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Supplementary Appendix for Food Insecurity, Food 'Deserts', and Glycemic Control in Diabetes Patients: a Longitudinal Analysis

Technical Appendix

We followed established best practices for multi-level model building.(1) We fit models using maximum likelihood estimation via PROC MIXED in SAS version 9.4. An important part of building multi-level models is selecting the appropriate covariance structure. In this case, based on subject matter knowledge, we suspected that an autoregressive covariance structure would be appropriate, as the outcome was hemoglobin A1c values. Since these values changes slowly over a period of approximately 3 months, the results are likely to be more similar when measured closer together in time than when measured further apart. We confirmed this by examining the Akaike information criterion and the Bayes information criterion, finding that an autoregressive correlation structure minimized the values compared with other correlation structures (variance components, unstructured, or compound symmetry).

To calculate intraclass correlations (ICC), we followed the recommendations of Bell et al, and fit null (intercept only) models.(1) The ICCs were then calculated as:

$ICC_{\text{census tract}} = \sigma^2_{\text{census tract}} / \sigma^2_{\text{census tract}} + \sigma^2_{\text{individual}} + \sigma^2_{\text{residual}}$

$ICC_{\text{individual}} = \sigma^2_{\text{individual}} / \sigma^2_{\text{census tract}} + \sigma^2_{\text{individual}} + \sigma^2_{\text{residual}}$

We also examined whether it was necessary to account for within clinic clustering for the patients. To do this, we calculated intraclass correlation coefficients in null models in which hemoglobin a1c observations were clustered within patients, who were clustered within clinics. In these models, clinic explained only 2% of variation in hemoglobin a1c. Most guidelines call for accounting for clustering when the percentage of variation explained is above 5 or 10%, so we did not include a clinic level random effects term in our models.

To allow for a flexible functional form in our models for the relationship between time and age with hemoglobin a1c, we modeled these factors with cubic polynomials (time) and quadratic polynomials (age). We ultimately removed these higher order terms, however, as they did not add explanatory power to the model. We also used random slopes for time, food insecurity, and food access, to allow the change in hemoglobin a1c over time to vary between these groups.

Using the notation that t = measurement time, I = the individual, and j = the census tract, in general our models followed the form:

Level 1 [HbA1c Measurement Occasion]: $y_{tij} = \beta0_{ij} + \beta1_{ij}(Time_{tij}) + e_{tij}$

Level 2 [Individual]: $\beta0_{ij} = \delta00_j + U0_{ij}$

$\beta1_{ij}[\text{food insecurity}] = \delta10_j + U1_{ij}$

Level 3 [Census tract]: $\delta00_j = \gamma000 + V00_j$

$\delta10_j[\text{food access}] = \gamma100 + V10_j$

This yields a general composite equation of $Y_{tij} = (\gamma000 + V00_j + U0_{ij}) + (\gamma100 + V10_j + U1_{ij})(Time_{tij}) + e_{tij}$

The key coefficients in the model were a term for the exposure of interest (either food insecurity status [1/0] or living in an area with poor food access [1/0]), a term for months of time since baseline, and an interaction (product) term for the exposure*time. The remaining factors listed in the full models were included to adjust for possible confounding. We did not use any time-lagged variables. Level 2 of the model had a random intercept term and a random slope term for food insecurity. Level 3 of the model had a random intercept term and a random slope term for food access.

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References

1. Bell BA, Ene M, Smiley W, Schoeneberger JA. A Multilevel Model Primer Using SAS® PROC MIXED (Paper 433-2013) [Internet]. SAS Global Forum 2013; [cited 2017 Aug 11]. Available from: http://support.sas.com/resources/papers/proceedings13/433-2013.pdf

Supplementary Table 1. Demographics and clinical characteristics of those who could and could not be geocoded to establish physical food access

	Not Geocoded N=20	Geocoded N=391	P
	% or mean (SD)	% or mean (SD)	
Food Insecure	10.00	20.21	0.39
Age, y	63.65	61.94	0.59
Female	35.00	48.08	0.36
Race/Ethnicity			0.59
Non-Hispanic White	70.00	79.03	
Non-Hispanic Black	10.00	7.67	
Hispanic	15.00	8.95	
Asian/Other/Multi	5.00	4.35	
Education			0.80
< High School Diploma	15.00	14.36	
High School Diploma	20.00	27.18	
> High School Diploma	65.00	58.46	
Insurance			0.83
Private	45.00	50.94	
Medicare	35.00	26.42	
Medicaid	10.00	13.48	
Uninsured/Self-Pay	10.00	9.16	
Born Outside U.S.	30.00	20.00	0.27
Low Health Literacy	40.00	27.58	0.31
Took Survey in Spanish	5.00	5.12	1.00
Age at Diabetes Diagnosis, y	53.50	49.74	0.32
Charlson Score	5.15	4.85	0.68
Insulin Use	35.00	53.96	0.11
Statin Use	90.00	83.38	0.75
ACEi/ARB Use	85.00	81.33	1.00

