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Telemedicine use and decrements to type 2 diabetes and hypertension care during the COVID-19 pandemic

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Abstract

Background We examine pandemic-era quality of care changes associated with telemedicine use among adults with type 2 diabetes and/or hypertension across ten health systems.

Methods Patient-level encounter and laboratory data ($n = 1,963,563$) were analyzed for pre-pandemic (March 13, 2019 to December 31, 2019) and pandemic (March 13, 2020 to December 31, 2020) periods. Generalized linear models with binomial distribution functions and log links estimated the association of telemedicine use with four outcomes: 1) hemoglobin A1c (HbA1c) testing, 2) HbA1c control (< 8.0%), 3) blood pressure (BP) testing, and 4) BP control (< 140 / 90 mmHg), controlling for patient characteristics, system fixed effects, and with propensity score weights.

Results In adjusted analyses, telemedicine use was associated with lower odds of HbA1c (aOR = 0.74, $p < 0.05$) and BP (aOR = 0.40, $p < 0.01$) testing for adults with type 2 diabetes, but not HbA1c or BP control. Among hypertension-only patients, telemedicine use was associated with lower odds of BP testing (aOR = 0.10, $p < 0.001$), but not BP control. Compared to pre-pandemic telemedicine use, pandemic period telemedicine use was associated with lower odds of HbA1c and BP monitoring.

Discussion Telemedicine use was associated with lower odds of HbA1c monitoring for adults with type 2 diabetes and lower odds of BP testing for adults with type 2 diabetes and/or hypertension.

Conclusion As telemedicine continues to be used for diabetes and hypertension care, remote monitoring, standing orders, and community pharmacy partnerships may be necessary supplements to telemedicine to assure high quality care, especially when in-person care options are limited.

Keywords Telemedicine, Hypertension, Diabetes, COVID-19 pandemic, Quality of care

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Background

The COVID-19 pandemic accelerated the use of telemedicine for chronic medical conditions, as in-person care was restricted to minimize the transmission of SARS-CoV-2 [1–3]. The early pandemic period was unique because of shelter-in-place ordinances, reduced and suspended clinic operations, and strong encouragement of patients to avoid in-person care. Many health care organizations invested extensively in their telemedicine infrastructure during the emergency period, but the policy changes needed to support remote chronic care management are still lacking [4, 5]. Understanding the quality impacts of early pandemic-era in-person care disruptions can provide information to help health care systems better prepare for future disruptions to in-person care.

Adults with type 2 diabetes and/or hypertension had telemedicine encounters to support routine monitoring [6] because they were vulnerable to hospitalizations and death when infected with SARS-CoV2 [7]. Blood pressure (BP) and hemoglobin A1c (HbA1c) monitoring, however, declined nationally during the early pandemic [2, 8, 9]. Health care systems varied in their adoption of telemedicine for adults with type 2 diabetes and/or hypertension, with evidence indicating adoption levels ranging from 11 to 42% of total encounters at the peak of pandemic-era telemedicine utilization but leveled off to 17% by Week 13 of the emergency period in 2020 [10] and nationally, telemedicine use declined even further in 2021 to approximately 8% of encounters [11]. These trends indicate that telemedicine has not been well sustained after the pandemic emergency period, which is problematic because some patients prefer telemedicine for chronic care management and pervasive non-clinical staffing shortages make delivering fully in-person care operationally infeasible for many health care organizations. Clarifying the quality impacts on telemedicine use can help organizations prioritize policies and practices to improve the effectiveness of telemedicine.

Health care organizations have widely adopted diabetes care management processes, including patient reminders for preventive or follow-up care, patient education, provider alerts, quality of care monitoring and feedback, and registry use [12, 13]. Robust diabetes care management processes of practices with the ten health systems could have helped maintain quality of care for adults with type II diabetes during the early pandemic. Health care organizations generally maintained access to routine HbA1c testing during the pandemic, but evidence indicates that remote blood pressure monitoring was not routinely available to adult patients with diabetes and/or hypertension [2, 8, 9]. Some organizations developed innovative ways to promote self-measured BP and improve access to BP screening during the pandemic, including using care team approaches and "drive-through" BP assessment in partnership with community pharmacies [14–17]. Based on these observations, we hypothesized that blood pressure testing was maintained to a greater degree for adults with type II diabetes during the pandemic period compared to hypertension-only. We also posited that telemedicine use was more strongly associated with blood pressure testing and control for adults with type II diabetes compared to those with hypertension-only.

Materials and methods

Data

Data are sourced from Optum data available to AMGA (American Medical Group Association), a nonprofit trade association representing more than 400 multispecialty medical groups and health systems with a total of more than 177,000 physicians. Some AMGA members contributed data to a common data repository managed by Optum and through a partnership with AMGA provided access to their data. Because the data elements are derived from electronic health records (EHRs), practice management systems, disease registries, and population health software, data are mapped and normalized to allow valid and reliable comparisons across organizations. The ten system members of AMGA represent a diverse population of health care systems across urban, suburban, and rural locations in 9 U.S. states and range in size from 14 to 638 practice locations and 70 to 2,100 physician full-time equivalents (Supplementary Table A1).

The pre-COVID-19 period spans from March 13, 2019 to December 31, 2019 and the COVID-19 period spans from March 13, 2020 to December 31, 2020. Patient-level encounter and laboratory data from pre-COVID-19 and COVID-19 periods were analyzed and compared. Because we were interested in care quality for established patients with type 2 diabetes and/or hypertension, we focused on adult patients with these diagnoses and qualifying encounters during the 15-month the pre-pandemic (January 1, 2018 to March 12, 2019) and pandemic (January 1, 2019 to March 12, 2020) "activity windows" prior to each study period. This enabled us to compare quality of care received during the pre-pandemic (March 13, 2019 to December 31, 2019) and pandemic (March 13, 2020 to December 31, 2020) study periods among an established group of adult patients. The study timelines are detailed in Supplementary Fig. A1.

Of 2,858,026 eligible adult patients with type 2 diabetes and/or hypertension, a total of 894,463 patients (31.3%) were excluded for having diagnoses of gestational or steroid-induced diabetes ($n=68,584$, 2.4%), type 1 diabetes ($n=19,664$, 0.7%), polycystic ovary syndrome ($n=11,832$, 0.4%), end-stage renal disease ($n=36,636$, 1.3%), receipt of hospice or palliative care ($n=14,791$, 0.5%), anemia ($n=13,732$, 0.5%), and/or pregnancy ($n=15,043$, 0.5%). Patients who died during activity windows and study periods ($n=28,701$, 1.0%) were also excluded. We were interested in examining the association of telemedicine use for established patients of the health systems, so adults without at least one clinician encounter in the "activity windows" were excluded ($n=685,480$, 24.0%). Analytic sample exclusions are detailed in Supplementary Table A2.

