QUALITY IMPROVEMENT ARTICLE

Metabolic bone disease of prematurity screening and individualized enteral mineral supplementation in high-risk neonates: a quality improvement initiative

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OBJECTIVE: Prompted by an alarmingly low screening rate for metabolic bone disease of prematurity (MBDP), we aimed to increase MBDP screening with serum calcium, phosphorous, and alkaline phosphatase at four to six weeks of life in infants born at <1500 g and <32 gestational weeks from a baseline of 27.37% to 90% within one year.
STUDY DESIGN: We used the Institute for Healthcare Improvement's Model for Improvement as a framework. A key driver diagram informed the interventions which were carried out through four Plan-Do-Study-Act cycles.
RESULTS: There were 129 and 130 neonates in the pre-intervention baseline group and post-intervention MBDP bundle group, respectively. MBDP bundled primary screening rates increased from 27.37% to 95.56% ($p < 0.001$). Furthermore, 20% of infants had an individualized change in their enteral mineral supplementation after the initiative.
CONCLUSIONS: An interdisciplinary team-based quality improvement approach was effective in altering clinical practice to improve screening and subsequent treatment for MBDP.

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INTRODUCTION

Metabolic bone disease of prematurity (MBDP) is a common comorbidity in premature infants caused by bone mineralization reduction due to inadequate prenatal and postnatal calcium and phosphate accretion compared to expected for infants of similar birth weight and gestational age that is characterized by biochemical abnormalities or radiographic changes [1, 2]. It is a complex multifactorial disease that may be a consequence of several prenatal and postnatal risk factors. In utero, 80% of calcium and phosphorous accretion occur during the third trimester of gestation with placental transfer of these minerals peaking up to 120 mg/kg/day and 60 mg/kg/day, respectively [3, 4]. Therefore, it is not surprising that one of the most strongly associated risk factors for the development of MBDP is a younger gestational age as the extremely premature infant will not have participated in this critical gestational period. Additional prenatal risk factors include those that impair the placental transfer of these essential minerals such as pre-eclampsia, chorioamnionitis, or other disorders leading to placental insufficiency. Lower birth weights are associated with placental insufficiency and is another important risk factor in developing MBDP [5]. Postnatally, infants affected by conditions that prevent optimal mineral intake such as those receiving prolonged parenteral nutrition or having compromised feeding tolerance are at a higher risk of developing MBDP. Infants that are exposed to medications which reduce mineral stores such as loop diuretics, caffeine, or glucocorticoids are also at increased risk [6, 7]. Additionally, the mechanical stimulation that a fetus experiences in the intrauterine environment to stimulate bone formation and growth is difficult to replicate postnatally which may also contribute to decreased bone mineralization after birth [8].

Although significant advancements in neonatal nutritional management have improved our overall care for infants with MBDP, increasing survival of younger and smaller infants still makes MBDP a significant comorbidity in the neonatal intensive care unit (NICU). The true disease incidence is hard to quantify due to differing definitions but is reported as high as 23% in very low-birthweight (VLBW) infants and 55% in extremely low-birthweight infants [1, 2]. Clinical manifestations of MBDP usually do not appear until late into the disease process. Infants may present with decreased linear growth, radiologic rickets, spontaneous fractures, respiratory distress from chest wall instability which may lead to difficulty weaning ventilator support, or features of hypocalcemia [4]. In terms of evaluating longer-term impacts, Lucas et al. found that preterm infants with MBDP identified with elevated alkaline phosphatase values had reduced lengths at 9 months and 18 months postnatal age [9]. Longer term follow-up showed that children who had a history of MBDP were shorter at 9 to 12 years of age [10].

The ideal approach to this disease process is preventative nutrition and timely screening of at-risk infants with the goal of optimizing nutrition early before it can result in adverse health outcomes. The gold standard for assessing bone mineralization in infants is dual energy X-ray absorptiometry, but there are not

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good standardized normative data and it is often not a feasible test to obtain in the neonatal population [11]. As the use of dual energy X-ray absorptiometry is mostly limited to the research setting, a combination of serum biochemical markers, urinary markers, and radiologic studies is more commonly used in the clinical setting to aid in the diagnosis of MBDP [12–14]. As there is no single perfect diagnostic test, clinicians must employ a combination of tests to improve the sensitivity and specificity of diagnosing MBDP [12]. There are numerous suggested algorithms published, but no single one is widely used in practice [2, 4, 6, 14–16]. The American Academy of Pediatrics also released guidelines in 2013, but there remains significant practice variation amongst neonatologists when it comes to timing of screening, tests used for screening, and treatment of MBDP [17–19].

