An Initiative to Decrease Laboratory Testing in a NICU

Christopher J. Klunk, MD, MS,[a] Renee E. Barrett, MD,[a] Steven M. Peterec, MD,[a] Eleanor Blythe, PA,[b] Renee Brockett, APRN,[b] Marta Kenney, RN,[b] Amber Natusch, RN,[b] Caitlin Thursland, RN,[b] Patrick G. Gallagher, MD,[a] Richard Pando,[c] Matthew J. Bizzarro, MD[a]

abstract

BACKGROUND AND OBJECTIVES: Laboratory testing is performed frequently in the NICU. Unnecessary tests can result in increased costs, blood loss, and pain, which can increase the risk of long-term growth and neurodevelopmental impairment. Our aim was to decrease routine screening laboratory testing in all infants admitted to our NICU by 20% over a 24-month period.

METHODS: We designed and implemented a multifaceted quality improvement project using the Institute for Healthcare Improvement's Model for Improvement. Baseline data were reviewed and analyzed to prioritize order of interventions. The primary outcome measure was number of laboratory tests performed per 1000 patient days. Secondary outcome measures included number of blood glucose and serum bilirubin tests per 1000 patient days, blood volume removed per 1000 patient days, and cost. Extreme laboratory values were tracked and reviewed as balancing measures. Statistical process control charts were used to track measures over time.

RESULTS: Over a 24-month period, we achieved a 26.8% decrease in laboratory tests performed per 1000 patient days (∽51 000 fewer tests). We observed significant decreases in all secondary measures, including a decrease of almost 8 L of blood drawn and a savings of $258 000. No extreme laboratory values were deemed attributable to the interventions. Improvement was sustained for an additional 7 months.

CONCLUSIONS: Targeted interventions, including guideline development, dashboard creation and distribution, electronic medical record optimization, and expansion of noninvasive and point-of-care testing resulted in a significant and sustained reduction in laboratory testing without notable adverse effects.

Full article can be found online at www.pediatrics.org/cgi/doi/10.1542/2020-000570

[a]*Yale School of Medicine, Yale University, New Haven, Connecticut;* [b]*Yale New Haven Children's Hospital, New Haven, Connecticut; and* [c]*Yale New Haven Hospital Information Technology Services, New Haven, Connecticut*

Dr Klunk participated in guideline development and development of all phases of ongoing plan-do-study-act (PDSA) cycles, drafted the initial manuscript, and reviewed and revised the final manuscript; Dr Barrett participated in the development and implementation of all phases of ongoing PDSA cycles, led the statistical analysis and development of control and Pareto charts, contributed to the initial draft of the manuscript, and reviewed and revised the final manuscript; Dr Peterec conceptualized and designed the initiative from the earliest stages, participated in guideline and PDSA cycles development, and reviewed the final manuscript; Ms Blythe, Brockett, Kenney, Natusch, and Thursland assisted in guideline and PDSA cycle development, provided staff education, and reviewed the final manuscript; Dr Gallagher assisted in guideline development and development of PDSA cycles and reviewed the final manuscript; Mr Pando developed and modified our electronic data dashboard and reviewed the final manuscript; Dr Bizzarro conceptualized and designed the initiative from the earliest stages, identified individuals with the skillsets necessary for an effective collaborative team, led guideline development, participated in all phases of ongoing PDSA cycles, collaborated with Richard Pando in the design and development of the dashboard interface, and reviewed and revised the final manuscript; and all authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

DOI: https://doi.org/10.1542/peds.2020-000570

Accepted for publication Dec 7, 2020

Address correspondence to Christopher J. Klunk, MD, MS, NICU, Ascension Seton Medical Center, 1201 W. 38th Street, Austin, TX 78705. E-mail: christopher_klunk@mednax.com

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275).

Copyright © 2021 by the American Academy of Pediatrics

FUNDING: Internal funding for creation of an electronic data dashboard and additional technical support for alterations to the electronic medical record was provided by Yale New Haven Hospital.

POTENTIAL CONFLICT OF INTEREST: The authors have indicated they have no potential conflicts of interest to disclose.

To cite: Klunk CJ, Barrett RE, Peterec SM, et al. An Initiative to Decrease Laboratory Testing in a NICU. *Pediatrics*. 2021;148(1):e2020000570

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

INTRODUCTION

Problem Description

Laboratory testing is performed frequently in the NICU for diagnostic and screening purposes and to guide clinical management. Exposure of the developing brain to repeated painful procedures may have a deleterious effect on cognitive and motor development, somatic growth, and pain processing, and can increase the risk of future anxiety and depression.[1–3] In the short-term, frequent blood sampling may precipitate anemia and the need for transfusion.[4,5] A better understanding of the magnitude of harm related to repeated laboratory testing in the NICU population could change the perception of a test being "just another heel stick."

Available Knowledge

Neonates admitted to an ICU undergo ∽7.5 to 17.3 painful procedures per day, with more procedures occurring in the most vulnerable infants of lower gestational age (GA).[6] Although opinions vary on what constitutes "painful," the burden is considerable,[1–3,7–12] and the necessity of each laboratory test must be carefully considered. Authors of a retrospective review of preterm infants determined that interventions in response to abnormalities on a screening hemogram occurred in only 8.4% of infants <28 weeks' GA, 4.6% of those 28 to 31 weeks' GA, and 0% of infants 32 to 34 weeks' GA.[13]

Rationale

In December 2016, 2 team members attended a seminar on the effects of pain on the developing brain and then conferred with colleagues in Yale Internal Medicine who had conducted a successful effort to improve inpatient laboratory test use.[14] After collecting baseline use data and reviewing existing practices, we proceeded with the assumption that some screening tests were not necessary for patient care. We hypothesized that a reduction in such testing could be achieved without negatively impacting care and, in turn, could decrease pain, blood loss, and costs.

