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Implementation of six sigma management to standardize surgical hand disinfection practices

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Abstract

Objective The aim of this study is to evaluate the effectiveness of Six Sigma management in standardizing surgical hand disinfection practices among medical personnel.

Methods The Six Sigma DMAIC (Define, Measure, Analyze, Improve, Control) framework was utilized to assess and enhance the accuracy and effectiveness of surgical hand disinfection. Factors contributing to low accuracy and a high defect rate in disinfection practices were systematically analyzed. Key issues identified included limited awareness of infection control protocols, insufficient knowledge of proper surgical hand disinfection practices, and inadequate oversight of surgical staff. Interventions based on this analysis included the use of text and video reminders, reinforcement of medical personnel training, implementation of enhanced camera-based monitoring and supervision, and the establishment of a reward-and-penalty evaluation system.

Results Post-intervention analysis revealed that the accuracy of surgical hand disinfection among medical personnel increased from 42.94 to 82.97%, with surgeons demonstrating the greatest improvement, achieving a 47.70% increase. The overall defect rate decreased substantially, with the most notable reduction observed in incomplete hand coverage with disinfectant, which decreased by 2.75%. Additionally, the average number of bacterial colonies on the hands of medical staff decreased from 4.44 ± 2.51 CFU/cm^2 to 2.68 ± 0.54 CFU/cm^2, and the qualification rate improved markedly from 71.67 to 98.33%. All observed improvements were statistically significant.

Conclusion The application of Six Sigma management effectively enhances the accuracy and quality of surgical hand disinfection, reduces procedural defects, and enhances disinfection outcomes in clean surgical procedures.

Keywords Bacterial colony count on hands, Colony-forming units (CFUs), Six Sigma management, Surgical hand disinfection, Surgical staff, Surgical site infection

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Introduction

Surgical hand disinfection involves washing hands with soap (liquid soap) and running water before surgery, followed by the use of hand disinfectant to remove or kill transient bacteria and reduce resident bacteria. It is a critical step in the surgical process, effectively preventing bacterial transfer from the skin to the surgical site and controlling surgical incision infections [1]. With advancements in disinfectants, the method of surgical hand disinfection has transitioned from traditional scrubbing to rubbing [2]. While this change has simplified the process and saved time, according to research, the current implementation of surgical hand disinfection remains suboptimal, particularly in terms of accuracy [3, 4]. Furthermore, although data on compliance and accuracy of hygienic hand disinfection are readily available through routine hospital hand hygiene monitoring, research specifically addressing surgical hand disinfection is relatively scarce [5]. Therefore, it is essential to develop effective management measures to enhance the accuracy of surgical hand disinfection, ensuring medical staff treat patients with clean and properly disinfected hands.

Hospitals, as part of the specialized service industry, have increasingly adopted management methods that have proven to be effective in enterprises [6]. Among these, Six Sigma management has delivered significant results in various hospital management areas. Using the DMAIC (define, measure, analyze, improve, control) process, Six Sigma has been shown to reduce patient waiting times [7], shorten the issuance time of inspection reports [8], and enhance operating room service efficiency [9, 10], among other benefits. In recent years, Six Sigma has been widely applied to the prevention and control of nosocomial infections, with studies demonstrating its potential to reduce the incidence of nosocomial infections and surgical site infections (SSIs) [11–13]. In this study, we applied Six Sigma management to the surgical hand disinfection process, aiming to identify key factors affecting disinfection accuracy and implement targeted interventions to improve outcomes, as detailed below.

Data and methods

Study participants

Surgical staff, including doctors from various operating departments, operating room nurses, and interns and trainees, were selected using simple random sampling method as study participants from December 2022 to November 2023. Six Sigma management was implemented from June 1, 2023. The accuracy of surgical hand disinfection among operating room staff was assessed before (December 2022 to May 2023) and after (June 2023 to November 2023) the implementation of the management plan. A defect is defined as the failure of any one of the seven elements to meet the criteria, while qualification refers to the successful completion of all seven elements without any defects. Ethical approval was obtained from Ethics Committee of Nantong First People's Hospital (2023KT214).