P values for categorical variables from Fisher's exact test given small sample size. Abbreviations: ACEi = angiotensin converting enzyme inhibitor; ARB = angiotensin receptor blocker

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Supplementary Table 2. Full Models for Food Insecurity and Low Physical Food Access (1 and 10 Definition)

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.5566	<.0001	0.3560	0.7573
Time	0.0033	0.1139	-0.0008	0.0073
Food Insecure*Time	-0.0030	0.5029	-0.0119	0.0059
Age	0.0366	0.1758	-0.0164	0.0896
Age, squared	-0.0004	0.0537	-0.0009	0.0000
Female	-0.0982	0.1885	-0.2445	0.0482
Race/Ethnicity				
Non-Hispanic White	-0.7673	0.0003	-1.1869	-0.3476
Non-Hispanic Black	-0.6775	<.0001	-1.0080	-0.3469
Hispanic	-0.4204	0.0358	-0.8129	-0.0279
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.1354	0.2899	-0.1154	0.3863
High School Diploma	-0.1948	0.0263	-0.3666	-0.0230
> High School Diploma	Referent	n/a	n/a	n/a
Insurance				
Private	0.2592	0.0577	-0.0085	0.5269
Medicare	-0.1594	0.1229	-0.3619	0.0431
Medicaid	0.0961	0.4477	-0.1521	0.3443
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0618	0.5135	-0.2472	0.1236
Took Survey in English	-0.3835	0.1140	-0.8592	0.0922
Age at Diabetes Diagnosis, y	-0.0131	0.0031	-0.0218	-0.0044
Charlson Score	-0.0181	0.1964	-0.0456	0.0094
No Insulin Use	-0.7909	<.0001	-0.9686	-0.6133
No Statin Use	-0.2689	0.0121	-0.4788	-0.0590
Low physical food access, 1 and 10	0.0930	0.5453	-0.2096	0.3957
Low Vehicle Access	-0.1584	0.2987	-0.4581	0.1412
Median Family Income of Census Tract, $	0.0000	0.2439	0.0000	0.0000
Census Tract Poverty Rate	0.0115	0.2097	-0.0065	0.0296
Outpatient Visits during Study, count	-0.0057	<.0001	-0.0076	-0.0038
Covariance Parameter Estimates				
Covariance Parameter	Level	Estimate	P	
Variance	**CensusTract**	0.4281	<.0001	
AR(1)	**CensusTract**	-0.1358	0.4569	
Variance	**mrn(CensusTract)**	0.0008	<.0001	
AR(1)	**mrn(CensusTract)**	1.0000	.	
Residual		0.7708	<.0001	

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Supplementary Table 3. Full Models for Food Insecurity and Low Physical Food Access (1 and 10 Definition), Food Access by Time Interaction

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.5363	<.0001	0.3393	0.7333
Time	0.0046	0.0309	0.0004	0.0088
Age	0.0361	0.1813	-0.0168	0.0890
Age, squared	-0.0004	0.0562	-0.0008	0.0000
Female	-0.0951	0.2072	-0.2442	0.0541
Race/Ethnicity				
Non-Hispanic White	-0.7684	0.0010	-1.2029	-0.3339
Non-Hispanic Black	-0.6787	0.0003	-1.0209	-0.3365
Hispanic	-0.4186	0.0438	-0.8249	-0.0124
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.1308	0.3095	-0.1241	0.3857
High School Diploma	-0.1934	0.0305	-0.3680	-0.0188
> High School Diploma	Referent	n/a	n/a	n/a
Insurance				
Private	0.2536	0.0664	-0.0175	0.5247
Medicare	-0.1607	0.1231	-0.3658	0.0445
Medicaid	0.0926	0.4660	-0.1588	0.3440
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0618	0.5175	-0.2537	0.1302
Took Survey in English	-0.3893	0.1366	-0.9228	0.1442
Age at Diabetes Diagnosis, y	-0.0132	0.0028	-0.0219	-0.0046
Charlson Score	-0.0179	0.2020	-0.0453	0.0096
No Insulin Use	-0.7893	<.0001	-0.9712	-0.6074
No Statin Use	-0.2707	0.0171	-0.4894	-0.0519
Low physical food access, 1 and 10	0.1547	0.3270	-0.1555	0.4649
Low food access*Time	-0.0075	0.0728	-0.0156	0.0007
Low Vehicle Access	-0.1586	0.2984	-0.4584	0.1412
Median Family Income of Census Tract, $	0.0000	0.2435	0.0000	0.0000
Census Tract Poverty Rate	0.0115	0.2109	-0.0065	0.0295
Outpatient Visits during Study, count	-0.0057	<.0001	-0.0076	-0.0038
Covariance Parameter Estimates				
Covariance Parameter	Level	Estimate	P	
Variance	**CensusTract**	0.4295	<.0001	
AR(1)	**CensusTract**	-0.1333	0.4670	
Variance	**mrn(CensusTract)**	0.0008	<.0001	
AR(1)	**mrn(CensusTract)**	1.0000	.	
Residual		0.7706	<.0001	