Prior to the start of this initiative, no standard screening practice guidelines existed in our two NICUs which led to a wide variability in local practice. To support this observation, we conducted a brief needs assessment investigating the number of patients born < 1500 grams and < 32 gestational weeks who received screening with at least a serum calcium, phosphorous, and alkaline phosphatase at four to six weeks of life. We found that only 12.90% of patients discharged in December 2020 were screened appropriately. These data showed a compelling need for practice improvement in our NICUs.

Our primary aim was to increase primary tiered screening with serum calcium, phosphorous, and alkaline phosphatase at four to six weeks of life in all infants born <1500 g and <32 gestational weeks from a baseline of 27.37% from July 2020 to June 2021 to 90% within one year. Our secondary aim was to assess the proportion of infants who had a change in their nutritional management with increased enteral supplementation with calcium, phosphorous, and/or vitamin D after the start of this initiative.

METHODS

Study design and improvement model

This is a pre-/post-intervention study design using quality improvement (QI) framework.

The Model for Improvement was used as a framework to guide this QI project [20]. SQUIRE 2.0 standards were followed for reporting [21].

Study setting

Riley Children's Health at Indiana University Health is a large, urban pediatric medical center with two academic NICUs. The level IV NICU has ~625 admissions annually, of which 30% are inborn and 100 patients are VLBW. The level III NICU has approximately 900 admissions annually, of which 96.5% are inborn and 145 patients are VLBW. The two NICUs are located in the same building but in separate towers. Every neonatal-perinatal medicine fellow and a small number of neonatologists practice in both of the NICUs. The majority of neonatologists and the rest of the disciplines spend their clinical time at only one of the NICUs. Each unit has its own separately dedicated dietitians and pharmacists. Prior to our initiative, there were no existing MBDP screening or treatment guidelines for infants hospitalized in our units.

Population and study groups

The study population included all infants admitted to our NICUs who were born <1500 g and <32 gestational weeks. Since our focus was on screening at 4–6 weeks of life, we excluded patients that died or were transferred from our units before 4 weeks of life and patients that were admitted after 6 weeks of life.

Infants admitted during the baseline pre-intervention period from July 2020 to June 2021 comprised the Baseline group. Infants admitted during the post-intervention period, from July 2021 to December 2022 and discharged before June 2023, comprised the MBDP Bundle group. The MBDP Bundle group included all patients admitted to the level IV NICU from July 2021 and those patients admitted to the level III once the initiative was expanded to that unit in January 2022.

Formation of an interdisciplinary team

In 2021, we formed a core interdisciplinary QI team consisting of neonatologists, a neonatal fellow, a pediatric endocrinologist, neonatal nurse practitioners, physician assistants, registered nurses, neonatal dietitians, and a clinical neonatal pharmacist.

Development of study interventions

A key driver diagram developed by the QI interdisciplinary team helped us identify potential interventions to improve the MBDP screening for high-risk infants (Supplementary Fig. 1). Key drivers included development of standardized screening guidelines, education highlighting the standardization of screening, timely identification of high-risk infants, and ease of ordering screening tests. We had multiple interventions divided into four PDSA cycles throughout the study period (Table 1).

Interventions to provide standardized screening. The QI interdisciplinary team performed an extensive literature review of various screening markers available in the clinical setting and suggested screening practices by experts in the field to inform the development of a stepwise MBDP screening algorithm for our NICUs (Fig. 1). This algorithm specifies which patients are eligible for screening, when to screen those patients, and with what tests to screen. To improve buy-in from providers and minimize unnecessary blood draws, testing is recommended in a stepwise fashion which consists of primary tier and secondary tier screening tests. The algorithm also provides guidance on how often to follow normal or abnormal test results. Obtaining X-rays was intentionally not included in our algorithm as bone mineralization must decrease significantly for radiologic sequelae to be evident and our goal was to detect MBDP prior to significant demineralization. We disseminated the algorithm to neonatal providers in multiple ways such as introduction of the algorithm in a routine update email for advanced practice providers, addition of the

Table 1. PDSA Cycles.