Specific Aims

The primary aim with this interprofessional collaborative effort was to reduce the rate of laboratory testing in the entire Yale New Haven Children's Hospital (YNHCH) NICU population by 20% over 24 months (January 1, 2017–December 31, 2018) and to sustain the effort (January 1, 2019–July 31, 2019). The purpose with this article is to describe the process by which a change in clinical care was brought about and to discuss management of barriers to change that can aid in implementation of similar programs.

METHODS

Context

YNHCH is a nonfreestanding children's hospital in New Haven, Connecticut. Our 68-bed level IV NICU supports a high-risk delivery service and is a regional referral center for infants with complex medical and surgical conditions. In our NICU, patient-care rounds are led by an attending neonatologist or neonatal-perinatal medicine fellow and includes advanced practice providers, nurses, residents, and medical students. Decisions regarding the frequency of routine laboratory studies are based on team discussion with final approval from the attending. Orders are placed by advanced practice providers and residents.

Interventions

Team Assembly, Guideline, and Dashboard Development

We designed and implemented a multifaceted project using the Institute for Healthcare Improvement's Model for Improvement. In January 2017, a multidisciplinary team was assembled to explore the scope of the problem, identify measures, and design and execute plan-do-study-act (PDSA) cycles. A key driver diagram was developed (Fig 1), and baseline data were obtained. In the absence of published data, we chose the lowest monthly rate of laboratory testing observed during our baseline period (which in March 2014 was 20% below the mean testing rate) as our postintervention goal.

A Pareto chart was created to prioritize interventions (Fig 2), and guideline development was conducted through an iterative process involving regular meetings of invested clinical staff. No laboratory-based practice guideline existed in our NICU at the time. Guideline design was aimed at screening and not intended to address clinical scenarios (eg, when to obtain a blood gas in a neonate with respiratory failure). Applicable data and expert opinion were used, when possible. Recommendations regarding testing frequency were categorized by test and subcategorized by degree of illness, prematurity, postmenstrual and chronological age, and comorbid conditions. Proposed schedules did not account for abnormal results, which necessitated more frequent and additional testing. Educational efforts were conducted, feedback was sought from staff and from our NICU Family Advisory Council, guidelines were modified, and final distribution occurred in January 2018.

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

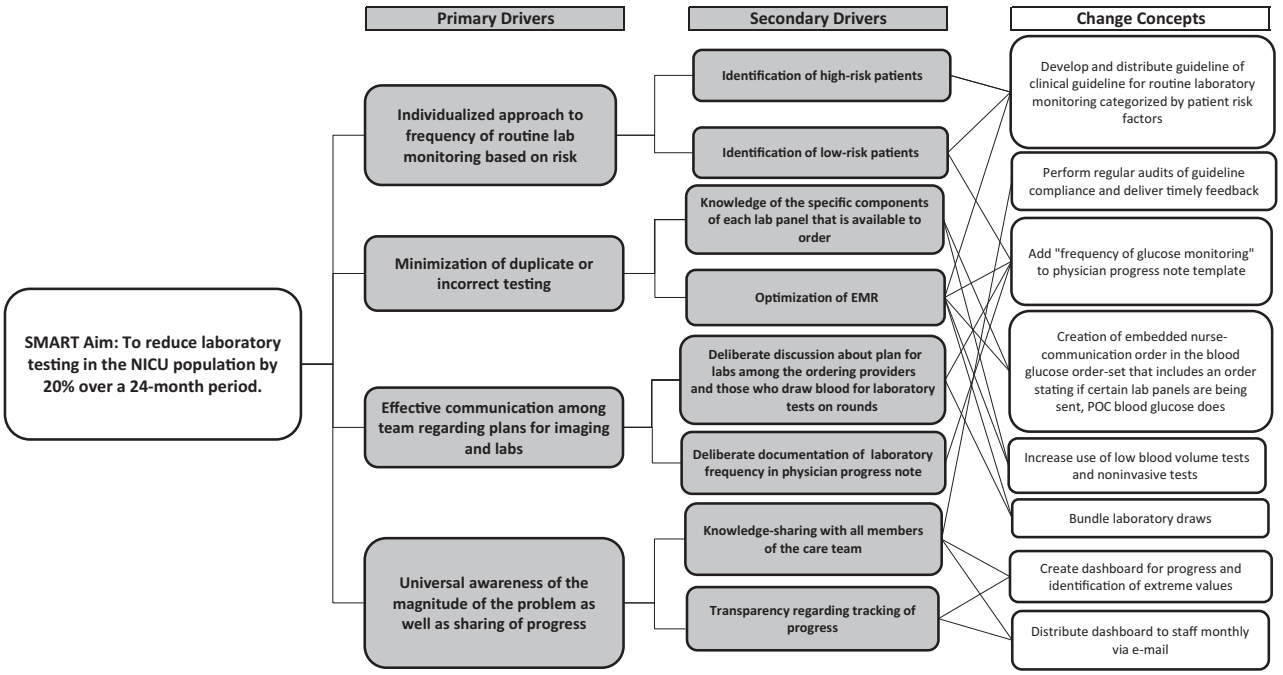

FIGURE 1
Key driver diagram used to achieve goal of reducing laboratory testing in the NICU. SMART, specific, measurable, achievable, realistic, and time-bound.

In March 2018, our information technology service's joint data analytics team created an electronic dashboard linked to our electronic medical record (EMR), allowing us to prospectively monitor every test performed in our NICU. Displayed data compared baseline and current laboratory studies

