Kidney Medicine

A CKD Clinical Decision Support System: A Cluster Randomized Clinical Trial in Primary Care Clinics

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Rationale & Objective: The study aimed to develop, implement, and evaluate a clinical decision support (CDS) system for chronic kidney disease (CKD) in a primary care setting, with the goal of improving CKD care in adults.

Study Design: This was a cluster randomized trial.

Setting & Participants: A total of 32 Midwestern primary care clinics were randomly assigned to either receive usual care or CKD-CDS intervention. Between April 2019 and March 2020, we enrolled 6,420 patients aged 18-75 years with laboratory-defined glomerular filtration rate categories of CKD Stage G3 and G4, and 1 or more of 6 CKD care gaps: absence of a CKD diagnosis, suboptimal blood pressure or glycated hemoglobin levels, indication for angiotensin-converting enzyme inhibitor or angiotensin receptor blocker but not prescribed, a nonsteroidal anti-inflammatory agent on the active medication list, or indication for a nephrology referral.

Intervention: The CKD-CDS provided personalized suggestions for CKD care improvement opportunities directed to both patients and clinicians at primary care encounters.

Outcomes: We assessed the proportion of patients meeting each of 6 CKD-CDS quality metrics representing care gap resolution after 18 months.

Results: The adjusted proportions of patients meeting quality metrics in CKD-CDS versus usual care were as follows: CKD diagnosis documented (26.6% vs 21.8%; risk ratio [RR], 1.17; 95% CI, 0.91-1.51); angiotensin-converting enzyme inhibitor or angiotensin receptor blocker prescribed (15.9% vs 16.1%; RR, 0.95; 95% CI, 0.76-1.18); blood pressure control (20.4% vs 20.2%; RR, 0.98; 95% CI, 0.84-1.15); glycated hemoglobin level control (21.4% vs 22.1%; RR, 1.00; 95% CI, 0.80-1.24); nonsteroidal anti-inflammatory agent not on the active medication list (51.5% vs 50.4%; RR, 1.03; 95% CI, 0.90-1.17); and referral or visit to a nephrologist (38.7% vs 36.1%; RR, 1.02; 95% CI, 0.79-1.32).

Limitations: We encountered an overall reduction in expected primary care encounters and obstacles to point-of-care CKD-CDS utilization because of the coronavirus disease 2019 pandemic.

Conclusions: The CKD-CDS intervention did not lead to a significant improvement in CKD quality metrics. The challenges to CDS use during the coronavirus disease 2019 pandemic likely influenced these results.

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Primary care clinicians play a crucial role in caring for adults with chronic kidney disease (CKD). Effective care by primary care clinicians is essential to mitigate the worldwide burden of CKD.[1,2] Substantial evidence exists that CKD progression can often be delayed or prevented by optimal control of blood pressure (BP) and glycated hemoglobin (A1C),[3] use of medications like angiotensin-converting enzyme inhibitors (ACEis) or angiotensin receptor blockers (ARBs),[3] and avoiding nonsteroidal anti-inflammatory drugs (NSAIDs). Furthermore, referrals to nephrologists are recommended for individuals with advanced CKD.[2-4]

However, many patients with CKD in glomerular filtration rate (GFR) categories G3 or G4 (GFR of 15-59 mL/min/1.73 m^2) do not receive the recommended guideline-based care.[3-9] Preliminary data for this study showed that nearly two-thirds of these patients had BP equal to or exceeding 130/80 mm Hg, half of those with diabetes had an A1C of 7% or higher, and only 1 in 4 had undergone albuminuria testing within the past year. For those with hypertension or albuminuria (without hyperkalemia), only about half were prescribed an ACEi or ARB. Moreover, less than half of patients with CKD stages G3bA2, G3bA3, or G4 had seen a nephrologist within the last 2 years.

The deficiencies in CKD care are more prevalent when patients with laboratory-confirmed CKD and/or their clinicians are unaware of the CKD diagnosis.[10] Data from a 2018 Veterans Affairs CKD national surveillance study showed that more than half of patients with CKD based on GFR values had no diagnostic codes for CKD.[11] National health and nutrition examination survey data indicated no significant improvement in patients with CKD awareness between 1999 and 2016.[12,13]

Primary care clinicians frequently cite various barriers to delivering optimal CKD care, including incomplete knowledge of CKD guidelines, challenges in translating guidelines into practice, competing clinical demands, difficulties in care coordination, and a low prioritization of CKD care quality perhaps because of the lack of CKD-specific quality measures.[14-16] In this context, there is reason to believe that deploying well-designed clinical

PLAIN-LANGUAGE SUMMARY

This study aimed to improve the management of chronic kidney disease (CKD) through a clinical decision support (CDS) system. It involved 32 primary care clinics and 6,420 patients with CKD who had 1 or more of 6 CKD care improvement opportunities. The CDS provided personalized suggestions to both patients and clinicians about CKD care opportunities during primary care visits. After 18 months, the study found no significant differences between patients in clinics with CKD-CDS compared with usual care in diagnosing CKD, prescribing recommended medications, controlling blood pressure or glycated hemoglobin, nonsteroidal anti-inflammatory agent usage, or nephrology referrals. The coronavirus disease 2019 pandemic may have influenced results by introducing unforeseen implementation challenges, reduced visits, and less than expected CDS exposure.

decision support (CDS) during primary care encounters for patients having laboratory evidence of CKD could enhance recognition and management.[16]

In previous work we developed, implemented, and evaluated primary care CDS systems that were aimed at improving uncontrolled cardiometabolic conditions, such as diabetes and hypertension. The results of clinic randomized trials for these earlier CDS systems demonstrated significant improvement in glycemic and BP control,[17] reduced 10-year cardiovascular risk,[18,19] improved BP recognition in adolescents,[20] and cost effectiveness.[21,22] Clinician surveys during these trials demonstrate high levels of primary care clinician satisfaction with the CDS system.[18] Given the positive outcomes of CDS for other chronic diseases, there was great potential for the CKD-CDS to improve CKD care management in the same primary care setting using a similar implementation strategy.

