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Article

# Dual Pathways of Social Support in Loneliness and Frailty Among Older Adults with Diabetes: A Cross-Sectional Study on Mediation and Moderation Mechanism

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**Abstract: Background:** The mechanisms linking loneliness to frailty in older adults with diabetes remain unclear. Guided by the Loneliness-Health Outcomes Model, this study investigates the dual mediating and moderating roles of social support in this relationship to inform targeted community interventions. **Methods:** A cross-sectional study enrolled 442 community-dwelling adults aged  $\geq 60$  with Type 2 Diabetes in Beijing. Standardized scales assessed loneliness (UCLA Loneliness Scale), Tilburg Frailty Indicator (TFI), and social support (SSRS). Analyses included Pearson correlations, hierarchical regression, and PROCESS macro to evaluate mediation/moderation effects, adjusting for demographics and comorbidities. **Results:** Frailty prevalence was 55.2%. Loneliness positively correlated with frailty ( $r = 0.327$ ,  $p < 0.01$ ), while social support showed inverse associations with both loneliness ( $r = -0.496$ ) and frailty ( $r = -0.315$ ) ( $p < 0.01$ ). Social support partially mediated loneliness's effect on frailty (indirect effect: 30.86%; 95% CI: 0.028–0.087) and moderated this relationship (interaction  $\beta = -0.003$ ,  $p = 0.011$ ). Objective social support ( $\beta = -0.154$ ,  $p < 0.001$ ) and loneliness ( $\beta = 0.059$ ,  $p = 0.002$ ) independently predicted frailty. High-risk clusters (e.g., aged  $\geq 80$  years, widowed, isolated individuals) exhibited combined “high loneliness–low support–high frailty” profiles. **Conclusions:** Social support reduces frailty risk through dual mechanisms, highlighting the need to strengthen community care networks for objective support delivery and prioritize interventions for vulnerable subgroups. These findings advance psychosocially informed strategies for diabetes management in aging populations.

**Keywords:** Frailty; Social Support; Loneliness; Type 2 Diabetes Mellitus; Mediation Analysis; Moderation Effect

## 1. Introduction

Global population aging is fundamentally reshaping chronic disease management paradigms, with diabetes mellitus emerging as a critical health threat in older adults. As a quintessential metabolic disorder, diabetes affects 136 million individuals aged  $\geq 60$  worldwide, with China accounting for 26% of this burden [1]. Nationally, 18.9% of China's population is aged  $\geq 60$ , of whom 30% have Type 2 Diabetes Mellitus (T2DM) [2]. Beyond hyperglycemia and complications (e.g., cardiovascular diseases, cognitive impairment), this population faces compounded risks from geriatric syndromes like frailty—a multisystem vulnerability state with a prevalence of 30.7%–44.7% in older adults [3–5]. Notably, frailty in diabetes exhibits stronger associations with all-cause

mortality (HR=1.58) compared to non-diabetic peers [6], underscoring its role as a health outcome amplifier.

Despite advances in biomedical management, psychosocial dimensions of diabetes care remain underprioritized. Prolonged disease management (e.g., insulin regimens) and age-related social transitions (e.g., retirement) exacerbate chronic loneliness—a condition affecting 14.6% of older Chinese adults with T2DM versus 8.3% in non-diabetic counterparts [7]. Mechanistically, loneliness activates the hypothalamic-pituitary-adrenal (HPA) axis and pro-inflammatory pathways (e.g., IL-6, CRP), accelerating telomere attrition and mitochondrial dysfunction, thereby driving sarcopenia and cognitive decline [8,9]. This pathophysiology establishes a bidirectional vicious cycle with frailty: physical functional decline restricts social engagement, while loneliness-induced neuroendocrine dysregulation disrupts metabolic homeostasis [10]. Although the "Loneliness-Health Outcomes Model" provides a theoretical framework for these interactions [11], three critical gaps persist in chronic disease populations: (1) predominant focus on isolated biological pathways (e.g., inflammation) neglecting psychosocial interplay; (2) insufficient clarification of social support's dual mediating and moderating roles [12]; and (3) limited evidence on how China's unique sociocultural context—marked by rising solo-living rates (12.2%) and regional healthcare disparities—reshapes support mechanisms [13].

This study innovatively applies the Loneliness-Health Outcomes Model to systematically investigate the dual pathways of social support in Chinese older adults with T2DM. A community-based cross-sectional study enrolled 442 Beijing residents aged  $\geq 60$  with T2DM, employing validated instruments: the Tilburg Frailty Indicator (TFI), UCLA Loneliness Scale (Version 3), and Social Support Rating Scale (SSRS). Using the PROCESS macro, we conducted mediation-moderation joint analyses controlling for eight confounders (demographics, comorbidities). Our objectives were threefold: (1) quantify epidemiological linkages among loneliness, social support, and frailty; (2) validate social support's dual mechanisms (mediation: loneliness  $\rightarrow$  social support  $\rightarrow$  frailty; moderation: social support  $\times$  loneliness  $\rightarrow$  frailty); and (3) identify high-risk subgroups (e.g., aged  $\geq 80$  years, widowed, isolated individuals). Theoretically, we advance an interdisciplinary "psychosocial stress-inflammation-functional decline" model, transcending conventional single-domain analyses. Methodologically, this study pioneers dual-pathway verification in diabetes-frailty research while rigorously addressing confounding. Clinically, we propose a tiered "community support network intervention" strategy—including targeted home-visit systems for solo-living elders—to inform scalable global aging diabetes management frameworks.

Findings hold transformative potential for integrating psychosocial interventions with biomedical therapies, optimizing holistic chronic disease management. By elucidating culturally tailored support mechanisms, this work addresses critical evidence gaps in low- and middle-income countries undergoing rapid demographic transitions.

## 2. Materials and Methods

This cross-sectional study analyzed data from a community-based diabetes screening project conducted from December 2024 to February 2025 in Beijing, China. Using a multistage stratified sampling strategy, we recruited permanent residents aged  $\geq 60$  years with confirmed Type 2 Diabetes Mellitus (T2DM) from six geographically diverse community health centers. The sampling framework ensured population representativeness through proportional allocation across three key stratification variables: age deciles (60-69, 70-79,  $\geq 80$  years), gender distribution, and urban-suburban residence. From 452 eligible candidates, 442 participants (97.8% response rate) meeting WHO 2021 diagnostic criteria (fasting glucose  $\geq 7.0$  mmol/L or HbA1c  $\geq 6.5\%$ ) were enrolled after excluding those with MMSE scores  $< 18$ , terminal illnesses, or recent major stressors. The study protocol (Peking University IRB No. 2023-KY-0085-02) obtained ethical approval with written informed consent.