PDSA Cycle #	Date	Process Change
1	July 2021–September 2021	• Development and implementation of screening algorithm • Dietitians to touch base with medical team every Friday • Education to providers through various division presentations • RN educator takes lead on educating unit nurses on initiative • Visual aids available in workrooms • Reference material posted electronic resources for providers
2	October 2021–December 2021	• Individual review of missed screens and targeted education to provider teams • Incorporating screening as a part of the "to do" checklist in patient chart
3	January 2022–September 2022	• Expand to Level III NICU • Resident education provided in initial nutrition lecture • Algorithm incorporated in resident rounding binders for easy reference
4	October 2022–December 2022	• EMR flags for dietitians • EMR order set for tests and supplements

EMR electronic medical record, *PDSA* Plan-Do-Study-Act, *RN* registered nurse.

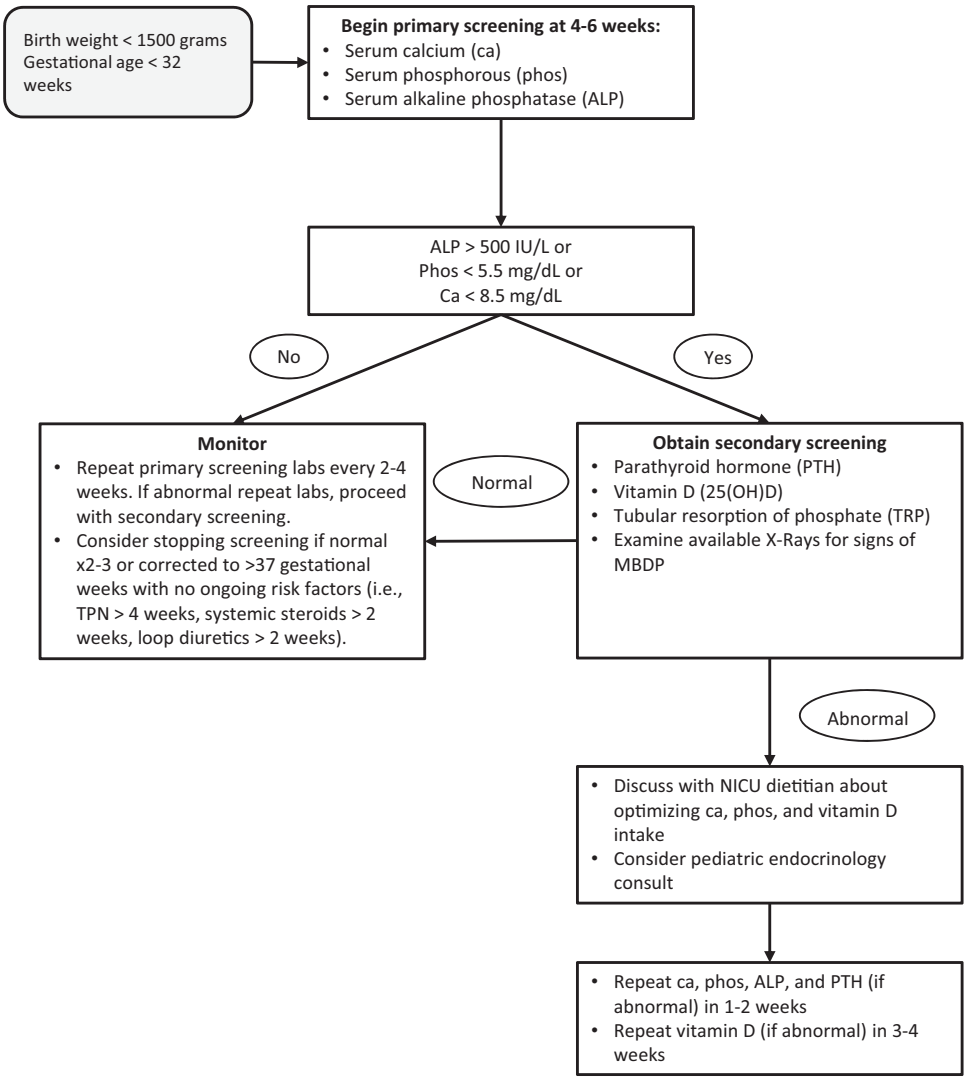

Fig. 1 Algorithm for MBDP primary and secondary screening. ALP alkaline phosphatase, MBDP metabolic bone disease of prematurity, NICU neonatal intensive care unit, PTH parathyroid hormone, Phos phosphorus, TPN total parenteral nutrition.

algorithm in the shared online clinical guidelines portal for all providers, and posting of physical copies for reference in provider workrooms.