This trial faced unforeseen challenges because of disruptions caused by the coronavirus disease 2019 (COVID-19) pandemic, such as a sharp decrease in office-based clinical encounters, clinic closures, and the sudden widespread use of virtual encounters. These challenges and necessary study adaptations have been previously documented.[23] Recognizing this limitation, we report the results of this NIH-funded project to develop, implement, and rigorously evaluate a CKD-specific primary care CDS intervention in a cluster randomized trial. The goal was to improve CKD detection and care using a CDS system that minimized disruption to clinic workflows.[17-19]

METHODS

Hypothesis, Study Design, and Study Site

This cluster randomized trial aimed to assess whether implementing the CKD-CDS intervention in primary care would improve CKD recognition by primary care clinicians and improve essential aspects of evidence-based CKD care.

The study took place in 32 primary care clinics within a 47-clinic multispecialty care system across Minnesota and Wisconsin. Clinics were selected based on specific criteria: they needed a sufficient number of adults with CKD GFR categories G3 and G4 (GFR of 15-59 mL/min/1.73 m^2), use EpiCare electronic health record (EHR) software, already use the CDS system for cardiovascular disease and diabetes, and be within a 30-mile radius of 1 of the 2 nephrologist subspecialty care groups associated with the care system, which also documented their encounters within the same EHR. Referrals to nephrology outside of these 2 nephrologist specialty groups were rare in these clinics.

The study employed a clinic cluster randomized trial design, with 32 eligible clinics randomized into either CKD-CDS intervention or the usual care group (Fig 1). The CKD-CDS intervention occurred during primary care encounters of eligible patients in intervention clinics over 12 months, with outcome assessment conducted 18 months after their index visit. With almost no staff crossover between clinics, the risk of clinician contamination in the usual care group was minimal with the clinic randomized design.

Randomization Procedure

Eligible clinics were randomized in a 1:1 ratio to either receive the CKD-CDS intervention or usual care using covariate constrained restricted randomization.[24] This computerized process balanced clinic characteristics that could affect the intervention or its implementation. Five clinic covariates were balanced across treatment groups, including care delivery system affiliation; participation in a concurrent clinical trial on CDS to improve medication adherence, the number of patients with CKD in the year preceding randomization, the proportion of patients with Medicaid health insurance coverage; and scores on the care system's quality measure for hypertension. The study team was blinded during the randomization process, but after randomization, the study team could not be blinded to allocation because of staff training and implementation requirements at the intervention clinics.

Study Participants

Patients aged 18-75 years with GFR laboratory evidence of CKD stage G3 (GFR of 30-59 mL/min/1.73 m^2 on the most recent GFR in the last 5 years and confirmed with GFR 15-59 mL/min/1.73 m^2 on the next most recent GFR) or CKD stage G4 (GFR 15-29 mL/min/1.73 m^2 on the most recent GFR result in the last 5 years) were identified at clinic encounters. The index visit was defined as the first visit at a randomized clinic after the CDS intervention go-live date when a patient who met these GFR criteria also had evidence of 1 of the 6 CKD care gaps defined in Table 1. Patients with evidence of kidney failure