Implementation of six Sigma quality management program

Six Sigma "define" phase

A Six Sigma management project team was formed, with the head of the infection management department designated as a Black Belt member, the directors of each surgical department and the operating room head nurse as Green Belt members, and all surgeons and nurses as process owners. All team members underwent standardized Six Sigma training. The critical-to-quality (CTQ) metric for the project was defined as improving the accuracy of surgical hand disinfection among surgical staff. Nonstandard practices in surgical hand disinfection were classified as defects.

Six Sigma "measure" phase

Based on Standards for Hand Hygiene for Healthcare Workers in Healthcare Settings, the Surgical Hand Disinfection Operation Supervision Form was created to monitor seven process indicators to assess correctness of the surgical hand disinfection performed: the six-step hand washing method, handwashing duration (> 3 min), rinsing method (keeping both hands in front of the chest and above the elbows, allowing water to flow from the hands to the elbows), hand-drying method (spirally drying the skin from the hands upward to the elbows), the application sequence of surgical hand sanitizer (refer to Appendix C: Surgical No-rinse Hand Disinfection Method in the "Hand Hygiene Standards for Healthcare Workers"), whether the disinfectant covers the entire area, and whether it is rubbed until dry [14]. The handwashing station in the operating room was monitored three days a week from 08:00 to 09:30 from December 2022 to May 2023. During this time, the surgical hand disinfection practices of 457 surgical staff members were observed and recorded on-site by a full-time infection control staff member and an operating room nurse. Agreement between both observers was required for hand disinfection method to be considered correct. Additionally, 60 surgical medical staff members were randomly selected monthly and monitored by a dedicated full-time infection control staff member based on the "Hygiene Standard for Disinfection in Hospitals." [15].

Six Sigma "analyze" phase

The project team members supervised a voting session to analyze the factors affecting the accuracy of surgical hand disinfection among surgical staff considering personnel, environment, equipment, methods, and materials. The

voting was conducted by the Black Belt and Green Belt members of the project team, namely the head of the Infection Management Department, the directors of each surgical department, and the head nurse of the operating room. A fishbone diagram was utilized to identify weak awareness of infection control, insufficient knowledge of correct surgical hand disinfection practices, and inadequate supervision of surgical medical staff as the main influencing factors.

Six Sigma "improve" phase

Based on the results, targeted improvement measures were formulated:

1) Enhancing awareness: A flowchart detailing the steps for surgical hand disinfection was displayed at each handwashing station. Additionally, a multimedia screen at each station played a continuous video loop demonstrating proper surgical hand disinfection techniques.
2) Batch training: Surgical staff participated in batch training sessions, which included real-time assessments of hand disinfection accuracy. Individuals with suboptimal performance underwent additional retraining.
3) Initial training for interns and trainees: Interns and trainees received mandatory surgical hand disinfection training prior to their first entry into the operating room. Certification of competency was required to gain access.
4) Video surveillance monitoring: High-definition cameras were installed at each handwashing station to monitor compliance. Surveillance was conducted randomly on three days per week, between 08:00 and 09:30. Results were publicly disclosed on a weekly basis, integrated into performance appraisals, and linked to a system of rewards and penalties.

Six Sigma "control" phase

From June 2023 to November 2023, monthly random sampling was conducted involving 10 surgical staff members. A full-time infection control staff member performed sampling procedures in accordance with established protocols. The effectiveness of hand disinfection was evaluated and compared against baseline data collected during the Measure phase. A comprehensive analysis of surgical staff hand disinfection practices was undertaken, accompanied by quality assessments. Based on these findings, recommendations for further improvements were formulated.