An algorithm for supplementation recommendations was also developed to provide guidance on initiation and titration of enteral calcium, phosphorous, and/or vitamin D supplementation (Supplementary Table 1). These supplements are recommended in addition to our existing feeding protocol which, at baseline, already uses high mineral fortification with bovine-derived Human Milk Fortifier and liquid protein until closer to discharge (providing ~180 mg/kg of calcium and 100 mg/kg of phosphorous with 150 mL/kg/day of 24 kcal/oz fortified breast milk).

Interventions to provide education to all disciplines. There were various timed educational efforts to increase provider knowledge and buy-in for MBDP screening in both units. The project was introduced through a formal presentation to the neonatology division with subsequent yearly updates. The objective of these yearly divisional updates was to provide education on the disease, importance of screening, and the initiative's progress to the providers.

As a part of our workflow, the majority of tests for patients are ordered by advanced practice providers and residents. Thus, the QI team felt it necessary to provide additional targeted education to these groups to encourage buy-in and success. For advanced practice providers, education and reminders were incorporated through their regularly scheduled update emails. Residents rotating in the NICU receive an established series of basic neonatology lectures as a part of their rotation. Education regarding MBDP was added to one of their first lectures focused on nutrition in the neonate.

Interventions for timely patient identification. Although we encouraged all members of the team to be cognizant of when patients were due for their screenings, we identified our NICU registered dietitian team as the best discipline to have the primary responsibility of identifying when patients were due for their screening and relaying that to the primary medical teams. To make identifying eligible patients easier for the NICU dietitians, our subsequent PDSA cycles focused on incorporating the electronic medical record (EMR) in flagging when patients were due for this screening.

Interventions for making ordering tests and supplements more effective. Developing an order set in our EMR was key for test ordering ease. This order set was reviewed by our clinical informatics team before being made available to providers. The order set has a link to the algorithm and is organized by primary tier tests, secondary tier tests, and supplements. Our secondary tier tests consist of serum and urine tests that we did not routinely obtain in our NICU prior to this initiative. In our subsequent PDSA cycles, we identified this coordination of serum and urine tests may be a reason for suboptimal compliance for secondary tier screening. For example, calculating the tubular resorption of phosphate requires a combination of serum and urinary values. Our intervention implementing a central order set helped address this barrier.

Prior to the start of this initiative, patients were rarely prescribed enteral calcium and or phosphorous supplements leading to many providers being unfamiliar with different formulations. The order set contains the various recommended formulations of enteral calcium or phosphorous supplements for providers to easily select. Recommendations on starting dose, titration of supplement, and maximum dose are also included in the order comments for each supplement.

Interventions for minimizing laboratory draws. We recognized that this new algorithm for MBDP screening may require more blood for serum tests from a patient population that is at risk for iatrogenic anemia from laboratory tests. For this reason, we investigated how much blood is required for each test with our lab services department and found the ideal combination of orders that would incorporate all the necessary MBDP screening tests and require the least amount of blood volume. Since there is a two-week window in ordering the recommended primary tier screening tests, we encouraged the NICU dietitian team to discuss with the medical team when any tests could be coordinated with other blood work to minimize additional blood loss from laboratory draws.

Measures

The primary measure was the proportion of infants admitted each month that received primary tier screening with serum calcium, phosphorous, and alkaline phosphatase at four to six weeks of life. The secondary measure included the proportion of infants who had a change in nutritional management defined by an increase in calcium, phosphate, and/or vitamin D supplementation due to MBDP diagnosis. Our process measures closely aligned with our primary and secondary measures due to the nature of the initiative and included compliance with primary tier screening and compliance with secondary tier screening in infants with abnormal primary tier screening results. Balancing measures reflected potential adverse events of routine blood screening such as iatrogenic anemia and was monitored via the number of packed red blood cell transfusions during hospitalization. A second balancing measure was the number of times medications for severe constipation were administered as additional enteral calcium and/or phosphorous supplementation may result in constipation. Finally, the proportion of infants in each study group with non-traumatic bone fractures was also used as a balancing measure.

Data collection

Data for the Baseline group were retrospectively collected using the Vermont Oxford Network database. Data for the MBDP Bundle group were prospectively collected by weekly review of all admissions to the units. Data collected for both study groups included patient demographics and birth history, nutritional information at the time of primary tier screening and any subsequent follow-up screening, discharge information and discharge diagnoses, and growth anthropometrics at birth, 36 weeks postmenstrual age, and at discharge.

Study definitions

We used Bell Stage II or greater to define necrotizing enterocolitis [22]. For chronic lung disease, we used Jensen's classification of bronchopulmonary dysplasia [23].

