

An Overview of Quality Improvement in the Neonatal Intensive Care Unit

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OBJECTIVES *After completing this article, readers should be able to:*

1. Describe a brief history of quality improvement in health care.
2. Explain how quality improvement has been used in the neonatal intensive care unit.
3. Describe key quality improvement models in health care, including Model for Improvement, Lean, Six Sigma, and Lean Six Sigma.

ABSTRACT

In this review, we provide a comprehensive overview of quality improvement (QI) methodologies within the neonatal intensive care unit (NICU), underlining their significance in enhancing health care quality and outcomes. We begin with an exploration into the history and application of QI in health care, with a particular focus on the NICU. We then delve into QI methodologies: the Model for Improvement, Lean, Six Sigma, and Lean Six Sigma. Through examining these models, we underscore the importance of integrating QI practices to strengthen patient safety and clinical outcomes in NICUs and broader health care settings.

INTRODUCTION

The National Academy of Medicine, formerly the Institute of Medicine, defines quality health care as “the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge.”¹ It further expands this definition by listing 6 key domains of focus for quality health care: safety, patient experience, effectiveness, efficiency, equity, and timeliness.¹ To achieve high quality in health care, there needs to be continuous evaluation and measurable improvements. This is where quality improvement (QI) methodology is pivotal; it provides a structured and data-driven approach to identify and fix inefficiencies, errors, and deficiencies, leading to

ABBREVIATIONS

LSS	Lean Six Sigma
NICU	neonatal intensive care unit
PDSA	plan, do, study, act
QI	quality improvement

AUTHOR DISCLOSURE: Dr Vartanian has received consulting fees from the Vermont Oxford Network. Dr Pural has disclosed no financial relationships relevant to this article. This commentary does not contain a discussion of an unapproved/investigative use of a commercial product/device.

Accepted for Publication Date: May 29, 2025

<https://doi.org/10.1542/neo.27-7-036>

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improved quality of care and progress. As best defined by Paul B. Batalden and Frand Davidoff, QI is “the combined and unceasing efforts of everyone—health care professionals, patients and their families, researchers, payors, planners and educators—to make the changes that will lead to better patient outcomes (health), better system performance (care) and better professional development.”² Simply stated, it is the responsibility of every health care provider and system to continuously improve to ensure the highest quality of care possible. In this review, we provide a comprehensive overview of QI methodologies within the neonatal intensive care unit (NICU), underlining their significance in enhancing health care quality and outcomes.

BACKGROUND OF QI

QI and research are both important methodologies in the advancement and application of health care. Whereas the goals of research are to generate new and generalizable knowledge, QI methodology uses this knowledge to improve outcomes in the local context.³ Undoubtedly, clinical and/or basic science research has deep roots in medicine. Contrastingly, QI in health care came to the forefront in the 1990s and early 2000s with the establishment of non-profit groups, task forces, and publications focused on reducing the burden of error in medicine.⁴ Perhaps the 2 most notable publications were *To Err is Human: Building a Safer Health System* and *Crossing the Quality Chasm* by the National Academy of Medicine.^{1,5} *To Err is Human* examined medical errors, acknowledging that errors need to be addressed with a system-wide approach rather than placing blame on individuals. It established an objective to reduce medical errors and improve patient safety through the redesign of safer health systems. *Crossing the Quality Chasm* delved further into what is needed to achieve quality health care in these systems.

With the burden of medical errors and inadequate care exposed, there has been a sustained and evolving focus on reducing harm. This attention comes from various entities, including government agencies, hospital systems, external groups, and hospital accreditation organizations, all investing in ways to continually improve health care quality, a commitment that persists to this day. Adapting from industry, various QI approaches including the Model for Improvement, Lean, and Six Sigma have emerged as methods to improve the quality of health care.