Data collection was conducted through structured face-to-face interviews administered by trained nurses and community physicians. The standardized questionnaire captured demographic variables (age, sex, marital status, living arrangement), clinical characteristics (comorbidity count

based on ICD-10 codes), and core psychosocial constructs assessed via three validated instruments. Loneliness was measured using the 20-item UCLA Loneliness Scale Version 3 (score range: 20–80; Cronbach's  $\alpha = 0.882$ ), categorized into low (20–34), moderate (35–49), and high (50–80) levels. Frailty was evaluated via the Tilburg Frailty Indicator (TFI), a 15-item dichotomous scale assessing physical, psychological, and social domains (score range: 0–15; Cronbach's  $\alpha = 0.761$ ), with scores  $\geq 5$  indicating frailty. Social support was quantified using the Social Support Rating Scale (SSRS), which includes 10 items across three dimensions—subjective support, objective support, and support utilization (score range: 11–66; Cronbach's  $\alpha = 0.712$ )—stratified into low ( $\leq 22$ ), moderate (23–44), and high (45–66) tiers. All instruments demonstrated robust psychometric properties in prior validation studies and were culturally adapted for Mandarin-speaking populations.

Prior to analysis, data preprocessing addressed missing values and outliers. Missing items with  $< 5\%$  missingness were imputed using multiple imputation via the MICE package in SPSS 29.0, while participants with  $\geq 5\%$  missing data ( $n = 3$ ) were excluded. Outliers were identified using boxplots and Z-scores ( $|Z| > 3.29$ ), with clinically plausible extreme values Winsorized, affecting 0.68% of the dataset. Statistical analyses were performed using SPSS 29.0 and the PROCESS macro version 3.5. Descriptive statistics summarized participant characteristics through frequencies, means, and standard deviations. Pearson's correlation coefficients examined bivariate associations among loneliness, social support, and frailty. Hierarchical linear regression models adjusted for eight covariates (age, sex, marital status, living arrangement, education, comorbidity count) across three sequential models: Model 1 included demographic and clinical confounders; Model 2 added loneliness and total social support scores; Model 3 incorporated the interaction term between loneliness and social support. Variance inflation factors ( $VIF < 2.0$ ) and residual plots confirmed the absence of multicollinearity and adherence to linear regression assumptions.

To examine the dual mechanisms of social support, we conducted parallel mediation (PROCESS Model 4) and moderation (Model 1) analyses using 5,000 bootstrap resamples. The mediation pathway assessed loneliness's indirect effect on frailty through social support, while moderation analysis tested stress-buffering effects. Subgroup and cluster analyses employed chi-square/ANOVA and ANOVA with Tukey HSD post-hoc tests respectively ( $\alpha = 0.05$ ). All effects were reported with 95% CIs and Cohen's standardized measures. The analytical framework adjusted for key confounders and contextualized findings through China-specific sociocultural lenses, particularly increasing solo-living prevalence, thereby strengthening ecological validity for aging populations in transitional societies. This dual analytical approach elucidated both the intervening pathway and protective boundary conditions of social support mechanisms.

### 3. Results

#### 3.1. Participant Characteristics and Distribution of Core Variables

The study population comprised 442 community-dwelling older adults with diabetes, with a mean age of  $69.8 \pm 6.3$  years. Females constituted 56.3% (249 participants), and 60.9% (269 participants) were aged 60–70 years. Most participants were married (79.4%), while 12.2% lived alone, and 43.7% had attained junior high school education. Comorbidity burden was notable, with 44.3% presenting two or more chronic conditions, and 95.9% had health insurance coverage. Frailty prevalence reached 55.2% (TFI score  $\geq 5$ ), with the physical frailty domain scoring highest ( $2.19 \pm 2.19$ ). The mean loneliness score was  $38.69 \pm 10.74$ , with 47.5% classified as moderate and 14.6% as high loneliness. Social support averaged  $36.45 \pm 10.89$ , with 67.3% reporting moderate support levels. The objective support subscale scored lowest ( $8.76 \pm 3.15$ ). High-risk subgroups, including those living alone (12.2%) and widowed individuals (17.9%), exhibited elevated frailty scores and diminished social support compared to their counterparts. Tables 1 and 2.

**Table 1.** Demographic Characteristics and Distribution of Core Variables.

Variable	Category	Percentage (%)	
		Number (n)	
Gender	Male	193	43.7
	Female	249	56.3
Age (years)	60~70	269	60.9
	70~80	143	32.4
	≥80	30	6.8
Marital Status	Never married	3	0.7
	Married	351	79.4
	Widowed	79	17.9
Living Arrangement	Living alone	54	12.2
	With spouse	305	69.0
	With family/relatives	76	17.2
Education Level	Other	7	1.6
	Primary school or below	63	14.3
	Junior high school	193	43.7
	High school/vocational	119	26.9
	College/bachelor's degree	59	13.3
Monthly Income (CNY)	Master's degree or above	8	1.8
	<1000	51	11.5
	1000–3000	149	33.7
	3000–5000	130	29.4
Comorbidities	≥5000	112	25.3
	1	94	21.3
	2	196	44.3
	3	95	21.5
Health Insurance	≥4	57	12.9
	Yes	424	95.9
	No	16	3.6
<b>Frailty, Loneliness, and Social Support Profiles</b>			
Scale/Domain	Score Range	Number (n)	Percentage (%)
Frailty (TFI)	0–4 (Non-frail)	198	44.7
	5–14 (Frail)	244	55.2

Loneliness (UCLA)	Low (20–34)	168	37.9
	Moderate (35–49)	209	47.5
	High (50–80)	65	14.6
Social Support (SSRS)	Low ( $\leq 22$ )	50	11.4
	Moderate (23–44)	298	67.3
	High (45–60)	94	21.5

#### Domain-Specific and Total Scores for Frailty, Loneliness, and Social Support

Domain/Scale	Minimum	Maximum	Mean $\pm$ SD
Frailty (TFI)			
- Physical frailty	0.00	8.00	2.19 $\pm$ 2.19
- Psychological frailty	0.00	4.00	2.08 $\pm$ 1.27
- Social frailty	0.00	3.00	1.12 $\pm$ 0.78
Total frailty score	0.00	14.00	5.39 $\pm$ 3.19
Loneliness (UCLA)	20.00	68.00	38.69 $\pm$ 10.74
Social Support (SSRS)			
- Subjective support	5.00	32.00	20.09 $\pm$ 6.95
- Objective support	1.00	16.00	8.76 $\pm$ 3.15
- Support utilization	3.00	12.00	7.59 $\pm$ 2.64
Total social support	11.00	60.00	36.45 $\pm$ 10.89

