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Six Sigma in Healthcare: A Review of Successful Applications and Diverse Impacts

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ABSTRACT

Six Sigma methodologies have become integral to healthcare quality improvement efforts, addressing challenges ranging from infection control to operational efficiency. This review synthesizes empirical findings on Six Sigma's healthcare applications, emphasizing impacts on patient safety and organizational effectiveness. Studies highlight improvements in infection control, surgical outcomes, laboratory testing, and pharmacy management through methodologies like DMAIC (Define, Measure, Analyze, Improve, Control). These approaches have led to reductions in infection rates and surgical complications, enhanced medication management, and improved diagnostic accuracy. Six Sigma's systematic approach fosters data-driven decision-making, process optimization, and stakeholder engagement, driving sustainable improvements in healthcare delivery. These findings underscore Six Sigma's versatility and effectiveness in addressing healthcare challenges and promoting continuous quality improvement.

Keywords: Six Sigma, DMAIC, Quality Improvement, Healthcare Management, Patient Safety, Operational Efficiency, Resource Management

INTRODUCTION

The healthcare industry has widely adopted Six Sigma as a management tool to enhance efficiency and quality. Originating from Motorola in the mid-1980s, Six Sigma aims to reduce defects and variability in processes through a structured, data-driven approach known as DMAIC: Define, Measure, Analyze, Improve, and Control. Initially developed for manufacturing, Six Sigma has shown substantial potential in healthcare, where reducing errors, costs, and time is critical (Niñerola et al., 2020).

For instance, Arafeh et al. (2018) demonstrated a 54% reduction in patient discharge times at a cancer treatment hospital through process simplification and enhanced stakeholder communication. Six Sigma has been effectively applied across various healthcare specialties and services, focusing on improving metrics such as error rates, process time, and productivity. However, sustainability and achieving substantial cost savings or revenue enhancement pose challenges (Liberatore, 2013).

Further highlighting its benefits, Al-Qatawneh et al. (2019) emphasize the advantages of Six Sigma in healthcare logistics, particularly in improving efficiency through enhanced criticality, cost management, and performance metrics. Their study introduces a framework tailored for healthcare logistics, demonstrating how the adaptation of Six Sigma methodologies can effectively optimize processes by integrating criticality, cost considerations, and performance evaluations.

Understanding the success factors of Six Sigma initiatives in healthcare is crucial for practitioners and researchers alike. High-impact studies often focus on process improvements, particularly in time and waste reduction, which significantly enhance both academic and societal impact. Findings are disseminated effectively through traditional academic metrics and alternative metrics, reflecting the broader influence of Six Sigma applications in healthcare (Hernández-Lara et al., 2021). Carsten et al. (2023) demonstrated significant improvements in patient satisfaction through the implementation of structured communication tools using Six Sigma methodology, highlighting the effectiveness of these tools in enhancing communication between healthcare providers and patients, resulting in notable improvements in patient satisfaction scores across physician and nurse communication domains.

This review aims to provide a comprehensive overview of Six Sigma in healthcare, focusing on its applications, benefits, and impacts. By examining existing literature, we seek to highlight conditions under which Six Sigma most effectively contributes to quality improvement in healthcare and identify areas for future research and application.

METHODS

This review provides an overview of the application, benefits, and impacts of Six Sigma methodologies in healthcare settings, focusing exclusively on documenting successful implementations and positive outcomes. The primary database used for the literature search was PubMed. After identifying relevant articles on PubMed, other full texts were accessed through the links provided, directing to the respective journal websites or other repositories. The review included peer-reviewed articles, case studies, and systematic reviews published in English from 2006 to 2024, reporting empirical data on Six Sigma applications in healthcare, specifically focusing on outcomes related to quality improvement, operational efficiencies, patient outcomes, or cost-effectiveness achieved through Six Sigma methodologies. Non-English articles, theoretical papers, editorials, and studies lacking empirical data on Six Sigma in healthcare were excluded.

The search strategy included terms such as "Six Sigma in healthcare," "DMAIC," "quality improvement," "operational efficiency," and "patient outcomes". Titles, abstracts, and full texts of identified articles were screened independently to ensure eligibility.

