetes management factors, the model's fit indices indicate potential areas for refinement in future research.

4.3 Model 2: Extended Analysis

- **Model Specification**

Model 2 builds upon Model 1 by introducing a direct pathway from demographic structure (D) to treatment adherence (T), while maintaining the relationships with complications and side effects (E). This extension allows examination of how demographic factors influence treatment adherence patterns alongside their combined effects on complications.

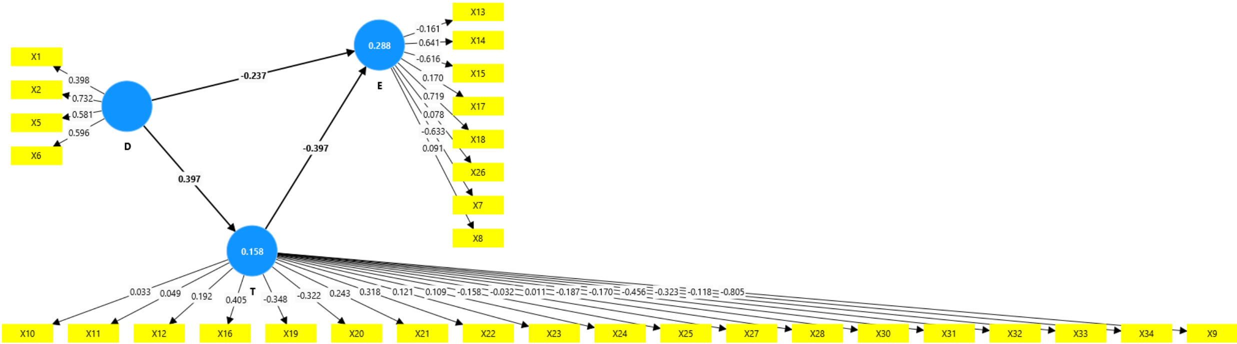

Figure 2: Model 2 representation

- **Results**

Table 5: Path Coefficients

Path	Coefficient
D → E	-0.237
D → T	0.397
T → E	-0.397

Table 6: Model Explanatory Power

Variable	R-square	R-square adjusted
E	0.288	0.284
T	0.158	0.156

Table 7: Effect Sizes (f-square)

Path	Value
D → E	0.066
D → T	0.187
T → E	0.186

Table 8: Reliability and Validity Measures

Variable	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
D	0.413	0.408	0.671	0.347
E	-0.657	0.581	0.013	0.222
T	0.328	0.502	0.107	0.088

Table 9: Model Fit Indices

Metric	Saturated model	Estimated model
SRMR	0.095	0.095
d_ULS	4.502	4.502
d_G	1.042	1.042
Chi-square	1882.53	1882.53
NFI	0.106	0.106

- **Key Findings**

Path Analysis:

Demographic factors negatively affect complications (D → E: -0.237)

Demographics positively influence treatment adherence (D → T: 0.397)

Treatment adherence negatively affects complications (T → E: -0.397)

- **Model Performance:**

Explains 28.8% of variance in complications (E)

Accounts for 15.8% of variance in treatment adherence (T)

Effect sizes suggest stronger impacts for D → T and T → E compared to D → E

- **Reliability Concerns:**

D and T show moderate internal consistency

E exhibits low reliability

Model fit indices indicate need for refinement

The model reveals important relationships between demographics and treatment adherence but suggests the need for measurement improvements, particularly in complications assessment.

4.4 Model 3: Comprehensive Analysis

- **Model Specification**

Model 3 introduces a more comprehensive approach by examining the interactions between demographic factors, treatment adherence, and complications severity. The model consists of four key components:

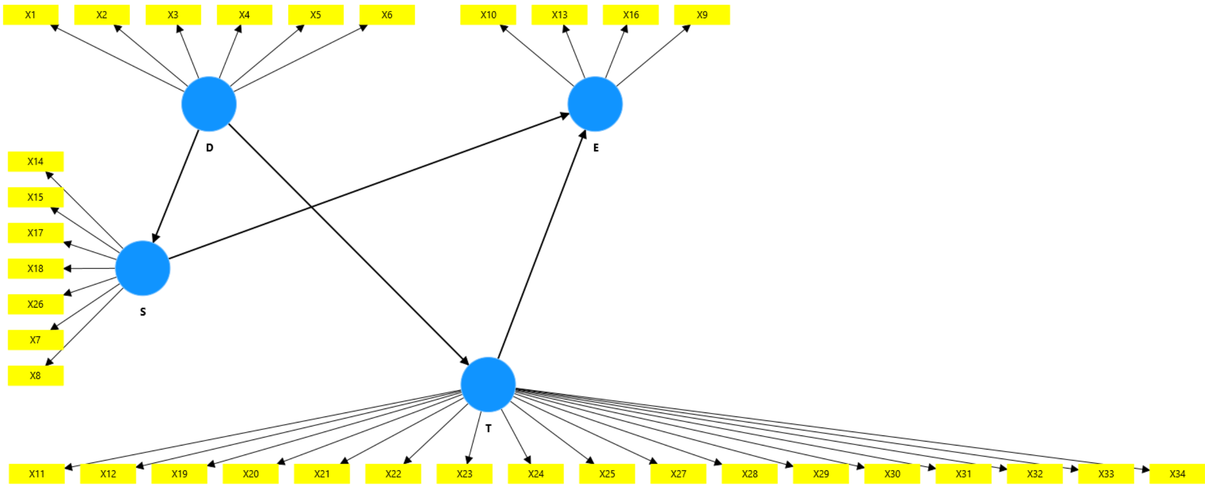

Figure 3: Model 3 representation

Table 10: Model 3 Variables and Indicators

Component	**Description**	**Indicators**
Demographic Structure (D)	Demographic factors	X1, X2, X3, X4, X5, X6
Treatment Adherence (T)	Treatment regimens and follow-up	X19, X20, X22, X23, X24, X25, X27, X28, X29, X30, X31, X32, X33, X34, X12, X11, X21
Complications Severity (S)	Diabetes-related complications	X7, X8, X14, X17, X18, X26, X15
Diabetes Management (E)	Overall management aspects	X9, X10, X13, X16

- **Results**

Table 11: Path Coefficients Analysis

Path	**Original sample**	**Sample mean**	**Standard deviation**	**T statistics**	**P values**
D → S	-0.407	-0.411	0.092	4.398	0.000
D → T	-0.070	0.050	0.170	0.409	0.683
S → E	-0.366	-0.242	0.265	1.381	0.167
T → E	-0.245	-0.078	0.295	0.829	0.407

Table 12: Confidence Intervals and Bias Analysis

Path	**Original sample**	**Sample mean**	**Bias**	**2.5%**	**97.5%**
D → S	-0.407	-0.411	-0.005	-0.464	0.409
D → T	-0.070	0.050	0.120	-0.400	0.199
S → E	-0.366	-0.242	0.124	-0.491	0.351
T → E	-0.245	-0.078	0.166	-0.420	0.388

Table 13 : Indirect Effects Analysis

Path	**Original sample**	**Sample mean**	**Standard deviation**	**T statistics**	**P values**
D → T → E	0.017	0.018	0.044	0.387	0.699

Path	Original sample	Sample mean	Standard deviation	T statistics	P values
D → S → E	0.149	0.099	0.114	1.303	0.193

- **Key Findings**

Significant Relationships:

Only D → S shows statistical significance ($p < 0.001$)

Strong negative relationship between demographic factors and complications severity (-0.407)

Non-significant Pathways:

D → T: No significant relationship between demographics and treatment adherence

S → E: Complications severity does not significantly affect management

T → E: Treatment adherence shows no significant impact on management

Indirect Effects:

Neither D → T → E nor D → S → E pathways show statistical significance

Both indirect paths have p-values exceeding 0.05

The model reveals that while demographic factors significantly influence complications severity, other relationships, including indirect effects, lack statistical significance. This suggests the need for further investigation into the complex interactions between these variables in diabetes management.