The final analytic sample included 1,963,563 adults with type 2 diabetes and/or hypertension, which represents 68.7% of the unrestricted patient sample, and included 946,209 patients (48.2%) in the pre-pandemic study period and 1,017,354 patients (51.8%) in the pandemic study period. The analytic sample included all outpatient adult primary care (Internal Medicine, Family Medicine, Urgent Care, Geriatrics) and specialist (Cardiology, Endocrinology, Orthopedics, Urology, Neurology, etc.) encounters and included all clinician types (physician, nurse practitioner, physician's assistant, nurse, nutritionist, pharmacist, mental health therapist, etc.). We stratified patients into two groups: 1) adults diagnosed with type 2 diabetes with or without hypertension ($n=642,224$, 32.7%), referred to as the "diabetes" sample herein, and 2) adults diagnosed with hypertension but not type 2 diabetes ($n=1,321,339$, 67.3%), referred to as the "hypertension-only" sample herein. We examined the 2 subgroups separately because compared with hypertension alone, managing diabetes entails addressing more standards of care [6] and primary care practices were more likely to have established diabetes care management processes in place before the pandemic compared to processes for hypertension [12, 18].

The encounter-level data documented telemedicine (remote video, audio only, or e-visit use [3]) and patient characteristics. E-visits include clinician-patient communication about treatment through secure electronic messaging.

Outcome measures

The four study outcomes are: 1) HbA1c testing, defined as having at least one HbA1c test, 2) HbA1c control, defined as the last recorded HbA1c result being less than 8.0%, 3) BP testing defined as receipt of at least one BP assessment, and 4) BP control, defined using an indicator indicating whether the patient's last recorded systolic and diastolic BP values were below 140 mmHg and 90 mmHg, respectively. All four study outcomes were assessed for the sample of adults with diabetes, while only the hypertension study outcomes (#3 and #4) were assessed for the sample of adults with hypertension-only. The latest clinical values during each study period were analyzed.

Main independent variables

The main independent variables are 1) patient-level telemedicine use, 2) a study period indicator (pre-COVID-19 vs. COVID-19), and 3) an interaction between telemedicine use and the study period to assess differential associations of telemedicine and study outcomes by period. Telemedicine use is defined as having at least one telemedicine encounter (audio, video, or e-visit) during each of the study periods. Telemedicine use was assessed separately for the pre-pandemic (March 13, 2019 to December 31, 2019) and pandemic (March 13, 2020 to December 31, 2020) study periods.

Control variables

Patient characteristics included as control variables in regression analyses are patient age, race/ethnicity, sex, marital status, the annual median household income of the patient's zip code, urbanicity of patient's U.S. census tract of residence (metropolitan (50,000 or more population), micropolitan (10,000–49,000 population), small town (2,500–9,999 population), and rural (< 2,500 population) areas). We also controlled for health insurance type, total ambulatory encounters, Charlson comorbidity index, [19] and comorbidity indicators of diagnoses of atherosclerotic cardiovascular disease, chronic kidney disease, heart failure, obesity, and opioid use disorder. For the diabetes sample, we controlled for diabetes and hypertension treatment. For the hypertension-only sample, we controlled for hypertension treatment. The diabetes and hypertension medication categories are listed in Supplementary Table A3.

Statistical analyses

For descriptive analyses, we compared patient demographic and clinical characteristics based on a four-part categorical variable based on pandemic period utilization: 1) telemedicine only, 2) in-person only, 3) both telemedicine and in-person, and 4) no encounters. The four study outcomes and the mean telemedicine and in-person encounters per patient were compared for the pre-COVID-19 and COVID-19 periods. For these analyses, t-tests were used to assess differences in unadjusted means for the four study outcomes (comparing study outcomes for the pre-COVID-19 and COVID-19 study periods).

We estimated generalized linear models (GLM) with binomial distribution functions and log links to examine the association of telemedicine use (as a binary variable) with each of the study outcomes separately for the type 2 diabetes and hypertension-only samples. In regression models for both samples, we controlled for the number of patient encounters during the pandemic study period, patient age, race, ethnicity, marital status, urbanicity of residence, insurance type, diabetes and hypertension treatment, and comorbidities. For the diabetes sample, we also controlled for the patient's last pre-pandemic period HbA1c and SBP values. For the hypertension sample, we also controlled for the patient's last pre-pandemic period SBP value. SBP was included because it is a more frequent cardiovascular risk factor than diastolic BP (DBP) [20].

Inverse propensity treatment weighting (IPTW) in the form of average treatment effect on the treated was used [21], which assesses the extent to which adults who did not have telemedicine encounters are statistically equivalent to adults who had telemedicine encounters after balancing covariates. Propensity scores were generated using logistic regression to estimate each patient's probability of using telemedicine in the pre-pandemic period [22]. Each patient's IPTW was calculated as the ratio of their actual use of telemedicine (0,1) to their probability of using telemedicine. Weights were calculated separately for each period. The following variables were used to estimate the propensity scores for the generalized linear models: patient age, sex, and insurance type. We used the *psmatch2* module in Stata [23] to assess covariate balance before and after weighting and we included covariates in the propensity score that had standardized (%) bias of 10% or less between patients who used telemedicine and those who did not. Other control variables were not included in the propensity scores because their inclusion did not improve covariate balance, and sometimes resulted in worse balance for other covariates (Supplementary Figs. A4 and A5). Models also included health system fixed effects (dummy variables for each health system) to account for unmeasured system-level factors associated with telemedicine use and the study outcomes.

Variance inflation factors (VIFs) were calculated, and we considered a VIF of greater than 2.0 as an indication of potential collinearity [24]. Finally, we estimated predicted probabilities of study outcome measures by telemedicine use and study period using main model coefficients. Marginal effects for each of the study outcomes for each of the 10 health systems were also estimated. All analyses were conducted using Stata 13.1.