Statistical analysis

Descriptive analyses were used to describe infant demographics and risk factors (frequency distributions (%) for categorical variables and mean (standard deviation (SD)) for continuous variables). The differences between the study groups were assessed by one-way ANOVA for continuous variables and chi-square or Fisher's exact test as appropriate for categorical variables. Two-sided tests were used with P value < 0.05 as statistically significant. Analyses were performed using SAS for windows version 9.4 (SAS Institute, Cary, NC). QI Macros (Version 2021.10) for Microsoft Excel was used to create a run chart for our primary measure to evaluate the impact of our initiative over time. The baseline median was calculated using data from July 2020 to June 2021. Established health care data rules were used to evaluate for evidence of nonrandom signals of change [24].

Ethical considerations

This project's protocol was submitted and reviewed by the Indiana University Human Research Protection Program. Since the project was undertaken as a QI initiative, it was deemed exempt from review by the Indiana University Institutional Review Board.

RESULTS

The study included 259 total patients, of whom 129 were in the Baseline group and 130 who were in the MBDP Bundle group. Infant characteristics such as gestational age, birth weight, sex, race/ethnicity, age at admission, level of NICU at the time of primary tier screening, NICU length of stay, and postnatal risk factors were not significantly different between the two study groups. The Baseline group had a statistically significant higher proportion of patients born to mothers with hypertensive disorders (Table 2). The remaining prenatal and postnatal risk factors were not significantly different between the two study groups.

Primary measure

After completing four PDSA cycles, our primary tier screening rate improved from 27.37% in the Baseline group to 95.56% in the MBDP Bundle group (Fig. 2, Supplementary Table 2). There was evidence of a nonrandom signal of improvement in January 2022, which prompted revision of the median. Ultimately, the bundled primary tier screening rate exceeded our project's primary aim.

Secondary measure

Of all the patients in the MBDP Bundle group, a total of 26 (20.0%) had a change in their nutritional management during their admission (Fig. 3). Change in management was individualized to each patient's primary and secondary screening results and diagnosis of calcium, phosphorous, and/or vitamin D deficiency (Supplementary Table 3). Enteral calcium supplement doses ranged from 20-40 mg/kg/day of elemental calcium. Enteral phosphorous supplement doses ranged from 20-32 mg/kg/day of elemental phosphorous. Additional vitamin D supplementation ranged from 200 to 1000 IU/day. One patient had an increase in fortification from 24 kcal/ounce to 27 kcal/ounce to provide additional minerals. Calcium and phosphorus supplements were continued until deficiencies were corrected and none of the patients required discharge on an additional calcium or phosphorous supplement. All patients were continued on our standard discharge dose of 400 IU/day of vitamin D, and none were discharged on an increased dose from standard.

Process and balancing measures

Overall compliance with bundled primary tier screening throughout the intervention period was high at 95.38%. Overall compliance with secondary screening in those patients with abnormal primary tier screening results in the MBDP Bundle group was 79.63%. Compliance with secondary screening improved throughout the post-intervention period with subsequent PDSA cycles that addressed ease of ordering tests. The number of packed red blood cell transfusions throughout a patient's admission (5.59 ± 4.92 vs 7.01 ± 5.51 transfusions, $p = 0.052$) and the number of times medications for severe constipation were used (0.46 ± 4.84 vs 0.96 ± 5.22 doses, $p = 0.44$) did not significantly differ in the Baseline and MBDP Bundle groups. There were three patients in each the Baseline and MBDP Bundle group with non-traumatic fractures identified throughout the study period (2.33% vs 2.34%, $p = 1.00$).

DISCUSSION

Our interdisciplinary QI approach resulted in significant improvement in our screening rate for MBDP, and ultimately, we were able to surpass our goal of 90% screening for all VLBW infants born <32 weeks gestation. Additionally, this study was also associated with a clinically significant proportion of patients undergoing a change

Table 2. Infant demographics and risk factors for MBDP [22, 23].