5. Comprehensive Model Comparison Analysis

5.1 Statistical Performance Across Models

- **Model 1 vs. Model 2 Performance**

Table 14: Direct Comparison Metrics

Metric	Model 1	Model 2	Difference	Significance
Average Loss	28.636	29.860	-1.224	p = 0.041
BIC	-119.040	-112.677	-6.363	-
Akaike Weight	0.960	0.040	0.920	-
R-square (E)	0.296	0.288	0.008	-

- **Model 2 vs. Model 3 Performance**

Table 15 : Path Coefficient Comparison

Path	Model 2	Model 3	Change
D → E	-0.237	0.166	+0.403
D → T	0.397	-0.070	-0.467
T → E	-0.397	-0.245	+0.152
Additional Model 3 Paths:			
D → S	-	-0.407*	-
S → E	-	-0.366	-

Path	Model 2	Model 3	Change
*Statistically significant at $p < 0.001$			

- **Model 1 vs. Model 3 Performance**

Table 16 : Structural Comparison

Aspect	Model 1	Model 3	Implication
Path Coefficients D → E	-0.273	0.166	Relationship direction changed
Path Coefficients T → E	-0.401	-0.245	Effect strength decreased
Model Complexity	Lower	Higher	Trade-off between comprehensiveness and parsimony
Significant Paths	2	1	Fewer significant relationships in complex model

5.2 Interpretative Analysis

Our comparative analysis of the three structural equation models reveals important insights into the relationships between demographic factors, treatment adherence, and diabetes complications. The progression from Model 1 to Model 3 demonstrates an evolution in complexity and understanding, with each model offering distinct advantages and limitations.

In comparing Models 1 and 2, statistical performance metrics show that Model 1 generally demonstrates superior fit. The average loss for Model 1 (28.636) is significantly lower than Model 2 (29.860), with this difference being statistically significant ($p = 0.041$). Model 1 also shows better overall fit indices, with a lower BIC value (-119.040 compared to -112.677) and a substantially higher Akaike weight (0.960 versus 0.040). The explained variance in complications (E) is slightly higher in Model 1 (R-square = 0.296) compared to Model 2 (R-square = 0.288).

The comparison between Models 2 and 3 reveals interesting shifts in relationship patterns. The path coefficient for the demographic factors to complications relationship (D → E) changes from negative in Model 2 (-0.237) to positive in Model 3 (0.166), suggesting a fundamental change in the understood relationship when considering complication severity as a separate factor. Similarly, the relationship between demographics and treatment adherence (D → T) shows a dramatic shift from positive (0.397) to negative (-0.070), while the treatment adherence to complications relationship (T → E) maintains its negative direction but weakens (-0.397 to -0.245). Notably, Model 3 introduces two new pathways, with the relationship between demographics and severity (D → S) showing strong statistical significance ($p < 0.001$).

When comparing Models 1 and 3 directly, we observe substantial changes in both structure and effectiveness. The fundamental D → E relationship not only weakens but reverses direction (-0.273 to 0.166), while the T → E relationship maintains its negative direction but loses strength (-0.401 to -0.245). This evolution comes with a clear trade-off between model complexity and statistical significance, as the number of significant paths decreases from two in Model 1 to just one in Model 3.

The structural evolution across models reflects increasing complexity in understanding diabetes management. Model 1 provides a straightforward examination of direct effects, Model 2 introduces mediation effects, and Model 3 incorporates interaction effects through the addition of severity as a distinct construct. This progression reveals how the D → E relationship weakens across models, while the T → E effect becomes less pronounced, particularly as the S variable is introduced and changes the dynamic of these relationships.

Statistical performance patterns across the models indicate that predictive accuracy generally decreases as model complexity increases. Model 1 shows the strongest overall prediction capabilities, while Model 2 maintains reasonable accuracy despite its increased complexity. Model 3, while offering the most comprehensive theoretical framework, shows mixed results in terms of predictive accuracy. The pattern of path significance also follows this trend, with fewer significant relationships emerging as model complexity increases, though the D → S relationship in Model 3 maintains strong significance.