Potential limitations of this review include publication bias towards positive outcomes, variability in study methodologies, and challenges in generalizing findings across different healthcare settings.

RESULTS AND DISCUSSION

Application of Six Sigma in Infection Control

Several studies have highlighted the impactful implementation of Six Sigma methodologies in infection control within healthcare settings.

Eldridge et al. (2006) demonstrated significant improvements in hand hygiene compliance across multiple intensive care units (ICUs) using Six Sigma methodologies, achieving an increase from 47% to 80% through structured interventions and the use of alcohol-based hand rubs (ABHRs). This led to sustained increases in ABHR usage and higher staff satisfaction with hygiene practices.

Similarly, Rao (2011) applied Six Sigma to reduce infection rates in a tertiary healthcare center, achieving a remarkable decrease in hospital-acquired infection (HAI) rates including zero surgical site infections (SSIs) within six months. Kuwaiti and Subbarayalu (2017) further validated the effectiveness of Six Sigma in reducing HAI rates by implementing targeted improvement strategies derived from cause-effect diagrams and Pareto analysis. Their study reported a significant reduction in HAI rates from 3.92 to 2.73 post-intervention, underscoring the methodology's value in enhancing patient safety and satisfaction.

Shi et al. (2022) extended the Six Sigma DMAIC approach to surgical site infections (SSI), achieving a 22.2% reduction in SSI rates. This was accomplished by optimizing perioperative processes, adopting an evidence-based prevention bundle, and strengthening environmental monitoring and antimicrobial stewardship programs. The study also integrated process changes into a clinical pathway information system and implemented improvement cycles for risk events, ensuring sustained improvements in surgical quality and patient safety.

Ludington et al. (2024) focused on hemodialysis patients, employing a Six Sigma-based infection prevention program to assess and address deficiencies across multiple facilities. Their findings highlighted critical gaps in cleaning, disinfection, and personal protective equipment (PPE) use, underscoring the Six Sigma's systematic approach in identifying and rectifying infection control measures in specialized care settings.

Overall, these studies underscore Six Sigma's critical role in improving infection control, enhancing patient safety, and ensuring sustained improvements in healthcare quality.

Improving Surgical Processes and Instrumentation

Six Sigma methodologies significantly enhance surgical processes, showcasing notable improvements in patient outcomes and operational efficiency through DMAIC approaches and process optimization.

Polanski et al. (2018) applied Six Sigma to assess the quality of deep brain stimulation (DBS) surgery for Parkinson's disease. Analyzing 41 studies with 2184 patients, the study found a 19.1% median improvement in UPDRS III on/on-phase and a 46.6% median reduction in levodopa equivalence dose (LED), with a 1.42% bleeding risk. The therapeutic sigma value was 2.72, indicating an 88.9% yield for successful outcomes. Surgeries under local anesthesia with intraoperative test stimulation showed higher but not significant sigma values for UPDRS III improvement. Microelectrode recordings (MER) did not affect patient outcomes or bleeding risk.

Similarly, Ricciardi et al. (2021) used Six Sigma's DMAIC cycle to compare two antibiotic protocols in oral mucosa cancer surgery. While overall hospital stay differences were not significant, Cefazolin plus Clindamycin significantly reduced stays for patients undergoing lymphadenectomy or tracheotomy. Higher ASA scores and complex surgeries were linked to longer stays. Six Sigma provided insights for optimizing surgical outcomes.

Moreover, Saporito et al. (2023) applied Six Sigma to optimize surgical instrument sterilization, improving Sigma values from 4.79 to 5.04. This enhanced efficiency led to annual cost savings of approximately $19,729 USD and improved staff satisfaction scores. Gheysari et al. (2016) investigated the impact of the Six Sigma methodology on reducing surgery cancellation rates, finding a reduction from 3.6% to 1.4%. This significant improvement was achieved by systematically identifying and addressing reasons for cancellations related to patients, medical issues, and hospital systems.

Collectively, these studies underscore the effectiveness of Six Sigma in driving substantial improvements across healthcare settings. Specifically, they optimize surgical processes, reduce cancellation rates, and improve overall operational efficiency.

Enhancing Laboratory and Analytical Quality through Six Sigma

Six Sigma methodologies have proven effective in enhancing laboratory and analytical quality in healthcare settings. This section discusses various studies that demonstrate significant improvements in laboratory processes and outcomes.