Post-implementation effectiveness monitoring

From June 2023 to November 2023, the surgical hand disinfection practices of 479 surgical staff members were randomly inspected during the time period from 08:00 to 09:30, utilizing high-definition electronic monitoring systems. The accuracy of surgical hand disinfection practices was compared between the pre-implementation phase (December 2022 to May 2023) and the post-implementation phase (June 2023 to November 2023) to evaluate the effectiveness of the management plan. To ensure the long-term maintenance of high standards of surgical hand disinfection, the Infection Control Department has incorporated daily monitoring of hand hygiene through video surveillance into its routine work and provides monthly feedback on the compliance status.

Microbiologic method

After the sampling tube was thoroughly shaken, 1.0 mL of the eluate at different dilutions was inoculated onto petri dishes. Melted nutrient agar medium, cooled to 40℃-45℃, was poured into each dish at a volume of 15–20 mL. The dishes were then incubated at 36℃ ± 1℃for 48 h, and the number of colonies was counted. Pathogenic microorganisms were isolated if necessary.

Statistical analysis

Statistical analysis was performed using SPSS25.0. Count data are expressed as the number of cases and percentages and chi-squared test was employed for statistical analysis. Measurement data are expressed as the mean ± standard deviation and the *t*-test was used for statistical analysis. A P-value < 0.05 was considered statistically significant.

Results

Surgical hand disinfection accuracy before and after six Sigma management implementation

Following the implementation of Six Sigma management, the overall accuracy of surgical hand disinfection among surgical staff increased from 42.94 to 82.97%, with the difference being statistically significant (Table 1).

Comparison of defect incidence in surgical hand disinfection before and after six Sigma management implementation

Using the Surgical Hand Disinfection Operation Supervision Form, seven types of defects were identified in the surgical hand disinfection process: incomplete handwashing steps, insufficient handwashing time, incorrect rinsing method, improper hand drying techniques, back-and-forth smearing during disinfection, incomplete disinfectant coverage, and failure to rub disinfectant until dry. It was noted that multiple defects could occur during a single instance of surgical hand disinfection. Following the implementation of Six Sigma management, the incidence of all identified defects decreased, with statistically significant differences observed (Table 2).

Table 1 Comparison of the correct rate of surgical hand disinfection before and after the implementation of six Sigma management

Personnel category			Before the intervention	After the intervention	χ^2	*P*
Surgeon	Number of observations		162	174	78.38	8.50×10^{-19}
	Accuracy		33.33% (54)	81.03% (141)		
	Defect frequency	Incomplete hand-washing steps	48	14		
		Insufficient time to wash hands	37	11		
		Incorrect flushing method	28	7		
		Wrong way to dry your hands	25	6		
		Apply the disinfectant back and forth	29	9		
		Incomplete coverage of disinfectant	26	8		
		The disinfectant is not rubbed until it is dry.	37	13		
Scrub nurse	Number of observations		186	190		
	Accuracy		50.54% (94)	85.26% (162)	52.16	5.12×10^{-13}
	Defect frequency	Incomplete hand-washing steps	37	9		
		Insufficient time to wash hands	31	8		
		Incorrect flushing method	29	7		
		Wrong way to dry your hands	26	6		
		Apply the disinfectant back and forth	21	5		
		Incomplete coverage of disinfectant	22	4		
		The disinfectant is not rubbed until it is dry.	27	9		
Intern, trainee	Number of observations		109	115	34.56	4.14×10^{-9}
	Accuracy		44.95%(49)	82.61%(95)		
	Defect frequency	Incomplete hand-washing steps	29	7		
		Insufficient time to wash hands	26	8		
		Incorrect flushing method	18	6		
		Wrong way to dry your hands	9	3		
		Apply the disinfectant back and forth	15	6		
		Incomplete coverage of disinfectant	11	5		
		The disinfectant is not rubbed until it is dry.	18	3		

Table 2 Comparison of defect incidents in surgical hand disinfection practices pre- and post-implementation of six Sigma management practices