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Supplementary Table 4. Full Models for Food Insecurity and Low Physical Food Access (Modified Retail Food Environment Index Definition)

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.7882	<.0001	0.5248	1.0515
Time	0.0031	0.1755	-0.0014	0.0077
Food Insecure*Time	-0.0041	0.4571	-0.0148	0.0067
Age	0.0294	0.3873	-0.0373	0.0960
Age, squared	-0.0004	0.1229	-0.0010	0.0001
Female	-0.0403	0.6558	-0.2178	0.1371
Race/Ethnicity				
Non-Hispanic White	-0.6524	0.0061	-1.1181	-0.1867
Non-Hispanic Black	-0.6617	0.0015	-1.0689	-0.2544
Hispanic	0.0944	0.7134	-0.4096	0.5984
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.3798	0.0126	0.0817	0.6779
High School Diploma	-0.3260	0.0027	-0.5386	-0.1135
> High School Diploma	Referent	n/a	n/a	n/a
Insurance				
Private	0.4610	0.0062	0.1314	0.7907
Medicare	-0.1312	0.3110	-0.3852	0.1228
Medicaid	-0.1982	0.2175	-0.5133	0.1170
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0551	0.6418	-0.2876	0.1773
Took Survey in English	0.2899	0.3419	-0.3082	0.8879
Age at Diabetes Diagnosis, y	-0.0060	0.2621	-0.0165	0.0045
Charlson Score	-0.0164	0.3133	-0.0483	0.0155
No Insulin Use	-0.9880	<.0001	-1.1960	-0.7799
No Statin Use	0.0418	0.7435	-0.2090	0.2927
MRFEI	-0.0065	0.5565	-0.0283	0.0153
Low Vehicle Access	0.0035	0.9839	-0.3350	0.3419
Median Family Income of Census Tract, $	0.0000	0.5689	0.0000	0.0000
Census Tract Poverty Rate	-0.0015	0.9005	-0.0250	0.0220
Outpatient Visits during Study, count	-0.0042	0.0004	-0.0066	-0.0019
Covariance Parameter Estimates				
Covariance Parameter	Level	Estimate	P	
Variance	**CensusTract**	0.8206	<.0001	
AR(1)	**CensusTract**	0.0000	.	
Variance	**mrn(CensusTract)**	0.0008	<.0001	
AR(1)	**mrn(CensusTract)**	1.0000	.	
Residual		0.7479	<.0001	

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Supplementary Table 5. Full Models for Food Insecurity and Low Physical Food Access (1/2 and 10 Definition)