IMPACT OF QI IN NEONATAL CARE

Innovation and advancement in prenatal and neonatal care alongside QI have led to improved neonatal outcomes in

the NICU over the last 2 decades. This has been demonstrated by a decrease in mortality and morbidity rates, especially for infants born between 25 and 28 weeks' gestation, along with an overall increase in survival of younger gestational age infants.^{6–11} Notably, there has been a significant decrease in variation of outcomes of major morbidities between hospitals, with more than 75% of NICUs in the United States in 2014 performing as well or better than the top 25% of NICUs¹² in comparison with 2005. Table 1 provides notable QI publications that have cited improved neonatal outcomes in key clinical areas such as line infections, delayed cord clamping, necrotizing enterocolitis, retinopathy of prematurity, infant growth, severe intraventricular hemorrhage, and late-onset sepsis.^{27,28} These highlighted QI efforts are a mix of unit-based projects and multisite collaborations through organizations such as the Vermont Oxford Network or Children's Hospitals Neonatal Consortium and state-based collaborations. Unfortunately, despite these commendable improvements, there continues to be considerable intercenter variation, continued medical errors resulting in harm, and measurable room for improvement in neonatal care.^{28,29}

QI METHODOLOGIES

Established QI methodologies provide essential theory, a formal structure for improvement, and an abundance of tools to aid NICUs to analyze performance and conduct and sustain QI to reduce variation and optimize outcomes. Amid a variety of methodologies, the 3 more commonly used in health care are the Model for Improvement, Lean, and Six Sigma. The Model for Improvement is a QI methodology used commonly in the NICU.³¹ Created by the Associates in Process Improvement, its architecture is built on the foundation of Edward Deming's work, a pioneer in QI in the manufacturing industry. Using 3 fundamental questions accompanied by plan, do, study, act (PDSA) cycles, the Model for Improvement provides a structure for developing, testing, and implementing change (Figure 1).^{32,33} The user applies the model by answering 3 fundamental questions. The initial question, “what are we trying to accomplish?,” challenges the user to establish goals and develop an aim statement.³² The second question, “how will we know that a change is an improvement?,” establishes outcome and process measures for the project, challenging the users to identify how they will know if their project is accomplishing its desired goals and provide feedback.³² The third question, “what change can we make that will result in improvement?,” asks the user to identify what change(s) is/are needed to accomplish the

TABLE 1. NICU QI Projects

Publication	Group	Outcome and Year of the Project
California statewide quality improvement QI collaborative to reduce neonatal central line–associated blood stream infections ¹³	CPQCC	Decrease in central line infections in the NICU (2006–2007)
Ohio statewide QI collaborative to reduce late-onset sepsis in preterm infants ¹⁴	Ohio Perinatal Quality Collaborative	Reduction in late-onset sepsis (2008–2009)
Implementation of evidence-based potentially better practices to decrease nosocomial infections ¹⁵	VON	Decrease in nosocomial infections (1997–2000)
Comprehensive oxygen management for the prevention of VON ¹⁶	Pediatrix	Reduction in ROP (2003–2008)
Collaborative QI to promote evidence-based surfactant for preterm infants: a cluster-randomized trial ¹⁷	VON	Increased evidence-based surfactant use (1999–2001)
Promoting antenatal steroid use for fetal maturation ¹⁸	CPQCC	Improved antenatal steroid administration in neonates (2001)
Reduction of BPD after participation in the Breathsavers Group ¹⁹	VON	Reduction of BPD (2001–2003)
Collaborative QI for neonatal intensive care, NIC/Q Project Investigators ²⁰	VON	Reduction in late-onset sepsis and rate of oxygen supplementation at 36 weeks' PMA (1994–1997)
Improving admission temperature in ELBW infants: a hospital-based multi-intervention QI project ²¹	Single center	Improvement in admission temperature in ELBW infants (2007–2008)
A QI project to increase breast milk use in VLBW infants ²²	CPQCC	Increase in breast milk feeding and decrease in NEC (2008–2010)
Nosocomial infection reduction in VLBW infants with a statewide QI model ²³	CPQCC	Reduction in nosocomial infections in VLBW infants (2002–2006)
A cluster-randomized trial of benchmarking and multimodal QI to improve rates of survival free of BPD for infants with birth weights <1250 g ²⁴	National Institute of Child Health and Human Development Neonatal Research Network	Improvement in care practice but no reduction in rate of BPD (1998–2000)
How Intermountain trimmed health care costs through robust QI efforts ²⁹	Multicenter	Reduced NICU admissions and reduction in cost (2011)
Evaluation, development, and implementation of potentially better practices in NICU nutrition ²⁶	VON	Improved growth, reduced length of stay and cost (2003)

Abbreviations: BPD, bronchopulmonary dysplasia; CPQCC, California Perinatal Quality Care Collaborative; ELBW, extremely low birthweight; NEC, necrotizing enterocolitis; NIC/Q, Newborn Improvement Collaborative for Quality; NICU, neonatal intensive care unit; PMA, postmenstrual age; QI, quality improvement; ROP, retinopathy of prematurity; VLBW, very low birthweight; VON, Vermont Oxford Network.