Characteristic	Baseline ($N = 129$)	MBDP Bundle ($N = 130$)	*P* value
Gestational age in weeks, mean (SD)	27.05 (2.31)	26.67 (2.35)	0.21
Birth weight in grams, mean (SD)	991.39 (265.00)	950.15 (290.75)	0.23
Sex			0.95
Female, *n* (%)	62 (48.06)	62 (47.69)	
Male, *n* (%)	67 (51.94)	68 (52.31)	
Race			0.41
Asian, *n* (%)	2 (1.55)	6 (4.62)	
Black, *n* (%)	46 (35.66)	41 (31.54)	
Native Hawaiian or Other Pacific Islander, *n* (%)	1 (0.78)	1 (0.77)	
White, *n* (%)	70 (54.26)	66 (50.77)	
Unknown/Refused, *n* (%)	10 (7.75)	16 (12.31)	
Age at admission (days), mean (SD)	5.17 (9.88)	6.27 (11.16)	0.40
Admission unit			0.66
Level III NICU, *n* (%)	60 (46.51)	64 (49.23)	
Level IV NICU, *n* (%)	69 (53.49)	66 (50.77)	
NICU length of stay in days, mean (SD)	96.22 (49.99)	107.84 (56.10)	0.08
Prenatal risk factors			
Antenatal corticosteroids, *n* (%)	89 (68.99)	77 (59.23)	0.10
Intrauterine growth restriction, *n* (%)	11 (8.53)	15 (11.36)	0.42
Chorioamnionitis, *n* (%)	6 (4.65)	5 (3.85)	0.75
Maternal hypertension, *n* (%)	32 (24.81)	19 (14.62)	0.04
Preeclampsia, *n* (%)	35 (27.13)	37 (28.46)	0.81
Pregestational or gestational diabetes, *n* (%)	8 (6.20)	15 (11.54)	0.13
Postnatal risk factors			
Chronic lung disease, *n* (%)	95 (73.64)	97 (74.62)	0.97
Medical/surgical NEC or SIP, *n* (%)	7 (5.42)	18 (13.85)	0.50
Prolonged TPN (>4 weeks), *n* (%)	21 (16.28)	29 (22.31)	0.21
Prolonged use of steroids (>2 weeks), *n* (%)	111 (86.05)	107 (82.31)	0.41
Prolonged use of caffeine (>2 weeks), *n* (%)	122 (94.57)	12 (9.23)	0.41
Prolonged use of loop diuretics (>2 weeks), *n* (%)	18 (13.95)	124 (95.38)	0.77

NEC necrotizing enterocolitis, *NICU* neonatal intensive care unit, *SD* standard deviation, *SIP* spontaneous intestinal perforation, *TPN* total parenteral nutrition.

in their nutritional management throughout the duration of their hospitalization after intervention. These nutritional changes were unique and individualized to their specific mineral deficiencies leading to MBDP.

The primary strategy for management of MBDP is centered around prevention of further sequalae through early detection followed by optimization of calcium, phosphorous and vitamin D intake [2]. A prior study showed implementing a screening, prevention, and management policy led to a decreased rate of MBDP [25]. Furthermore, Chin et al. showed that implementing a standardized MBDP protocol led to adequate mineral supplementation and decreased rate of MBDP [26]. In 2022, a QI initiative by Krithika and colleagues resulted in decreased MBDP rates by early calcium and phosphorous supplementation via fortification, parenteral and enteral nutrition optimization [27]. Although both the study by Krithika et al. and this study optimized enteral calcium and phosphorous, the two studies differed in the way those nutrients were optimized. Unlike the study population for Krithika et al., our study population was already routinely on feeds with high mineral fortification once they reached 80 ml/kg/day of enteral feed volume, and those on central parenteral nutrition had these supplements added to their parenteral nutrition early. However, our study is unique from previously published studies in that many of our patients were started on individualized doses of enteral calcium and phosphorous due to mineral deficiencies noted on screening despite being on feeds fortified with higher mineral content.

A strength of our study setting was the great interdisciplinary collaboration with team members from various backgrounds and experiences committed to achieving the same project goal. Notably, our NICU dietitians were intimately involved with the project from the beginning as vital champions. They were also crucial resources for all the NICU providers from a day-to-day standpoint. Most level III and IV NICUs have some dietitian involvement in patient care, and there is ample literature that shows successful study results due to close collaboration with this discipline [28–31]. The recently published AAP Standards of for Levels of Neonatal Care emphasize multidisciplinary involvement of all disciplines in neonatal quality and safety activities as well as dedicated registered dietitians with specialized neonatal nutrition training who collaborate with the medical team [32]. Our dietitians attended daily medical rounds where they reviewed MBDP screening tests, interpreted the results, and provided recommendations on supplement doses as a part of the nutritional discussion. Having these champions present, visible, and integrated into discussion on rounds was essential to the success of our project.