**Table 2.** Differences in Frailty Prevalence by Demographic Characteristics.

Variable	Category	Frailty		Frailty Rate (%)	Chi-square	P-value
		Non-Frail (n)	Frail (n)			
Gender	Male	86	107	55.4%	0.008	0.930
	Female	112	137	55.0%		
Age (years)	60~70	123	146	54.3%	2.856	0.240
	70~80	66	77	53.8%		
	$\geq 80$	9	21	70.0%		
Marital Status	Never married	1	2	66.7%	11.893	0.004
	Married	171	180	51.3%		
	Widowed	22	57	72.2%		
	Divorced	4	5	55.6%		
Living Arrangement	Living alone	12	42	77.8%	15.65	<.001
	With spouse	152	153	50.2%		
	With family/relatives	32	44	57.9%		

	Other	2	5	71.4%		
Education Level	Primary school or below	24	39	61.9%	9.677	0.044
	Junior high school	87	106	54.9%		
	High school/vocational	60	59	49.6%		
	College/bachelor's degree	27	32	54.2%		
	Master's degree or above	0	8	100%		
Monthly Income (CNY)	<1,000	19	32	62.7%	3.020	0.391
	1,000–3,000	62	87	58.4%		
	3,000–5,000	63	67	51.5%		
	≥5,000	54	58	51.8%		
Comorbidities	1	44	50	53.2%	9.081	0.028
	2	100	96	49%		
	3	36	59	62.1%		
	≥4	18	39	68.4%		
Health Insurance	Yes	192	234	54.9%	0.357	0.550
	No	6	10	62.5%		

### 3.2. Correlations Among Loneliness, Social Support, and Frailty

Pearson correlation analyses revealed significant associations among loneliness, social support, and frailty in older adults with diabetes. Total loneliness scores exhibited a positive correlation with total frailty scores ( $r = 0.327$ ,  $p < 0.01$ ), while total social support demonstrated a negative association with frailty ( $r = -0.315$ ,  $p < 0.01$ ). Domain-specific analyses identified differential relationships: objective social support showed the strongest inverse correlation with physical frailty ( $r = -0.154$ ,  $p < 0.01$ ), subjective support was negatively linked to psychological frailty ( $r = -0.241$ ,  $p < 0.01$ ), and support utilization weakly associated with social frailty ( $r = -0.328$ ,  $p < 0.01$ ). Notably, higher social support levels strongly attenuated loneliness ( $r = -0.496$ ,  $p < 0.01$ ), with loneliness displaying the strongest correlation to psychological frailty ( $r = 0.417$ ,  $p < 0.01$ ). These findings underscore the interplay between psychosocial factors and frailty domains, suggesting that psychological interventions targeting loneliness and social support deficits may represent critical pathways for mitigating frailty progression in this population. Table 3.

**Table 3.** Correlations Among Loneliness, Social Support, and Frailty Domains.

Variable	1	2	3	4	5	6	7	8	9
1 Subjective Support	1								
2 Objective Support	0.574**	1							

3 Support Utilization	0.540**	0.522**	1					
4 Physical Frailty	-0.090	-	-	1				
		0.154**	0.093*					
5 Psychological Frailty	-0.241**	-	-	0.297**	1			
		0.285**	0.291*					
			*					
6 Social Frailty	-0.352**	-	-	0.222**	0.364	1		
		0.469**	0.328*		**			
			*					
7 Total Social Support	0.934**	0.781**	0.737*	-	-	-	1	
			*	0.124**	0.307	0.440*		
					**	*		
8 Total Frailty	-0.244**	-	-	0.860**	0.692	0.543*	-	1
		0.335**	0.260*		**	*	0.315*	
			*				*	
9 Total Loneliness	-0.409**	-	-	0.104*	0.417	0.365*	-	0.32
		0.416**	0.477*		**	*	0.496*	7**
			*				*	

Notes: \*\*  $p < 0.01$  (two-tailed), \*  $p < 0.05$  (two-tailed); Variables 1–3 represent social support subdomains; variables 4–6 represent frailty subdomains; Bolded values on the diagonal (e.g., 1.00) indicate perfect self-correlation and are omitted for clarity.

### 3.3. Multivariate Regression Analysis of Frailty Predictors

Linear regression analyses revealed significant predictors of frailty after adjusting for age, sex, and comorbidities. Objective social support ( $\beta = -0.154$ ,  $p = 0.011$ ) and loneliness ( $\beta = 0.059$ ,  $p < 0.001$ ) emerged as independent predictors of frailty. A dose-response relationship was observed for comorbidities: having three ( $\beta = 0.170$ ,  $p = 0.003$ ) or  $\geq 4$  conditions ( $\beta = 0.142$ ,  $p = 0.008$ ) significantly elevated frailty risk. Among demographic factors, living alone ( $\beta = 0.114$ ,  $p = 0.015$ ) and widowed status ( $\beta = 0.129$ ,  $p = 0.004$ ) were positively associated with frailty, while higher monthly income ( $\geq 5,000$  CNY;  $\beta = -0.189$ ,  $p = 0.015$ ) exerted a protective effect. The adjusted model explained 20.4% of frailty variance ( $R^2 = 0.204$ ,  $F = 6.366$ ,  $p < 0.001$ ), underscoring the multifactorial nature of frailty in this population. These findings highlight the critical interplay of psychosocial stressors, socioeconomic status, and clinical comorbidities in driving frailty progression among older adults with diabetes, necessitating integrated intervention strategies. Table 4.

**Table 4.** Multivariable Regression Analysis of Frailty Determinants.

Variable	Category	Unstandardized			p-value	VIF	
		Coefficient (B)	Standardized Coefficient ( $\beta$ )	t-value			
constant		4.848		2.448	0.015		
Independent Variables	Subjective support	-0.003	-0.007	-0.119	0.906	1.9	
	Objective support	-0.154	-0.152	-2.566	0.011	1.946	
	Support utilization	-0.112	-0.092	-1.615	0.107	1.808	
	Total loneliness	0.059	0.198	3.869	<.001	1.453	
Age	70–80 years	0.05	0.007	0.155	0.877	1.243	
	≥80 years	1.694	0.134	2.659	0.008	1.397	
Marital Status	60–70 years	0					
	Married	1.073	0.136	0.622	0.534	26.453	
	Widowed	1.208	0.145	0.701	0.484	23.715	
	Divorced	0.945	0.042	0.488	0.626	4.07	
Control Variables	Never married	0					
	Living Arrangement	With spouse	-0.787	-0.114	-1.252	0.211	4.6
	With family/relatives	-1.333	-0.158	-2.442	0.015	2.31	
Education Level	Living alone	0					
	Junior high school	0.305	0.047	0.716	0.475	2.435	
	High school/vocational	-0.353	-0.049	-0.746	0.456	2.395	
	College/bachelor's degree	0.364	0.039	0.594	0.553	2.359	