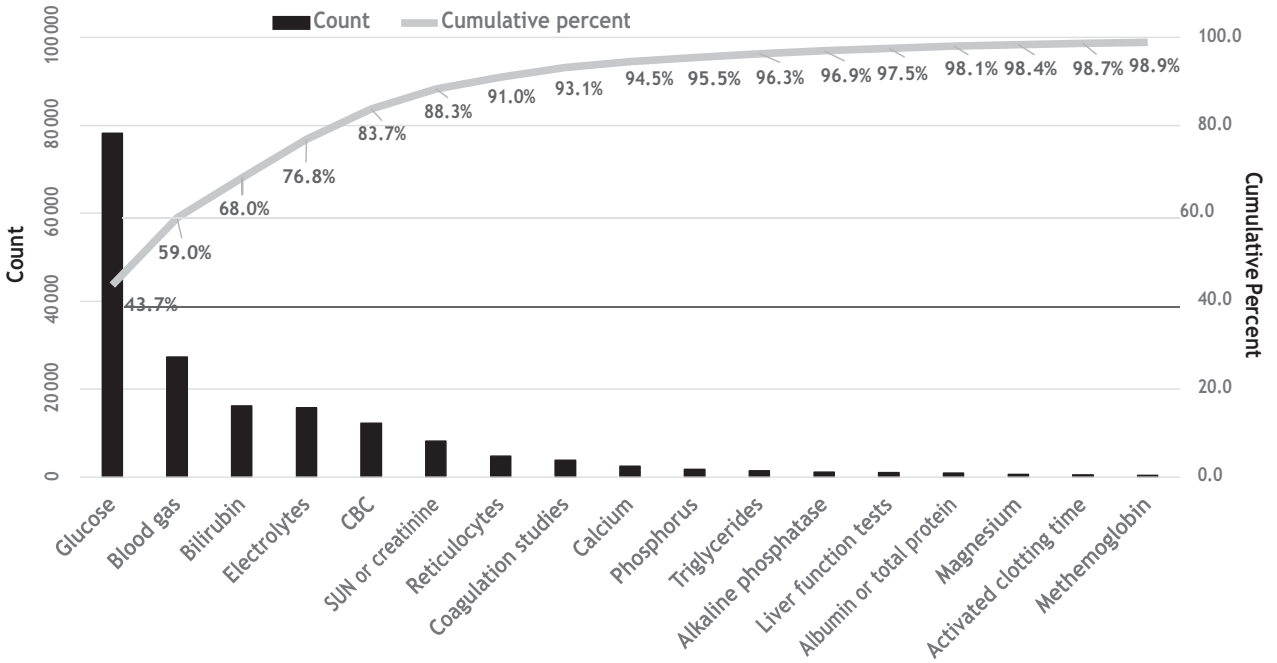

FIGURE 2
Pareto chart depicting the cumulative percentage of specific laboratory tests performed during the baseline period (January 1, 2014, through December 31, 2016). CBC, complete blood count; SUN, serum urea nitrogen.

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

performed per 1000 patient days (PDs), blood volume taken, and the frequency of selected extreme laboratory values (ie, balancing measures), with subcategorization available by birth weight, day of life, time period, and ordering physician (Supplemental Fig 7).

Blood Glucose Screening

Pareto analysis revealed that glucose levels accounted for 43.7% of all laboratory studies performed (Fig 2). Subsequent efforts focused on interventions to safely decrease glucose monitoring. Our NICU policy stated that every newborn admitted, irrespective of GA and diagnosis, necessitated hourly glucose screening for 6 hours. In the absence of supporting data, this "one-size-fits-all" approach was abandoned, and individualized risk-based screening was implemented in March 2018. EMR note templates were modified to include displays of recent glucose values and a hard stop necessitating daily documentation of the desired screening frequency. This stimulated discussion and allowed for a clearly prescribed plan. An order set was developed to support this practice change, and a PDSA cycle was performed aimed at avoiding duplicate glucose testing (an order modification included a reminder not to perform simultaneous point-of-care [POC] testing if a laboratory panel containing glucose was obtained). Implementation occurred in May 2018.

Monthly Dashboard Distribution

In April 2018, monthly automated dashboard distribution via electronic mail to all clinical staff was initiated to allow for transparency of tracked measures and stimulate discussion and feedback. The dashboard was also available via the hospital intranet. In December 2018, a modification allowed stratification by attending neonatologist. Each laboratory test was linked in the EMR to the attending of record or to the admitting neonatologist. Attending physicians could view their baseline and current performance data compared with the entire faculty (Supplemental Fig 8).

Transcutaneous Bilirubin and Carbon Dioxide Monitoring

Transcutaneous bilirubin (TCB) monitoring for neonates ≥35 weeks' GA was implemented in June 2018 accompanied by guideline development and extensive education focusing on proper and safe use based on American Academy of Pediatrics' guidelines.[15] This included the recommendation that a serum bilirubin be obtained for a TCB value within 70% of phototherapy level. Additional transcutaneous carbon dioxide monitors were purchased in July 2018. Guidelines specified that a blood gas be obtained to verify correlation when the monitor was first placed, once daily, and at the clinical discretion of the treating team (eg, if extreme values were noted).

Expanded POC Testing

In January 2018, new POC testing devices were trialed that could measure several high-yield analytes, including glucose, blood gas, bilirubin, hemoglobin, sodium, potassium, chloride, and ionized calcium. They used a fraction of the blood required for central testing and allowed the ability to order individual tests instead of laboratory panels. Use was suspended in February 2018 because of calibration issues and reimplemented in June 2018.

Measures

The primary outcome measure was total number of laboratory tests performed per 1000 PD and included every blood test (POC or central laboratory) performed in our NICU. Secondary outcome measures included blood glucose and serum bilirubin tests per 1000 PD. These outcomes were identified as vital contributors to the total number of tests performed during the baseline period, thus warranting targeted interventions. Blood loss was included as an additional outcome measure and estimated by multiplying the number of each specific laboratory test performed by the minimum amount of blood required to perform that test. Cost estimates for each laboratory test were obtained via our hospital finance division. The direct cost of a test performed in our central laboratory included all costs associated with resulting that test. This encompassed supplies (including the cost to lease instrumentation), courier expenses for transport of specimens, and salaries of laboratory technologists. Labor was included in the estimate because the volume of tests performed in the central laboratory directly affects the number of technologists required to be on staff. Estimates for POC testing, which is performed exclusively by NICU nurses, was based solely on supply costs. Unlike central laboratory testing, POC testing is performed at the bedside (ie, a courier is not required) and the volume of POC tests performed has no influence on salaries or staffing ratios. The initial cost to purchase POC testing and noninvasive monitoring devices was not included in our estimates because they were not specifically acquired for the purpose of this initiative.