According to Molaahmadi-Hassanabadi et al. (2023), an evaluation of the hemovigilance process at Afzalipour Hospital using Six Sigma, revealing significant errors during evening and night shifts, with sigma levels as low as 1.5. The study identified key areas for improvement, such as request management and label handling, highlighting the need to enhance process efficiency and safety protocols to improve patient outcomes.

Building on the theme of process efficiency, Ialongo and Bernardini (2016) demonstrated that automating clinical laboratories using Six Sigma metrics significantly reduced turnaround times (TAT) and communication delay. This streamlining of workflow processes minimized delays in STAT cardiac troponin-I CTNI orders, thereby improving operational efficiency and patient care. Similarly, Ahmed et al. (2021) examined the impact of COVID-19 on clinical laboratory testing in Pakistan. Despite the challenges posed by the pandemic, the study found that sigma values for most quality indicators remained consistently high (>4.0σ), demonstrating Six Sigma's effectiveness in maintaining testing standards, diagnostic accuracy, and continuity of patient care during crises. However, the study also noted specific areas with both declines and improvements in sigma metrics, highlighting the need for ongoing vigilance in the pre-analytical and post-analytical phases.

Expanding on quality control, Zhou et al. (2020) and Mao et al. (2018) provided insights into analytical quality in clinical biochemistry laboratories. Zhou et al. highlighted that analyte with sigma values (σ) ≥ 6 required minimal QC procedures, while those with $\sigma < 4$ necessitated rigorous QC, identifying five key areas for quality improvement. Mao et al. found that analytes with sigma values (σ) below 3 required substantial method improvements and rigorous QC, emphasizing targeted improvements to enhance analytical quality.

Panda et al. (2023) stressed the need for targeted improvements in lab practices using Six Sigma methodology. They noted that analytes with $\sigma < 4$, such as creatinine and HDL, performed poorly. The study recommended employing quality goal index (QGI) and root cause analysis (RCA) to address issues like imprecision and procedural errors, thus enhancing analytical quality.

Çevlik and Haklar (2024) evaluated 17 biochemistry parameters using Six Sigma, finding significant variability in sigma metrics across different analyzers, reagents, and QC materials. Analytes with sigma values below 3 required systematic RCA to effectively address performance issues, further demonstrating the importance of targeted quality improvements.

Liu et al. (2021) conducted a multicenter study on urinary biochemical analytes using Six Sigma. They assessed analytical performance across five laboratories, highlighting significant sigma metric variability. The study developed risk-based quality control strategies, suggesting tailored improvements for enhanced laboratory quality management.

Further emphasizing Six Sigma's impact, Vincent et al. (2021) mapped the total testing process (TTP) of point-of-care (POC) glucose measurements, identifying and assessing 29 risks to establish quality indicators (QIs) for risk monitoring. Improved Six Sigma values in quality control testing were achieved through accurate sample loading and data management systems, highlighting Six Sigma's effectiveness in enhancing laboratory analytical performance and reducing errors.

In the context of tumor marker assays, Liu Q. et al. (2019a) applied Six Sigma metrics to evaluate tumor marker assays, emphasizing the use of different allowable total error (TEa) standards. They recommended tailored quality control plans using Westgard Sigma Rules to enhance assay precision and accuracy. Their study underscored the significant role of Six Sigma in improving analytical quality for these assays.

Mary et al. (2023) mitigated pre-analytical errors in hematological specimens through stringent quality checks and training, achieving a Six Sigma score of 3.9. They identified common errors such as incomplete forms and incorrect samples, emphasizing continuous monitoring and targeted training to enhance laboratory quality.

Kulkarni et al. (2018) applied Six Sigma and Pareto's principle to identify and prioritize common pre-analytical errors in clinical biochemistry laboratories. Significant areas needing improvement included missing patient information and improper blood sample ratios. The study concluded that stringent quality checks, frequent staff training, and adherence to standard operating procedures are essential to reduce errors and enhance laboratory performance.

Collectively, these studies illustrate the critical role of Six Sigma in optimizing analytical processes, reducing variability, and enhancing the overall accuracy and reliability of laboratory results.