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.5591	<.0001	0.3586	0.7597
Time	0.0033	0.1156	-0.0008	0.0073
Food Insecure*Time	-0.0031	0.5003	-0.0120	0.0058
Age	0.0362	0.1806	-0.0168	0.0893
Age, squared	-0.0004	0.0572	-0.0008	0.0000
Female	-0.0997	0.1822	-0.2462	0.0468
Race/Ethnicity				
Non-Hispanic White	-0.7804	0.0003	-1.2003	-0.3605
Non-Hispanic Black	-0.6744	<.0001	-1.0034	-0.3453
Hispanic	-0.4329	0.0306	-0.8254	-0.0405
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.1296	0.3098	-0.1206	0.3798
High School Diploma	-0.1982	0.0237	-0.3699	-0.0265
> High School Diploma	Referent	n/a	n/a	n/a
Insurance				
Private	0.2602	0.0564	-0.0071	0.5276
Medicare	-0.1568	0.1294	-0.3595	0.0459
Medicaid	0.0966	0.4456	-0.1517	0.3448
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0624	0.5095	-0.2478	0.1231
Took Survey in English	-0.3980	0.1006	-0.8731	0.0772
Age at Diabetes Diagnosis, y	-0.0133	0.0028	-0.0220	-0.0046
Charlson Score	-0.0187	0.1821	-0.0461	0.0088
No Insulin Use	-0.7891	<.0001	-0.9670	-0.6111
No Statin Use	-0.2661	0.0131	-0.4762	-0.0560
Low physical food access, 1/2 and 10	-0.0189	0.9143	-0.3641	0.3264
Low Vehicle Access	-0.1339	0.4260	-0.4647	0.1969
Median Family Income of Census Tract, $	0.0000	0.2479	0.0000	0.0000
Census Tract Poverty Rate	0.0092	0.3152	-0.0088	0.0273
Outpatient Visits during Study, count	-0.0057	<.0001	-0.0076	-0.0038
Covariance Parameter Estimates				
Covariance Parameter	Level	Estimate	P	
Variance	**CensusTract**	0.2060	<.0001	
AR(1)	**CensusTract**	1.0000	.	
Variance	**mrn(CensusTract)**	0.0008	<.0001	
AR(1)	**mrn(CensusTract)**	1.0000	.	
Residual		0.7708	<.0001	

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Supplementary Table 6. Full Models for Food Insecurity and Low Income Plus Low Physical Food Access (1 and 10 Definition)

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.5724	<.0001	0.3722	0.7726
Time	0.0033	0.1079	-0.0007	0.0074
Food Insecure*Time	-0.0031	0.5010	-0.0119	0.0058
Age	0.0368	0.1744	-0.0163	0.0898
Age, squared	-0.0004	0.0518	-0.0009	0.0000
Female	-0.0932	0.2118	-0.2396	0.0532
Race/Ethnicity				
Non-Hispanic White	-0.7878	0.0002	-1.2079	-0.3677
Non-Hispanic Black	-0.6105	0.0002	-0.9353	-0.2857
Hispanic	-0.3942	0.0488	-0.7863	-0.0021
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.1547	0.2266	-0.0961	0.4055
High School Diploma	-0.1774	0.0413	-0.3478	-0.0070
> High School Diploma	Referent	n/a	n/a	n/a
Insurance				
Private	0.2631	0.0543	-0.0049	0.5311
Medicare	-0.1557	0.1328	-0.3589	0.0474
Medicaid	0.0999	0.4311	-0.1489	0.3487
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0484	0.6084	-0.2337	0.1369
Took Survey in English	-0.3983	0.1012	-0.8747	0.0781
Age at Diabetes Diagnosis, y	-0.0134	0.0027	-0.0221	-0.0046
Charlson Score	-0.0189	0.1770	-0.0464	0.0086
No Insulin Use	-0.7946	<.0001	-0.9729	-0.6164
No Statin Use	-0.2737	0.0108	-0.4840	-0.0634
Low Income and Low Food Access, 1 and 10	0.3125	0.3460	-0.3418	0.9667
Low Vehicle Access	-0.1346	0.3854	-0.4396	0.1703
Outpatient Visits during Study, count	-0.0056	<.0001	-0.0075	-0.0037
Covariance Parameter Estimates				
Covariance Parameter	Level	Estimate	P	
Variance	**CensusTract**	0.8944	<.0001	
AR(1)	**CensusTract**	-0.5789	<.0001	
Variance	**mrn(CensusTract)**	0.0008	<.0001	
AR(1)	**mrn(CensusTract)**	1.0000	.	
Residual		0.7709	<.0001	

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Supplementary Table 7. Distribution of outpatient visit and hemoglobin A1c assessment frequency

	Food Secure, %	Food Insecure, %	P	Adequate Food Access, %	Low Food Access, %	P
Outpatient visits during study period			0.3391			0.2117
0	2.15	0.00		1.48	1.68	
1	0.31	1.25		0.37	0.84	
2	0.31	1.25		0.74	0.00	
3-4	0.62	0.00		0.00	1.68	
5+	96.62	97.50		97.42	95.80	
Hemoglobin A1c assessments during study period			0.5446			0.2056
0	0.00	0.00		0.00	0.00	
1	2.46	0.00		1.48	2.52	
2	0.92	1.25		0.37	2.52	
3-4	4.31	3.75		4.06	5.04	
5+	92.31	95.00		94.10	89.92	

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Supplementary Table 8. Full Models for Food Insecurity and Low Income Plus Low Physical Food Access (1 and 10 Definition)