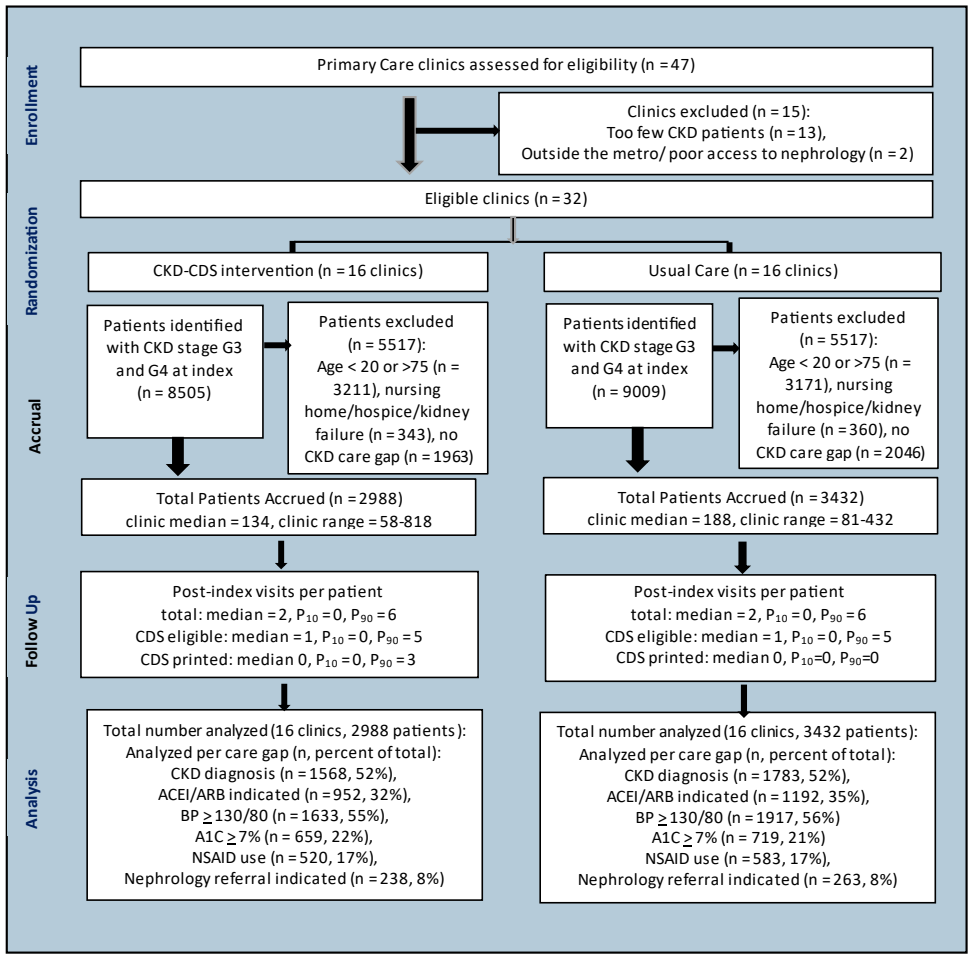

Figure 1. CONSORT flow diagram.

(kidney failure diagnosis, receiving dialysis, after kidney transplant, or GFR of <15 mL/min/1.73 m^2), recent pregnancy, active cancer, or use of hospice or palliative care did not qualify for an index visit at that encounter. Study patients were accrued between April 2019 and March 2020, with an 18-month observation period beginning on their index date. Patients were assigned to the study arm of the clinic where their index visit occurred.

Protection of Human Participants

Study procedures were reviewed in advance, approved, and monitored by the HealthPartners institutional review board (17-353). The institutional review board granted a waiver of written informed consent for primary care clinicians and patients because CDS was limited to evidence-based recommendations included in national guidelines.

Intervention

The CKD-CDS intervention comprised 3 main features: exchange and evaluation of EHR data at every primary care encounter to identify CKD study–eligible patients with care gaps and generate evidence-based personalized care suggestions; provision of these CDS-generated care suggestions on printed interfaces to both primary care clinicians and patients at clinical encounters; and display of the CDS-generated suggestions within the EHR with facilitation of clinician actions through quick orders for care suggestions involving test ordering (eg, creatinine/GFR and albumin-to-creatinine ratio [ACR]), prescribing medications (eg, ACEi or ARB), or referrals to nephrology.

A description of the development process, technology, and security process for the CKD-CDS has been previously documented.[2,3] The patient interface listed kidney health as a priority to encourage discussion about CKD with their primary care clinician (see example in Fig 2). The primary care clinician interface and EHR display listed the patient's individualized care gaps and offered treatment suggestions using algorithms that incorporated laboratory data, medications, comorbid conditions, allergies, and other treatment considerations (see example in Fig 3). The CKD-CDS was incorporated into a larger CDS system already in place within the care system that included CDS for diabetes and cardiovascular risk factors such as hypertension, lipids, smoking, and obesity. An important aspect of the standardized CDS workflow in all clinics was reliance on

Table 1. The Six CKD Quality Metric Outcomes—Definitions and Eligibility Requirements

CKD Quality Metric	Definition of Care Gap Identified at Index that was Required for Each Outcome Denominator	Quality Metric Definition—Evaluated Through 18 Mo After Index
CKD recognized	A diagnosis of CKD is not identified on the problem list or at more than one encounter diagnoses in the previous 2 y (ICD10 N18.3 or higher or N19)	CKD diagnosis code assigned at an outpatient encounter, or the entry of CKD diagnosis on the problem list, from index through 18 mo after index
ACEi or ARB prescribed	No ACEi or ARB on the active medication list when indicated for either diagnosed hypertension or urine ACR ≥ 30 mg/g, and GFR ≥ 30 mL/min/1.73 m^2, and no hyperkalemia in the last year	Prescription for an ACEi or ARB medication in the 18 mo after index
Blood pressure at goal	BPs at the current and most recent visit ≥ 130/80 mm Hg	Mean of the last 2 systolic BPs < 130 mm Hg and mean of the last 2 diastolic BP's < 80 mm Hg in the 18 mo after index using outpatient office BP measurements
A1C at goal	Diagnosed diabetes and most recent A1C in the last 12 mo ≥7.0%	Last A1C value in the 18 mo after index <7.0%
NSAID not identified on the active medication list	≥1 NSAID medications (other than aspirin) on the active medication list	No NSAID medications (other than aspirin) on the active medication list at last visit in 18 mo after index
Nephrology referral or visit completed	No nephrology visit in the last 12 mo for patients with G4 CKD (GFR 15-29 mL/min/1.73 m^2), or G3bA2 CKD (GFR 30-44 mL/min/1.73 m^2 with ACR ≥30 mg/g), or A3 (ACR ≥300 mg/g)	Referral or consult order to nephrology or a nephrology visit identified in the EHR in the 18 mo after index

Abbreviations: ACEi, angiotensin-converting enzyme inhibitor; ACR, albumin-to-creatinine ratio; ARB, angiotensin receptor blocker; BP, blood pressure; CKD, chronic kidney disease; EHR, electronic health record; GFR, glomerular filtration rate; NSAID, nonsteroidal anti-inflammatory drugs.

rooming staff (the staff who typically prepare a patient for a primary care visit and obtain vital signs) to open and print the patient and clinician interfaces at the beginning of the encounter using a best practice alert programmed to appear on the EHR screen for targeted patients within seconds of a BP entry. The rooming staff could open and print the patient and clinician interface with only 1 click on a URL link embedded in the best practice alert. The rooming staff handed the patient version to the patients to review while they were waiting to be seen.

