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The Improving Renal Outcomes Collaborative: Blood Pressure Measurement in Transplant Recipients

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abstract

BACKGROUND AND OBJECTIVES: Hypertension is highly prevalent in pediatric kidney transplant recipients and contributes to cardiovascular death and graft loss. Improper blood pressure (BP) measurement limits the ability to control hypertension in this population. Here, we report multicenter efforts from the Improving Renal Outcomes Collaborative (IROC) to standardize and improve appropriate BP measurement in transplant patients.

METHODS: Seventeen centers participated in structured quality improvement activities facilitated by IROC, including formal training in quality improvement methods. The primary outcome measure was the proportion of transplant clinic visits with appropriate BP measurement according to published guidelines. Prospective data were analyzed over a 12-week pre-intervention period and a 20-week active intervention period for each center and then aggregated as of the program-specific start date. We used control charts to quantify improvements across IROC centers. We applied thematic analysis to identify patterns and common themes of successful interventions.

RESULTS: We analyzed data from 5392 clinic visits. At baseline, BP was measured and documented appropriately at 11% of visits. Center-specific interventions for improving BP measurement included educating clinic staff, assigning specific team member roles, and creating BP tracking tools and alerts. Appropriate BP measurement improved throughout the 20-week active intervention period to 78% of visits.

CONCLUSIONS: We standardized appropriate BP measurement across 17 pediatric transplant centers using the infrastructure of the IROC learning health system and substantially improved the rate of appropriate measurement over 20 weeks. Accurate BP assessment will allow further interventions to reduce complications of hypertension in pediatric kidney transplant recipients.

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Chronic kidney disease (CKD) and end-stage kidney disease (ESKD) are associated with an immense burden of cardiovascular risk throughout the life span.[1–5] Although mortality rates remain low compared with adults, children with ESKD have 30- to 50-fold higher cardiovascular mortality compared with the general pediatric population.[4–6] Kidney transplant is the optimal treatment to reverse many pathophysiologic features of ESKD that

	State	Visits
Lucile Packard Children's Hospital / Stanford	CA	704
Children's Healthcare of Atlanta / Emory	GA	672
Mattel Children's Hospital / UCLA	CA	496
Children's of Alabama / UAB	AL	463
C.S. Mott Children's Hospital / Michigan Medicine	MI	426
Phoenix Children's Hospital	AZ	416
Seattle Children's Hospital	WA	342
Children's Hospital Colorado	CO	293
Children's Hospital of Pittsburgh	PA	265
Ann & Robert H. Lurie Children's Hospital of Chicago	IL	260
Children's Mercy Hospital Kansas City	MO	237
Riley Hospital for Children at IU Health	IN	208
University of Minnesota Masonic Medical Center	MN	150
Johns Hopkins Children's Center	MD	137
Cardinal Glennon Children's Hospital	MO	126
University of Iowa	IA	102
Cohen Children's Medical Center	NY	95
17 centers	***Total:***	***5392***

FIGURE 1
The IROC learning health system. Pins represent locations of IROC member centers as of March 2019; the dark blue pins identify centers that contributed data for this study. The star identifies Cincinnati Children's Hospital Medical Center as the coordinating center for IROC. The table details the location and number of visits contributed by each center. AL, Alabama; AZ, Arizona; CA, California; CO, Colorado; GA, Georgia; IA, Iowa; IL, Illinois; IN, Indiana; IU, Indiana University; MD, Maryland; MI, Michigan; MN, Minnesota; MO, Missouri; NY, New York; PA, Pennsylvania; UAB, The University of Alabama at Birmingham; UCLA, University of California, Los Angeles; WA, Washington.

contribute to cardiovascular disease.[7] Despite these improvements, cardiovascular risk remains fivefold higher after kidney transplant compared with children without kidney disease, attributable in part to residual vascular disease and hypertension.[5,8] In recent studies of pediatric kidney transplant recipients, authors have shown the prevalence of uncontrolled casual hypertension in clinics is 50% to 80% and that of uncontrolled ambulatory hypertension (assessed by 24-hour ambulatory blood pressure monitoring [ABPM]) is 36% to 62%.[8–12] This is clinically relevant because uncontrolled casual and ambulatory hypertension are associated with decreased patient and allograft survival after kidney transplant.[9,11] Importantly, transplant failure with a subsequent return to dialysis significantly decreases life expectancy while increasing annual health care costs by threefold compared with patients with a functioning transplant.[13] Thus, to decrease morbidity and improve allograft and patient survival, systems-based approaches are needed to appropriately diagnose, treat, and control hypertension in kidney transplant recipients.[14]