	β	p-value	Lower 95% Confidence Interval	Upper 95% Confidence Interval
Food Insecure	0.5370	<.0001	0.3476	0.7263
Age	0.0356	0.1878	-0.0174	0.0886
Age, squared	-0.0004	0.0587	-0.0008	0.0000
Female	-0.0981	0.1886	-0.2444	0.0482
Race/Ethnicity				
Non-Hispanic White	-0.7732	0.0003	-1.1930	-0.3534
Non-Hispanic Black	-0.6761	<.0001	-1.0067	-0.3456
Hispanic	-0.4160	0.0377	-0.8083	-0.0237
Asian/Other/Multi	Referent	n/a	n/a	n/a
Education				
< High School Diploma	0.1294	0.3395	-0.1362	0.3949
High School Diploma	-0.2269	0.0151	-0.4098	-0.0439
> High School Diploma	Referent	n/a	n/a	n/a
Education*Time Interaction				
< High School Diploma*Time	0.0008	0.8863	-0.0098	0.0114
High School Diploma*Time	0.0044	0.3013	-0.0039	0.0127
> High School Diploma*Time	Referent	n/a	n/a	n/a
Insurance				
Private	0.2556	0.0612	-0.0120	0.5233
Medicare	-0.1605	0.1203	-0.3630	0.0420
Medicaid	0.0926	0.4645	-0.1557	0.3410
Uninsured/Self-Pay	Referent	n/a	n/a	n/a
Adequate Health Literacy	-0.0615	0.5152	-0.2469	0.1239
Took Survey in English	-0.3821	0.1153	-0.8578	0.0936
Age at Diabetes Diagnosis, y	-0.0131	0.0031	-0.0218	-0.0045
Charlson Score	-0.0180	0.1987	-0.0455	0.0095
No Insulin Use	-0.7920	<.0001	-0.9696	-0.6143
No Statin Use	-0.2711	0.0114	-0.4810	-0.0612
Low Income and Low Food Access, 1 and 10	0.0942	0.5405	-0.2087	0.3971
Low Vehicle Access	-0.1571	0.3030	-0.4570	0.1427
Outpatient Visits during Study, count	0.0000	0.2508	0.0000	0.0000

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Supplementary Table 9. Hemoglobin A1c by food insecurity and food access in sequential models

	Mean Hemoglobin A1c, %	95% CI	Difference	p	Change in difference per month	95%CI	p
Model A: Exposure and time only model							
Food Insecure	7.8	7.7 to 7.9	0.5	<.0001	-0.003	-0.01 to 0.005	0.43
Food Secure	7.4	7.3 to 7.4					
Low Food Access	7.3	7.2 to 7.3	-0.3	0.04	-0.003	-0.01 to 0.005	0.48
Adequate Food Access	7.5	7.5 to 7.6					
Model B: Demographic covariate model							
Food Insecure	7.7	7.5 to 7.8	0.3	0.005	-0.001	-0.008 to 0.006	0.79
Food Secure	7.4	7.2 to 7.5					
Low Food Access	7.3	7.1 to 7.5	-0.2	0.46	-0.004	-0.01 to 0.003	0.27
Adequate Food Access	7.5	7.4 to 7.6					
Model C: Clinical covariate model							
Food Insecure	7.5	7.4 to 7.7	0.4	<.0001	-0.0004	-0.007 to 0.007	0.91
Food Secure	7.1	7.0 to 7.3					
Low Food Access	7.1	6.9 to 7.3	-0.2	0.47	-0.005	-0.01 to 0.001	0.12
Adequate Food Access	7.3	7.3 to 7.4					
Model D: Full multilevel model							
Food Insecure	7.6	7.2 to 7.9	0.5	<.0001	-0.003	-0.01 to 0.01	0.50
Food Secure	7.1	6.8 to 7.3					
Low Food Access	7.3	6.9 to 7.6	-0.04	0.33	-0.007	-0.02 to 0.001	0.07
Adequate Food Access	7.3	7.0 to 7.6					

Food access defined using the 1 mile in urban areas and 10 miles in rural areas definition; mean hemoglobin A1c, and the difference in mean hemoglobin A1c was calculated using least squares means. *Model A includes only food security or food access, time, and their interaction. Model B adds age, age squared, gender, race/ethnicity, education, insurance, health literacy, and language to model A. Model C adds age at diabetes diagnosis, baseline Charlson comorbidity score, insulin use, statin use, and number of outpatient visits to model B. Model D adds median family income, poverty rate, and vehicle access, along with random effects for repeated measures within individuals and within census tracts, to model C. Model D results are also presented in Table 2 of the main manuscript.