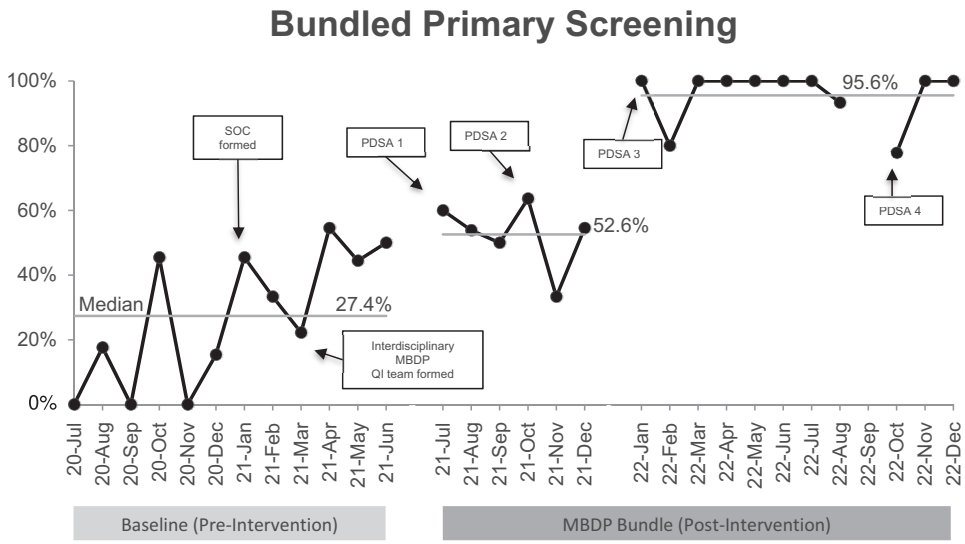

Fig. 2 Annotated run chart of bundled primary tier screening rate. The percentage is calculated based on all VLBW patients born < 32 gestational weeks admitted to the level IV and level III NICUs that month. No patients admitted in September 2022 qualified for screening. PDSA 1: Pilot at level IV NICU with algorithm dissemination, interdisciplinary education efforts, and identification of high-risk patients by NICU dietitians. PDSA 2: Individual chart review of patients with missed screening and targeted education efforts toward care teams. PDSA 3: Formal expansion of initiative to the level III NICU and education efforts targeted at resident physicians and resident physician assistants. PDSA 4: EMR order set and EMR flags. MBDP metabolic bone disease of prematurity, PDSA Plan-Do-Study-Act, QI quality improvement, SOC scholarly oversight committee, VLBW very low-birthweight.

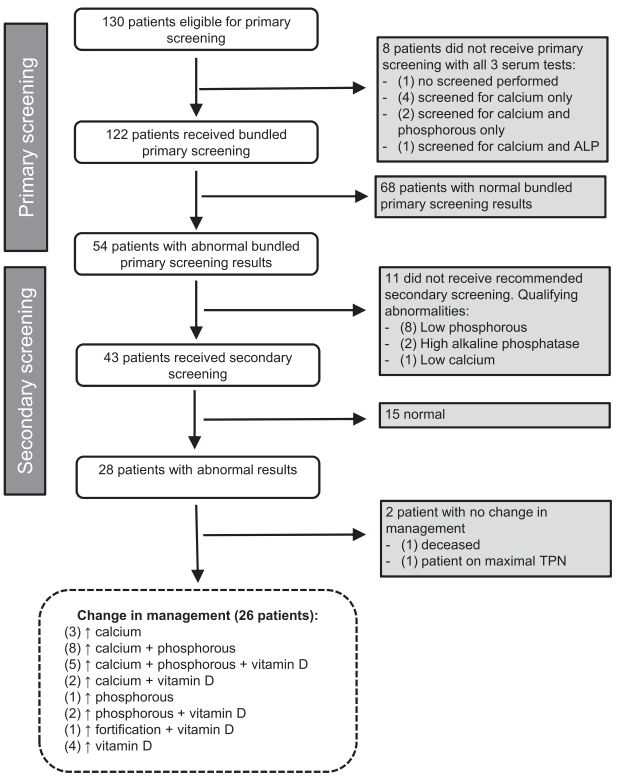

Fig. 3 Study flow diagram of individualized enteral supplementations.

QI initiatives are highly valued at our institution and staff from all disciplines are encouraged to participate in QI efforts. Because of this culture, many of our interdisciplinary team members already had the knowledge and skills to effectively apply rigorous QI methodologies before implementing this project. Importantly, our project leaders also had a strong foundation and background in QI to lead this project. Furthermore, our team also had sufficient resources, time, and support from unit leadership. A culture that prioritizes work focused on improving processes and patient outcomes through QI contributed to the success of our project and may be vital in other similar initiatives [33–35].