Published clinical practice guidelines have detailed the elements of appropriate blood pressure (BP) measurement and classification when screening for elevated BP in children and adolescents, including those with CKD and ESKD.[15,16] Oscillometric BP measurement is viewed as an acceptable screening tool, but elevated readings should be confirmed by appropriate manual BP measurements (auscultatory BP using an aneroid sphygmomanometer) that include (1) using the right upper extremity when possible, (2) measuring arm circumference to ensure the correct cuff size is used, (3) documenting BP cuff size, (4) resting quietly for 5 minutes before measuring BP, and (5) using the average of 2 BP readings.[15,16] This specific guidance from the 2004 "The Fourth Report on the Diagnosis, Evaluation, and Treatment of High Blood Pressure in Children and Adolescents" was recently reaffirmed in the "Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents."[15,16] However, previous studies have revealed extensive variability in BP measurement and control across kidney transplant centers,[12,17] highlighting the need for a standardized process.

Children with kidney transplants require multidisciplinary clinic visits to manage comorbidities resulting from CKD and long-term exposure to immunosuppression.[18] This presents an opportunity to apply quality improvement (QI) methodology to streamline integration of appropriate BP measurement into clinic workflow. In 2015, we formed the Improving Renal Outcomes Collaborative (IROC), a multicenter learning health system whose vision is to partner with patients who have kidney disease and their caregivers to achieve health, longevity, and quality of life equivalent to the general population. Our first collaborative QI project used the newly developed IROC infrastructure to standardize BP measurement across member centers. Our primary hypothesis was that with coordinated training and access to QI tools, the IROC learning health system would increase the percentage of pediatric kidney transplant clinic visits in which BP is measured

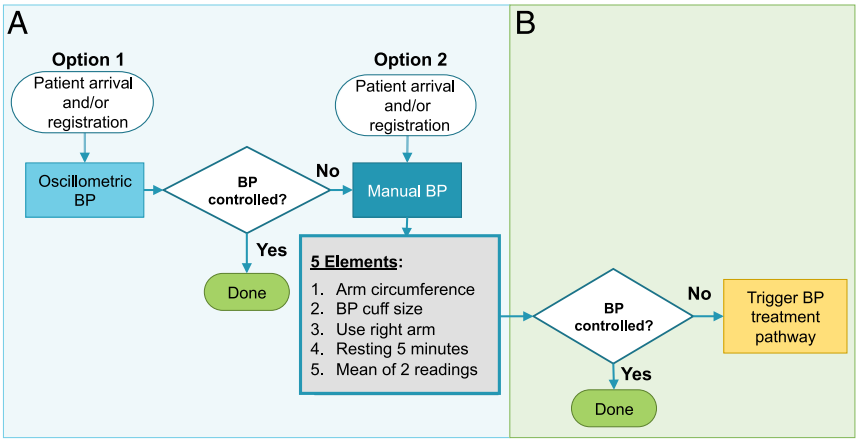

FIGURE 2

Standardized BP measurement protocol for outpatient clinic. A, Measurement. B, Treatment. Option 1 included an oscillometric screening that was confirmed by using a manual reading if uncontrolled (>90th percentile for age and/or height via the fourth report[16]). Option 2 used universal manual readings to classify BP. Uncontrolled BP triggered a treatment pathway developed at each center.

appropriately to ≥85% within 20 weeks.

METHODS

Context and Study Design

Individual centers joined IROC on a rolling basis from August 2016 through July 2018 as legal and regulatory agreements were approved at each site. Each new IROC center was enrolled in this multicenter QI project to improve appropriate BP measurement at the time of joining IROC. The primary intervention was structured small-group learning sessions led by a centralized network resource, which enabled local QI teams to implement QI methods at their respective centers. Centers collected baseline data during a 12-week pre-intervention run-in period, during which they concurrently developed tailored interventions to improve appropriate BP measurement. "Postintervention" data were collected at each center for a total of 20 weeks after deploying their interventions. This study was approved as human subjects QI research by the Institutional Review Board (IRB) at Cincinnati Children's Hospital Medical Center under a master reliance IRB agreement that was approved by each participating center. This agreement allowed Cincinnati Children's Hospital Medical Center to act as the IRB of record for the study.

QI Fundamentals Course and Group Learning

Participating centers engaged in small-group online interactive workshops to learn QI methods ("Quality Improvement Fundamentals" [QIF] course) taught by QI consultants from Cincinnati Children's Hospital Medical Center. The course was designed by using the Model for Improvement created by Associates in Process Improvement and adopted by the Institute for Healthcare Improvement.[19] QIF was initially offered by the Cincinnati Children's learning health systems core collaborative group (fall 2016) and consisted of 7 monthly online sessions taught by QI consultants with experience in health care settings. In addition to the first 11 IROC centers, the initial QIF course included centers from other learning health systems not focused on kidney transplant or BP measurement for their improvement projects. Feedback from IROC participants indicated that the presence of centers from other networks with different improvement goals detracted somewhat from their learning experience.