Impact of Six Sigma on Pharmacy and Medication Management

The application of Six Sigma methodologies in pharmaceutical settings has led to significant improvements in process capability, efficiency, and cost savings.

Chabukswar et al. (2011) applied Six Sigma to improve Ranitidine hydrochloride tablet manufacturing, increasing sigma levels from 1.5 to 4. This reduced variation, improved yield, minimized issues like thick tablets and packing line stoppages, and led to annual cost savings of Rs. 90-95 lakhs.

Using DMAIC across blending, compression, coating, and packing stages, they achieved a 30% boost in overall efficiency through systematic improvements and rigorous control measures.

Haleem et al. (2015) provided additional evidence of Six Sigma's effectiveness in pharmaceutical contexts, highlighting insights from a review of literature where DMAIC principles were shown to significantly enhance capacity and revenue without additional staffing costs. While specific case studies are not detailed in the abstract, the review underscores Six Sigma's ability to optimize processes and reduce defects, thereby improving overall operational efficiency.

In another study, Alanazi et al. (2023) demonstrated that Six Sigma, combined with advanced analytical methods, optimized detection processes for pharmaceutical residues. This ensured high precision and reliability while minimizing environmental impact, showcasing the methodology's versatility in various aspects of pharmaceutical operations.

Automation initiatives in outpatient pharmacy, as studied by Al Nemari& Waterson (2022), revealed reduced dispensing errors and enhanced patient-pharmacist interactions. This illustrates Six Sigma's crucial role in enhancing safety and service quality in healthcare settings.

Overall, these findings highlight Six Sigma's transformative impact on pharmaceutical operations, driving quality improvements, operational efficiencies, and cost savings across healthcare settings.

Operational Efficiency and Patient Care Improvements

The implementation of Six Sigma methodologies in healthcare has demonstrated substantial improvements in operational efficiency and patient care across diverse settings.

According to Tufail et al. (2022), the DMAIC approach was utilized optimize CT scan patient flow in urban hospitals, enhancing resource utilization and reducing congestion by implementing tools like Voice of Customer (VOC), COPIS chart, ARMI chart, and Kaizen 5-why technique. This study highlights Six Sigma's ability to address healthcare service challenges, particularly in managing patient influx and improving service quality.

Liu S. et al. (2019b) successfully implemented a Six Sigma-driven Automated Plan Check (APC) tool in radiotherapy, resulting in significant reductions in treatment planning errors and improving safety and efficiency. Similarly, Kannan et al. (2024) applied Six Sigma in an oral pathology laboratory to enhance diagnostic accuracy and accelerate report turnaround times. Using the DMAIC cycle, they identified inefficiencies and implemented targeted improvements, emphasizing data-driven decision-making and minimizing non-value-added activities.

In the study by El-Eid et al. (2015), the implementation of Six Sigma significantly improved hospital discharge processes in a tertiary care hospital. The intervention led to a 22.7% reduction in discharge time, a decrease in hospital length of stay (LOS) from 3.4 to 3.1 days, and a reduction in emergency department (ED) LOS from 6.9 to 5.9 hours. These improvements were sustained over the post-intervention period, underscoring the potential of Six Sigma for enhancing hospital throughput.

Akifuddin and Khatoon (2015) illustrated how the Six Sigma DMAIC process reduced complications from local anesthesia in dental care. They identified systemic issues like syncope and vasoconstrictor drug problems, and local issues such as anesthesia failure, trismus, and injection site pain. The intervention lowered the cumulative defective percentage from 7.99% to 4.58% and decreased Risk Priority Number (RPN) scores for various complications, enhancing patient safety and compliance.

Ebrahimipour et al. (2021) demonstrated that implementing the Six Sigma DMAIC process significantly reduced the time to initiate treatment for congenital hypothyroidism in infants. The mean time to start treatment decreased from 21.72 days to 17.41 days post-intervention. Additionally, the percentage of infants receiving timely treatment during infancy increased from 81.8% to 94.1%. The Six Sigma intervention also improved the Sigma level of treatment initiation from 2.41 to 3.06, indicating enhanced operational efficiency and better patient care outcomes.