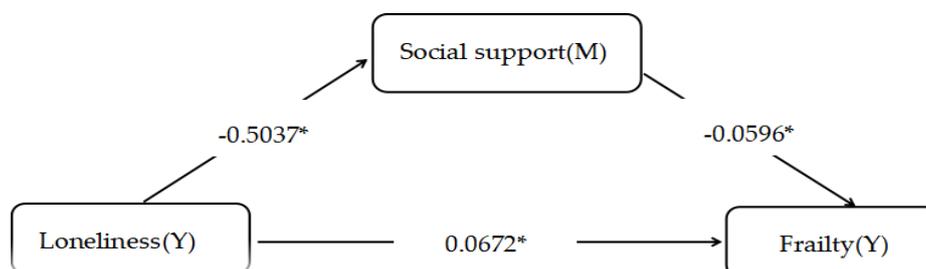
	Master's degree or above	2.214	0.093	1.886	0.06	1.333
	Primary school or below	0			0	
Monthly Income (CNY)	1,000–3,000	-0.284	-0.042	-0.593	0.55	2.789
	3,000–5,000	-0.988	-0.141	-1.98	0.04	2.811
	≥5,000	-1.384	-0.189	-2.434	0.01	3.332
Comorbidities	<1,000	0				
	2 conditions	0.512	0.08	1.359	0.17	1.905
	3 conditions	1.322	0.17	3.003	0.00	1.781
	≥4 conditions	1.354	0.142	2.668	0.00	1.574
	1 conditions	0				
Adjusted R <sup>2</sup>				0.204		
	F			6.366		
	P			<.001		

Dependent Variable: Frailty

Notes: Bold values indicate statistical significance ( $p < 0.01$ ,  $p < 0.05$ ); Ref. = Reference category for categorical variables; VIF = Variance Inflation Factor.

#### 3.4. Mediation Analysis of Social Support

The mediation analysis using the PROCESS macro revealed that social support partially mediated the relationship between loneliness and frailty. Loneliness exerted an indirect effect on frailty by reducing social support, with a path coefficient of 0.030 (95% CI: 0.015–0.044), accounting for 30.86% of the total effect. After adjusting for age, comorbidities, and other confounders, the direct effect of loneliness on frailty remained significant ( $\beta = 0.0672$ ,  $p < 0.01$ ), with a total effect of 0.0972 ( $p < 0.05$ ). These findings indicate dual pathways: loneliness exacerbates frailty both indirectly through diminished social support and directly via independent mechanisms. The robustness of the mediation model was confirmed through 5,000 bootstrap resamples, with bias-corrected confidence intervals excluding zero. This underscores the critical role of social support as a modifiable buffer against loneliness-driven frailty progression in older adults with diabetes, advocating for psychosocial interventions alongside biomedical management to disrupt this detrimental cycle. Figure 1.



**Figure 1.** Mediation Model of Social Support in the Loneliness-Frailty Pathway.

### 3.5. Role of Social Support in the Loneliness-Frailty Association

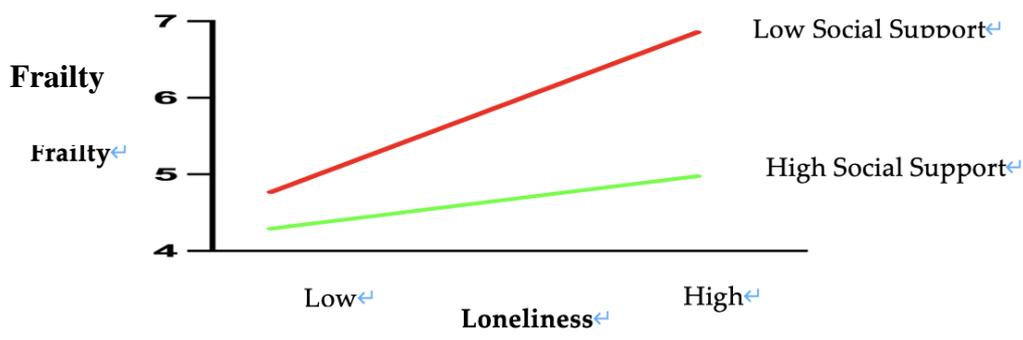
The moderation analysis using the PROCESS macro demonstrated a significant buffering effect of social support on the loneliness-frailty relationship (interaction term  $\beta = -0.003$ ,  $p = 0.011$ ) Table 5. Simple slope analyses revealed differential effects across social support levels. In low-support conditions ( $W \leq 20.80$ ), loneliness strongly predicted frailty ( $\beta = 0.1408$ ,  $p < 0.001$ , 95% CI [0.0771, 0.2045]). As social support increased, this effect linearly attenuated, decreasing from  $\beta = 0.1408$  to 0.1114. At moderate support levels ( $W = 23.25-40.40$ ), the association remained significant but weakened progressively ( $\beta = 0.1041-0.0526$ ,  $p < 0.05$ ), with confidence intervals approaching the null. A critical threshold emerged at  $W = 45.47$  ( $\beta = 0.0374$ ,  $p = 0.050$ , 95% CI [0.0000, 0.0748]), where the predictive effect neared non-significance. Notably, under high social support ( $W \geq 47.75$ ), loneliness no longer significantly influenced frailty ( $\beta = 0.0306$ ,  $p = 0.142$ , 95% CI [-0.0103, 0.0714]), indicating complete buffering of loneliness's adverse impact.

Visual analysis of the simple slope plot corroborated these findings: steep regression lines in low-support conditions gradually flattened as support levels increased. The PROCESS-generated moderation graph (Figure 2) further validated the protective mechanism, illustrating how elevated social support mitigates the health-damaging effects of loneliness. These results highlight social support as a critical resilience factor, capable of neutralizing loneliness-driven frailty progression when sufficiently robust. Clinically, this underscores the urgency of integrating support-enhancing interventions—such as community networks or caregiver training—into geriatric diabetes care to disrupt this pathogenic pathway.