Each model offers distinct practical implications for diabetes management research and practice. Model 1's superior statistical fit and clear relationships make it ideal for predictive purposes, while Model 2's incorporation of mediation effects provides valuable insights into treatment pathways. Model 3, despite its limitations in statistical significance, offers the most comprehensive theoretical understanding of diabetes management dynamics.

These findings suggest important trade-offs between model complexity and statistical power. While simpler models may provide clearer statistical relationships, more complex models offer richer theoretical insights despite reduced statistical significance. This pattern highlights the importance of choosing analytical approaches based on specific research objectives, whether they prioritize predictive accuracy, mechanistic understanding, or comprehensive theoretical frameworks.

6. Clinical Implications and Recommendations

Our comparative analysis of the three structural equation models yields significant implications for clinical practice and healthcare policy in diabetes management. The findings suggest several important considerations for healthcare providers and policymakers, particularly in the context of the Saudi Arabian healthcare system.

The strong predictive power of demographic factors in Model 1, coupled with the treatment adherence pathways revealed in Model 2 and the complexity of interactions demonstrated in Model 3, emphasizes the need for a multi-faceted approach to diabetes management. Healthcare providers should prioritize comprehensive patient assessment that considers not only clinical factors but also demographic characteristics and treatment adherence patterns. This is particularly crucial given the significant relationship between demographic factors and complication severity ($D \rightarrow S$: -0.407, $p < 0.001$) identified in our analysis.

The study's findings suggest that healthcare delivery systems should be restructured to accommodate these complex relationships. Treatment strategies should be tailored to specific demographic profiles while maintaining strong focus on adherence monitoring and support. This could involve the implementation of standardized assessment protocols that consider both demographic risk factors and adherence patterns, enabling early identification of high-risk patients and timely intervention.

Resource allocation in healthcare facilities should reflect these priorities, with particular emphasis on preventive care and patient education. Healthcare providers should develop targeted support systems that address the specific needs of different demographic groups, particularly those identified as having higher risk profiles. This might include enhanced follow-up protocols for high-risk patients and specialized education programs designed to improve treatment adherence among specific demographic groups.

Healthcare policy recommendations emerging from this research include the development of integrated care pathways that account for both demographic factors and treatment adherence patterns. Screening and monitoring protocols should be standardized across healthcare facilities, with particular attention to risk stratification based on demographic characteristics. Regular monitoring schedules should be established, with frequency adjusted according to individual risk profiles.

The development of demographic-specific intervention programs represents another crucial area for policy focus. These programs should be designed to address the unique challenges and needs of different patient groups, as identified in our model analyses. Support systems for treatment adherence should be strengthened, particularly in populations where demographic factors suggest increased risk of complications.

Resource planning at the healthcare system level should prioritize the allocation of resources based on population demographics, with particular attention to areas where intervention is most likely to be effective. This includes investment in preventive care programs and patient education initiatives, which our analysis suggests may be particularly important in managing complication risks.

Furthermore, the findings indicate the need for continuous professional development programs that help healthcare providers better understand and address the complex relationships between demographic factors, treatment adherence, and health outcomes. These programs should emphasize the importance of individualized care approaches while maintaining consistency in basic assessment and intervention protocols.

Implementation of these recommendations requires careful consideration of local healthcare system capabilities and resources. Healthcare facilities should prioritize interventions with the strongest evidence of impact, while maintaining flexibility to adjust approaches based on local needs and capabilities. Regular evaluation of intervention effectiveness should be conducted, with adjustments made based on observed outcomes.

7. Conclusion

This research provides comprehensive insights into the complex dynamics of diabetes management in Al-Ahsa, Saudi Arabia, through the application of three progressive PLS-SEM models. The study examined the intricate relationships between demographic factors, treatment adherence, and diabetes complications, yielding significant findings that contribute to both theoretical understanding and practical application in healthcare delivery.

Our analysis, progressing from a basic structural model to increasingly complex frameworks, revealed several crucial patterns. Model 1 demonstrated that demographic factors and treatment adherence have significant direct effects on complications, with path coefficients revealing that improvements in these areas correlate with reduced complications ($D \rightarrow E$: -0.273, $T \rightarrow E$: -0.401). The superior statistical fit of this model (BIC = -119.040, Akaike weight = 0.960) suggests its particular utility for predictive purposes in clinical settings.