Data Collection

The CKD-CDS system collected data from the EHR during all visits of study-eligible patients across all randomized clinics. Data elements included demographics, vitals, medications, comorbid conditions, and laboratory data from 2 years preceding each visit. Data elements for calculating study outcomes were collected from EHR production tables and CDS web service analytic tables over the 18 months following the index visit. Missing laboratory values, vital signs, or medications were interpreted as care processes or tests not performed or medication not prescribed rather than missing values.

Statistical Analysis

Each of the 6 quality metric outcomes representing care gap resolution was analyzed separately using data from patients with each care gap at their index visit. Intent-to-treat analyses modeled the binary outcomes for all patients, regardless of the number of postindex visits or the clinic location in the subsequent 18 months. A generalized linear mixed model (GzLMM) with a binomial distribution, log link function, and random clinic intercept were used to account for the intraclass correlation (ICC) among patients within clinics. The primary predictor was a fixed treatment group indicator with covariates for balancing variables. RRs and 2-sided 95% confidence intervals (CIs) are presented to characterize treatment effects. Unadjusted linear mixed models were used to compare patient characteristics at index by treatment group.

Secondary analyses were conducted for each CKD quality metric using data from patients who accrued into the study early, up to September 13, 2019. These patients had at least 6 months of follow-up before the COVID-19–related clinic disruptions that began on March 13, 2020. These models followed the same specifications as the primary analysis but with a smaller sample.

Additional secondary analyses were performed using data from patients with any of the CKD-specific care gaps at index. These models predicted binary outcomes that indicated fewer or no remaining CKD care gaps at 18 months after index, with a fixed predictor for the number of CKD care gaps at index. The models were otherwise specified similarly to the primary analysis.

A priori power analyses estimated the minimum detectable difference for each study outcome based on