On the basis of this feedback, QIF was redesigned in 2017 to exclusively include the 6 centers that joined IROC later and had not participated in the 2016 general QIF course. This IROC-specific version still consisted of 7 monthly online sessions but was designed around improving appropriate BP measurement and taught by the IROC QI consultant (D.S.D.). The content expertise provided by the dedicated IROC QI consultant enhanced application of QI methods among IROC centers. Practice pattern modification and application of learned QI methods were subsequently reinforced in monthly video teleconferences and at semiannual IROC learning sessions attended in person by representatives from each center.

Participating Sites

Participating sites included 17 IROC centers located throughout the United States with low (3–7 visits per week; n = 6), medium (7–13 visits per week; n = 5), and high (14–22 visits per week; n = 6) outpatient pediatric kidney transplant clinic volumes (Fig 1).

Interventions

With guidance from QIF coursework, each center collected baseline BP measurement data to help develop a list of perceived barriers to improving appropriate BP measurement as well as center-specific interventions to address those barriers. Participating sites were tasked with developing a local QI team; project charter; SMART (specific, measurable, applicable, realistic, and timely) aim; process maps; and key driver diagrams to design and implement plan-do-study-act (PDSA) ramps to drive improvement in appropriate BP measurement. QI teams at each center included various combinations

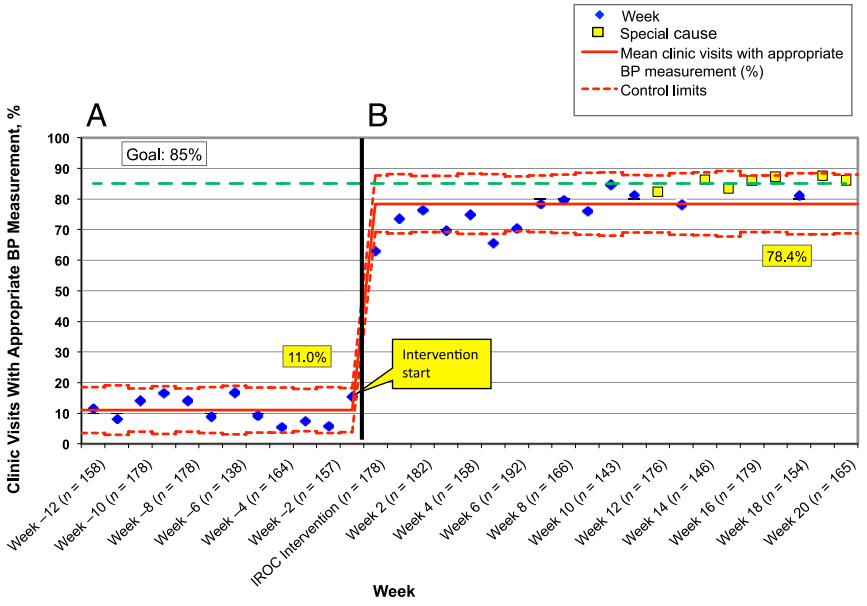

FIGURE 3
Control chart (p-chart) of appropriate BP measurement across 17 centers. A, Baseline period. B, Active intervention period. Mean BP was measured appropriately at an average of 11% of clinic visits at baseline. During the active intervention period, totaling 20 weeks after interventions were deployed, the mean rate of appropriate BP measurement increased to 78% of visits. Toward the end of the active intervention, there was special-cause variation noted on the control chart. The special-cause signal was 4 out of 5 successive points $>1\ \sigma$ from the mean on the same side of the centerline.[20]

of physicians, transplant coordinators, clinic nurses, pharmacists, research nurses, medical assistants, clinic staff, and parents or caregivers of transplant recipients. The course material guided the development of interventions at each center, with specific deliverables to be shared between centers at monthly video teleconferences. Common interventions were assigning team member roles, training of clinic staff, providing tools and supplies to reliably perform appropriate BP measurement, and developing alerts for providers. Tailored interventions were deployed at each center after collecting pre-intervention baseline BP data for 12 weeks. The active intervention period collected data at each center for 20 weeks after each center-specific intervention was deployed.

TABLE 1 Percent of All Centers Performing and Documenting Each of the 5 Elements of an Appropriately Measured BP During the 12-Week Baseline Period, According to the Fourth Report Guidelines

Element of Appropriate Manual BP Measurement	Consistently Performing Before Intervention, %			
	All Centers (n = 17)	Low Volume (n = 6)	Medium Volume (n = 5)	High Volume (n = 6)
Measure arm circumference (in cm)	6	17	0	0
Document BP cuff size	24	17	60	0
Allow 5 min of rest before measuring BP	12	0	20	17
Use the right upper extremity when possible	47	33	60	50
Average 2 manual BP readings	6	0	0	17

Data were self-reported by each center in response to a query during the QIF course about manual BP practice patterns. Data are also categorized according to subgroups of clinic volumes during the study.