Process measures included guideline compliance via EMR audits, which were conducted by the team leader. Given the breadth of the guideline, adherence to a single test was selected as a representative

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

measure of compliance. Additional audits occurred when new practices were introduced (eg, TCB monitoring). Deviations, if deemed inappropriate, were addressed in real time via direct feedback.

Balancing measures represented an objective assessment of whether interventions to decrease laboratory use resulted in more extreme values. Values were linked to the EMR of each corresponding infant to facilitate individual review and informal root cause analysis and included sodium levels >160 or <120 mmol/L, total calcium levels >13 or <6 mg/dL, hematocrits <20%, and glucose levels <25 mg/dL. Total serum bilirubin was not chosen given complexities in determining a single extreme threshold secondary to the influence of GA, risk factors, and hour of life.

Analysis

Statistical process control was evaluated through creation of control charts for each metric and tracked in real time, with u-charts primarily used given large subgroup sizes, and an XmR chart to assess cost. Published rules for evaluating special versus common cause variation were applied.[16] The mean was calculated by using 36 data points from the baseline period and adjusted when 8 or more consecutive data points were on the same side of the mean in the setting of an attributable intervention. A timeline of introduction of interventions was superimposed on each chart to assess impact. Baseline and performance rates were compared for each outcome.

Ethical Considerations

Laboratory testing that inflicts harm without reasonable hope of providing benefit conflicts with the physician's mandate primum non

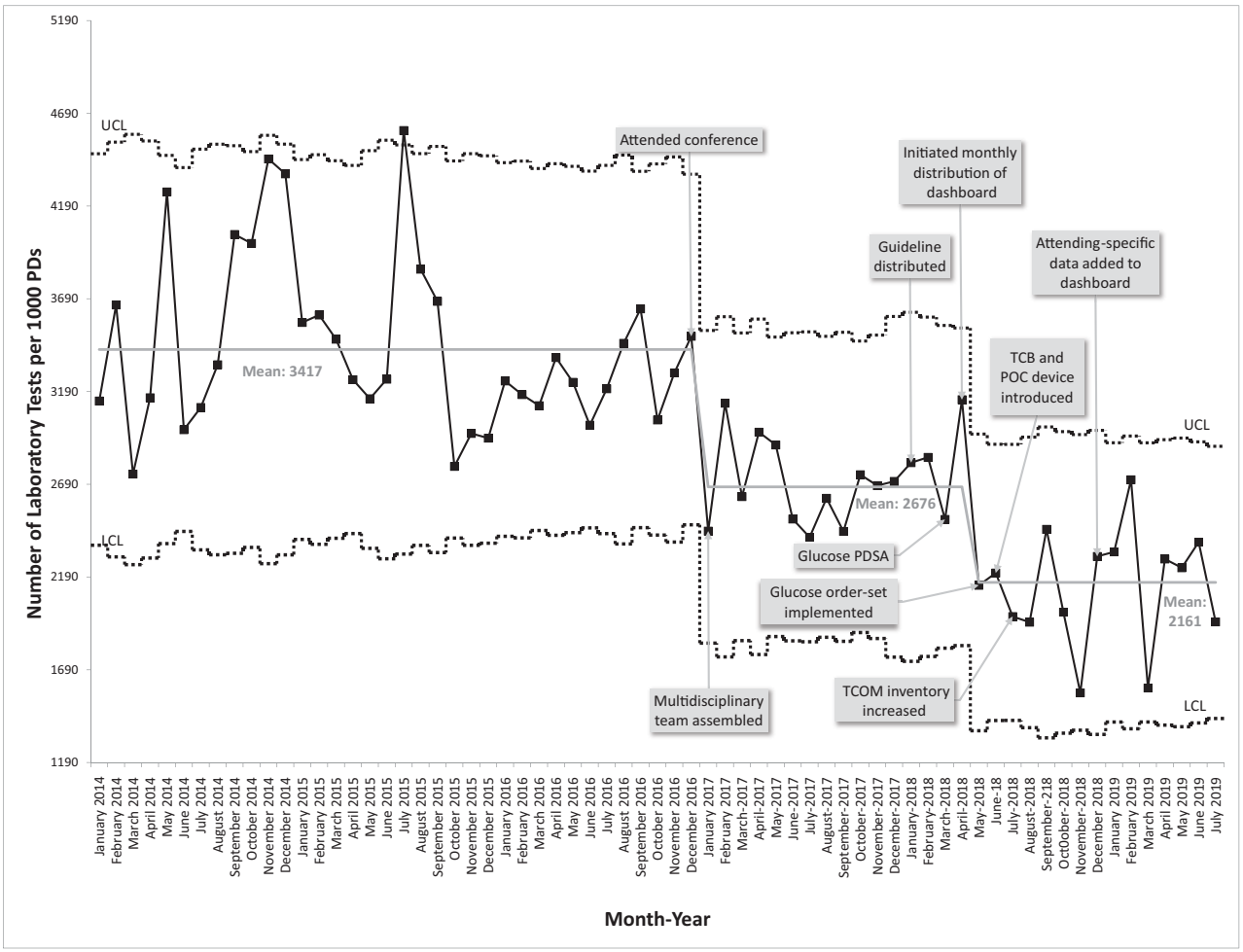

FIGURE 3
Annotated control chart (u-chart) depicting number of total laboratory tests performed per 1000 NICU PDs by month from January 1, 2014, through July 31, 2019. LCL, lower control limit; TCOM, transcutaneous carbon dioxide monitor; UCL, upper control limit.

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

nocere. The difficulty is in determining which tests are unnecessary. Interventions involved increasing awareness, encouraging open dialogue, using validated, noninvasive instruments, and creating practice guidelines within accepted standards of care. These were not experimental interventions but, rather, accepted and necessary aspects of the practice of medicine.

This project met specified criteria for a quality improvement initiative and was therefore deemed exempt from review by our institutional review board.