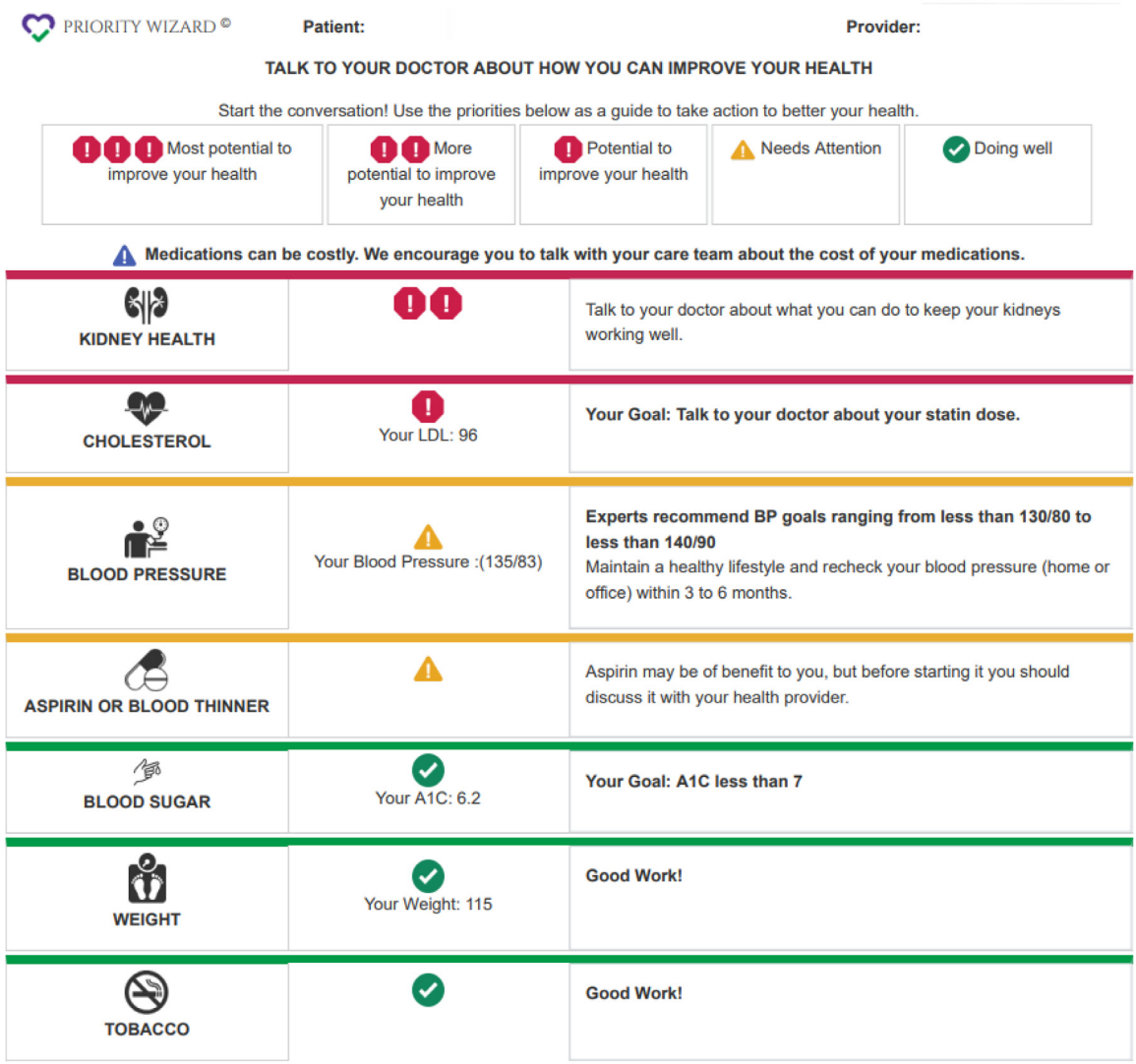

Figure 2. Patient version of clinical decision support-chronic kidney disease interface.

sample size, event rates, and ICC estimated from pilot data. The study was powered (80%, 2-sided $\alpha = 0.05$) to detect clinically meaningful between-group differences of at least 10% (BP control, ACEi or ARB use, and glucose control) or 20% (CKD recognition and nephrology referral).

RESULTS

Characteristics of Study-Eligible Patients

Table 2 shows the characteristics of the study sample consisting of 6,420 patients with laboratory-defined CKD who had an index visit with at least one identified care gap. At the index visit, the mean age was 66.1 years, 56.4% were female, and 84.1% were White. Among them, 72.4% had CKD stage G3a, 22.2% had CKD stage G3b, and 5.5% had CKD stage G4. Patients in CKD-CDS clinics had slightly higher diastolic BP (DBP) at index (CKD-CDS mean BP = 77.4 mm Hg, usual care mean BP = 76.4 mm Hg), and, among those with a hypertension diagnosis, 60.6% in CKD-CDS versus 57.1% in usual care were prescribed an ACEi or ARB. More patients with CKD-CDS had an ACR test value at index (CKD-CDS 47.9% and usual care 44.3%). No other statistically significant treatment group differences were observed in patient characteristics or in the proportion of patients eligible for each care gap analysis. Table 3 displays the number and percent of eligible study patients with each of the 6 care gaps at index. The number eligible for each care gap analysis ranged from 501 (nephrology referral) to 3,551 (BP control).

Main Outcomes

Table 4 presents the main outcomes of the trial. The greatest improvement in quality metric was observed for CKD recognition, in which 26.6% of CKD-CDS and 21.8% of usual care patients had a CKD diagnosis documented in the EHR within 18 months after index (risk ratio [RR], 1.17; 95% CI, 0.91-1.51), although this was not statistically significant ($P = 0.21$). None of the CKD quality

Figure 3. Clinician version of clinical decision support-chronic kidney disease interface.

metric improvements were clinically or statistically significant. In absolute terms, patients in the CKD-CDS group, relative to usual care, had higher percentages of NSAIDs not identified on the active medication list (51.5% vs 50.4%) and nephrology referral or visits (38.7% vs 36.1%), but lower percentages of orders for ACEi or ARBs (15.9% vs 16.1%) and lower percentage with BP less than 130/80 mm Hg.

Postindex Patient Visit Patterns

Fig 4 illustrates the pattern of intervention-eligible visits. Of note, the care system began restricting in-person primary care visits in March 2020, resulting in a sharp decrease in the number of CKD-CDS eligible postindex visits. Postindex visits reached their nadir in April 2020 and largely returned to prepandemic levels as of June 2020. The print rates of the CDS interfaces for eligible patient encounters were about 67% in CKD-CDS clinics in the months before March 2020. The CKD-CDS interface and print capabilities were disabled in March 2020 because of major clinic disruptions and restored in August 2020 with added functionality to view interfaces in video visits. The print rates improved but did not return to prepandemic levels after the intervention was restored. Fig 4 also demonstrates some crossover contamination of usual care patients who were seen in CKD-CDS clinics for postindex visits (2.6%). After August 2020, the CKD-CDS was programmed not to display for usual care patients at CKD-CDS clinics and that risk of contamination was essentially eliminated.

Secondary Analysis

Table 5 summarizes the results of secondary analyses, estimating CKD-CDS effectiveness among the 3,833 patients with at least 6 months of follow-up before the COVID-19 pandemic clinic disruptions. Adjusted RRs for CKD diagnosis (RR, 1.16; 95% CI, 0.90-1.50), ACEi or ARB orders (RR, 0.93; 95% CI, 0.71-1.22), and NSAID not on the active medication list (RR, 1.05; 95% CI, 0.88-1.24) were similar to those of the primary analysis. Adjusted RRs for BP <130/80 mm Hg (RR = 1.06),

Table 2. Index Visit Characteristics of Patients with CKD and at Least 1 Care Gap by Treatment Group