Participating sites had a choice of 2 standardized protocols for BP measurement: (1) oscillometric screening followed by manual BP measurements to confirm any elevated BP readings or (2) universal manual BP measurements (Fig 2). We decided a priori to use the 90th percentile cutoffs for sex, age, and height from the fourth report to define an elevated BP reading[16] because most centers joined the project in 2016 but others joined in 2017 after publication of the updated clinical practice guideline.[15] We collected the following data from each clinic visit at all sites: (1) measurement protocol (oscillometric or manual), (2) for oscillometric readings, whether normal or elevated (to determine if a manual BP should have also been obtained), and (3) performance of each of the 5 manual BP elements (Fig 2).[15,16]

Measures

The primary outcome measure was the percent of weekly outpatient transplant clinic visits with appropriately measured BP, defined as either an oscillometric screening BP less than the 90th percentile for sex, age, and height or a manual BP that documented all 5 elements in published clinical practice guidelines (Fig 2).[15,16] We performed subgroup analysis of the primary outcome on the basis of clinic volumes (low, medium, and high) and the version of the QIF course in which each center participated.

Data Analysis

We used quantitative QI methods to visualize improvement in appropriate BP measurement over the 20-week active intervention. Statistical process control (SPC) charts were developed by using total weekly clinic visits from all 17 centers as the denominator and total visits when BP was measured appropriately as the numerator. Data were captured by center and aggregated by aligning the intervention start dates across

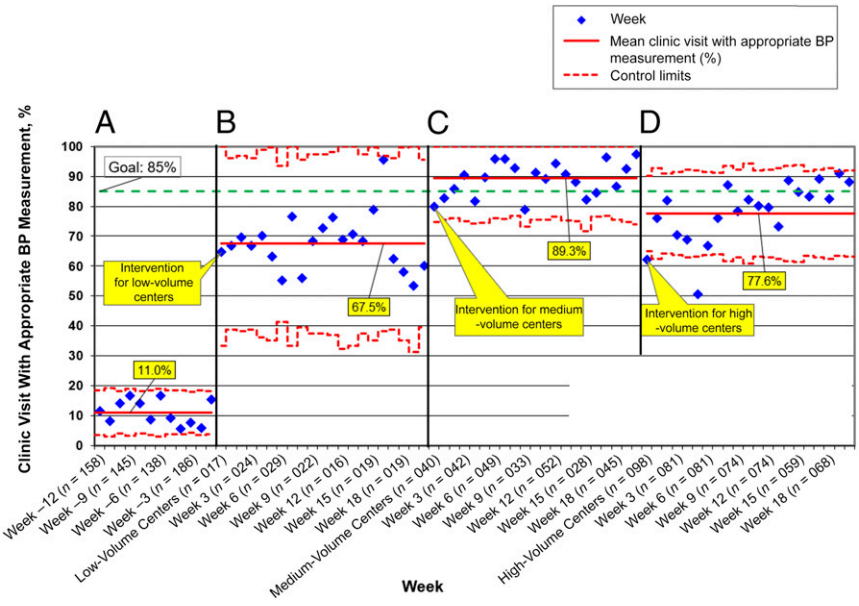

FIGURE 4

SPC chart (p-chart) illustrating subgroup analysis for the percentage of clinic visits with appropriate BP measurement. A, Baseline period for all centers. B, Active intervention for low-volume centers. C, Active intervention for medium-volume centers. D, Active intervention for high-volume centers. Data from all centers were grouped together for the 12-week baseline period. Results during the 20-week active intervention are compared between low-, medium-, and high-volume centers.

centers, such that the 12-week baseline period and intervention start date aligned for data visualization. The specific calendar dates of these periods varied by center. Centerlines and 3-σ control limits were defined by using standard approaches. Special-cause variation was defined as 8 consecutive data points above the centerline as well as 4 out of 5 data points >1 σ above the centerline.[20] Centerline and control limits were adjusted as the start of special cause variation but only if a minimum of 12 data points were available for appropriate centerline and control limit estimation.[21] For subgroup analysis, we combined data from all centers in the baseline period but plotted postintervention data separately by subgroup according to clinic volume and by QIF course version.