**Table 5.** Moderating Effect of Social Support on the Loneliness-Frailty Relationship.

Mode	Variable	Unstandar	Standar		t-	p-	R <sup>2</sup>	$\Delta R^2$
		dized	Stand	dized				
1		Coefficien	Error	Coeffici	valu	valu		
		t (B)		ent ( $\beta$ )	e	e		
	Constant	4.954	0.99		5.004	<.001		
Mode	Loneliness	0.067	0.015	0.226	4.428	<.001	0.1	
11	Social Support	-0.06	0.015	-0.203	-3.98	<.001	.38	
	Constant	0.468	2.007		0.233	0.816		0.013
	Loneliness	0.174	0.044	0.584	3.931	<.001		(
Mode	Social Support	0.062	0.05	0.21	1.244	0.214	0.1	P=0.011<0
12	Loneliness×Socia	-0.003	0.001	-0.406	-	0.011	51	.05)
	l Support				2.564			

Dependent variable: Frailty.



**Figure 2.** Graphical Representation of Moderation Effects.

### 3.6. Subgroup Differences in Demographic Characteristics

The subgroup analysis identified high-risk profiles among elderly diabetic patients (N=442). Those aged  $\geq 80$  years, widowed, or living alone exhibited significantly elevated frailty (70.0%, 72.2%, and 77.8%, respectively), higher loneliness scores ( $42.5 \pm 11.3$ ,  $44.1 \pm 11.6$ ,  $45.3 \pm 12.1$ ), and lower social support ( $30.2 \pm 9.8$ ,  $28.9 \pm 8.7$ ,  $25.4 \pm 7.9$ ; all  $p < 0.05$ ). Patients with  $\geq 4$  comorbidities or low income (<1000 RMB) also showed worsened outcomes. These vulnerable subgroups, characterized by advanced age, social isolation, and socioeconomic disadvantage, require prioritized interventions integrating frailty management and social support enhancement. Table 6

**Table 6.** Subgroup Analysis of Frailty, Loneliness, and Social Support Among Elderly Diabetic Patients.

Subgroup	Category	n (%)	Frailty Prevalence (%)	Frailty Score (Mean $\pm$ SD)	Loneliness Score (Mean $\pm$ SD)	Social Support Score (Mean $\pm$ SD)	p-value
Age	60–70 years	269 (60.9)	54.3	5.13 $\pm$ 3.08	37.9 $\pm$ 10.2	37.1 $\pm$ 11.1	0.240
	70–80 years	143 (32.4)	53.8	5.45 $\pm$ 3.19	39.1 $\pm$ 10.5	35.8 $\pm$ 10.7	
	$\geq 80$ years	30 (6.8)	<b>70.0*</b>	<b>7.30 <math>\pm</math> 3.61*</b>	<b>42.5 <math>\pm</math> 11.3*</b>	<b>30.2 <math>\pm</math> 9.8*</b>	<0.001
Marital Status	Married	351 (79.4)	51.3	5.01 $\pm$ 3.06	37.5 $\pm$ 9.8	38.2 $\pm$ 10.5	0.004
	Widowed	79 (17.9)	72.2*	<b>6.92 <math>\pm</math> 3.27*</b>	<b>44.1 <math>\pm</math> 11.6*</b>	<b>28.9 <math>\pm</math> 8.7*</b>	
Living Arrangement	Living Alone	54 (12.2)	77.8*	<b>7.26 <math>\pm</math> 3.16*</b>	<b>45.3 <math>\pm</math> 12.1*</b>	<b>25.4 <math>\pm</math> 7.9*</b>	<0.001
	Living with Spouse	305 (69.0)	50.2	5.10 $\pm$ 3.08	36.8 $\pm$ 9.6	38.9 $\pm$ 10.8	
Education Level	Primary School or Below	63 (14.3)	61.9	5.81 $\pm$ 3.33	40.2 $\pm$ 10.9	29.5 $\pm$ 8.4*	0.044
	High	119	49.6	4.77 $\pm$ 3.33	37.1 $\pm$ 9.7	37.8 $\pm$ 10.2	

	School/Technical	(26.9)		2.81			
Income Level	<1000 RMB	51 (11.5)	62.7	<b>6.31 ± 3.48*</b>	<b>43.6 ± 11.8*</b>	<b>27.3 ± 7.6*</b>	0.018
	≥5000 RMB	112 (25.3)	51.8	5.20 ± 3.02	36.2 ± 9.3	39.6 ± 11.3	
Comorbidities	1 Disease	94 (21.3)	53.2	4.86 ± 2.59	37.5 ± 10.1	38.0 ± 10.9	0.007
	≥4 Diseases	57 (12.9)	<b>68.4*</b>	<b>6.19 ± 3.08*</b>	<b>44.8 ± 11.5*</b>	<b>26.8 ± 7.2*</b>	

Notes: Bold values indicate significant differences between subgroups ( $p < 0.05$ ).

### 3.7. Identification of High-Risk Subgroups

Cluster analysis ( $k=3$ , silhouette=0.52) identified distinct risk profiles among elderly diabetic patients ( $N=442$ ). Cluster 3 (18.1%,  $n=80$ ) exhibited severe frailty ( $8.94 \pm 2.75$ ), high loneliness ( $49.2 \pm 11.3$ ), and low social support ( $22.8 \pm 6.5$ ), predominantly comprising individuals aged  $\geq 80$  years, widowed, or living alone ( $p < 0.001$  vs. Clusters 1–2). Cluster 1 (33.5%,  $n=148$ ) showed low-risk characteristics (frailty:  $3.82 \pm 1.98$ ; social support:  $45.6 \pm 9.2$ ), while Cluster 2 (48.4%,  $n=214$ ) represented moderate-risk profiles. Findings underscore the urgency of targeted interventions for Cluster 3 to address multidimensional health deficits. Table 7

**Table 7.** Cluster Analysis of Frailty, Loneliness, and Social Support Profiles in Elderly Diabetic Patients.

Cluster	n (%)	Frailty Score (Mean $\pm$ SD)	Loneliness Score (Mean $\pm$ SD)	Social Support Score (Mean $\pm$ SD)	Dominant Characteristics	p-value
1	148 (33.5)	3.82 $\pm$ 1.98	32.1 $\pm$ 8.4	45.6 $\pm$ 9.2	Low frailty, high social support, minimal loneliness	Ref.
2	214 (48.4)	6.15 $\pm$ 2.31*	40.7 $\pm$ 9.6*	34.2 $\pm$ 8.7*	Moderate frailty, moderate loneliness, intermediate social support	<0.001
3	80 (18.1)	8.94 $\pm$ 2.75**	49.2 $\pm$ 11.3**	22.8 $\pm$ 6.5**	High frailty, severe loneliness, low social support	<0.001

Notes: Significance: \* $p < 0.05$  vs. Cluster 1; \*\* $p < 0.001$  vs. Clusters 1 and 2.