		Usual Care	CKD-CDS	All	*P*
Study eligible	N	3,432	2,988	6,420	
Male	n (%)	1,445 (42.1)	1,353 (45.3)	2,798 (43.6)	0.06
Female	n (%)	1,987 (57.9)	1,635 (54.7)	3,622 (56.4)	
Age (y)	Mean ± SD	66.1 ± 7.9	66.2 ± 7.6	66.1 ± 7.8	0.69
Native American, Alaskan	n (%)	16 (0.5)	12 (0.4)	28 (0.4)	0.71
Asian	n (%)	142 (4.1)	119 (4.0)	261 (4.1)	0.63
Black, African American	n (%)	260 (7.6)	278 (9.3)	538 (8.4)	0.28
Hawaiian, Pacific Islander	n (%)	7 (0.2)	3 (0.1)	10 (0.2)	0.29
White	n (%)	2,903 (84.6)	2,496 (83.5)	5,399 (84.1)	0.26
Other, Unknown, Multiple	n (%)	104 (3.0)	80 (2.7)	184 (2.9)	0.93
Hispanic, Latino	n (%)	77 (2.2)	48 (1.6)	125 (1.9)	0.34
not Hispanic, Latino	n (%)	3,355 (97.8)	2,940 (98.4)	6,295 (98.1)	
GFR category for CKD					
G3a, GFR 45-59	n (%)	2,472 (72.0)	2,173 (72.7)	4,645 (72.4)	0.74
G3b, GFR 30-44	n (%)	764 (22.3)	659 (22.1)	1,423 (22.2)	0.99
G4, GFR 15-29	n (%)	196 (5.7)	156 (5.2)	352 (5.5)	0.55
Diabetes					
Diabetes diagnosed	n (%)	1,276 (37.2)	1,139 (38.1)	2,415 (37.6)	0.48
A1C documented	n (%)	1,273 (99.8)	1,131 (99.3)	2,404 (99.5)	0.13
A1C	M (SD)	7.6 (3.8)	7.5 (1.5)	7.5 (3.0)	0.33
	Median	7.2	7.2	7.2	
A1C ≥ 8%	n (%)	369 (29.0)	313 (27.7)	682 (28.4)	0.60
A1C < 8%	n (%)	904 (71.0)	818 (72.3)	1,722 (71.6)	
Hypertension					
Hypertension diagnosed	n (%)	2,928 (85.3)	2,512 (84.1)	5,440 (84.7)	0.72
Index SBP	M (SD)	134.2 (17.3)	134.4 (17.4)	134.0 (17.4)	0.27
Index DBP	M (SD)	76.4 (11.9)	77.4 (11.9)	76.9 (11.9)	0.02
BP greater or equal to 140/90 mm Hg	n (%)	904 (30.9)	795 (31.6)	1,699 (31.2)	0.09
ACR category					
Urine ACR documented	n (%)	1,519 (44.3)	1,430 (47.9)	2,949 (45.9)	0.03
A2 or A3, (urine ACR ≥ 30)	n (%)	698 (20.3)	680 (22.8)	1,378 (21.5)	0.19
A1, urine ACR < 30	n (%)	821 (23.9)	750 (25.1)	1,571 (24.5)	
Medications identified on the active medication list at index visit					
Antihypertensive	n (%)	2,932 (85.4)	2,542 (85.1)	5,474 (85.3)	0.91
Lipid	n (%)	2,262 (65.9)	2,008 (67.2)	4,270 (66.5)	0.36
Aspirin	n (%)	1,996 (58.2)	1,771 (59.3)	3,767 (58.7)	0.80
Glucose, oral	n (%)	866 (25.2)	794 (26.6)	1,660 (25.9)	0.58
Glucose, insulin	n (%)	511 (14.9)	462 (15.5)	973 (15.2)	0.86
NSAID	n (%)	636 (18.5)	565 (18.9)	1,201 (18.7)	0.80
ACEi or ARB	n (%)	1,720 (50.1)	1,575 (52.7)	3,295 (51.3)	0.08
ACEi or ARB, if diagnosed hypertension	n (%)	1,672 (57.1)	1,523 (60.6)	3,195 (58.7)	0.05
ACEi or ARB, if proteinuria	n (%)	465 (66.6)	483 (71.0)	948 (68.8)	0.18

Abbreviations: A1C, glycated hemoglobin; ACEi, angiotensin-converting enzyme inhibitor; ACR, albumin-to-creatinine ratio; ARB, angiotensin receptor blocker; BP, blood pressure; CDS, clinical decision support; CKD, chronic kidney disease; DBP, diastolic blood pressure; GFR, glomerular filtration rate; NSAID, nonsteroidal anti-inflammatory drug, SBP, systolic blood pressure.

A1C <7% (RR = 1.11), and nephrology referral (RR = 1.19) among early enrollees were more favorable than those observed in the whole sample, but for all outcomes, confidence limits spanned unity. We did not make direct comparisons between early and late enrollees.

Among the 4,079 patients who had at least 1 CKD-specific care gap at index, a higher proportion of those in the CKD-CDS had fewer remaining care gaps at 18 months after index (RR, 1.24; 95% CI, 0.92-1.68) or no (RR, 1.21; 95% CI, 0.87-1.68) (Table 6). However, the estimated CKD-CDS effectiveness for the composite care gap outcome, and the individual care gaps, did not reach statistical significance even when limited to the smaller sample of patients with at least 6 months of follow-up

Table 3. Care Gaps Identified at Index Visit

		Usual Care (n = 3,432)	CKD-CDS (2,988)	All (6,420)	*P*
CKD not recognized	n (%)	1,783 (52.0)	1,568 (52.5)	3,351 (52.2)	0.69
ACEi or ARB use indicated	n (%)	1,192 (34.7)	952 (31.7)	2,144 (33.4)	0.10
BP over goal	n (%)	1,917 (55.9)	1,633 (54.7)	3,550 (55.3)	0.88
A1C over goal	n (%)	719 (20.9)	659 (22.1)	1,378 (21.5)	0.48
NSAID on the active medication list	n (%)	583 (17.0)	520 (17.4)	1,103 (17.2)	0.87
Nephrology referral indicated	n (%)	263 (7.7)	238 (8.0)	501 (7.8)	0.95

Abbreviations: A1C, glycated hemoglobin; ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; BP, blood pressure; CDS, clinical decision support; CKD, chronic kidney disease; NSAID, nonsteroidal anti-inflammatory drug.

before the COVID-19 pandemic clinic disruptions (fewer gaps RR, 1.27; 95% CI, 0.94-1.70; no gaps RR, 1.25; 95% CI, 0.89-1.75).