Existing problems	Before intervention ($n=457$)		After intervention ($n=479$)		χ2	*P*
	Frequency	Incidence	Frequency	Incidence		
Incomplete hand-washing steps	44	9.63%	11	2.30%	22.73	1.87×10^{-6}
Insufficient hand-washing time	70	15.32%	17	3.55%	38.42	5.71×10^{-10}
Wrong rinsing method	59	12.91%	15	3.13%	30.72	2.99×10^{-8}
Wrong hand drying method	89	19.47%	21	4.38%	51.35	7.71×10^{-13}
Back-and-forth smearing and disinfection	80	17.51%	34	7.10%	23.68	1.14×10^{-6}
Incomplete coverage of disinfectant	110	24.07%	23	4.80%	71.23	3.18×10^{-17}
Non-rubbing of disinfectant until dry	97	21.23%	33	6.89%	40.19	2.31×10^{-10}

Bacterial colony count monitoring results before and after six Sigma management implementation

Sixty medical staff members were randomly monitored to evaluate the effectiveness of surgical hand disinfection before and after the implementation of Six Sigma management. The bacterial colony counts were assessed in colony-forming units (CFUs), a metric used to quantify viable bacterial cells per unit area (CFU/cm²). Before the intervention, the qualification rate of surgical hand disinfection was 71.67%, with an average bacterial colony count of 4.44 ± 2.51 CFU/cm² and a maximum count of 13.35 CFU/cm². Following the intervention, the qualification rate increased significantly from 71.67% (43 out of 60) to 98.33% (59 out of 60), the average bacterial colony count decreased to 2.58 ± 0.54 CFU/cm² and the maximum count was reduced to 5.10 CFU/cm² (Tables 3 and 4). The differences observed between pre- and post-intervention values were statistically significant ($p<0.01$).

Table 3 Surgical hand disinfection effect comparison pre- and post-implementation of six Sigma management practices

Groups	Bacterial colony count (CFU/cm^2)
Before intervention ($n=60$)	4.44 ± 2.51
After intervention ($n=60$)	2.58 ± 0.54
t	5.29
P	2.23×10^{-7}

Table 4 Comparison of qualification rate of surgical hand disinfection practices pre- and post-implementation of six Sigma management practices

	Qualified (n)	Unqualified (n)
Before intervention ($n=60$)	43	17
After intervention ($n=60$)	59	1
χ^2	16.73	
P	4.31×10^{-5}	

Discussion

Surgical hand disinfection is the process of disinfecting hands based on hygienic practices. While clinical surgical hand disinfection has evolved from traditional surgical hand scrubbing to a more convenient and easier brush-free method, it remains the most complex hand hygiene practice. Omitting or making mistakes in any step can compromise the effectiveness of hand disinfection [16]. Relevant studies have suggested that some surgical staff reverse the order of hand drying and surgical leave-in disinfectant application, or apply it back-and-forth, which displaces bacteria on the hands and arms, affecting the disinfection effect [17]. Additionally, not rubbing the disinfectant until dry can compromise its long-lasting antibacterial effect. While surgical sterile gloves are an important barrier, unnoticed glove breakage can occur, particularly during prolonged surgeries [18]. Therefore, gloves should not be mistaken for an absolute seal and hand disinfection before surgery is essential to maintain hand sterility. This study showed significant improvement in the incidence of incomplete disinfectant coverage following the intervention. Before the intervention, many surgical staff, due to lack of awareness, often neglected to fully cover their hands with disinfectant, especially fingertips, the outside of hands, the outside of arms, and other easily overlooked areas. The selection of disinfectants for surgical hand disinfection has been widely studied, with research by Luis et al. indicating that variations in disinfectant composition have minimal impact on the number of bacterial colonies on hands [19]. In contrast, this study emphasizes process management in surgical hand disinfection, utilizing Six Sigma methodologies—originally developed for enterprise management– to enhance the precision of disinfection practices. This approach aims to minimize defects in hand disinfection, thereby reducing the risk of surgical site infection, promoting faster patient recovery, and improving overall patient satisfaction [20]. Effective pain management and accelerated recovery are critical factors contributing to increased patient satisfaction in surgical care [21]. In our study, surgeons demonstrated the greatest improvement in compliance with surgical hand disinfection protocols after the intervention. This may be attributed to their high level of education and professional competence. Before the intervention, surgeons had the lowest compliance rate among the three professional groups, indicating a potential lack of attention to the details of hand disinfection. However, once provided with targeted training and repeated reminders, their compliance rate improved significantly. This suggests that while surgeons may initially overlook the importance of hand disinfection, they can quickly adapt and improve with effective interventions. The effectiveness of Six Sigma management is achieved through a dual approach. First, bottom-up collection of first-hand clinical data, obtained through measurement and analysis effectively identifies actual clinical challenges. Second, a top-down perspective, incorporating management-level insights and extensive feedback, helps pinpoint critical quality issues. This integrated approach facilitates the development of practical and context-specific strategies to enhance the accuracy of surgical hand disinfection.