Network Learning and Thematic Analysis

We applied thematic analysis to evaluate and describe interventions from individual centers.[22] More than 100 documents submitted by participating centers during the QIF course were reviewed to identify patterns and common themes. The documents included project charters, SMART (specific, measurable, applicable, realistic, and timely) aim statements, PDSA worksheets, PDSA ramps, key driver diagrams, and process maps that provided in-depth information about each center's process for improving BP measurement. We conducted a thematic analysis in 2 phases using commonly used words and phrases from QIF course documents. We first generated a semantic level of themes, which was then re-evaluated to assess underlying ideas and assumptions to conceptualize modified practice patterns and generate latent themes.[23]

RESULTS

A total of 17 IROC centers provided BP measurement data from 5392 transplant clinic visits during the project period (August 2016–July 2018). During the 12-week pre-intervention baseline period, 11% of 2109 visits documented an appropriately measured BP (Fig 3). By self-report, centers were least likely to measure arm circumference or average 2 BP readings. However, none of the 5 BP elements were documented as performed in more than half of the centers (Table 1). The 20-week active intervention period included data from 3283 visits after deploying center-specific interventions developed during the baseline period. The mean percentage of clinic visits in which BP was measured appropriately increased from 11% to 78%. Notably, we observed continuous improvement throughout the active intervention period including several data points indicating special-cause variation with appropriate BP measurement rates at or above our project goal of 85% (Fig 3). We did not shift the centerline again, however, because <12 data points were recorded after the special cause (see Methods section).

In subgroup analysis, we noted that although all centers improved on average, medium-volume centers achieved higher mean appropriate BP measurement rates (89.3%) than those of low- (67.5%) or high-volume centers (77.6%) (Fig 4). We also found that centers in the IROC-specific version of the QIF course had higher appropriate BP measurement rates than those in the general version (84.3% vs 76.2%) (Fig 5). Clinic volumes varied according to QIF course, with 3 of 6 (50%) low-volume centers, 2 of 5 (40%) medium-volume centers, and 1 of 6 (17%) high-volume centers taking the IROC-specific version.

Emerging semantic themes of successful interventions described in the QIF course assignments were (1) identify staff roles and clinic flow to improve BP measurement, (2) train

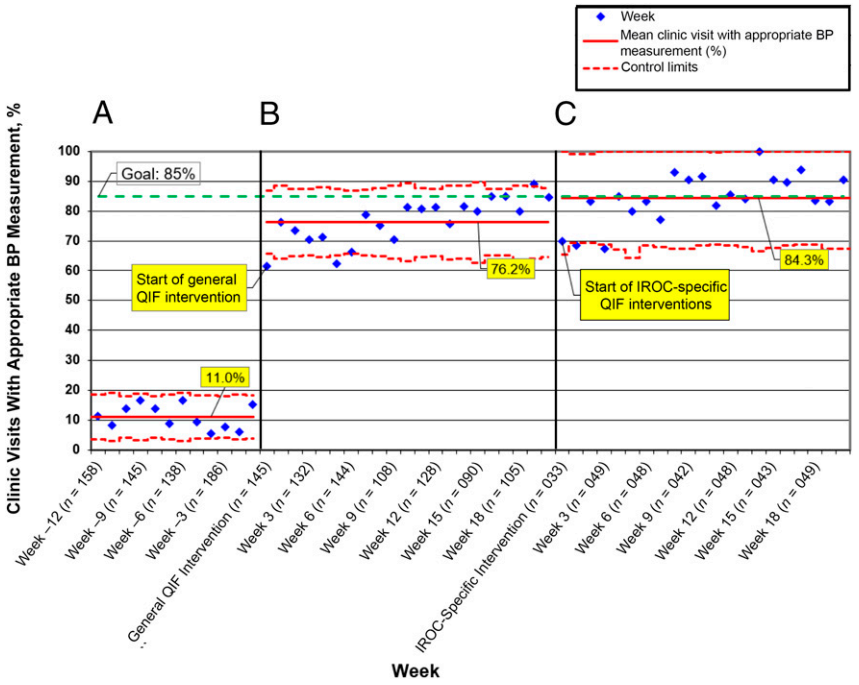

FIGURE 5

SPC chart illustrating subgroup analysis for the percentage of visits with appropriate BP measurement. A, Baseline period for all centers. B, Active intervention with general QIF version. C, Active intervention with IROC-specific QIF version. Data from all centers were grouped for the 12-week baseline period. Results during the 20-week active intervention were compared between centers completing general (n = 11) versus IROC-specific (n = 6) versions of the QIF course.

and equip clinic staff to obtain appropriate BP measurement, (3) document appropriate BP measurement, and (4) alert providers of abnormal BP readings. Four interrelated latent themes were conceptualized from the semantic themes: (1) achieving buy-in from stakeholders, (2) optimizing clinic efficiency, (3) maintaining tools needed to obtain and document accurate BP measurements, and (4) ensuring clinic staff retain competency and value the importance of accurate BP measurement (Fig 6). Semantic and latent themes emerging from the site level continuously fed into and perpetuated learning at the network level (Fig 7).