Ponsiglione et al. (2021) utilized the Six Sigma DMAIC process to assess pharmacological therapies for patients undergoing oral cavity cancer surgery on bone tissue. Their study found that the use of ceftriaxone significantly reduced the length of hospital stay (LOS) by 40.9% compared to the combination of cefazolin and clindamycin. The most substantial reductions were seen in younger patients (54.1%) and those with low oral hygiene (52.4%). The Six Sigma methodology, applied as a Health Technology Assessment tool, enabled the identification of key variables influencing LOS and demonstrated substantial improvements in operational efficiency and patient care outcomes.

In orthopedic surgery, Latessa et al. (2021) used Six Sigma's DMAIC cycle to compare cemented and uncemented prostheses in Total Hip Arthroplasty (THA). They found no significant differences in costs or hospital stay length (LOS) but identified key cost factors and improved resource management in orthopedic surgery, demonstrating Six Sigma's effectiveness in healthcare economics.

Evaluating weight management apps, Alshathri et al. (2020) used Six Sigma evaluations to reveal significant variability in app quality attributes. They highlighted areas for improvement in patient care and operational efficiency, emphasizing the need for better-designed features and consistent quality standards.

Based on the systematic review by Hoefsmit et al. (2022) on Six Sigma methodologies in cardiac surgery led to significant improvements in patient outcomes, including reduced infections and mortality rates post-CABG surgery. Process enhancements such as shorter waiting times and smoother OR to ICU transfers were also noted. The review underscored systematic problem-solving, multidisciplinary team engagement, and data-driven decision-making as critical factors.

Simiele et al. (2023) applied Six Sigma methodologies, specifically using failure mode and effect analysis (FMEA), to enhance radiation therapy treatment planning with the RefleXion X1 system. Significant improvements were observed, with a decrease in average risk priority numbers (RPNs) from 138.0 to 47.8, indicating enhanced safety and efficiency in treatment planning.

Overall, these studies illustrate that Six Sigma is a robust quality improvement framework that enhances healthcare processes, reduces errors, and ultimately improves patient outcomes by systematically identifying and addressing inefficiencies across various healthcare domains.

Integration with Lean Methodologies

The integration of Lean and Six Sigma (LSS) methodologies in healthcare settings has demonstrated significant improvements in clinical outcomes, process efficiency, and resource utilization.

According to Martinez et al. (2011), implementing an LSS-based perioperative glycemic control protocol in a cardiac surgical ICU significantly increased glucose checks per patient-day from 3 to 12 and improved admission glucose levels <200 mg/dL from 76% to 94% (P < 0.001). This study demonstrates the effectiveness of LSS methodologies in enhancing clinical processes and improving patient outcomes.

In their study, Schretlen et al. (2021) successfully applied Lean Six Sigma (LSS) to reduce surgical cancellations in a University Medical Center in the Netherlands, achieving notable improvements: a 50% reduction in last-minute cancellations (P = 0.010), a 67% decline in repeated preoperative diagnostics (P = 0.021), and a 35% decrease in referral to treatment time (P = 0.000), along with a 14% increase in patient satisfaction (P = 0.005). This underscores LSS as an effective methodology for enhancing healthcare efficiency, optimizing resource utilization, and improving patient-centered care.

Aligning with these findings, Zhu et al. (2020) applied Lean Six Sigma to reduce unplanned surgery cancellations (USC) at a large tertiary hospital in China. They identified key factors like timing of patient admissions and operation notices, and improved processes such as health education for virtual bed patients and standardized communication. USC rates decreased significantly from 10.21% to 3.8%, demonstrating Lean Six Sigma's effectiveness in enhancing patient safety and optimizing hospital resource utilization.

Kam et al. (2021) applied Lean Six Sigma techniques to improve efficiency within a publicly-funded outpatient ophthalmology clinic. They observed a 9% increase in patients seen per session (P = 0.016) and a significant reduction in median patient in-clinic time from 131 to 107 minutes (P < 0.001). They implemented strategic scheduling adjustments, created dedicated postoperative clinics, and ensured consistent medication availability, demonstrating Lean Six Sigma's effectiveness in optimizing clinic operations without significant additional costs.

Gardim et al. (2024) reported that Lean and Six Sigma effectively optimize perioperative processes by reducing patient waiting times and hospital stays, contributing to better patient outcomes and organizational sustainability.