Sensitivity analyses

Four sensitivity analyses were conducted to assess whether the main results were consistent with different definitions of telemedicine use. First, we assessed whether having more exposure to telemedicine was associated with differences in quality compared to less exposure to telemedicine. To examine this, we defined telemedicine use as a 3-level categorical variable: 1) no telemedicine encounters, 2) one telemedicine encounter, and 3) two or more telemedicine encounters. A second sensitivity analysis assessed whether video-based telemedicine encounters were differentially associated with quality of care, compared to overall telemedicine encounters. The standard telemedicine definition prior to the pandemic-related flexibilities was limited to video-based telemedicine encounters [25], thereby restricting telemedicine encounters to only include video-based encounters which comprised 72.0% of all telemedicine encounters. Our third sensitivity analyses re-estimated the main regression model with interaction terms for telemedicine and the urbanicity of patients' residence (metropolitan, micropolitan, small town, and rural) to assess whether telemedicine was more beneficial for non-metropolitan residents. As a fourth sensitivity analysis, we assessed the consistency of the main results when differences-in-differences (DiD) logit regression models with patient fixed effects were used to estimate telemedicine effects, which allows for stronger causal inference.

Results

Of the 1,017,354 adult patients in the pandemic study period, 48.6% had only in-person encounters, 5.6% had only telemedicine encounters, 25.2% had both telemedicine and in-person encounters, and 20.5% did not have any encounters. All patient demographic and clinical characteristics assessed were differentially distributed across the four groups ($p < 0.001$) (Table 1). For example, patients who used telemedicine only or both telemedicine and in-person visits were more likely use to be of younger age (ages 35–44 and ages 45–55), have higher zip-code level median household income, and reside in a metropolitan area compared to patients with only in-person encounters.

HbA1c testing among adults with type 2 diabetes declined from 66.9% to 62.4% measured between the pre-COVID-19 and COVID-19 study periods ($p < 0.001$) (Table 2). Among those measured, mean HbA1c values increased significantly from 7.18% (standard deviation, SD = 1.47) to 7.21% (SD = 1.50) ($p < 0.001$), but the proportion of with uncontrolled HbA1c remained consistent over time (78.7% vs. 78.2%). Among all patients in the analytic sample, BP measurement declined from 80.9% to 74.1% ($p < 0.001$) and among those assessed, a lower proportion of patients had BP under control during the pandemic period (60.9% vs. 55.0%, $p < 0.001$).

Adjusted analyses

In adjusted analyses for adults with type 2 diabetes, the pandemic period was associated with lower odds of HbA1c (adjusted odds ratio, aOR = 0.91, $p < 0.001$) and BP (aOR = 0.60, $p < 0001$) testing, as well as HbA1c (aOR = 0.96, $p < 0.001$) and BP (aOR = 0.93, $p < 0.001$) control (Table 3). Results of the adjusted analyses for

Table 1 Patient characteristics during the COVID-19 pandemic study period (March 13, 2020 to December 31, 2020), by patient exposure to telemedicine

	All Pandemic Period Patients	Telemedicine only	Telemedicine and in-person	In-person only	No Encounters
Patient N	1,017,354	57,450 (5.6%)	256,798 (25.2%)	494,676 (48.6%)	208,430 (20.5%)
	Mean/SD	Mean/SD	Mean/SD	Mean/SD	Mean/SD
Age Categories					
18–34 (%)	2.6	3.7	2.2	2.0	4.4
35–44 (%)	6.9	9.9	6.5	5.8	9.3
45–55 (%)	16.6	20.2	16.2	15.4	19.3
56–64 (%)	22.9	23.8	22.4	23.0	23.1
65–74 (%)	27.7	24.0	29.0	29.2	23.3
75–84 (%)	17.3	12.6	17.9	18.8	14.2
85 and over (%)	6.0	5.8	5.9	5.9	6.4
Female (%)	51.9	53.0	56.3	50.4	49.7
Race/Ethnicity[a]					
Hispanic (%)	3.9	3.7	4.5	3.4	4.4
White (%)	77.5	75.1	77.3	79.8	72.8
Black (%)	5.1	6.5	5.9	4.3	5.5
Asian (%)	1.2	1.4	1.0	1.2	1.4
Others (%)	12.3	13.3	11.2	11.3	15.8
Marital Status					
Divorced (%)	8.7	8.4	9.2	8.3	9.1
Married (%)	59.0	56.6	59.4	61.7	52.7
Never married (%)	13.6	14.0	13.0	12.8	15.9
Widowed (%)	9.8	8.4	10.5	10.1	8.5
Other marital status (%)	9.0	12.7	7.9	7.1	13.8
Annual median household income ($)	61,962 (20,745)	64,980 (21,449)	63,299 (20,530)	61,076 (20,464)	61,583 (21,303)]
Urbanicity of Residence					
Metropolitan (%)	76.0	83.5	81.4	73.8	72.7
Micropolitan (%)	10.4	6.4	8.1	11.7	11.4
Small town (%)	7.3	4.7	5.5	8.1	8.3
Rural (%)	5.2	3.9	3.7	5.6	6.4
Insurance Type					
Commercial (%)	36.3	44.3	33.3	35.1	40.5
Medicare (%)	54.4	46.3	57.3	56.9	47.2
Medicaid (%)	3.4	3.1	3.8	2.8	4.5
Dual Medicare/ Medicaid (%)	1.2	1.1	1.8	1.1	0.8
Other (%)	4.7	5.2	3.7	4.1	6.9
Comorbidities					
Charlson comorbidity index	1.7 (2.1)	1.5 (2.0)	2.2 (2.3)	1.6 (2.0)	1.2 (1.8)
Type 2 diabetes only (%)	7.8	7.7	6.8	7.2	10.3
Hypertension- only (%)	67.2	68.7	63.0	68.0	70.0
Type 2 diabetes and hypertension (%)	25.0	23.6	30.2	24.8	19.6
Atherosclerotic CVD (%)	30.0	24.0	37.9	30.4	21.3
Heart failure (%)	8.9	7.4	13.1	8.1	6.3
Chronic kidney disease (%)	16.8	14.8	22.9	16.7	9.9
Mental health illness (%)	42.8	44.4	55.6	40.5	31.8
Obesity (%)	35.7	37.8	45.0	34.4	26.6
Opioid use disorder (%)	2.3	2.2	3.9	1.7	1.5

Table 1 (continued)