DISCUSSION

Using the infrastructure of the IROC learning health system, we standardized appropriate BP measurement across 17 pediatric kidney transplant centers to become consistent with published guidelines. We observed rapid improvement after deploying center-specific interventions developed during the baseline period. Mean performance for the entire 20-week intervention period was 78%, but performance continued to improve throughout the project such that several weeks of performance at or above our project goal were observed by the end of the intervention period.

This achievement was made possible by formal education in QI methodology and tools, small-group shared learning via video teleconference, in-person networkwide learning sessions, and network-level benchmarking. A substantial improvement occurred within the first week of IROC-based interventions at individual centers. This rapid improvement likely reflected the immediate impact of tailored interventions developed during the baseline period as well as improved documentation of existing appropriate BP measurement. Multicenter, collaborative QI projects have been more effective at achieving rapid practice pattern modification compared to projects conducted at individual centers.[24] IROC provided infrastructure to support small-group interactive workshops (QIF course) to enhance adoption of QI methods at individual sites. The learning and teaching feedback that occurred in the small-group setting was further amplified to the whole network during semiannual IROC learning sessions. Lessons learned at the network level further influence and reinforce the sustainability of QI projects at individual sites (Fig 7). This project is a successful example of scalable, problem-based blended learning.

Although published guidelines for appropriate BP measurement in children have existed for many years, previous studies indicate the application of these guidelines is inconsistent in clinical settings, hindering efforts to control hypertension.[25–29] We found that only 11% of transplant clinic visits had documented an appropriately measured BP during the baseline period despite the staffing of clinics by pediatric nephrologists with expertise in hypertension. ABPM is considered the gold standard for diagnosing hypertension.[9,30,31] However, ABPM is not cost-effective or feasible to obtain serially within individual patients over a short time and must be supplemented by casual BP measurement to allow proper titration of antihypertensive medications.[14] Protocol-driven clinic BP measurements have been comparable to ambulatory BP

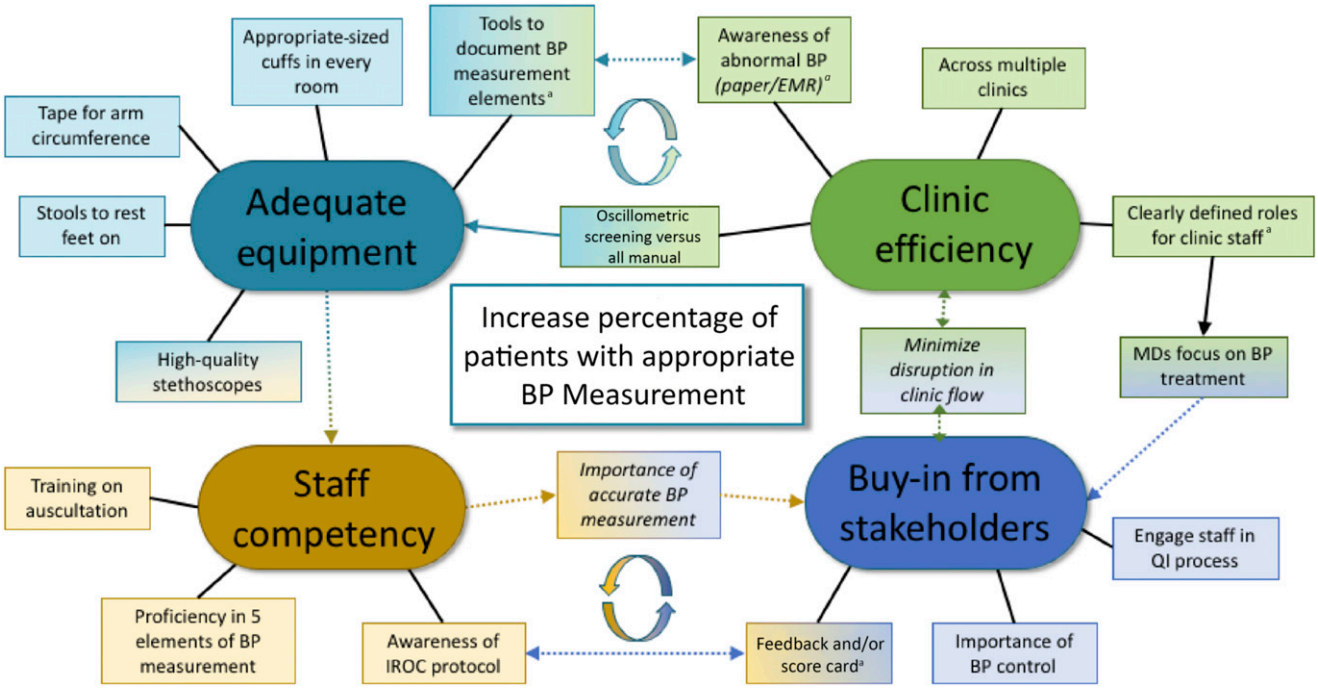

FIGURE 6

Thematic analysis of center-specific interventions to increase appropriate BP measurement (small boxes) yielded 4 interrelated latent themes for success: achieving buy-in from stakeholders, optimizing clinic workflow and efficiency, adequately equipping clinic, and training staff in appropriate BP measurement. Italic font denotes bridging themes. [a] High-consensus themes. MD, medical doctor.