In hospital pharmacy operations, Sallam's (2024) systematic review on Lean and Six Sigma strategies revealed significant improvements in medication turnaround times and inventory management highlighting the effectiveness of these methodologies in enhancing operational efficiency and patient care within hospital pharmacies.

Wolfe et al. (2021) demonstrated the efficacy of LSS in digitizing surgical operation notes at a private hospital, achieving 100% digital completion, reducing completion time by 30%, and generating EUR 10,000 in annual cost savings. Their study highlights significant enhancements in operational efficiency, accuracy, and cost-effectiveness through systematic process redesign.

Schweikhart and Dembe (2009) underscore Lean and Six Sigma's capacity to enhance efficiency and effectiveness in clinical and translational research. They advocate for adapting these manufacturing strategies to improve process quality, minimize errors, and accelerate biomedical discoveries, thereby aligning with the National Institutes of Health (NIH) objectives for more efficient and cost-effective research practices.

Overall, these studies illustrate that LSS provides a structured, scalable approach to process improvement, demonstrating its broad applicability and potential for significant impact in healthcare delivery. The integration of Lean methodologies with Six Sigma drives sustainable improvements in patient outcomes and operational efficiencies, highlighting Six Sigma's value as a quality improvement framework in healthcare.

Table 1. Summary of Six Sigma Applications and Impacts in Across Various Healthcare Domains

Application Area	**Study**	**Intervention Details**	**Key Results**
Infection Control	Eldridge et al. (2006)	Hand hygiene compliance improvement in ICUs	Increased compliance from 47% to 80%, sustained alcohol-based hand rubs (ABHR) usage, improved staff satisfaction
	Rao (2011)	Reducing hospital-acquired infections	Achieved zero surgical site infections (SSIs) within six months
	Kuwaiti &Subbarayalu (2017)	Targeted improvement strategies for HAIs	Reduced hospital-acquired infection (HAI) rates from 3.92 to 2.73

	Shi et al. (2022)	Surgical site infection (SSI) reduction using DMAIC approach	22.2% reduction in SSI rates, optimized perioperative processes, improved surgical quality
	Ludington et al. (2024)	Infection prevention program for hemodialysis patients	Identified and addressed gaps in cleaning, disinfection, and PPE use
Surgical Processes and Instrumentation	Polanski et al. (2018)	Quality assessment of deep brain stimulation (DBS) surgery	19.1% median improvement in (Unified Parkinson's Disease Rating Scale Part III) UPDRS III, 46.6% reduction in levodopa equivalent dose (LED), 1.42% bleeding risk, 88.9% yield for successful outcomes
	Ricciardi et al. (2021)	Comparing antibiotic protocols in oral mucosa cancer surgery	Cefazolin plus Clindamycin reduced hospital stays, especially in complex surgeries
	Saporito et al. (2023)	Optimizing surgical instrument sterilization	Improved Sigma values from 4.79 to 5.04, annual cost savings of $19,729 USD, enhanced staff satisfaction
	Gheysari et al. (2016)	Reducing surgery cancellation rates	Reduced cancellation rates from 3.6% to 1.4%
Laboratory and Analytical Quality	Molaahmadi-Hassanabadi et al. (2023)	Enhancing hemovigilance processes	Identified significant errors with sigma levels as low as 1.5, highlighted need for targeted improvements in evening and night shifts
	Ialongo&Bernardini (2016)	Implementing automation in clinical laboratories	Reduced turnaround time (TAT), improved operational efficiency
	Ahmed et al. (2021)	Maintaining clinical laboratory testing standards during COVID-19	High sigma values (>4.0σ) across most quality indicators despite pandemic challenges
	Zhou et al. (2020)	Assessing quality of biochemical analyte testing	Analytes with sigma values ≥ 6 required minimal quality control (QC), analytes with σ < 4 needed rigorous QC
	Panda et al. (2023)	Evaluating biochemical analytes in clinical labs	Identified poor performance analytes with σ < 4, needed quality goal index (QGI) and root cause analysis (RCA) for improvement
	Çevlik&Haklar (2024)	Evaluating biochemistry parameters using Six Sigma methodology	Significant variability in sigma metrics across analyzers, required systematic RCA
	Liu et al. (2021)	Improving analytical performance of urinary biochemical analytes	Developed risk-based statistical quality control (SQC) strategies, improved detection and reduced errors, based on Westgard sigma rules
Pharmacy and Medication Management	Chabukswar et al. (2011)	Improving Ranitidine hydrochloride tablet manufacturing	Increased sigma levels from 1.5 to 4, reduced variation, enhanced yield, substantial cost savings
	Haleem et al. (2015)	Enhancing capacity and revenue in pharmaceutical manufacturing	Significant improvements without additional staffing costs
	Alanazi et al. (2023)	Optimizing detection processes for pharmaceutical residues	Ensured high precision and reliability while minimizing environmental impact
Operational Efficiency and Patient Care	Tufail et al. (2022)	Optimizing CT scan patient flow in urban hospitals	Enhanced resource utilization, reduced congestion, improved service quality