	All Pandemic Period Patients	Telemedicine only	Telemedicine and in-person	In-person only	No Encounters
Encounter Categories					
Total encounters					
0 (%)	20.5	-	-	-	100.0
1–2 (%)	35.7	84.8	15.2	55.7	-
3+ (%)	43.8	15.2	84.8	44.3	-
Telemedicine encounters					
0 (%)	69.1	-	-	100.0	100.0
1 (%)	18.2	61.5	58.4	-	-
2+ (%)	12.7	38.5	41.6	-	-
Diabetes Treatment[b]	$n=333,635$	$n=17,987$	$n=95,014$	$n=158,172$	$n=62,462$
No diabetes prescriptions (%)	29.9	28.7	22.4	28.0	46.1
Diabetes treated, non-insulin only (%)	45.2	46.5	46.6	49.2	32.7
Diabetes treated, insulin +/- other Rx (%)	24.9	24.8	31.0	22.7	21.2
Hypertension Treatment					
No hypertension (%)	7.8	7.7	6.8	7.2	10.3
Hypertension-treated (%)	75.8	75.6	83.5	79.5	57.43
No hypertension prescriptions (%)	16.4	16.8	9.6	13.3	32.3

[a] Race and ethnicity variables were combined into a single race/ethnicity variable. Patients of Hispanic ethnicity were categorized as Hispanic, irrespective of their race. Patients of non-Hispanic ethnicity were categorized based on their race

[b] Diabetes treatment is only assessed for adults with diagnosed type 2 diabetes

Table 2 Unadjusted differences in telemedicine use and outcome measures, by pre-COVID-19 and COVID-19 pandemic study periods

	Overall	Pre-COVID-19 study period	COVID-19 study period	T-test Difference
Patient n	642,224	308,589	333,635	
HbA1c testing (%)	64.6	66.9	62.4	-0.04***
Patient n[a]	414,761	206,424	208,337	
HbA1c % (mean, SD)	7.19 (1.48)	7.18 (1.47)	7.21 (1.50)	0.03***
HbA1c control[b] (%)	78.4	78.7	78.2	-0.005***
Patient n[c]	1,963,563	946,209	1,017,354	
Blood pressure testing (%)	77.4	80.9	74.1	-0.07***
Patient n[d]	1,519,234	765,181	754,053	
Blood pressure control[d] (%)	74.7	75.3	74.2	-0.011***
Total telemedicine encounters per patient (mean, SD)	0.29 (0.88)	0.00 (0.07)	0.56 (1.16)	0.56***
Total in-person encounters per patient (mean, SD)	2.85 (3.19)	3.31 (3.47)	2.42 (2.83)	-0.89***

N/S Not statistically significant at the $p<0.05$ level, *SD* Standard deviation

***, **, and * indicate $p<0.001$, $p<0.01$, and $p<0.05$, respectively

[a] Includes adults with type 2 diabetes and HbA1c testing

[b] HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%

[c] Includes adults with type 2 diabetes and/or hypertension

[d] Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively

the hypertension-only sample indicate similar decrements to BP testing (aOR = 0.60, $p<0.001$) and control (aOR = 0.92, $p<0.001$) during the pandemic period.

In adjusted analyses for adults with type 2 diabetes, telemedicine use was associated with lower odds of HbA1c (aOR = 0.74, $p<0.05$) and BP (aOR = 0.40, $p<0.01$) testing, but was not associated with HbA1c or BP control (Table 3). Among the hypertension-only sample, telemedicine use was also strongly associated with lower odds of BP testing (aOR = 0.10, $p<0.001$), but not BP

Table 3 Generalized linear models with stabilized inverse propensity treatment weighting: association between telemedicine exposure and study outcome measures

	Diabetes Sample				Hypertension-only Sample	
	HbA1c testing	HbA1c control[a]	Blood pressure testing	Blood pressure control[b]	Blood pressure testing	Blood pressure control[b]
Patient n	512,344	391,269	642,224	506,254	1,321,339	1,012,980
Main Independent Variables						
Post period	0.91***	0.96***	0.60***	0.93***	0.60***	0.92***
Telemedicine encounter	0.74*	0.90	0.40**	1.02	0.10***	0.97
Post period * telemedicine encounter	0.77*	1.18	0.15***	0.98	0.58***	1.05
Control Variables						
Total encounters						
0	0.01***	0.75***	0.00***	0.76***	0.00***	0.91***
1–2	0.27***	0.89***	0.06***	0.98**	0.07***	1.03***
3+ (reference)	-	-	-	-	-	-
Age Categories						
Age 18–34	0.43***	0.61***	0.64***	1.02	0.69***	0.91***
Age 35–44	0.55***	0.61***	0.61***	0.97	0.75***	0.89***
Age 45–55	0.68***	0.66***	0.71***	1.00	0.81***	0.95***
Age 56–64	0.85***	0.78***	0.79***	1.00	0.87***	1.00
Age 65–74 (reference)	-	-	-	-	-	-
Age 75–84	0.97**	1.14***	1.03	0.98	1.05**	0.94***
Age 85 and over	0.91***	1.19***	0.98	0.94***	1.02	0.88***
Female	0.93***	1.03**	0.95**	1.06***	1.10***	1.09***
Race/Ethnicity						
White (reference)	-	-	-	-	-	-
Hispanic	0.97	0.91***	1.00	0.99	0.93*	0.94***
Black	0.89***	1.02	0.98	0.82***	0.96	0.85***
Asian	1.28***	1.06	1.06	1.03	1.01	1.01
Other race	0.94***	0.95*	0.94*	0.92***	0.96*	0.93***
Marital Status						
Married (reference)	-	-	-	-	-	-
Divorced	0.88***	0.97	0.89***	0.94***	0.85***	0.94***
Never married	0.91***	0.94***	0.89***	0.97**	0.87***	0.95***
Widowed	0.95***	0.95**	0.93*	0.92***	0.90***	0.91***
Other marital status	0.76***	0.95*	0.70***	0.89***	0.70***	0.86***
Annual household median income (standardized)	1.06***	1.07***	1.00	1.08***	1.02**	1.07***
Urbanicity of Residence						
Metropolitan (reference)	-	-	-	-	-	-
Micropolitan	0.79***	0.97	1.14***	0.89***	1.06**	0.90***
Small town	0.82***	0.93***	0.96	0.90***	0.93***	0.92***
Rural	0.76***	0.93**	1.02	0.95***	1.00	0.93***
Insurance Type						
Commercial	1.10***	1.07***	1.27***	1.03	1.14***	1.01
Medicare/ Medicare Advantage (reference)	-	-	-	-	-	-
Medicaid	0.74***	0.98	0.97	0.95***	0.82***	0.88***
Dual Medicare/Medicaid	1.22***	0.94	0.93	0.91**	0.98	0.99
Other	0.94*	0.99	1.11**	0.94**	1.01	0.92***
Comorbidities						
Charlson comorbidity index	0.95***	0.99*	1.00	1.00	1.01*	1.00