Our initial PDSA cycles consisted of targeted educational efforts to all providers about the importance of screening. However, it was quickly recognized that education is typically one of the least sustainable forms of improvement. The subsequent PDSA cycles focused on having a point-of-care reference available in our EMR order set, online resources, and posted in provider rooms. We also leveraged the EMR system as much as we could to simplify and lessen the burden to workflow. We worked with our clinical informatics team to flag patients that were due for screening which then served as an automatic reminder to designated dietitians. Additionally, the order set was designed in a way to allow for ordering initial tests, scheduling follow-up tests, and prescribing supplements be in one central location in the EMR. Educational-based interventions are often great during the start of an initiative and may provide some short-term results. However, successfully sustained initiatives oftentimes require interventions that are more longstanding such as those targeting workflow, providing point-of-care reminders, and built into the EMR [36, 37].

A significant challenge we encountered was addressing the lack of screening in a unit that primarily relies on rotating trainees for ordering tests. Although many of our physicians and advanced practice providers practice at both NICUs, our overall screening rate did not reach our goal until we had PDSA cycles specifically addressing this barrier at the level III NICU starting in January 2022. As a part of the unit workflow, trainees typically carry a binder that holds their rounding sheets for their patients. We added the screening algorithm, a diagnosis, and treatment cheat sheet in the back of each binder. This served as not only a constant reminder to thinking about MBDP but also as a quick reference. Like many academic NICUs, the rounding team of our level III NICU is comprised of resident physicians and physician assistant residents rotating monthly. The constant turnover was a barrier that we addressed by further focusing on hardwired interventions and may be important to consider in similar units.

An important limitation to note is the baseline screening rate may be an overestimate of the true screening rate given that the observed trend of increased screening closely aligns with the beginnings of this initiative and formation of the interdisciplinary team. This may be attributable to the Hawthorne effect as it is possible those involved with the initiative may have been changing their screening practices already. In the end, buy-in prior to the project's start was successful which led to an upward shift starting in April 2021.

Having a step-wise screening approach was important to our interdisciplinary team thus, we modeled our algorithm after similar published algorithms [4, 6, 14, 15]. An intentional difference in our algorithm was that we did not include radiological studies for screening. Bone mineralization must decrease by 20-40% for sequalae to be evident on X-rays and our goal was to detect MBDP prior to significant demineralization [38]. Quantitative ultrasound was not a part of the algorithm as well given our institution, like many others, did not have a machine that was feasible to use in neonates.

To evaluate the contextual variables impacting our QI initiative adequately and understand the limitations to generalizability of our work, we used the Model for Understanding Success in Quality tool [39]. The success of our QI initiative was strongly influenced by our alarmingly low baseline screening rate identified in our needs assessment. Once these data were disseminated to our providers, the assessment served as a triggering event and motivation for change. Variations in screening practices across NICUs may influence the generalizability of our initiative to other units with variations in existing practices. At the microsystem level, our leadership has instilled a culture that values and emphasizes QI initiatives. Differences in unit culture and values may lead to alternative outcomes. Finally, our interdisciplinary QI team was not only represented by professionally diverse medical team members, but we had intimate involvement from individuals with longstanding experience and expertise in QI skills. QI team factors such as team composition, team member engagement, knowledge of QI methodologies, and prior experience with QI projects have led to the success of this QI initiative and should be a strong consideration for others starting their own QI initiatives.

CONCLUSIONS

MBDP causes significant morbidity in patients necessitating that clinicians identify and treat affected patients early before progression of disease. Our study highlights that quality improvement methodologies, including the implementation of a tiered screening algorithm, can improve screening and subsequent treatment of MBDP. This study provides a framework for developing and implementing a similar QI initiative. Improving diagnosis and targeting nutritional supplementation for this population could make a significant impact on long-term outcomes. To advance our understanding of these longer-term impacts, further research needs to be conducted evaluating the impact of additional enteral calcium, phosphorous, and vitamin D supplementation.

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AUTHOR CONTRIBUTIONS

All authors were all involved int eh conceptualization of this study and in implementation of the quality improvement initiative. PC was responsible for collecting data through chart review. PC, KH, and BS were responsible for data analysis. PC drafted the initial manuscript. All authors were involved in reviewing and editing the manuscript. All authors agree to be accountable for all aspects of the work and final approval of the version to be published.

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COMPETING INTERESTS

The authors declare no competing interests.

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