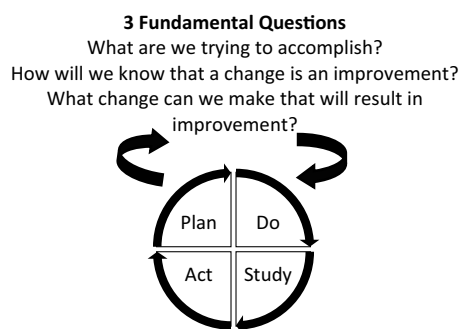


FIGURE 1. Model for Improvement.

goal.³² In clinical practice, many clinicians will identify a change idea based on their experience or exposure.

The Model for Improvement ensures that the QI team is evaluating the larger context and ensuring QI efforts are aligned with a common goal and measurable outcome.

Once these foundational questions are answered and change ideas selected, the ideas are tested in small tests of change (the PDSA cycle). This cycle allows teams to test, learn, adapt, abandon, and/or implement change in a cyclical manner (Figure 2) and then is scaled to address the larger context.^{32,33} As users familiarize themselves with the Model for Improvement, additional universal QI tools can assist them in answering the Model for Improvement questions and have success in their PDSA cycles. Examples of these include key driver diagrams, Pareto charts, and run charts and statistical process control charts to evaluate data. Explanation of these tools are beyond the scope of this article but will be available in subsequent NeoQuality articles in *NeoReviews*. The Model for Improvement is the most cited QI methodology in the NICU with significant success. Many of the listed QI initiatives in Table 1 were based on the Model for Improvement. In addition, large quality collaboratives such as the Vermont Oxford Network and the Children's

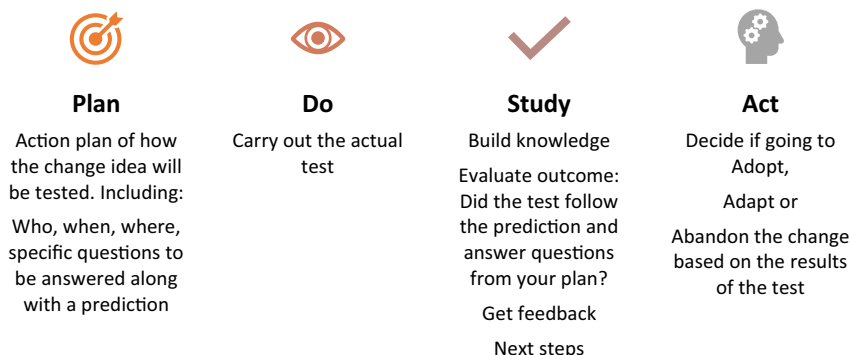


FIGURE 2. Plan, do, study, act cycle.

Hospitals Neonatal Consortium use the Model for Improvement as their core methodology.

Lean, another continuous improvement methodology, originated from the Toyota production company and was adopted into health care systems in the 2000s.³⁴ In manufacturing, its primary goal is eliminating waste that does not benefit the customer.³⁵ In health care, Lean applies this concept of elimination of waste through the reduction of medical errors and through improvement in efficiency, clinical outcomes, and satisfaction and safety of patients and health care workers.³⁶ Lean defines 8 typical categories of waste (Figure 3) for teams to identify and improve.^{34,35} The main construct behind the Lean method for each project are as follows³⁷:

1. What is the value to the customer (ie, what is the problem that needs to be solved)?
2. Identify the value-added activities for each product and identify all the wasted steps (value stream mapping).
3. Create flow by removing waste from your value stream map.
4. Establish pull in every step of your map (ie, respond when there is demand).
5. Pursue perfection by making an organizational culture goal to continuously find ways to get better from frontline up to the top.

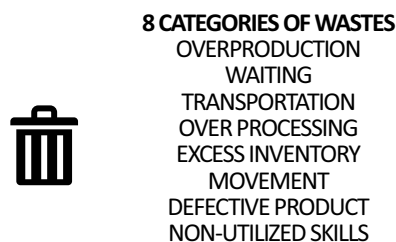


FIGURE 3. Eight categories of Waste Lean methodology.