Table 3 (continued)

	Diabetes Sample				Hypertension-only Sample	
	HbA1c testing	HbA1c control[a]	Blood pressure testing	Blood pressure control[b]	Blood pressure testing	Blood pressure control[b]
Atherosclerotic cardiovascular disease	0.84***	0.98	1.28***	1.05***	1.40***	1.05***
Heart failure	0.85***	0.99	1.16***	1.07***	1.19***	1.08***
Chronic kidney disease	1.31***	0.95***	1.23***	0.98*	1.22***	1.06***
Mental health illness	0.94***	0.99	1.05**	1.05***	1.01	1.04***
Obesity	1.14***	0.93***	1.17***	0.97***	1.11***	0.99*
Opioid use disorder	0.86***	1.02	0.85**	0.92***	0.92*	0.90***
Diabetes Treatment						
No diabetes prescriptions	0.47***	1.50***	0.83***	0.87***	N/A	N/A
Diabetes treated, non-insulin only (reference)	-	-	-	-	N/A	N/A
Diabetes treated, insulin +/- other Rx	0.72***	0.57***	0.83***	0.89***	N/A	N/A
Hypertension Treatment						
No hypertension	1.04*	1.18***	1.31***	1.30***	N/A	N/A
Hypertension-treated	1.21***	1.15***	1.78***	0.92***	1.8***	1.02***
No hypertension prescriptions (reference)	-	-	-	-	-	-
HbA1c, last value in pre-pandemic period	1.05***	0.41***	N/A	N/A	N/A	N/A
Systolic BP, last value in prep-pandemic period	N/A	N/A	1.00***	0.96***	1.00***	0.96***
Constant	14.84***	3,835.31***	1,335.45***	603.85***	743.10***	367.56***

Coefficients are reported in odds ratios

***, **, and * indicate $p < 0.001$, $p < 0.01$, and $p < 0.05$, respectively

[a] HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%. Only patients with HbA1c testing during the study period had HbA1c values

[b] Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively. Only patients with blood pressure testing during the study period had systolic and diastolic values

control. Importantly, type II diabetes patients without encounters during the pandemic period had very low odds of HbA1c testing and both patient samples had lower odds of blood pressure testing and control.

Figure 1 illustrates the adjusted study outcome levels based on predicted probabilities from the main regression results separately for the diabetes and hypertension-only samples, comparing the levels for pre-pandemic and pandemic study periods.

Interaction terms that assessed differential associations of telemedicine use and each of the study outcomes by study period indicate that, compared to telemedicine use in the pre-pandemic period, telemedicine use during the pandemic period was associated with lower odds of HbA1c testing for adults with type 2 diabetes (aOR = 0.77, $p < 0.05$) and lower odds of BP testing for both the diabetes (aOR = 0.15, $p < 0.001$) and hypertension-only (aOR = 0.58, $p < 0.001$) samples. Almost all the covariates included in adjusted analyses were significantly associated with the four study outcomes. Figure 2 illustrates the marginal effects of the pandemic period on the study outcomes and compares the changes for patients with and without telemedicine encounters in the pandemic period. Figure 3 illustrates the marginal effects for each study outcome separately for each of the ten health care systems, indicating that HbA1c and BP testing decrements associated with telemedicine use were highly consistent across systems.

Supplementary Figure A2 summarizes the propensity score balance statistics before and after IPTW for the sample of adults with type 2 diabetes and Supplementary Fig. A3 reports these balance statistics for the hypertension-only sample. All the main models had relatively low covariate imbalance between patients with and without telemedicine encounters during the pandemic period, as standardized bias estimates were all below 10%. Supplementary Figures A4 and A5 report balance statistics for propensity scores that included all covariates for the diabetes and hypertension-only samples, respectively, for which some variables had standardized biases that were > 10%.

Sensitivity analyses

Compared to patients without telemedicine encounters, adults with type 2 diabetes with one telemedicine encounter (aOR = 0.39, $p < 0.05$) or with 2 or more

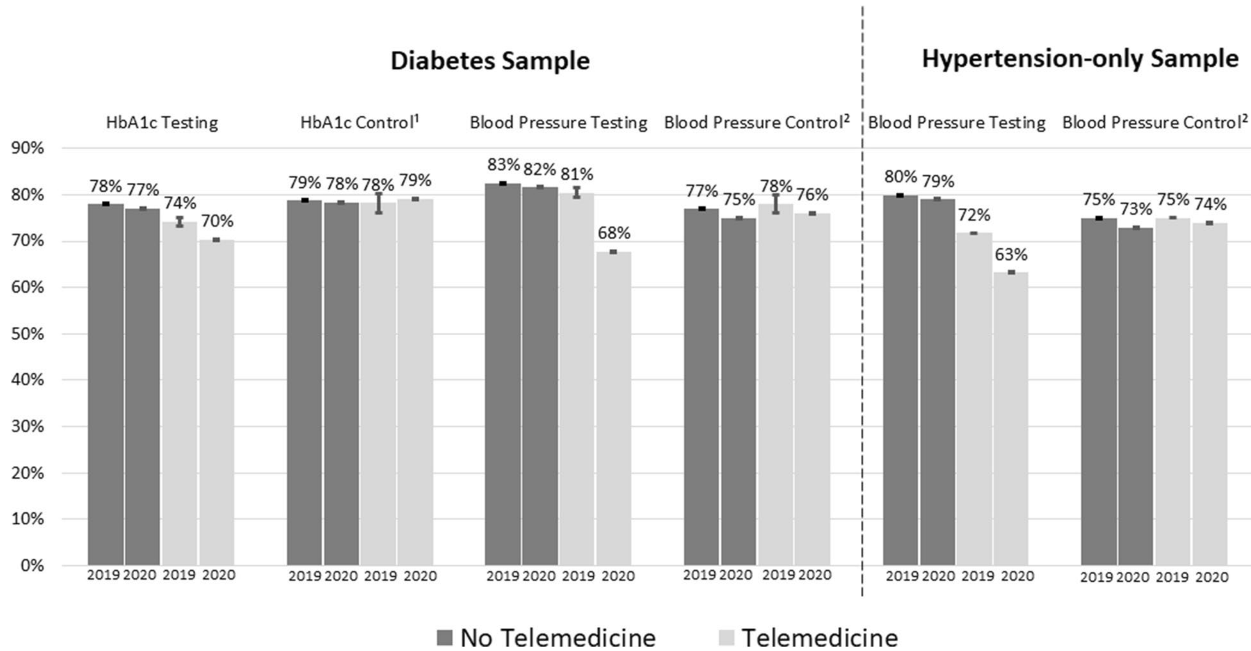

Fig. 1 Adjusted study outcomes, by year and telemedicine use. Note: Telemedicine use is defined as having at least one telemedicine encounter (audio, video, or e-visit). Adjusted outcomes account for all control variables included in the final multivariable regression models. [1]HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%. [2]Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively

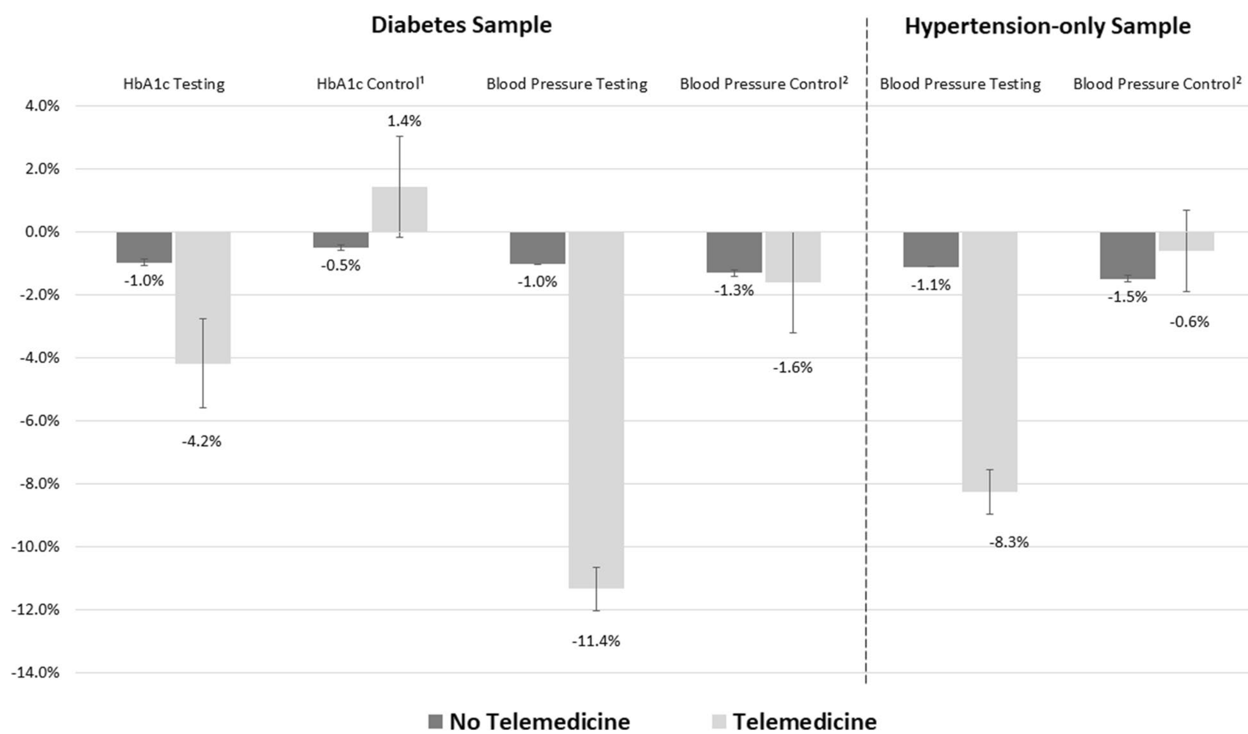

Fig. 2 Marginal effects of the COVID-19 pandemic on quality of diabetes and hypertension care, by telemedicine use. Note: Telemedicine use is defined as having at least one telemedicine encounter (audio, video, or e-visit). Marginal effects are estimated from the final multivariable regression models. [1]HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%. [2]Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively

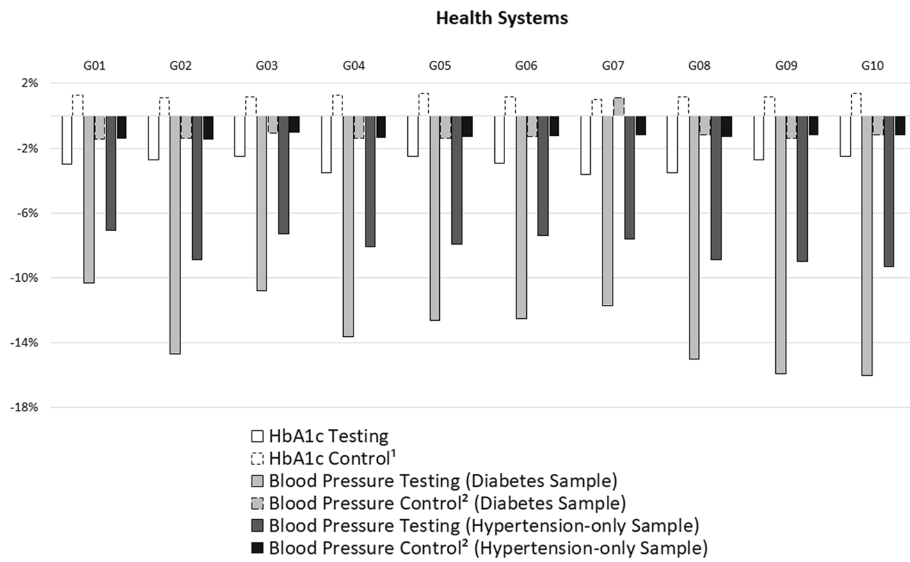

Fig. 3 Marginal effects of telemedicine on quality of diabetes and hypertension care across health systems. Note: Telemedicine use is defined as having at least one telemedicine encounter (audio, video, or e-visit). Marginal effects are estimated from the final multivariable regression models. [1]HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%. [2]Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively

telemedicine encounters (aOR = 0.21, $p < 0.05$) had lower odds of BP testing (Supplementary Table A4) and the effects were stronger in the pandemic period. Compared to hypertension-only patients with no telemedicine encounters, hypertension-only patients with one (aOR = 0.09, $p < 0.001$) or two or more telemedicine encounters (aOR = 0.06, $p < 0.001$) had lower odds of BP testing. Pandemic period telemedicine use was also associated with lower odds of BP testing compared to pre-pandemic telemedicine use. Figure 4 illustrates the adjusted study outcome levels for pre-pandemic and pandemic periods stratified by the three categories of telemedicine use.