DISCUSSION

The substantial gaps in care management for patients with CKD have been well established. Our study sought to address this issue by integrating CKD decision support into a pre-existing CDS system primarily aimed at managing cardiovascular risk factors and diabetes. The CDS system previously demonstrated significant improvements in patient outcomes in NIH-funded randomized trials, providing a solid basis for our hypothesis that CKD-specific CDS could similarly improve CKD care outcomes within the same clinical setting. The results of the study yield several key insights.

First, the CKD-CDS intervention did not lead to significant improvements in the quality metrics associated with CKD care, encompassing CKD recognition, BP and A1C control, ACEi or ARB use, NSAID use, or nephrology referrals. Unfortunately, other studies of CKD-CDS alone have also failed to significantly improve the care of patients with kidney disease.[25-29] For example, a clustered randomized trial of 30 clinical practices using EHRs showed that CKD-CDS plus practice facilitation intervention significantly improved the primary outcome of annualized GFR decline compared with the control group that received CKD-CDS alone.[27] The study was limited by an imbalance of higher dropout of control practices. For another example, an electronic decision support system for CKD and hypertension in a primary care environment with and without pharmacist counseling may have increased provider awareness of CKD but did not improve the primary outcome of the BP control.[29] Another intervention by Samal et al[28] that aimed to increase nephrology referrals paradoxically decreased nephrology referral rates. These studies, along with ours, highlighted important challenges to evaluating CDS interventions in real-world settings including low CDS use rates with noninterruptive point-of-care CDS, clinician contamination with patient randomized trials involving primary care clinician-based interventions, small sample sizes, and the potential need to include both patients and clinicians in the CDS process. Our study intended to overcome the limitations of previous studies by achieving high CDS use rates, employing clinic randomization to avoid contamination, a large sample size, and including both patient and clinician-directed CDS. However, our intervention did not bring about significant changes in CKD care even though we had seen positive results with similar interventions for diabetes, hypertension, and cardiovascular risk. The findings suggest that the mere deployment of CKD-CDS many not suffice to drive substantial changes in CKD care. Perhaps there are unique challenges to CKD-CDS that should not be underestimated. It is important that future studies incorporate evaluations of patient perceptions, values, self-determination (the right for patients to refuse treatment options), and cultural and ethnic preferences for how health information is divulged.

COVID-19 introduced unforeseen challenges, such as reduced in-person visits and decreased intervention

Table 4. Main Results: Number of Eligible Patients Meeting the CKD Quality Metric at 18 Months Postindex Visit by Treatment Group

	Usual care	CKD-CDS	RR[a]	95% CI	*P*
CKD diagnosis	389/1,783 (21.8%)	417/1,568 (26.6%)	1.17	(0.91-1.51)	0.21
ACEi/ARB order	192/1,192 (16.1%)	151/952 (15.9%)	0.95	(0.76-1.18)	0.61
BP < 130/80 mm Hg	388/1,917 (20.2%)	334/1,633 (20.4%)	0.98	(0.84-1.15)	0.84
A1C<7%	159/719 (22.1%)	141/659 (21.4%)	1.00	(0.80-1.24)	0.99
NSAID not on the active medication list	294/583 (50.4%)	268/520 (51.5%)	1.03	(0.90-1.17)	0.67
Nephrology referral or visit	95/263 (36.1%)	92/238 (38.7%)	1.02	(0.79-1.32)	0.86

Abbreviations: A1C, glycated hemoglobin; ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; BP, blood pressure; CDS, clinical decision support; CKD, chronic kidney disease; NSAID, nonsteroidal anti-inflammatory drug.
[a]Risk ratios (RRs) comparing the proportions in CKD-CDS relative to usual care are adjusted for clinic level balancing covariates.

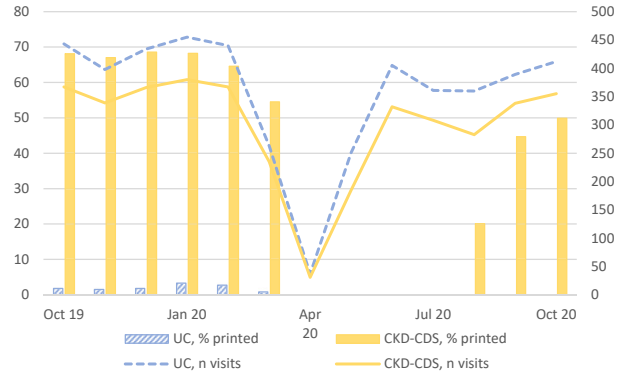

Figure 4. Intervention-eligible after index visits. Number of visits and percentage printed by treatment group.