RESULTS

Baseline Data

A total of 179 113 laboratory tests were performed on 2532 infants between January 1, 2014, and December 31, 2016 (3417 per 1000 PDs), including 78 237 glucose levels, 27 355 blood gases, and 16 242 serum bilirubin levels, and necessitating 33.4 L of blood.

Outcome Measures

We achieved a 26.8% reduction in our primary outcome measure (from a baseline mean of 3417 to 2501 laboratory tests per 1000 PDs) over 24 months and achieved sustainability (Fig 3). Shifts in the centerline for rates of all laboratory and glucose tests (Figs 3 and 4) were achieved in January 2017. Some immediate improvement may be attributed to the Hawthorne effect, but sustainment was likely related to team assembly, education, and practice guideline creation. A further shift in centerline for both statistical process control charts in May 2018 likely reflected a focus on glucose screening. The final rates of 2161 total laboratory studies (36.8% decrease from baseline) and 927 glucose levels per 1000 PD (37.9% decrease) were maintained through July 2019 and based on data from 2451 infants.

A shift in rates of serum bilirubin levels was noted in June 2017, which we attributed to practice guideline implementation. TCB monitoring likely resulted in a second centerline shift in October 2018. Overall, the rate of serum bilirubin tests decreased by 32.9% (313 to 210 tests per 1000 PD) (Fig 5). We also observed a 20% reduction in electrolyte testing, a 29% reduction in complete blood counts, and a 32.6% reduction in blood gases during the intervention period.

A shift in blood volume removal was noted in January 2017 and sustained, resulting in a 24%

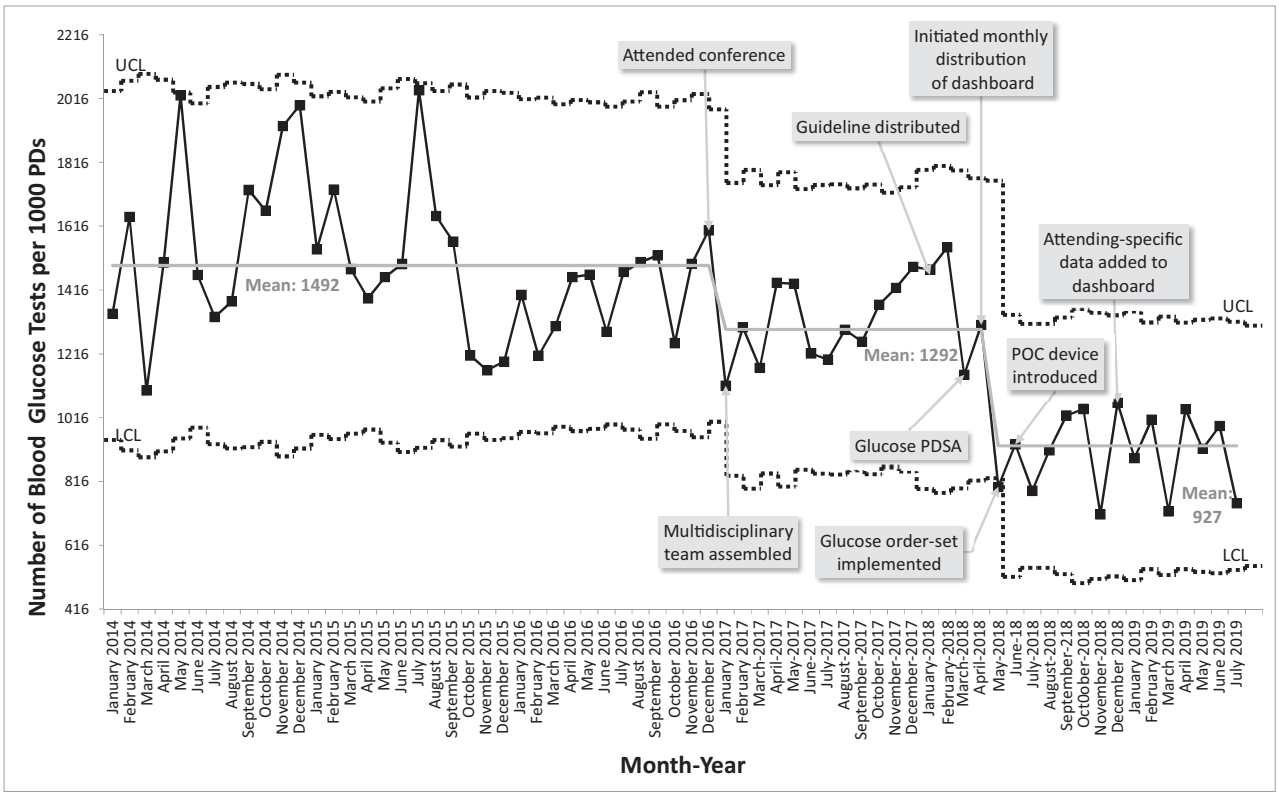

FIGURE 4
Annotated control chart (u-chart) depicting number of blood glucose tests performed per 1000 NICU PDs by month from January 1, 2014, through July 31, 2019. LCL, lower control limit; UCL, upper control limit.