Similar to the Model for Improvement, Lean provides tools that aid the user to achieve success along each step, including the A3 template, root cause analysis diagram, fish-bone diagram, 5 whys, and Gemba walk. Table 2 was created by the Institute for Healthcare Improvement, and it summarizes differences between Lean Methodology and the Model for Improvement.³⁸ Although Lean has been adapted by various health care organizations at a system level, neonatal-specific publications describing the use of Lean methodology are limited. Many QI improvements use Lean tools combined with other methodologies, such as the example of a single-center QI initiative using Lean with Model for Improvement to reduce unplanned extubations in the NICU.³⁹ A helpful commentary on how Lean and Model for Improvement can complement each other is available to assist teams in selecting the QI methodology to best address their concern.⁴⁰

A third QI methodology used in health care is Six Sigma. Six Sigma was developed by another manufacturing corporation, Motorola, in the 1980s. The goal of Six Sigma is to reduce errors and decrease variability using a 5 phase process known as DMAIC: define, measure, analyze, improve, and control.⁴¹ The name Six Sigma is derived from Motorola's goal of reducing production defects by 3.4 defects per million opportunities, which is Six Sigma levels of performance (ie, 99.99966% of the process or product is defect-free).^{34,41,42} As with Lean, Six Sigma began in the manufacturing industry, but the approach has been readily adjusted to meet the needs of the health care industry. Like Lean, publications solely using Six Sigma methodology are limited in neonatology as compared with departments such as radiology and surgery.⁴³

Lean Six Sigma (LSS), as the name suggests, combines the principles and tools of Lean and Six Sigma methodologies with the goal to reduce waste, variation, and defects to help create a quality product.⁴⁴ The methods complement each

TABLE 2. Differences Between Lean Methodology and the Institute for Healthcare Improvement’s Approach to Quality Improvement

Aspect	Lean	IHI-QI
Purpose	- Maximize customer-specified value of products or services. - Value includes cost, timeliness, absence of defects, and product or service features.	- Formulate and codify generalizable knowledge that yields predictable improvement in outcomes when applied in diverse systems. - When applied in health care, aims ideally balance patient experience, cost, and population health.
Origins	- Originated by engineers and managers working within an automotive manufacturing system. - Lean has since been extended with methods and principles for application in other contexts, including more recently in health care.	Developed primarily by consultants working first in automotive and electronics manufacturing and elaborated in health care systems by the IHI community.
Focus and scope	Methods are specialized for repetitive product production within a single enterprise (including suppliers and customers); generalized to services and clinical care (with adaptations).	- Approach is abstract, includes methods for problem and aim definition applicable to any system. - Many initiatives are concerned with spread of evidence-based practices across health care systems and coalitions of enterprises.
Key principles guiding improvement	“Value” definition provides criteria; value stream describes process. - Ideals and change concepts inherent in TPS form an integrated “template” that prompts ideas for problem mitigation and guides <i>kaizen</i> (continuous improvement).	- Profound Knowledge and the Model for Improvement apply to any system. - Program theory provides the aim and change concepts to guide testing. - Metrics provide criteria. - Iterative PDSA cycles are used in diverse conditions to develop, test, implement, and spread robust changes.
Measurement and data	- Data relevant to the process operations are embedded in the value stream as visual controls and charts showing performance over time. - Qualitative data, rooted in direct observations, is the basis for problem mitigation.	- Measures are defined as a component of content theory. - Organizational dashboards monitor performance at all levels. - PDSA-level measures evaluate changes. - Common vs special cause variation distinctions help guide management decisions. - Run and control charts with decision rules are used to evaluate the significance of changes.

Abbreviations: IHI, Institute for Healthcare Improvement; IHI-QI, Institute for Healthcare Improvement’s Approach to Quality Improvement; PDSA, plan, do, study, act; TPS, Toyota Production System.
Reprinted with permission from Institute for Healthcare Improvement.³⁸

other as Lean focuses on strategy and culture, whereas Six Sigma provides the complementary tools and techniques in greater detail.^{41,44,45} After successful implementation in non–health care industries such as Xerox, it was brought into the health care industry.⁴⁴ Similar to Six Sigma, LSS use is described within the adult inpatient and outpatient settings in both private and academic settings.⁴⁶ LSS has limited publications in the NICU environment.