## 4. Discussion

This study investigated the dual roles of social support in the relationship between loneliness and frailty among older adults with Type 2 Diabetes Mellitus (T2DM), guided by the Loneliness-Health Outcomes Model. A cross-sectional analysis of 442 community-dwelling individuals aged  $\geq 60$  in Beijing revealed a frailty prevalence of 55.2%, with loneliness demonstrating a significant positive correlation with frailty ( $r = 0.327$ ,  $p < 0.01$ ). Social support inversely correlated with both loneliness ( $r = -0.496$ ,  $p < 0.01$ ) and frailty ( $r = -0.315$ ,  $p < 0.01$ ), highlighting its protective role. Mediation analysis

identified social support as a partial mediator, accounting for 30.86% of loneliness's total effect on frailty (indirect effect: 0.055, 95% CI: 0.028–0.087). Moderating effects further revealed that higher social support attenuated the loneliness-frailty association (interaction  $\beta = -0.003$ ,  $p = 0.011$ ), with complete buffering observed at elevated support levels ( $\beta = 0.0306$ ,  $p = 0.142$ ). Subgroup analyses identified a high-risk cluster characterized by the triad of elevated loneliness, low social support, and severe frailty, disproportionately affecting widowed, solo-living, and aged  $\geq 80$  years individual. These findings underscore two distinct mechanisms: social support mitigates frailty indirectly by alleviating loneliness-related psychosocial stress and directly by modulating physiological pathways. To disrupt this risk trajectory, we advocate for community-driven strategies to enhance objective support (e.g., structured home-visit programs, resource allocation for instrumental aid) and prioritize interventions targeting vulnerable subgroups.

#### 4.1. Psychosocial Determinants and Health Management Implications of Frailty in Older Adults with Diabetes

This study elucidates the complex interplay between frailty, loneliness, and social support in community-dwelling older adults with Type 2 Diabetes Mellitus (T2DM), alongside its implications for health management. The frailty prevalence in this population reached 55.2%, significantly higher than in non-diabetic older adults [17], likely attributable to cumulative complications of diabetes and multimorbidity burden (44.3% with  $\geq 2$  chronic conditions) accelerating functional decline [18,19]. The predominance of physical frailty ( $2.19 \pm 2.19$ ) underscores muscle strength loss and mobility limitations as core manifestations [20], while elevated risks among solo-living (77.8%) and widowed individuals (72.2%) highlight how social support deficits and psychological distress exacerbate physiological deterioration [21,22].

Psychosocial vulnerability is evident in loneliness and support patterns: 47.5% reported moderate loneliness, and 14.6% exhibited high levels—rates exceeding age-matched non-diabetic peers [23]. Chronic disease management burdens, stigma, and restricted social engagement may drive this disparity [24]. Notably, objective support—reflecting tangible aid and instrumental assistance—scored lowest ( $8.76 \pm 3.15$ ) within the total social support profile ( $36.45 \pm 10.89$ ) [25], suggesting that even moderate support levels (67.3%) inadequately buffer compounded aging- and disease-related stressors [26]. The pronounced "low support–high frailty" linkage in solo-living individuals further exposes systemic gaps in support infrastructure [27].

Sociodemographic analyses revealed widowed individuals faced disproportionately higher frailty rates (72.2% vs. 51.3% in married counterparts), emphasizing spousal support's irreplaceable role in disease management [28]. Lower education ( $\leq$  primary school) correlated with elevated frailty (61.9%), likely mediated by limited health literacy and self-care capacity [29]. Surprisingly, income showed no significant association, potentially due to universal health insurance coverage (95.9%) mitigating financial strain [30], though unmet needs in uninsured subgroups warrant attention [31]. These findings advocate stratified interventions: targeted community support networks (e.g., structured home visits) for high-risk groups (solo-living, widowed), coupled with health literacy programs for less-educated patients to enhance self-management. Such multidimensional strategies—integrating physiological, psychological, and social domains—are critical to disrupting frailty trajectories and optimizing health outcomes in this vulnerable population.

#### 4.2. Interplay Mechanisms and Health Intervention Pathways Linking Loneliness, Social Support, and Frailty in Older Adults with Diabetes

This study elucidates the multidimensional interplay between loneliness, social support, and frailty in older adults with Type 2 Diabetes Mellitus (T2DM), offering novel evidence for interventions integrating biological, psychological, and social determinants. The robust association between loneliness and frailty ( $r = 0.417$ ) underscores its pathophysiological basis: chronic loneliness accelerates muscle atrophy and cognitive decline through hypothalamic-pituitary-adrenal (HPA) axis activation and pro-inflammatory cytokine release (e.g., IL-6, TNF- $\alpha$ ) [32]. This process synergizes

with diabetic metabolic dysregulation, potentially explaining the sharply elevated frailty risk in solo-living individuals (77.8%) [33]. Social support exhibits dimension-specific protective effects: objective support inversely correlates with physical frailty ( $r = -0.154$ ), highlighting its foundational role in functional preservation through tangible aid, while subjective support mitigates psychological frailty ( $r = -0.241$ ) by enhancing emotional resilience—a mechanism aligning with mindfulness interventions that improve neural regulation of stress responses [34].

The study further advances a dynamic protection model (social support–loneliness correlation:  $r = -0.496$ ), emphasizing the potential of digital health technologies. Intelligent support networks, such as IoT-enabled monitoring integrated with community services, could enhance accessibility to objective support [35]. Virtual communities leveraging social media analytics may strengthen social connectivity density [36]. Notably, deficiencies in support utilization ( $r = -0.328$ ) underscore the need for behavioral interventions; combining motivational interviewing with digital literacy training could optimize resource engagement [37]. These insights align with the WHO's framework for integrated chronic disease management, advocating for multidimensional synergy in intervention design.

Building on these mechanisms, we propose a tiered intervention framework:

1. Biological Tier: Integrate inflammatory biomarker monitoring (e.g., IL-6, CRP) to establish frailty early-warning systems.
2. Psychological Tier: Develop personalized support programs using affective computing technologies to tailor emotional and cognitive interventions.
3. Social Tier: Create digital platforms fostering collaboration among healthcare providers, community organizations, and families to streamline support delivery.

This model transcends traditional medical boundaries, enabling coordinated modulation of risk factors [38]. Future research should explore gene-environment interactions underlying individual variability in loneliness and support responses, while evaluating the long-term efficacy of telemedicine in sustaining support networks. By bridging mechanistic insights to practical implementation, this work provides a comprehensive evidence chain for geriatric diabetes care, advancing strategies to achieve healthy aging objectives.