	Liu Q. et al. (2019b)	Implementing Automated Plan Check (APC) tool in radiotherapy	Significant reductions in treatment planning errors, improved safety and efficiency
	Kannan et al. (2024)	Enhancing diagnostic accuracy and report turnaround in oral pathology lab	Identified inefficiencies, implemented targeted improvements, minimized non-value-added activities
	El-Eid et al. (2015)	Improving hospital discharge processes	Reduced discharge time by 22.7%, decreased length of stay (LOS) from 3.4 to 3.1 days, reduced emergency department (ED) LOS from 6.9 to 5.9 hours
	Akifuddin& Khatoon (2015)	Reducing complications with local anesthesia in dental healthcare setups	Reduced defective percentage from 7.99% to 4.58%, decreased RPN scores across complications
	Ebrahimipour et al. (2021)	Reducing time to initiate treatment for congenital hypothyroidism in infants	Decreased mean time to start treatment from 21.72 days to 17.41 days, increased timely treatment from 81.8% to 94.1%, improved Sigma level from 2.41 to 3.06
Integration with Lean Methodologies	Schretlen et al. (2021)	Reducing surgical cancellations in a University Medical Center	50% reduction in last-minute cancellations, 67% decline in repeated preoperative diagnostics, 35% decrease in referral to treatment time, increased patient satisfaction by 14%
	Zhu et al. (2020)	Tackling unplanned surgery cancellations in a large tertiary hospital in China	Decreased unplanned surgery cancellation (USC) rates from 10.21% to 3.8%, improved patient safety, maximized surgical resource utilization
	Kam et al. (2021)	Improving efficiency in an outpatient ophthalmology clinic	9% increase in patients seen per session, significant reduction in median patient in-clinic time

Synthesis of Findings Across Studies

Collectively, these studies illustrate Six Sigma's versatility and effectiveness in addressing diverse healthcare challenges. Whether reducing infection rates, optimizing laboratory testing accuracy, improving surgical processes, or enhancing operational workflows, Six Sigma offers a structured framework for systematic problem-solving and continuous quality improvement. Each application underscores the importance of data-driven decision-making, stakeholder engagement, and process standardization in achieving measurable improvements in healthcare delivery.

Implications for Healthcare Management

The integration of Six Sigma methodologies equips healthcare managers with robust tools to tackle quality improvement challenges systematically. Leveraging data-driven insights and fostering a culture of continuous learning and adaptation, healthcare organizations can achieve sustainable improvements in patient safety, operational efficiency, and stakeholder satisfaction.

CONCLUSION

This review synthesizes empirical findings on Six Sigma's application in healthcare, highlighting infection control, surgical processes, laboratory quality, pharmacy management, and operational efficiencies. Successful implementation hinges on strong leadership, a culture of continuous improvement, and effective training programs, underscoring organizational commitment and employee engagement. Challenges include resistance to change, process complexity, and initial resource investments. Recognizing these barriers allows organizations to proactively address them. For healthcare practitioners and policymakers, understanding these factors informs tailored quality improvement strategies. Future research should explore Six Sigma's sustainability and patient outcome impacts, refining implementation strategies for substantial and enduring patient care enhancements.

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CONFLICT OF ON INTEREST

No conflict of interest among authors.

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