readings in predicting cardiorenal outcomes in childhood CKD.[32] Recent studies in the Chronic Kidney Disease in Children cohort suggest that standardizing clinic BP measurement across multiple centers is feasible in the research setting.[33] Our study employed a protocol-driven approach to BP measurement in the clinical setting to produce "research-grade" data that can be used to properly categorize and manage abnormal BP across the IROC network.

When placed in context of previous QI studies that are focused on BP-related outcome measures, we achieved a large sample size and excellent improvement results over a relatively short time frame. Brady et al[34] used an electronic medical record–based provider alert to improve the recognition of abnormal BP. Over a 6-month intervention period with over 1300 encounters, they increased the recognition of abnormal BP in primary care clinics from 13% to 42%.[34] Heymann et al[35] used a mandatory electronic medical record field to improve documentation of BP measurement from 41% to 59% of patients seen at 9 clinics within a preferred provider organization. By comparison, the improvement framework of IROC increased appropriate BP measurement from 11% to 78% over 20 weeks, including data from 5392 encounters at 17 centers. We observed special-cause variation toward the end of the active intervention period, with appropriate BP measurement rates at or above our project goal of 85%. This was observed in the final 9 weeks of the project, but 12 would be required for a new estimate of mean performance. Therefore, it is likely that a longer observation period or additional IROC-based interventions would have allowed for a centerline shift at or above our goal.

Improvement occurred in aggregate across all 17 IROC centers, but in subgroup analysis, we found that medium-clinic-volume programs and those in the IROC-specific QIF course achieved the highest rates of appropriate BP measurement. One explanation is that resources in medium-volume programs may be better matched to the patient population, with sufficient staff to maintain a focused QI project without being overwhelmed by larger clinic volumes. Potential reasons for improved performance in the IROC-specific QIF course include content-specific QI training and enhanced ability to share content-specific barriers between participating centers. Because of small subgroup sizes, we were unable to test for interactions between QIF version and clinic volumes. Overall, the relatively small sample sizes limit the definitive conclusions that can be drawn from the subgroup analysis.