CONCLUSION

Each of the QI methodologies above provide a systematic and measurable way to improve the quality of care provided in the NICU. Amid published neonatology literature, the Model for Improvement approach is most prevalent, but other QI methodologies provide important tools that can be used as either a primary approach or an important adjunct. The future of QI will need to focus on collaboration of health care systems and merging of QI and research. In summary, it is

imperative for everyone involved in the health care system, especially complex systems like neonatal care, to understand and use solid QI tools so we can improve patient safety and clinical outcomes. As Edward Deming said, “Quality is everyone’s responsibility.”⁴⁷

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- Know principles of epidemiology and research design.

References

1. Institute of Medicine (US) Committee on Quality of Health Care in America. *Crossing the Quality Chasm: A New Health System for the 21st Century*. National Academies Press (US); 2001. Accessed September 21, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK222274/>

2. Whitfill T, Chang TP, Muhly WT, Hart JK. Simulation for quality improvement. In: Deutsch ES, Perry SJ, Gurnaney HG eds. *Comprehensive Healthcare Simulation: Improving Healthcare Systems*. Springer International Publishing; 2021:179–186.
3. Moses J. What's the Difference Between Research and Quality Improvement? Institute for Healthcare Improvement. Accessed October 11, 2023. <https://www.ihl.org/sites/default/files/lms/legacy/documents/OpenSchoolCourseTranscripts/Moses-ResearchVsQI.htm>
4. Marjoua Y, Bozic KJ. Brief history of quality movement in US healthcare. *Curr Rev Musculoskelet Med*. 2012;5(4):265–273. PubMed doi: 10.1007/s12178-012-9137-8
5. Institute of Medicine (US) Committee on Quality of Health Care in America. *To Err Is Human: Building a Safer Health System*. Kohn LT, Corrigan JM, Donaldson MS, eds. National Academies Press; 2000. Accessed September 21, 2023. <https://www.ncbi.nlm.nih.gov/books/NBK225182/>
6. Stoll BJ, Hansen NI, Bell EF, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Trends in care practices, morbidity, and mortality of extremely preterm neonates, 1993–2012. *JAMA*. 2015;314(10):1039–1051. PubMed doi: 10.1001/jama.2015.10244
7. Higgins BV, Baer RJ, Steurer MA, et al. Resuscitation, survival and morbidity of extremely preterm infants in California 2011–2019. *J Perinatol*. 2024;44(2):209–216. PubMed doi: 10.1038/s41372-023-01774-6
8. Stoll BJ, Hansen NI, Bell EF, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Neonatal outcomes of extremely preterm infants from the NICHD Neonatal Research Network. *Pediatrics*. 2010;126(3):443–456. PubMed doi: 10.1542/peds.2009-2959
9. Iams JD, Romero R, Culhane JF, Goldenberg RL. Primary, secondary, and tertiary interventions to reduce the morbidity and mortality of preterm birth. *Lancet*. 2008;371(9607):164–175. PubMed doi: 10.1016/S0140-6736(08)60108-7
10. Fanaroff AA, Stoll BJ, Wright LL, et al; NICHD Neonatal Research Network. Trends in neonatal morbidity and mortality for very low birthweight infants. *Am J Obstet Gynecol*. 2007;196(2):147.e1–147.e8. PubMed doi: 10.1016/j.ajog.2006.09.014
11. Bell EF, Hintz SR, Hansen NI, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Mortality, in-hospital morbidity, care practices, and 2-year outcomes for extremely preterm infants in the US, 2013–2018. *JAMA*. 2022;327(3):248–263. PubMed doi: 10.1001/jama.2021.23580
12. Rysavy MA, Li L, Bell EF, et al; Eunice Kennedy Shriver National Institute of Child Health and Human Development Neonatal Research Network. Between-hospital variation in treatment and outcomes in extremely preterm infants. *N Engl J Med*. 2015;372(19):1801–1811. PubMed doi: 10.1056/NEJMoa1410689