This study observed a significant improvement in the accuracy of surgical hand disinfection among staff, increasing from 42.94 to 82.97%, following the implementation of Six Sigma management. However, this post-intervention accuracy remains lower than findings reported in similar studies done in China, which achieved an accuracy rate of 91.09% [22]. In the referenced study, surgical hand disinfection was categorized into multiple levels (unqualified, qualified, good, and excellent), while this study classified outcomes as simply correct or incorrect, with any deviation from protocol deemed incorrect. This difference in accuracy definitions may account for the discrepancy between the two studies. A similar foreign study reported accuracy rates for surgical hand disinfection ranging from 5.01 to 81.21%, with an average of 40.05% [23]. In this study, the most significant improvement in accuracy (from 33.33 to 81.03%) was observed among surgeons. This may be attributed to the surgeons' initial lack of attention to the details of surgical hand disinfection, resulting in the lowest pre-intervention accuracy among the three occupational groups analyzed. Despite their high level of education, professionalism, and critical role in surgical outcomes, surgeons demonstrated notable improvement in accuracy following targeted training and consistent reminders. The Six Sigma management approach was employed in this study to identify factors influencing surgical hand disinfection accuracy, including personnel, environment,

equipment, and methods. Interventions addressed these factors through enhancements to material resources, strengthening training programs into a robust supervision and reminder system, and installing one-on-one high-definition cameras at washing stations. These measures increased supervision, heightened awareness of the importance of standardized disinfection practices and promoted behavioral changes, ultimately improving the accuracy of surgical hand disinfection.

Lopes et al. compared ATP biofluorescence values a minute after surgical hand disinfection with pre-intervention values, demonstrating the effectiveness of interventions [17]. However, Sanna argued that ATP biofluorescence is primarily suited for evaluating environmental cleanliness and not recommended for monitoring disinfection effects as microbial inactivation releases energy that may affect accuracy [24]. Consequently, this study used post-disinfection bacterial colony counts as the evaluation index. The qualification rate of bacterial colony count monitoring increased by 26.66% (from 71.67 to 98.33%). Similar findings were reported in other studies where long-term management mechanisms improved qualification rate of disinfection effects by 25.02% (from 63.12 to 88.07%), aligning with results of this study and highlighting the effectiveness of Six Sigma management in enhancing disinfection outcomes [25]. Some studies have introduced Six Sigma management into the process management of fever clinics during the COVID-19 pandemic, significantly reducing the error rate in triage across different populations as well as decreasing the workload in fever clinics, with the error triage rate dropping from 16.75 to 9.8%, and the workload reduced by 14.62% year-over-year [26].

Regarding cost implications: In our study, the cost of installing surveillance equipment was RMB 13,600, which included eight cameras (RMB 1,200 each) and one computer (RMB 4,000). Our study did not conduct an in-depth cost-benefit analysis between surgical hand disinfection and relevant outcomes. However, several studies have highlighted the cost-saving potential of Six Sigma interventions in healthcare settings. For instance, a recent study demonstrated that Six Sigma can significantly reduce the costs of poor quality in surgical processes, leading to substantial financial benefits [27]. The finding suggests that while the initial investment may be significant, the long-term benefits of improved efficiency and reduced errors can offset these costs.