Model 2 expanded our understanding by introducing mediation effects, revealing how demographic factors influence treatment adherence patterns, which in turn affect complication rates. This intermediate model, while showing slightly lower statistical fit than Model 1, provided valuable insights into the mechanisms through which patient characteristics influence health outcomes. The positive relationship between demographics and treatment adherence ($D \rightarrow T$: 0.397) highlighted the importance of considering patient backgrounds in developing adherence support strategies.

Model 3, the most comprehensive framework, incorporated complication severity as a distinct factor, revealing significant relationships between demographic factors and complication severity ($D \rightarrow S$: -0.407, $p < 0.001$). While this model showed reduced statistical significance in some relationships, it provided the most nuanced understanding of how different factors interact in diabetes management. The inclusion of severity as a separate construct emphasized the importance of considering disease progression in treatment planning.

These findings have important implications for clinical practice. Healthcare providers should implement comprehensive assessment protocols that consider demographic risk factors, monitor treatment adherence patterns, and regularly evaluate complication severity. Treatment strategies should be tailored to specific demographic profiles while maintaining strong focus on adherence support, particularly in populations identified as high-risk through our models.

The study's limitations, including its cross-sectional nature and regional specificity, suggest directions for future research. Longitudinal studies examining these relationships over time, investigation of additional socioeconomic factors, and validation of these findings in different geographical contexts would further enhance our understanding of diabetes management dynamics.

In conclusion, this research underscores the complexity of diabetes care and the importance of considering multiple factors in developing effective interventions. While simpler models may provide clearer statistical relationships, the complexity of diabetes management necessitates sophisticated approaches to capture its full dimensionality. These findings provide a foundation for evidence-based decision-making in diabetes care, particularly in the Saudi Arabian context, while suggesting pathways for future research and healthcare system development.

The integration of our findings into clinical practice has the potential to improve patient outcomes through:

- More accurate risk assessment based on demographic profiles
- Enhanced treatment adherence support systems
- Better-targeted interventions considering complication severity
- More efficient resource allocation in healthcare delivery

As diabetes continues to present a significant public health challenge in Saudi Arabia and globally, the insights gained from this study contribute to the ongoing development of more effective, personalized approaches to disease management. Future healthcare initiatives should build upon these findings while continuing to investigate additional factors that may influence diabetes outcomes.

Funding

This work was supported by the Deanship of Scientific Research at King Faisal University Grant No. KFU253649.

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Appendix

Diabetes Management Questionnaire (DMQ) Variables

Variable/Item	**Code**
Gender	X1
Age	X2
Nationality	X3
From which city in the Kingdom?	X4
Marital Status	X5
Employment Status	X6
Type of diabetes you have	X7
Since when were you diagnosed with diabetes?	X8
What medications do you use?	X9
What is the form of insulin you use?	X10
Who administers insulin to you?	X11
How often do you follow up with your diabetes doctor?	X12
What was your last measured HbA1c level?	X13
Have you been hospitalized due to diabetes?	X14
If yes, how many times have you been hospitalized due to diabetes?	X15
How often do you monitor your blood sugar at home?	X16
Do you suffer from hypoglycemia?	X17
Do you have any complications resulting from diabetes? Other accompanying diseases?	X18
Have you ever had a session with a specialist/doctor who guided you on how to use insulin?	X19
If yes, do you apply what you were told?	X20
Where do you store insulin?	X21
Where do you prefer insulin injections?	X22
How do you inject insulin?	X23
Do you gently mix insulin before using it?	X24
Do you change the injection site with each injection?	X25

Have you noticed any problems with injection sites?	X26
Do you sterilize the injection site?	X27
Do you change the insulin needle each time?	X28
When do you take long-acting insulin?	X29
Do you adhere to your insulin regimen?	X30
Regarding your meals, when do you take insulin?	X31
Are you aware of calculating carbohydrates to adjust insulin before meals?	X32
Do you increase insulin before meals?	X33
Where do you think you can get information about insulin use?	X34