13. Wirtschafter DD, Pettit J, Kurtin P, et al. A statewide quality improvement collaborative to reduce neonatal central line-associated blood stream infections. *J Perinatol*. 2010;30(3):170–181. PubMed doi: 10.1038/jp.2009.172
14. Kaplan HC, Lannon C, Walsh MC, Donovan EF; Ohio Perinatal Quality Collaborative. Ohio statewide quality-improvement collaborative to reduce late-onset sepsis in preterm infants. *Pediatrics*. 2011;127(3):427–435. PubMed doi: 10.1542/peds.2010-2141
15. Kilbride HW, Wirtschafter DD, Powers RJ, Sheehan MB. Implementation of evidence-based potentially better practices to decrease nosocomial infections. *Pediatrics*. 2003;111(4 Pt 2):e519–e533. PubMed doi: 10.1542/peds.111.SE1.e519
16. Ellsbury DL, Ursprung R. Comprehensive oxygen management for the prevention of retinopathy of prematurity: the Pediatrix experience. *Clin Perinatol*. 2010;37(1):203–215. PubMed doi: 10.1016/j.clp.2010.01.012
17. Horbar JD, Carpenter JH, Buzas J, et al. Collaborative quality improvement to promote evidence based surfactant for preterm infants: a cluster randomised trial. *BMJ*. 2004;329(7473):1004. PubMed doi: 10.1136/bmj.329.7473.1004
18. Wirtschafter DD, Danielsen BH, Main EK, et al; California Perinatal Quality Care Collaborative. Promoting antenatal steroid use for fetal maturation: results from the California Perinatal Quality Care Collaborative. *J Pediatr*. 2006;148(5):606–612. PubMed doi: 10.1016/j.jpeds.2005.12.058
19. Payne NR, LaCorte M, Karna P, et al; Breathsavers Group, Vermont Oxford Network Neonatal Intensive Care Quality Improvement Collaborative. Reduction of bronchopulmonary dysplasia after participation in the Breathsavers Group of the Vermont Oxford Network Neonatal Intensive Care Quality Improvement Collaborative. *Pediatrics*. 2006;118(suppl 2):S73–S77. PubMed doi: 10.1542/peds.2006-0913C
20. Horbar JD, Rogowski J, Plsek PE, et al; NIC/Q Project Investigators of the Vermont Oxford Network. Collaborative quality improvement for neonatal intensive care. *Pediatrics*. 2001;107(1):14–22. PubMed doi: 10.1542/peds.107.1.14
21. Billimoria Z, Chawla S, Bajaj M, Natarajan G. Improving admission temperature in extremely low birth weight infants: a hospital-based multi-intervention quality improvement project. *J Perinat Med*. 2013;41(4):455–460. PubMed doi: 10.1515/jpm-2012-0259
22. Lee HC, Kurtin PS, Wight NE, et al. A quality improvement project to increase breast milk use in very low birth weight infants. *Pediatrics*. 2012;130(6):e1679–e1687. PubMed doi: 10.1542/peds.2012-0547
23. Wirtschafter DD, Powers RJ, Pettit JS, et al. Nosocomial infection reduction in VLBW infants with a statewide quality-improvement model. *Pediatrics*. 2011;127(3):419–426. PubMed doi: 10.1542/peds.2010-1449
24. Walsh M, Laptook A, Kazzi SN, et al; National Institute of Child Health and Human Development Neonatal Research Network. A cluster-randomized trial of benchmarking and multimodal quality improvement to improve rates of survival free of bronchopulmonary dysplasia for infants with birth weights of less than 1250 grams. *Pediatrics*. 2007;119(5):876–890. PubMed doi: 10.1542/peds.2006-2656
25. James BC, Savitz LA. How Intermountain trimmed health care costs through robust quality improvement efforts. *Health Aff (Millwood)*. 2011;30(6):1185–1191. PubMed doi: 10.1377/hlthaff.2011.0358
26. Kuzma-O'Reilly B, Duenas ML, Greecher C, et al. Evaluation, development, and implementation of potentially better practices in neonatal intensive care nutrition. *Pediatrics*. 2003;111(4 Pt 2):e461–e470. PubMed doi: 10.1542/peds.111.SE1.e461
27. Fischer HR, Stewart DL. Quality improvement and safety in the neonatal intensive care unit. *Neoreviews*. 2017;18(4):e201–e208. doi: 10.1542/neo.18-4-e201