exposure. A secondary analysis conducted on a subgroup of patients with longer prepandemic follow-up produced more favorable point estimates for several outcomes but still did not reach statistical significance. Even after the pandemic subsided, the CDS workflows did not fully recover during the study, affecting the print rates of CKD-CDS materials. Print rates of CDS materials in the care system have only recently returned to prepandemic levels (70%-75% of targeted encounters), and the slow recovery may have been because of a combination of residual problems the care system experienced such as staff burnout and staffing shortages, patient access challenges and increased complexity of visits because of deferred care, and difficulty keeping up with training new staff on CDS workflow. In addition, although the intervention was adapted for primary care clinician viewing at telehealth encounters, the patient-direct aspects of the CDS designed to promote patient engagement were effectively abolished by inability to screen share or print materials. Future research should explore better ways to deploy CDS during telehealth visits, which have become a permanent part of health care delivery.

These study findings should also be considered in the light of the care system demographics (84% White) and potential cointerventions related to the health care system's focus on improving quality measures for hypertension, diabetes, and heart disease. Given that CDS was already in place for these conditions in usual care, it made it more difficult to isolate the potential effects of the CKD-specific intervention. The study also raised a dilemma posed by a CDS system that used a generalized patient-centered approach covering multiple chronic conditions. For patients with multiple care improvement opportunities, the order in which conditions and treatment suggestions are listed on interfaces could imply a higher priority for those listed first, or greater attention may be given to what is on the top of the list. In some cases, lower prioritization of CKD relative to other conditions like very poorly controlled diabetes or hypertension could decrease the likelihood of action for some CKD care opportunities. Further research on how the prioritization of clinical content on CDS materials influences outcomes is of interest.

In addition to the CKD care opportunities discussed within the scope of this study, clinical evidence now strongly supports the adoption of sodium-glucose cotransporter 2 (SGLT2) inhibitor use for patients with CKD to reduce the burden of kidney-related complications.[30-32] The guideline recommendations for SGLT2 inhibitors emerged after the CKD-CDS for this study was deployed. However, a treatment suggestion to consider initiating an SGLT2 inhibitor when indicated was integrated into the CKD-CDS later in the observation period. Future evaluation to assess the impact of this added treatment recommendation is warranted because SGLT2 inhibitors could further enhance CKD care and patient outcomes.

In summary, we conducted an ambitious randomized trial of CDS for patients with CKD stages G3 and G4 designed to improve CKD recognition and care in a primary care setting. The CKD-CDS intervention did not significantly improve any of the 6 CKD care quality metrics. The COVID-19 challenges underscore the importance of considering external factors when evaluating the impact of interventions in real-world settings. Despite difficulty drawing definitive conclusions from these results, the study highlights the high frequency of CKD care gaps and the importance of improving CKD care management. Future research should explore alternative interventions that integrate CKD-CDS with

Table 5. Main Results Limited to the Subset of Patients Who Had at Least 6 months of Follow-Up Before the CKD-CDS was Suspended Because of the Coronavirus Disease Pandemic

	Usual care	CKD-CDS	RR[a]	95% CI	*P*
CKD diagnosis	237/960 (24.7%)	251/864 (29.0%)	1.16	(0.90-1.50)	0.25
ACEi/ARB order	130/762 (17.1%)	101/608 (16.6%)	0.93	(0.71-1.22)	0.59
BP < 130/80 mm Hg	243/1,158 (21.0%)	216/970 (22.3%)	1.06	(0.87-1.28)	0.57
A1C<7%	109/500 (21.8%)	102/423 (24.1%)	1.11	(0.86-1.44)	0.42
NSAID not on active medication list	166/342 (48.5%)	155/305 (50.8%)	1.05	(0.88-1.24)	0.58
Nephrology referral	65/185 (35.1%)	62/149 (41.6%)	1.19	(0.87-1.63)	0.25

Abbreviations: A1C, glycated hemoglobin; ACEi, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; BP, blood pressure; CDS, clinical decision support; CKD, chronic kidney disease; NSAID, nonsteroidal anti-inflammatory drug.
[a]Risk ratios (RRs) comparing the proportions in CKD-CDS relative to usual care are adjusted for clinic level balancing covariates.

Table 6. Composite Measures of Fewer or no Remaining CKD-specific Care Gaps at 18 Months Among Patients With at Least One Gap at Index, Overall and in the Subset of People who had at Least 6 months of Follow-up Before the CKD-CDS was Suspended Because of the Coronavirus Disease 2019 Pandemic

	Usual Care	CKD-CDS	RR	95% CI	*P*
Overall, n	2,140	1,939			
Fewer gaps	704 (32.9%)	725 (37.4%)	1.24	(0.92-1.68)	0.15
No gaps	500 (23.4%)	535 (27.6%)	1.21	(0.87-1.68)	0.25
6-mo follow-up, n	1,207	1,095			
Fewer gaps	421 (34.9%)	431 (39.4%)	1.27	(0.94-1.70)	0.11
No gaps	311 (25.8%)	331 (30.2%)	1.25	(0.89-1.75)	0.19

Note: Risk ratios (RRs) comparing proportions in CKD-CDS relative to usual care are adjusted for clinic balancing covariates and number of CKD-specific care gaps at index.
Abbreviations: CDS, clinical decision support; CKD, chronic kidney disease.

other strategies to address the complex challenges of CKD care.

ARTICLE INFORMATION

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