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

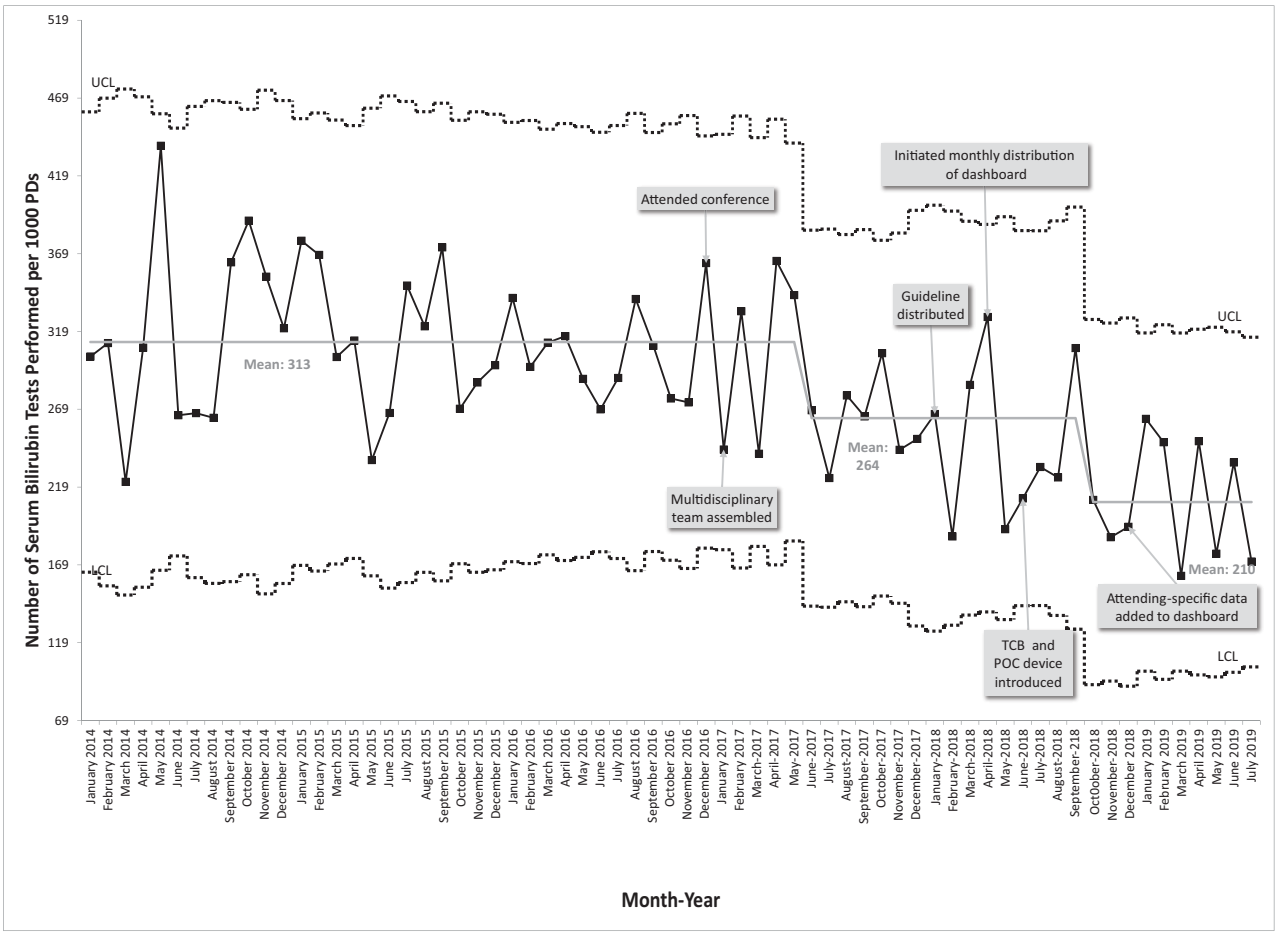

FIGURE 5

Annotated control chart (u-chart) depicting number of serum bilirubin tests performed per 1000 NICU PDs by month from January 1, 2014, through July 31, 2019. LCL, lower control limit; UCL, upper control limit.

decrease and an estimated savings of 7.9 L of blood over 31 months. We also noted an initial and sustained shift in the monthly cost of laboratory testing beginning in January 2017 (Fig 6). This 29% reduction equated to an estimated cost savings of $258 700 from January 1, 2017, through July 31, 2019, with variation in cost decreasing over time as care became more standardized.

Process Measures

Guideline adherence to screening complete blood count monitoring in the first 2 weeks of life for very low birth weight infants was assessed monthly as a surrogate marker for overall guideline compliance. Mean compliance was 87.9% (range: 69.5%–100%). Compliance with proper use of TCB monitoring (eg, correct GA, reflex serum bilirubin level obtained) was assessed every 2 to 4 weeks, with a mean compliance of 93.8% (range: 73.3%–100%).

Balancing Measures

Seven hundred twenty-one glucose values <25 mg/dL were identified (1.1% of all glucose values) in the intervention period. Given the volume of abnormal tests, rates were compared between baseline (15.5 per 1000 PD) and intervention periods (13.8 per 1000 PD), with no concerning trends noted. Extreme sodium, calcium, and hematocrit values were reviewed individually. Forty sodium values (0.3% of sodium values obtained) were investigated in 16 infants, 27 (67.5%) of which occurred in 8 neonates 22 to 25 weeks' GA in the first 5 days of life. The median time that a sodium value had been checked before an extreme value was 12 hours. Twenty-two extreme calcium values (0.2% of calcium values) were identified in 16 infants, 9 of which (40.9%) were the initial value obtained in the first day of life. In the remaining 13 cases, the median time from the last value checked was 12 hours. Twenty-one hematocrits <20% (0.2% of