28. Shah V, Warre R, Lee SK. Quality improvement initiatives in neonatal intensive care unit networks: achievements and challenges. *Acad Pediatr*. 2013;13(6)(suppl):S75–S83. PubMed doi: 10.1016/j.acap.2013.04.014
29. Ellsbury DL. Crossing the quality chasm in neonatal-perinatal medicine. *Clin Perinatol*. 2010;37(1):1–10. PubMed doi: 10.1016/j.clp.2010.01.001
30. Lachman P, Jayadev A, Rahi M. The case for quality improvement in the neonatal intensive care unit. *Early Hum Dev*. 2014;90(11):719–723. PubMed doi: 10.1016/j.earlhumdev.2014.09.003
31. Day C, Meyers J, Kaplan HC. A guide to critical appraisal of quality improvement reports. *Semin Perinatol*. 2024;48(3):151900. PubMed doi: 10.1016/j.semperi.2024.151900
32. Langley GJ, Moen RD, Nolan KM, Nolan TW, Norman CL, Provost LP. *The Improvement Guide: A Practical Approach to Enhancing Organizational Performance*. 2nd edition. Jossey-Bass; 2009.
33. Provost LP, Murray SK. *The Health Care Data Guide*. 2nd edition. Jossey-Bass; 2022.
34. Coughlin K, Posencheg MA. Common quality improvement methodologies including the Model for Improvement, Lean, and Six Sigma. *Clin Perinatol*. 2023;50(2):285–306.
35. Black J. *The Toyota Way to Healthcare Excellence: Increase Efficiency and Improve Quality with Lean*. 2nd edition. Health Administration Press; 2016.
36. D'Andreamatteo A, Ianni L, Lega F, Sargiacomo M. Lean in healthcare: a comprehensive review. *Health Policy*. 2015;119(9):1197–1209. PubMed doi: 10.1016/j.healthpol.2015.02.002
37. Netland TH, Powell DJ, eds. *The Routledge Companion to Lean Management*. Routledge; 2016.
38. Comparing Lean and Quality Improvement. Institute for Healthcare Improvement. Accessed October 12, 2023. https://www.ihl.org/library/white-papers/comparing-lean-and-quality-improvement?PostAuthRed=/resources/_layouts/download.aspx%3FSourceURL%3D/resources/Knowledge%20Center%20Assets/IHIWhitePapers%20-%20ComparingLeanandQualityImprovement_2e66fe05-fd59-4d8a-91d0-39522f754b85/IHIComparingLeanandQIWhitePaper.pdf
39. Powell BM, Gilbert E, Volsko TA. Reducing unplanned extubations in the NICU using lean methodology. *Respir Care*. 2016;61(12):1567–1572. PubMed doi: 10.4187/respcare.04540
40. Parry G. Lean and IHI's Approach to QI: Do You Have to Choose? Institute for Healthcare Improvement. June 15, 2016. Accessed November 2, 2023. <https://www.ihl.org/library/blog/lean-and-ihis-approach-qi-do-you-have-choose>
41. Sperl T, Ptacek R, Trewn J. *Practical Lean Six Sigma for Healthcare - Using the A3 and Lean Thinking to Improve Operational Performance in Hospitals, Clinics, and Physician Group Practices*. MCS Media, Inc; 2013.
42. Schroeder RG, Linderman K, Liedtke C, Choo AS. Six Sigma: definition and underlying theory. *J Oper Manage*. 2008;26(4):536–554. doi: 10.1016/j.jom.2007.06.007
43. Niñerola A, Sánchez-Rebull MV, Hernández-Lara AB. Quality improvement in healthcare: Six Sigma systematic review. *Health Policy*. 2020;124(4):438–445. PubMed doi: 10.1016/j.healthpol.2020.01.002
44. Ahmed S. Integrating DMAIC approach of Lean Six Sigma and theory of constraints toward quality improvement in healthcare. *Rev Environ Health*. 2019;34(4):427–434. PubMed doi: 10.1515/reveh-2019-0003
45. Shah J, Deshpande V. Lean Six Sigma: an integrative approach of Lean and Six Sigma methodology. *Int J Curr Eng Technol*. 2015;5:3528–3534.
46. Zimmermann GDS, Siqueira LD, Bohomol E. Lean Six Sigma methodology application in health care settings: an integrative review. *Rev Bras Enferm*. 2020;73(suppl 5):e20190861. PubMed doi: 10.1590/0034-7167-2019-0861
47. Quality Resources. ASQ. Accessed November 13, 2023. <https://asq.org/quality-resources/more-on-quality-quotes>