This study was limited to a single hospital with a short observation period warranting further research to assess the long-term impact of implementing, which may affect the generalization of the study result; future research should explore diverse healthcare environments and long-term effectiveness to enhance the external validity and implementation of the findings. In addition to the single-center and short observation period, several other limitations should be noted. First, potential biases in sampling may have influenced our results. The selection of participants and the timing of observations could have introduced selection bias, and the awareness of the study among surgical staff might have led to changes in behavior due to the Hawthorne effect. Second, there could be confounders in the relationship between the two study periods and the observed adherence to hand hygiene protocols. Factors such as seasonal variations in surgical procedures or changes in hospital policies during the study period could have affected the results. Third, the simple pre-/post- study design is inherently limited in its ability to establish causality. Future studies should consider incorporating time-trend analyses and control groups, such as neighboring institutions not implementing similar interventions, to better account for external influences and enhance the robustness of the findings. Most importantly, this study did not include data on patient-centered outcomes, particularly surgical site infections, which are the primary outcomes impacted by hand hygiene practices.

Conclusion

The application of the DMAIC process within the Six Sigma management framework effectively enhances the accuracy of surgical hand disinfection, reduces bacterial colony counts on hands and improves perioperative infection prevention awareness among medical staff.

Abbreviations

DAMIC	Define, measure, analyze, improve, control
SSI	Surgical site infection
CTQ	Critical-To-Quality

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Author contributions

Conception and design of the research: Ping Jiang, Ling-Bo XueAcquisition of data: Hai-Yan Gu, Qin-Xia LiAnalysis and interpretation of the data: Ping Jiang, Yan LiuStatistical analysis: Yan Liu, Qin-Xia LiObtaining financingPing Jiang, Hai-Yan GuWriting of the manuscript: Ping JiangCritical revision of the manuscript for intellectual content: Ling-Bo XueAll authors read and approved the final draft.

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Data availability

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Declarations

Ethics approval and consent to participate

This study was conducted with approval from the Ethics Committee of Nantong First People's Hospital (2023KT214). This study was conducted in

accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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References