Strengths of our study were the inclusion of 17 pediatric transplant

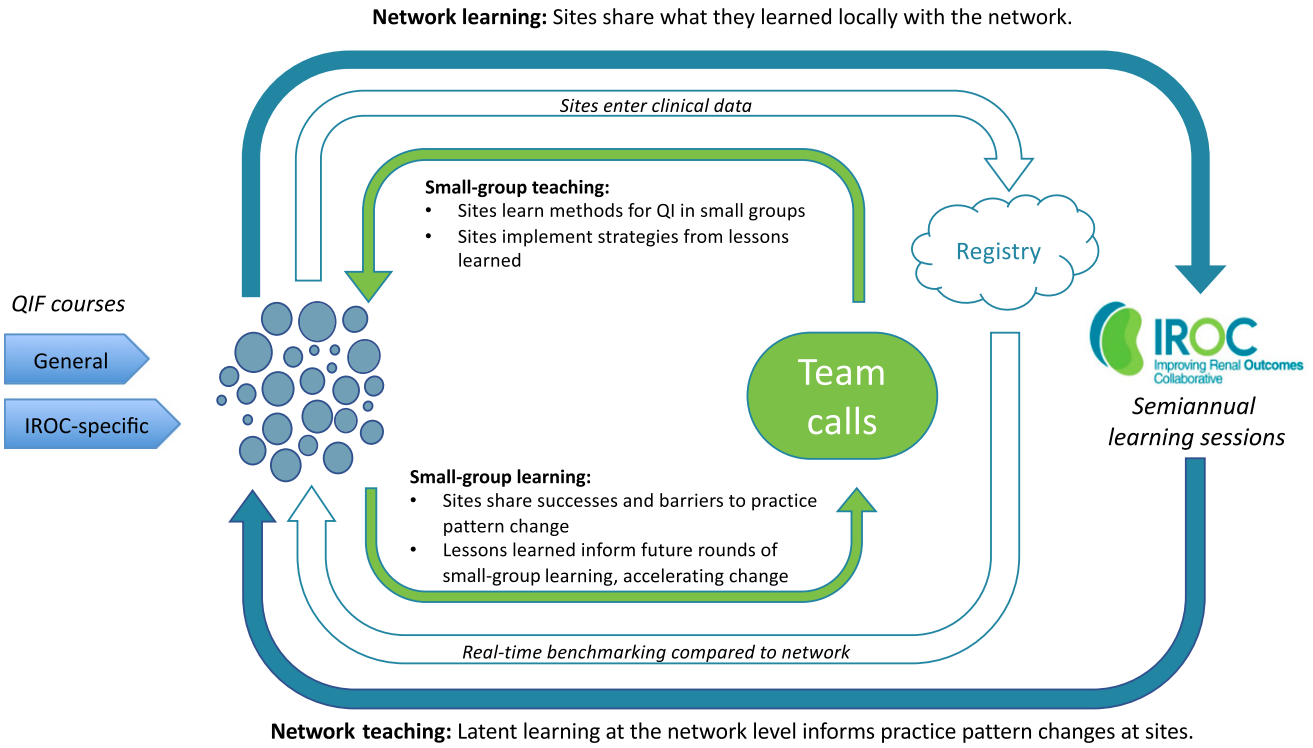

FIGURE 7
Practice pattern modification was reinforced and perpetuated via teaching and learning cycles between sites and their assigned small groups and between sites and the IROC network. A Web-based clinical data registry now also provides real-time benchmarking data for each site.

centers representing programs of differing size and geographic diversity. The large number of centers allowed us to prospectively study nearly 5400 clinic visits during a relatively short project period. We included nearly every clinic encounter meeting inclusion criteria to limit selection bias. We used standard QI methodology and training that could be scaled to a larger number of IROC centers in future QI cycles. Our approach could also be spread to other clinical settings where appropriate BP measurement is highly desirable, such as other solid-organ transplant clinics.

Despite these numerous strengths, our study has some limitations. This project was launched during the early phases of IROC development, limiting its scope to center-level interventions without granularity at the patient level. We were unable to examine the effects of age, height, or BMI on the ability to appropriately measure BP. We were unable to distinguish between visits when BP was measured inappropriately and those with appropriate BP measurement but inadequate documentation. We also were unable to examine improvements for individuals or subgroups of patients over time. QI team organization and local support for this project varied across centers and was not controlled for in data analysis. We were unable to account for all potential sources of confounding. Finally, the extent to which our findings apply to other outpatient clinical settings remains to be seen.

CONCLUSIONS

We used the infrastructure of the IROC learning health system, including formal education in QI methodology and tools, to standardize and improve appropriate BP measurement and documentation according to published guidelines at 17 pediatric transplant centers over 20 weeks. The success of this project supports the viability of networked learning occurring continuously within IROC and provides the foundation for additional collaborative projects across our expanding learning health system. IROC recently launched a Web-based data registry to provide real-time feedback and benchmarking to sites as well as stimulate new QI project ideas. Future directions include continued efforts to spread and sustain high rates of reliable appropriate BP measurement across all IROC centers (Fig 1) and improve BP control in the pediatric kidney transplant population.

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APPENDIX

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ABBREVIATIONS

ABPM: ambulatory blood pressure monitor
BP: blood pressure
CKD: chronic kidney disease
ESKD: end-stage kidney disease
IRB: institutional review board
IROC: Improving Renal Outcomes Collaborative
PDSA: plan-do-study-act
QI: quality improvement
QIF: Quality Improvement Fundamentals
SPC: statistical process control

Drs Seifert, Kamel, and Winterberg participated in the study design, data acquisition, analysis, and interpretation, wrote the initial draft, and helped revise subsequent drafts of the manuscript; Drs Barletta, Belsha, Chaudhuri, Flynn, Garro, George, Goebel, Kershaw, Matossian, Misurac, Nailescu, Nguyen, Pearl, Pollack, Pruette, Singer, VanSickle, Verghese, Warady, Weng, Wickman, and Wilson participated in the study design, data acquisition, analysis, and interpretation and helped revise subsequent drafts of the manuscript; Mr Warmin participated in data analysis and interpretation and helped revise subsequent drafts of the manuscript; Mr Dahale and Dr Hooper conceived and designed the study, participated in data acquisition, analysis, and interpretation, helped write the initial draft, and revised subsequent drafts of the manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

This work was presented in part at the annual meeting of the American Society of Nephrology Kidney Week, October 23–28, 2018, San Diego, CA; the 10th Congress of the International Pediatric Transplant Association, May 4–7, 2019, Vancouver, British Columbia, Canada; the annual meeting of the American Society of Pediatric Nephrology, April 27–30, 2019, Baltimore, MD; and the annual meeting of the American Transplant Congress, June 1–5, 2019, Boston, MA.

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