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

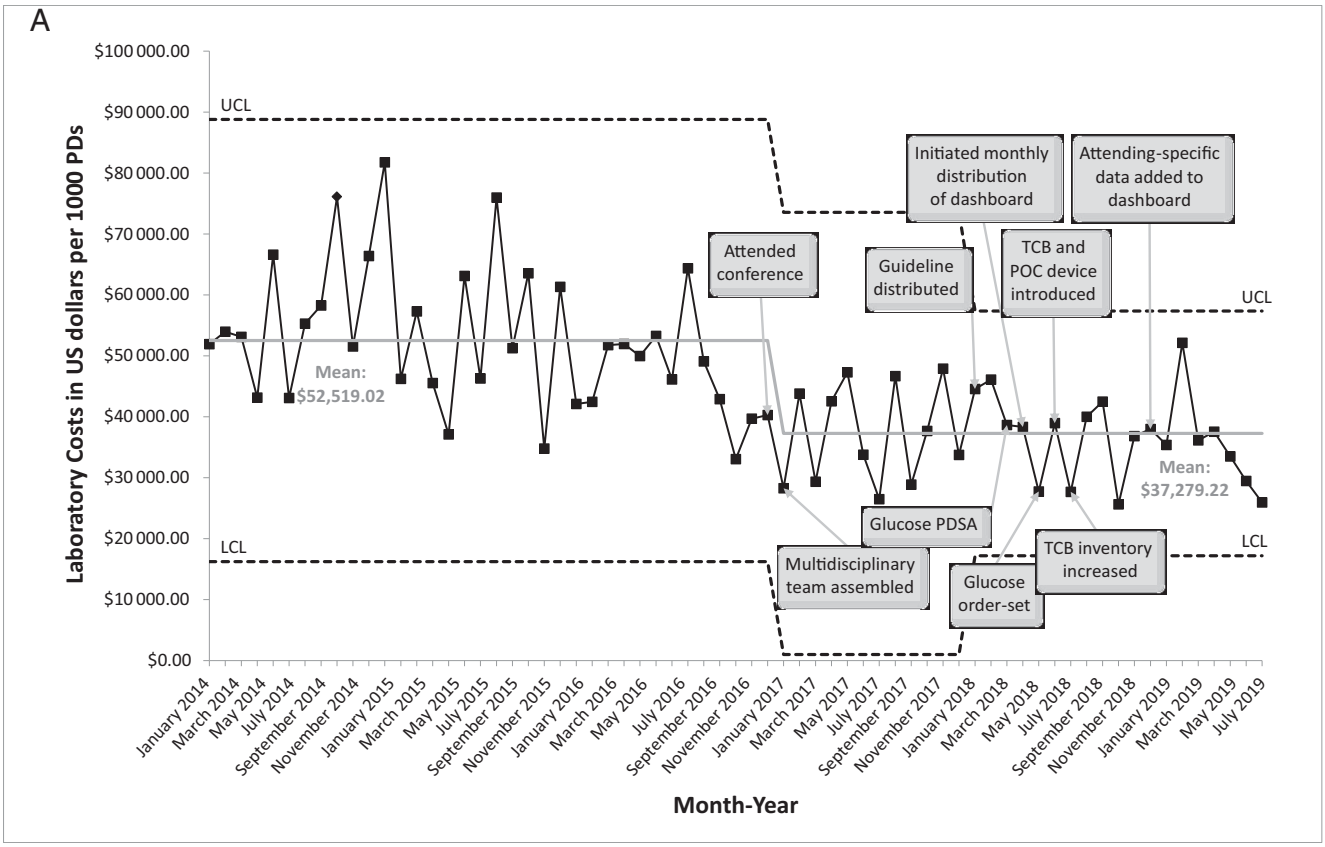

FIGURE 6

Annotated X and MR control charts depicting laboratory costs in US dollars per 1000 NICU PDs by month from January 1, 2014, through July 31, 2019. A, X-chart. B, MR chart. LCL, lower control limit; UCL, upper control limit.

hematocrit values) were identified in 20 infants, with 11 (52.4%) occurring in the setting of acute hemorrhage. On detailed review, no extreme values or known related complications (eg, symptomatic hypoglycemia) were attributed to practice changes related to our initiative. Although bilirubin was not assessed as a balancing measure, TCB implementation was audited for guideline compliance, and no deviations were found to have resulted in a need for, or delay in, intervention.

DISCUSSION

We achieved our primary aim of reducing laboratory testing in our

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

NICU with no identifiable relationship between interventions and perceived harm. Less quantifiable benefits can also be extrapolated. A decrease in testing reduces workload on laboratory staff, providing additional cost savings. The family experience may also be improved, because some of the anxiety associated with having an infant in the NICU may be allayed by less frequent blood draws. Although our project was conducted in a NICU, we believe that the bulk of our interventions, including educational efforts, guideline development, the use of POC testing and noninvasive monitoring, and creation of data dashboards linked to the EMR, are not unique to neonates and can be successfully replicated in other patient-care areas and populations.

Interpretation

Although it is difficult to identify one specific intervention that was most impactful, we believe that team formation, ongoing education, and practice guideline development and implementation to reduce variability in practice were critical steps in establishing a consistent approach to care that could be linked to balancing measures to alleviate concerns regarding practice changes. Additional key components included involvement of multiple stakeholders, transparency in process interventions, and ongoing public sharing of rationale and outcomes with staff and families, all of which helped foster a culture of questioning and conscientiousness toward testing. The interplay of these multiple interventions in turn aided in easing concerns and facilitating expanded use of new and existing technology in our NICU such as POC testing, which when implemented in the NICU has been shown to reduce laboratory testing, costs, and the need for transfusions.[17,18]

In a systematic review of 64 studies, Hiscock et al[19] determined that multifaceted efforts targeting both clinicians and families that combine process-based interventions, education, and audit and feedback achieved the most success in reducing unnecessary testing in children. Data from the NICU population in this review were limited to a single study aimed at improving quality and outcomes after creation of a "small baby unit," resulting in a 63% reduction in mean laboratory testing.[20] Interventions included formation of a multidisciplinary team, education, and creation of practice guidelines, with success attributed in large part to a dedicated team delivering consistent care. Although processes were similar, direct comparison of our data (which incorporated the entire NICU population) to a cohort limited to extremely low birth weight infants[20] is difficult given the influence of prematurity on the number of procedures performed.[6,21–23] Additionally, there is no clear standard for routine laboratory testing in the NICU, increasing the likelihood that baseline testing rates vary widely between institutions.

Limitations

It was difficult to measure a direct impact of our efforts on patient care. Although it can be inferred that a decrease in laboratory testing would translate into a directly proportional reduction in painful blood sampling, the number of needle or lancet sticks performed for each blood draw is not documented by staff and therefore could not be quantified and compared. Data were not reliably available to determine if the reduction in blood volume required for testing resulted in fewer red blood cell transfusions. We are also unable at this time to assess the impact of our effort on long-term outcomes, such as neurodevelopment.

Additional limitations concern estimates of blood loss. Multiple chemistry tests can be performed on a single blood sample, so although we were able to quantify the amount of blood required for each individual test, we could not account for bundling in either the baseline or intervention periods. At the onset of our initiative, we chose thresholds for balancing measures that we believed represented extreme values. It is recognized that thresholds less extreme may have also included actionable results. Last, although we accounted for fluctuations in census by expressing testing per 1000 PD, we could not account for fluctuations in acuity.