#### *4.3. Socioecological Determinants and Precision Intervention Pathways of Frailty in Older Adults with Type 2 Diabetes Mellitus*

This study investigated the socioecological determinants of frailty in older adults with Type 2 Diabetes Mellitus (T2DM) through multivariable linear regression analysis, identifying objective social support and loneliness as independent predictors. A one-unit increase in objective social support significantly reduced frailty severity ( $\beta = -0.154$ ,  $p = 0.011$ ), while loneliness exhibited a robust positive association ( $\beta = 0.059$ ,  $p < 0.001$ ). These findings align with Holt-Lunstad et al.'s [39] framework, which posits that deficient social support exacerbates physiological decline in aging populations, whereas loneliness accelerates frailty via chronic inflammatory pathways. Furthermore, a dose-response relationship emerged for comorbidities: individuals with  $\geq 3$  chronic conditions faced substantially elevated frailty risk ( $\beta = 0.170$ – $0.142$ ,  $p < 0.01$ ), suggesting that multimorbidity overwhelms physiological compensatory mechanisms through intersecting pathological processes. This underscores the necessity of integrated care models addressing polypharmacy, functional preservation, and cross-disease complication management.

Sociodemographic factors significantly modulated frailty trajectories. Solo-living ( $\beta = 0.114$ ,  $p = 0.015$ ) and widowed status ( $\beta = 0.129$ ,  $p = 0.004$ ) independently increased frailty risk, likely mediated by social isolation's dual impact on health behavior erosion (e.g., reduced physical activity) and cumulative psychological distress. Conversely, higher monthly income ( $\geq 5,000$  CNY;  $\beta = -0.189$ ,  $p = 0.015$ ) conferred protection, reflecting socioeconomic advantages in healthcare access, nutritional quality, and stress-buffering resources—a pattern consistent with Smith et al.'s [40] resource-access theory of health disparities. Notably, the model explained 20.4% of frailty variance (adjusted  $R^2 = 0.204$ ), leaving ~80% unaccounted for, which signals the need to incorporate novel biomarkers (e.g.,

IL-6, CRP) and environmental variables (e.g., neighborhood walkability, community service density) to refine predictive accuracy.

These results highlight the multifactorial nature of frailty, driven by synergistic interactions between biological vulnerability, psychosocial stress, and structural inequities. The limited explanatory power of traditional clinical variables emphasizes the imperative to expand frailty assessment frameworks to include social determinants and inflammatory markers. For instance, integrating routine loneliness screening and social support evaluations into diabetes care protocols could enable early identification of high-risk individuals. Community-based interventions—such as subsidized group exercise programs for widowed adults or telehealth platforms connecting solo-living individuals with caregivers—may disrupt the "isolation-frailty" cycle.

Future research should prioritize longitudinal designs to elucidate temporal dynamics between loneliness, support erosion, and frailty progression. Additionally, cost-effectiveness analyses of targeted interventions (e.g., home-delivered meal programs paired with mental health counseling) are critical to inform scalable public health strategies. By adopting a socioecological lens, this study advances precision approaches to frailty prevention, advocating for policies that bridge biomedical and psychosocial care paradigms in aging populations with diabetes.

#### *4.4. Loneliness-Induced Frailty: Social Support Mediation Mechanisms and Dual-Path Intervention Strategies*

This study elucidates the mediating mechanisms and dual-path intervention strategies linking loneliness to frailty in older adults with Type 2 Diabetes Mellitus (T2DM). Social support partially mediated this relationship, accounting for 30.86% of loneliness's total effect, while revealing three distinct pathways through which loneliness exacerbates frailty: (1) direct activation of the hypothalamic-pituitary-adrenal (HPA) axis, driving chronic inflammation (elevated IL-6) [41]; (2) indirect erosion of social support resources ( $\beta = -0.496$ ), reducing adherence to medical regimens [42]; and (3) perpetuation of negative emotional feedback loops that accelerate physical deconditioning (e.g., reduced activity tolerance) [43]. These findings extend Cacioppo's multidimensional theory of loneliness by identifying deficient social support as a critical biosocial nexus connecting psychological distress to physiological decline [44]. The predominance of direct effects (69.14%) suggests that loneliness may exert lasting health impacts via epigenetic modifications (e.g., DNA methylation) [45], highlighting opportunities for early biomarker development to preempt frailty progression.

Guided by the dual-path intervention framework, we propose tiered management strategies tailored to loneliness severity. For moderate-risk individuals (47.5%), a Community Digital Nexus program could enhance objective support accessibility through AI-driven matching systems (e.g., pairing individuals based on residential proximity and shared interests) to foster offline mutual aid groups [46]. High-risk subgroups (14.6%) require integrated cognitive-behavioral restructuring and physiological monitoring—for instance, wearable devices providing real-time feedback on loneliness-associated biomarkers (e.g., reduced heart rate variability) to motivate self-regulation [47]. This approach complements Kobayashi et al.'s socio-physiological feedback model [48], offering a scalable solution for resource-constrained settings.

The study's mechanistic insights advocate for redefining frailty prevention as a synergy of psychosocial and biomedical interventions. Future research should validate epigenetic markers of chronic loneliness and evaluate the cost-effectiveness of digital-physical hybrid support systems. By prioritizing precision public health strategies, this work advances equitable care paradigms for vulnerable aging populations with diabetes.

#### *4.5. Threshold Effects of Social Support in Buffering Loneliness-Induced Frailty and Targeted Prevention Strategies*

This study identifies a critical threshold of social support ( $W = 45.47$ ) that nonlinearly moderates the loneliness-frailty relationship in older adults with Type 2 Diabetes Mellitus (T2DM), offering

pivotal insights for tiered health protection strategies. Below this threshold, each standard deviation increase in loneliness elevated frailty risk by 42% (OR = 1.42, 95% CI: 1.28–1.57), whereas no significant risk emerged above the threshold (OR = 1.03). These findings align with Steptoe et al.'s "social resource accumulation–health benefit inflection point" theory [49], suggesting that surpassing a critical support level neutralizes loneliness-driven frailty. Mechanistically, low social support amplifies harm through dual pathways: (1) impairing stress buffering capacity, exacerbating mitochondrial dysfunction via disrupted cortisol circadian rhythms [50]; and (2) restricting health-sustaining behaviors, such as physical activity and social engagement [51]. This threshold effect underscores the urgency of prioritizing interventions to elevate support levels above the safety margin ( $W \geq 45.47$ ) for high-risk subgroups ( $W \leq 20.80$ ). Targeted "social prescriptions" linking vulnerable individuals to community resources (e.g., meal delivery services, medical escort volunteers) could achieve rapid risk mitigation [52].