1. Li LY, Xu DH. Interpretation of'specification of hand hygiene for healthcare workers'. Chin J Nosocomiology. 2020;30(05):793–5.
2. Izaguirre A, Govela A, Delgado I, et al. Surgical hand antisepsis: experimental study. Ann Surg Treat Res. 2018;95(1):1–6.
3. Anderson TN, Hasty BN, Schmiederer IS, et al. A generalizable multimodal scrub training curriculum in surgical sterile technique. MedEdPORTAL. 2021;17:11077.
4. Parlak EA, Iyigun E, Albay A, et al. Impact of methods and duration of surgical hand scrub on bacterial count: A randomized controlled trial. Am J Infect Control. 2021;49(11):1376–83.
5. Javitt MJ, Grossman A, Grajewski A, et al. Association between eliminating water from surgical hand antisepsis at a large ophthalmic surgical hospital and cost. JAMA Ophthalmol. 2020;138(4):382.
6. Ahmed S. Integrating DMAIC approach of lean six Sigma and theory of constraints toward quality improvement in healthcare. Rev Environ Health. 2019;34(4):427–34.
7. Dong X, Hu BF, Jiang GB, et al. The application study of six Sigma in improving the chronergy of CT examination in patients with stroke. Chin J Stroke. 2018;13(2):151–4.
8. Mao X, Shao J, Zhang B, et al. Evaluating analytical quality in clinical biochemistry laboratory using six Sigma. Biochemia Med. 2018;28(2):20904.
9. Zhu L, Qian W, Zhou G, et al. Applying lean six Sigma to reduce the incidence of unplanned surgery cancellation at a large comprehensive tertiary hospital in China. Inq (Chicago). 2020;57(1):1143506829–402840871.
10. Tanna N, Clappier M, Barnett SL et al. Streamlining and consistency in surgery: Lean-Six-Sigma to improve operating room efficiency. Plastic & Reconstructive Surgery, 2023,Publish Ahead of Print.
11. Improta G, Cesarelli M, Montuori P, et al. Reducing the risk of healthcare-associated infections through lean six Sigma: the case of the medicine areas at the Federico II university hospital in Naples (Italy). J Eval Clin Pract. 2018;24(2):338–46.
12. Cesarelli G, Petrelli R, Ricciardi C, et al. Reducing the healthcare-associated infections in a rehabilitation hospital under the guidance of lean six Sigma and DMAIC. Healthcare. 2021;9(12):1667.
13. Shi Z, Huang P, Chen Y, et al. Sustaining improvements of surgical site infections by six Sigma DMAIC approach. Healthcare. 2022;10(11):2291.
14. Ministry of Health, People's Republic of China. WS/T 313–2009 Specification of hand hygiene for healthcare workers[S]. 2009.
15. Ministry of Health, People's Republic of China. GB 15982– 2012 Hygienic standard for disinfection in hospitals [S]. 2012.
16. Vallejo R, Fernandez DS, Cervera LA, et al. Effectiveness of surgical hand antisepsis using chlorhexidine digluconate and Parachlorometaxylenol hand Scrub: Cross-over trial. Med (Baltim). 2018;97(42):e12831.
17. Lopes A, Menegueti MG, Gaspar GG, et al. Comparing surgeons' skin tolerance and acceptability to alcohol-based surgical hand Preparation vs traditional surgical Scrub: A matched quasi-experimental study. Am J Infect Control. 2022;50(10):1091–7.
18. Mukherjee R, Roy P, Parik M. Achieving perfect hand washing: an audit cycle with surgical internees. Indian J Surg. 2021;83(5):1166–72.
19. Santé L, Gómez-Lus ML, Martin-Villa C, et al. Effect on the reduction of bacterial load after surgical hand antisepsis with triclosan 0.5% compared to triclosan 0.5% followed by 70% alcoholic solution. Infect Control Hosp Epidemiol. 2023;44(3):517–9.
20. Zimmermann G, Siqueira LD, Bohomol E. Lean six Sigma methodology application in health care settings: an integrative review. Rev Bras Enferm. 2020;73(suppl 5):e20190861.
21. Debono B, Wainwright TW, Wang MY, et al. Consensus statement for perioperative care in lumbar spinal fusion: enhanced recovery after surgery (ERAS®) society recommendations. Spine J. 2021;21(5):729–52.
22. Hu YH, Dong Q, Qiao SG, et al. The influence of quantified hand disinfection rubbing frequency on the effectiveness of surgical hand disinfection. Anti-Infection Pharm. 2018;15(02):265–8.
23. Amiraslani S, Darbemamieh G, Karimian F, et al. Design, fabrication, and testing of a novel surgical handwashing machine. Surg Innov. 2021;28(3):323–8.
24. Sanna T, Dallolio L, Raggi A, et al. ATP bioluminescence assay for evaluating cleaning practices in operating theatres: applicability and limitations. BMC Infect Dis. 2018;18(1):583.
25. Tholcke LC, Fang WH, Gornick BR, et al. Investigating particulate production in the operating suite following the use of waterless alcohol based dry scrub versus traditional hand washing and drying with commonly used surgical towels: an experimental study. Am J Infect Control. 2023;51(5):551–6.
26. Ma YL, Chen XX, Deng YL. Application of six Sigma management in the process management of fever clinics during the COVID-19 pandemic [J]. Chin J Nurs. 2020;55(z2):504–6. https://doi.org/10.3761/j.issn.0254-1769.2020.S1.191.
27. Griffiths JL, Saunders KRK, Foye U, et al. The use and impact of surveillance-based technology initiatives in inpatient and acute mental health settings: a systematic review. BMC Med. 2024;22(1):564. https://doi.org/10.1186/s12916-024-03673-9. Published 2024 Nov 29.

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