The results of the second set of sensitivity analyses, where we restricted the definition of telemedicine use to include only video-based visits, yielded results nearly

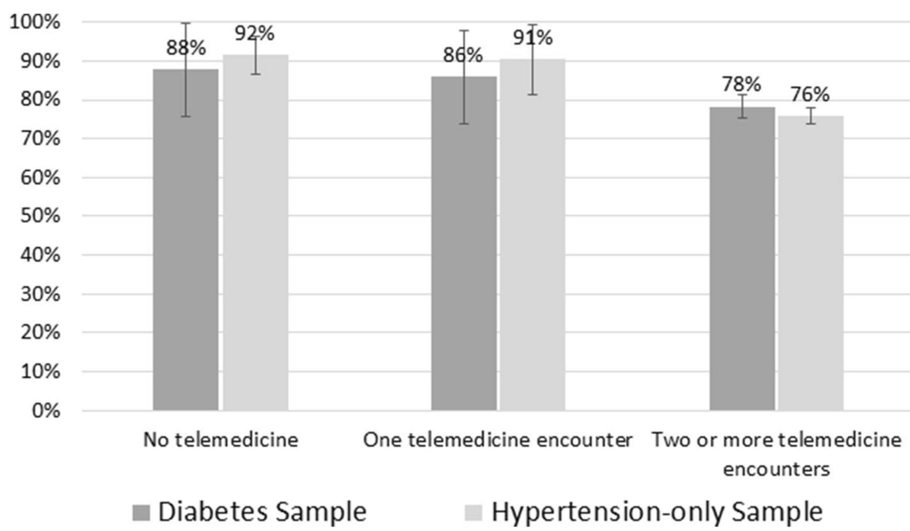

Fig. 4 Predicted probabilities of blood pressure testing by sample population and telemedicine encounters. Note: Telemedicine encounters include audio, video, and e-visits. Predicted probabilities account for all control variables included in the final multivariable regression models. [1]HbA1c is considered under control if the patient's HbA1c test result is less than 8.0%. [2]Blood pressure is considered under control if the patient's last recorded systolic and diastolic blood pressure values are below 140 mmHg and 90 mmHg, respectively

identical to those in the main models (Supplementary Table A5), although the effect of telemedicine use on HbA1c testing attenuated.

Our third sensitivity analysis that assessed differential associations of telemedicine and each study outcome by urbanicity found that telemedicine was associated with more consistent monitoring of adults with diabetes and/or hypertension residing in micropolitan areas and small towns compared to similar patients residing in metropolitan areas (Supplementary Table A6). Compared to telemedicine users with diabetes residing in metropolitan areas, telemedicine users with diabetes residing in micropolitan areas were more likely than to receive HbA1c (aOR = 1.19, $p < 0.001$) and blood pressure (aOR = 1.16, $p < 0.05$) testing, while telemedicine users with diabetes residing in small towns were more likely to receive blood pressure testing (aOR = 1.37, $p < 0.001$). Similarly, telemedicine users with hypertension-only residing in micropolitan areas (aOR = 1.13, $p < 0.01$) and small towns (aOR = 1.20, $p < 0.001$) were more likely to receive blood pressure testing compared to telemedicine users with hypertension-only residing in metropolitan areas.

Our fourth sensitivity analysis that used mixed effects logit DiD models to estimate telemedicine effects resulted in a major decrement to the analytic sample; only 12–26% of patients were retained across models due to perfect prediction. Telemedicine effects on HbA1c and BP testing were similar in magnitude as the main models (Supplementary Table A7), but the effects were not statistically significant due to low statistical power with the reduced sample size. For the hypertension-only sample, the effect of telemedicine use on BP testing (aOR = 0.06, $p < 0.001$) was consistent with the main model, but telemedicine use in the pandemic period was positively associated with BP control (aOR = 1.26, $p < 0.05$) for hypertension-only patients, in contrast to the main model.

Discussion

Our findings from established adult patients with type 2 diabetes and/or hypertension indicate that telemedicine use was associated with decrements to quality of care during the early pandemic period and that these decrements were highly consistent across the ten health care systems examined. Patient care processes for HbA1c and BP monitoring were substantially different from one another before the pandemic. BP was generally assessed at every in-person medical encounter, with a small minority of BP readings reported from patient self-reports from home [26, 27]. As a result, BP results were generally only documented in electronic health records if the screening was conducted as part of an in-person encounter. By contrast, many primary care practices use standing orders for HbA1c assessment for adults with type 2 diabetes at 6-month or annual intervals [28, 29]. Prior to the pandemic, patients did not need an in-person visit to receive HbA1c testing; instead, they visited a laboratory to have their blood drawn for their HbA1c assessment between visits [30]. This may be a major reason why pandemic period decrements to HbA1c testing were much smaller than decrements to BP testing.

Contrary to our expectations, decrements to BP testing and control were not larger for the hypertension-only sample compared to the type 2 diabetes sample. The results highlight the major challenge of remote BP monitoring, even for established adult patients with type 2 diabetes with regular interaction with health care systems. Evidence indicates that home and online management of BP with optional lifestyle advice and motivational support can improve BP management [31, 32]. During the early pandemic, however, health care organizations faced barriers of purchasing, acquiring, and deploying home BP monitors [33]. Moreover, teaching patients how to reliably obtain and report BP readings using a patient portal or phone line has been difficult for large health care systems to scale [5, 34]. These challenges likely account for the widespread decrements to BP monitoring associated with telemedicine use.

Importantly, our sensitivity analyses examining heterogeneous effects of telemedicine on quality of care by urbanicity indicate that, compared to telemedicine users residing in metropolitan areas, telemedicine users residing in micropolitan areas or small towns were more likely to have blood pressure testing during the early pandemic period. These results highlight that telemedicine use may have been more beneficial for maintaining quality of care for rural residents with diabetes and/or hypertension than for urban residents. These results are consistent with evidence that remote chronic care management is especially useful for maintaining quality of care for residents of small towns and rural areas, who often experience travel-related barriers to care [35].