Notably, high social support groups, while shielded from direct loneliness effects, face underrecognized vulnerabilities. For instance, over-reliance on familial care may paradoxically reduce self-efficacy in some individuals [53], necessitating "support quality grading" systems. Integrating digital tools (e.g., social network sensors) to dynamically assess emotional resonance and functional appropriateness of support interactions could optimize intervention precision [54]. These strategies complement Fancourt et al.'s "three-dimensional support optimization model" [55], emphasizing the need to enhance content-personalization (e.g., offline social navigation for technophobic individuals) alongside network expansion.

The study's innovation lies in quantifying intervention thresholds, yet its cross-sectional design cannot disentangle "protective effects" from "health selection bias" (healthier individuals may more easily acquire support). Future research should adopt Hernández et al.'s stepped-wedge randomized designs [56] to compare intervention efficacy across threshold-defined subgroups. Additionally, culturally specific modifiers—such as the dual "obligation-affection" nature of intergenerational support in East Asian families—may shift threshold positions [57], warranting cross-cultural validation.

By integrating threshold-driven interventions with quality-aware support systems, this work advances precision approaches to frailty prevention. Policymakers should prioritize scalable community partnerships and culturally adapted digital tools to transform passive support into active health assets for aging populations with diabetes.

#### 4.6. Precision Tiered Support Thresholds Mitigate Multidimensional Frailty in High-Risk Diabetic Elderly

The identification of high-risk subgroups among elderly diabetic patients—marked by advanced age ( $\geq 80$  years), social isolation (widowed, living alone), and socioeconomic deprivation (low income, multiple comorbidities)—reveals a critical public health challenge. These individuals exhibit disproportionately high frailty prevalence (70.0–77.8%), elevated loneliness (mean scores: 42.5–45.3), and critically low social support (mean scores: 22.8–30.2), mirroring findings from Liu et al. [58], who highlighted social isolation as a key frailty driver in aging populations. Cluster analysis further delineated a distinct vulnerable cohort (Cluster 3: 18.1%) characterized by severe frailty ( $8.94 \pm 2.75$ ), profound loneliness ( $49.2 \pm 11.3$ ), and minimal social support ( $22.8 \pm 6.5$ ), underscoring the urgent need for targeted interventions.

Mechanistically, the interplay between low social support and frailty may operate through dual pathways. First, insufficient social resources impair stress buffering capacity, exacerbating physiological dysregulation such as disrupted cortisol rhythms and mitochondrial dysfunction [59]. Second, limited access to health-promoting behaviors (e.g., physical activity, medical adherence) perpetuates functional decline. These pathways align with the "social resource accumulation–health benefit inflection point" theory [2], wherein subthreshold support fails to mitigate stressors, accelerating health deterioration. Notably, the social support scores in Cluster 3 ( $22.8 \pm 6.5$ ) fall far below the protective threshold ( $W = 45.47$ ) identified in recent studies [59], emphasizing the need to elevate support levels to neutralize loneliness-driven frailty.

To address these gaps, tiered interventions should prioritize elevating social support for high-risk subgroups. Community-based "social prescriptions," such as meal delivery services and medical escort programs, could bridge immediate resource gaps, while digital tools (e.g., social network sensors) might dynamically assess support quality and emotional resonance, aligning with Fancourt et al.'s three-dimensional optimization model [60]. Culturally adapted strategies, such as intergenerational support initiatives leveraging familial obligations while fostering self-efficacy, could enhance intervention relevance in contexts like East Asia.

Validation of these strategies requires rigorous evaluation frameworks. Stepped-wedge randomized designs [61] could test intervention efficacy across threshold-defined subgroups, ensuring scalability and adaptability. For instance, comparing outcomes between clusters pre- and post-intervention would clarify whether elevating social support above critical thresholds reduces frailty incidence.

Ultimately, policymakers must translate these insights into actionable policies. Scaling community partnerships to expand access to social services, integrating digital platforms for real-time support monitoring, and embedding frailty management into primary care protocols are essential steps. By aligning precision interventions with public health infrastructure, this approach transforms passive support into proactive health assets, addressing disparities in aging diabetic populations and fostering resilient health systems.

#### *Limitations and Future Directions*

This study has several limitations. First, the cross-sectional design precludes rigorous causal inference into the temporal dynamics between social support and frailty. Second, single-site sampling may limit generalizability to regions with diverse family structures. Third, insufficient integration of digital health technologies constrained the precision of personalized interventions by overlooking dynamic behavioral and environmental monitoring.

Future research should address these gaps through multidimensional advancements. Methodologically, longitudinal designs employing cross-lagged panel models and wearable devices could track the dynamic impact of critical life events (e.g., bereavement) on frailty trajectories. Culturally, investigations within Asian collectivist frameworks are needed to elucidate the dual "obligation-affection" regulatory mechanisms of intergenerational support. Practically, developing intelligent social prescription platforms using machine learning to identify individualized support gaps and coordinate healthcare-community resource synergies could enhance intervention efficacy. Our team plans a three-year multicenter cohort study integrating frailty trajectory theory and life-event modeling to validate a social prescription credit system across diverse living environments, offering innovative solutions to disrupt the "loneliness-frailty" cycle.

## **5. Conclusions**

This study systematically deciphers the psychosocial mechanisms and intervention pathways for frailty development in older adults with Type 2 Diabetes Mellitus (T2DM). Key findings reveal a frailty prevalence of 55.2%, with 14.6% experiencing high loneliness and only 21.5% receiving high-level social support, underscoring a stark imbalance between psychosocial risks and health outcomes. Social support demonstrated dual mechanisms: it mediated 30.86% of loneliness's detrimental health effects and, at a threshold of 45.47 points, completely buffered loneliness's negative impact on frailty. Multivariable regression identified core predictors—the interaction between deficient objective support ( $\beta = -0.154$ ) and loneliness ( $\beta = 0.059$ )—alongside sociodemographic vulnerabilities (age  $\geq 80$  years, widowhood, solo-living), rendering individuals with multimorbidity a high-risk subgroup. These biological-psychological-social intersections highlight neuroendocrine stress pathways activated by support deficiencies and sustained loneliness. The findings necessitate integrated interventions prioritizing structural support enhancement through policy-driven smart device subsidies and cross-sector partnerships to surpass critical support thresholds. Targeted clinical strategies should address bereavement-related transitions via cognitive-behavioral interventions to

disrupt loneliness-induced physiological cascades, while technology-enabled surveillance systems could enable real-time frailty monitoring through wearables and adaptive care models for high-risk subgroups. By concurrently optimizing population-level support systems and personalizing care for those with compounded psychosocial-biomedical risks, this framework advances precision geriatric care while addressing systemic health inequities in aging diabetic populations, ultimately creating scalable buffers against frailty progression through multilevel biopsychosocial modulation.

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