Conclusions

A multidisciplinary, multifaceted effort using staff and family education, practice guidelines, noninvasive testing, an electronic dashboard, prescriber audit and feedback, and shared data produced a significant and sustained decrease in laboratory testing in our NICU without perceived harm. We believe this intervention benefitted patients, families, staff, and the health care system and that the model is reproducible in other inpatient areas and can be applied to other forms of patient testing such as diagnostic imaging.

ACKNOWLEDGMENTS

We thank Drs Matthew Grossman and Scott Sussman for their input and guidance as well as the entire staff in the YNHCH NICU for their continued dedication to this effort and to our patient population.

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user

ABBREVIATIONSS

Abbreviations

EMR: electronic medical record
GA: gestational age
PD: patient day
PDSA: plan-do-study-act
POC: point-of-care
TCB: transcutaneous bilirubin
YNHCH: Yale New Haven Children's Hospital

REFERENCES

1. Walker SM. Long-term effects of neonatal pain. *Semin Fetal Neonatal Med*. 2019;24(4):101005
2. Anand KJS, Rovnaghi C, Walden M, Churchill J. Consciousness, behavior, and clinical impact of the definition of pain. *Pain Forum*. 1999;8(2):64–73
3. Valeri BO, Holsti L, Linhares MB. Neonatal pain and developmental outcomes in children born preterm: a systematic review. *Clin J Pain*. 2015;31(4):355–362
4. Widness JA, Madan A, Grindeanu LA, Zimmerman MB, Wong DK, Stevenson DK. Reduction in red blood cell transfusions among preterm infants: results of a randomized trial with an in-line blood gas and chemistry monitor. *Pediatrics*. 2005;115(5):1299–1306
5. Ree IMC, Lopriore E. Updates in neonatal hematology: causes, risk factors, and management of anemia and thrombocytopenia. *Hematol Oncol Clin North Am*. 2019;33(3):521–532
6. Cruz MD, Fernandes AM, Oliveira CR. Epidemiology of painful procedures performed in neonates: a systematic review of observational studies. *Eur J Pain*. 2016;20(4):489–498
7. Osman M, Elsharkawy A, Abdel-Hady H. Assessment of pain during application of nasal-continuous positive airway pressure and heated, humidified high-flow nasal cannulae in preterm infants. *J Perinatol*. 2015;35(4):263–267
8. Roofthooft DW, Simons SH, Anand KJ, Tibboel D, van Dijk M. Eight years later, are we still hurting newborn infants? *Neonatology*. 2014;105(3):218–226
9. Carbajal R, Rousset A, Danan C, et al. Epidemiology and treatment of painful procedures in neonates in intensive care units. *JAMA*. 2008;300(1):60–70
10. Britto CD, Rao Pn S, Nesargi S, et al. PAIN–perception and assessment of painful procedures in the NICU. *J Trop Pediatr*. 2014;60(6):422–427
11. Jeong IS, Park SM, Lee JM, Choi YJ, Lee J. The frequency of painful procedures in neonatal intensive care units in South Korea. *Int J Nurs Pract*. 2014;20(4):398–407
12. Cignacco E, Hamers J, van Lingen RA, et al. Neonatal procedural pain exposure and pain management in ventilated preterm infants during the first 14 days of life. *Swiss Med Wkly*. 2009;139(15–16):226–232
13. Kazmi SH, Caprio M, Boolchandani H, Mally P, Bailey S, Desai P. The value of routine laboratory screening in the neonatal intensive care unit. *J Neonatal Perinatal Med*. 2020;13(2):247–251
14. Harb R, Hajdasz D, Landry ML, Sussman LS. Improving laboratory test utilisation at the multihospital Yale New Haven Health System. *BMJ Open Qual*. 2019;8(3):e000689
15. Maisels MJ, Bhutani VK, Bogen D, Newman TB, Stark AR, Watchko JF. Hyperbilirubinemia in the newborn infant > or =35 weeks' gestation: an update with clarifications. *Pediatrics*. 2009;124(4):1193–1198
16. Benneyan JC, Lloyd RC, Plsek PE. Statistical process control as a tool for research and healthcare improvement. *Qual Saf Health Care*. 2003;12(6):458–464
17. Mahieu L, Marien A, De Dooy J, Mahieu M, Mahieu H, Van Hoof V. Implementation of a multi-parameter Point-of-Care-blood test analyzer reduces central laboratory testing and need for blood transfusions in very low birth weight infants. *Clin Chim Acta*. 2012;413(1–2):325–330
18. Madan A, Kumar R, Adams MM, Benitz WE, Geaghan SM, Widness JA. Reduction in red blood cell transfusions using a bedside analyzer in extremely low birth weight infants. *J Perinatol*. 2005;25(1):21–25
19. Hiscock H, Neely RJ, Warren H, Soon J, Georgiou A. Reducing unnecessary imaging and pathology tests: a systematic review. *Pediatrics*. 2018;141(2):e20172862
20. Morris M, Cleary JP, Soliman A. Small baby unit improves quality and outcomes in extremely low birth weight infants. *Pediatrics*. 2015;136(4). Available at: www.pediatrics.org/cgi/content/full/136/4/e1007
21. Barker DP, Rutter N. Exposure to invasive procedures in neonatal intensive care unit admissions. *Arch Dis Child Fetal Neonatal Ed*. 1995;72(1):F47–F48
22. Johnston C, Barrington KJ, Taddio A, Carbajal R, Filion F. Pain in Canadian NICUs: have we improved over the past 12 years? *Clin J Pain*. 2011;27(3):225–232
23. Chen M, Shi X, Chen Y, et al. A prospective study of pain experience in a neonatal intensive care unit of China. *Clin J Pain*. 2012;28(8):700–704

Downloaded from http://publications.aap.org/pediatrics/article-pdf/148/1/e2020000570/1182321/peds_2020000570.pdf
by University of Alberta user