We also found that patients with two or more telemedicine encounters were much less likely than patients with no telemedicine encounters to have BP testing. Our results are consistent with recent analyses of Medicare beneficiary data from 441 primary care clinics across 38 ACOs indicating that adults with hypertension with an in-person primary care visit were more likely to have a BP measurement than those with only a telemedicine visit (96% vs 32%) [36]. Our results, however, are in contrast to recent analyses of commercially-insured patients of a large national health plan, which found that adults with type 2 diabetes receiving in-person care alone were less likely to have their BP under control [37]. Similarly, a study of Louisiana Medicare beneficiaries with type 2 diabetes, found that telemedicine use was associated with lower pandemic-era mean HbA1c values, which translated to an increased likelihood of having HbA1c in control [38]. The mixed results may be due to different research designs, statistical methods, patient populations, and the ability of health systems to implement telemedicine across these studies. Future research should directly examine heterogenous quality impacts of telemedicine by patient subpopulations and quality measures, as well as the effect of telemedicine on quality of care beyond the early pandemic period.

The consistency of the BP monitoring decrements associated with telemedicine use across the ten health care systems highlight the pervasive negative association of telemedicine use with BP monitoring. The slow policy responses to expanding health insurance coverage for remote home BP monitors coupled with the discontinuation of telemedicine for diabetes and hypertension care management by health care systems indicate that the decrements to BP and HbA1c monitoring experienced in 2020 may reoccur if in-person care were to be limited in the future. The study findings underscore the merits of ongoing policy proposals that require health insurers to cover remote home BP monitors for patients as a durable medical equipment benefit for all adults with diabetes and/or hypertension [39].

Quality of care for patients who used telemedicine during the pandemic period might have been maintained through the consistent use of standing orders for HbA1c and BP monitoring and/or dedicated clinics for routine screening. Research examining patients' experiences of telemedicine during the pandemic indicate that difficulties with using patient portals and poor video quality could have impacted quality of care for telemedicine users with diabetes and/or hypertension [40]. To improve the reach of screening efforts, clinic-community pharmacy partnerships and other outreach methods may also be needed to consistently monitor HbA1c and BP during times when in-person care options are limited [14–16, 41].

Our results should be considered with some limitations. First, the 15-month activity window before each study period may have excluded established patients based on utilization prior to March of each year. Second, the study outcomes we assessed were annualized quality measures, but the study periods were 9 months (March 13 to December 31 of each year). Taken together, these patterns may have had countervailing effects. Third, our main GLM estimation approach has limits to causal inference but DiD models with a narrow patient sample examined as the third sensitivity analyses yielded consistent telemedicine effects except for BP control for the hypertension-only sample, which was positive and statistically significant, in contrast to a null effect in the main analyses. Despite these limitations, the study advances evidence by including all insurance types and patient ages and using a study design that enables stronger inferences for established patients of health care systems.

Conclusion

In conclusion, our analyses of telemedicine for established adult patients of ten health care systems found that telemedicine use was associated with lower odds of HbA1c and BP testing among adults with type 2 diabetes and with lower odds of BP testing among adults with hypertension-only. This is a major public health concern, as limited monitoring of BP and HbA1c can lead to high-cost exacerbations if cardiovascular risks are not well managed. The consistency of the quality decrements across ten health systems highlights the pervasive challenge of BP monitoring during the pandemic and beyond. Compared to telemedicine use, however, having no encounters during the pandemic period was associated with very low testing levels. Patients may have become accustomed to receiving remote care and prefer telemedicine over in-person encounters, so a combination of remote care monitoring, standing orders, community pharmacy partnerships, and innovative outreach methods may be needed to ensure routine BP and A1c assessments for patients who rely on telemedicine encounters over in-person care.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44247-023-00056-7.

Additional file 1: Figure A1. Dates Associated with Activity Windows and Study Periods. **Table A1.** Analytic Sample Exclusions. **Table A2.** Characteristics of the Ten Health Systems. **Figure A2.** Covariates Balance Using Stabilized Inverse Propensity Treatment Weighting Among Adults with Diabetes (Limited Covariates). **Figure A3.** Covariates Balance Using Stabilized Inverse Propensity Treatment Weighting Among Adults with Hypertension Only (Limited Covariates). **Figure A4.** Covariates Balance Using Stabilized Inverse Propensity Treatment Weighting Among Adults with Diabetes (Full Set of Covariates). **Figure A5.** Covariates Balance Using Stabilized Inverse Propensity Treatment Weighting Among Adults with Hypertension Only (Full Set of Covariates). **Table A3.** Prescriptions Categories. **Table A4.** Sensitivity Analysis 1: Association Between Telemedicine Encounter Categories and Outcome Measures using Generalized Linear Models with Stabilized Inverse Propensity Treatment Weighting. **Table A5.** Sensitivity Analysis 2: Association Between Telemedicine Video Exposure and Outcome Measures using Generalized Linear Models with Stabilized Inverse Propensity Treatment Weighting. **Table A6.** Sensitivity Analysis 3: Heterogeneity of Telemedicine Effects by Rurality: Association Between Telemedicine and Outcome Measures. **Table A7.** Sensitivity Analysis 4: Telemedicine Effects on Outcome Measures, estimated using Differences-in-Differences Regression (XTLOGIT).

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Authors' contributions
Concept and design (HPR, ELC, SMS); acquisition of data (ELC, CR, JTM); analysis and interpretation of data (HPR, ELC, KR, CR, JKC, JTM, SB, SMS); drafting of the manuscript (HPR, KR); critical revision of the manuscript for important intellectual content (HPR, ELC, KR, CR, JKC, JTM, SB, SMS); statistical analysis (HPR, KR); provision of patients or study materials (ELC, JKC); obtaining funding (HPR); administrative, technical, or logistic support (ELC, SB); and supervision (HPR, ELC, SB).

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Availability of data and materials
The data for this article were obtained through contractual arrangements with AMGA and Optum Labs. The data cannot be shared publicly per the research license agreement between AMGA and the University of California, Berkeley.

Declarations

Ethics approval and consent to participate
The University of California, Berkeley Office for the Protection of Human Subjects approved reliance on Dartmouth College's Committee for the Protection of Human Subjects institutional review board for study approval (#28763), which included a waiver of informed consent for secondary data analyses of de-identified electronic health record data. All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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