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ORIGINAL ARTICLE

Biochemical Markers and Public Health Measures in the Prevention and Management of Postoperative Complications in Pediatric Surgery

ARSHAD KAMAL[1], NAZIA JAMEEL[2], RAMSHA[3], AMJAD AZAM BALOCH[4], SURESH KUMAR[5], M. SHAKIL ZARI KHAWRI SIDDIQUI[6]
[1]*Assistant Professor, Department of Pediatric Surgery, Lady Reading Hospital, Peshawar, Pakistan*
[2]*Professor, Department of Community Medicine, Baqai Medical College, Karachi, Pakistan*
[3]*Demonstrator, Department of Community Medicine, Isra University, Islamabad, Pakistan*
[4]*Associate Professor, Muhammad Medical College / Ibn-e-Sina University, Mirpurkhas, Pakistan*
[5]*Senior Register Pediatric Surgery, Indus Hospital And Indus Health Network Karachi, Pakistan*
[6]*Associate Professor, Department of Biochemistry, Azra Naheed Medical College, Lahore, Pakistan*
Correspondence to: Arshad Kamal, Email: arshadkamal00981@gmail.com

ABSTRACT

Background: Postoperative complications in pediatric surgery contribute significantly to morbidity, prolonged hospitalization, and increased healthcare burden, particularly in resource-limited settings. Early biochemical indicators combined with preventive public health measures may improve clinical outcomes. This study assessed the predictive value of biochemical markers and the impact of public health interventions on postoperative complications among pediatric surgical patients.

Methods: A prospective multicenter study was conducted at the Department of Pediatric Surgery, Lady Reading Hospital Peshawar, and the Indus Hospital and Indus Health Network Karachi, from January 2022 to March 2023. A total of 100 pediatric patients aged 1 month to 12 years undergoing elective or emergency surgery were enrolled. Biochemical markers including C-reactive protein (CRP), procalcitonin (PCT), interleukin-6 (IL-6), and serum lactate were measured preoperatively and on postoperative Days 1, 3, and 5. Public health interventions were implemented simultaneously, consisting of enhanced infection-control measures, parental education, vaccination verification, environmental sanitation audits, and antibiotic stewardship practices. Postoperative complications and clinical outcomes were monitored and analyzed.

Results: Children who developed postoperative complications demonstrated significantly elevated levels of CRP, PCT, IL-6, and serum lactate at all postoperative time points. These biomarkers showed strong predictive value for surgical site infections, sepsis, and delayed wound healing. Public health measures substantially reduced postoperative morbidity, with decreases in surgical site infections, sepsis, delayed healing, and readmission rates. Relative reductions ranged from 30% to 45%, reflecting the effectiveness of combining preventive strategies with laboratory monitoring.

Conclusion: Biochemical markers serve as reliable predictors of postoperative complications in pediatric surgery. When integrated with structured public health interventions, they result in marked reductions in morbidity and improved postoperative recovery. This combined approach offers a practical and effective model for strengthening pediatric surgical outcomes in resource-limited healthcare environments.

Keywords: Pediatric surgery; postoperative complications; biochemical markers; CRP; procalcitonin; IL-6; serum lactate; public health measures; infection control; sepsis.

INTRODUCTION

Postoperative complications in pediatric surgery remain a significant global health problem, particularly in low- and middle-income countries where resource limitations, infectious disease burden, and gaps in preventive care disproportionately affect surgical outcomes[1]. Children represent a physiologically vulnerable population due to their immature immune systems, higher metabolic demands, distinct pharmacokinetics, and limited physiological reserves. As a result, even minor deviations in postoperative recovery can rapidly progress to serious complications such as surgical site infections (SSIs), sepsis, electrolyte imbalance, respiratory distress, anastomotic leaks, delayed wound healing, and prolonged hospital stays. These complications not only impact morbidity and mortality but also impose substantial emotional and financial burdens on families and healthcare systems[2,3].

Biochemical markers have emerged as essential tools for early recognition and monitoring of postoperative complications. Among these, C-reactive protein (CRP), procalcitonin (PCT), interleukin-6 (IL-6), and serum lactate are particularly valuable due to their sensitivity to early inflammatory changes, infection, and hemodynamic instability[4]. CRP is widely used to track postoperative inflammatory trends, while PCT has gained prominence as a highly specific biomarker for bacterial infection and sepsis. IL-6, a rapidly responding cytokine, indicates early postoperative stress and systemic inflammation[5]. Serum lactate, an indicator of tissue hypoperfusion and metabolic distress, is critical in predicting early postoperative deterioration, especially in emergency surgical settings. When interpreted together, these markers enable timely clinical decision-making and help identify children at risk before clinical symptoms fully manifest[6,7].

However, biochemical surveillance alone is insufficient for comprehensive postoperative care. An integrated public health perspective is essential to address preventable factors contributing to postoperative morbidity[8]. Evidence shows that hand-hygiene compliance, infection-prevention protocols, vaccination coverage, parental education, nutritional assessment, and antibiotic-stewardship programs significantly reduce postoperative complications. In pediatric populations, these interventions are particularly effective because children rely heavily on caregivers for hygienic practices, nutrition, and adherence to postoperative instructions. Furthermore, institutional public health strategies such as environmental sanitation audits, sterile equipment protocols, preoperative screening, and community-based awareness campaigns play a crucial role in improving surgical outcomes[9,10].

Despite advancements in pediatric surgical care, the integration of biochemical markers with preventive public health measures is inadequately implemented in many regions. Existing literature primarily focuses on either biomarker-based prediction models or hospital-based infection control strategies, with limited studies evaluating the combined impact of both approaches in pediatric populations. There is a need to generate evidence that bridges laboratory diagnostics with practical, scalable public health interventions[11].

The present study aims to evaluate the predictive role of key biochemical markers and assess the effectiveness of structured public health measures in preventing and managing postoperative complications in pediatric surgical patients. By examining both clinical and public health dimensions, this research provides an integrated framework for improving postoperative care, reducing preventable morbidity, and strengthening pediatric surgical outcomes at institutional and community levels[12].

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MATERIALS AND METHODS

Study Design and Setting: This prospective, multicenter observational study was conducted in the Department of Pediatric Surgery at Lady Reading Hospital (LRH), Peshawar, Pakistan, and the Indus Hospital and Indus Health Network Karachi, Pakistan. Both institutions are major tertiary-care pediatric referral centers that receive large numbers of surgical patients from urban and rural communities. The study duration extended from January 2022 to March 2023, allowing comprehensive data collection across seasonal variation and a full spectrum of surgical emergencies and elective procedures.

Study Population and Sample Size: A total of 100 pediatric patients were included in the study through consecutive sampling. All children aged between 1 month and 12 years who underwent emergency or elective surgical procedures at either of the two centers were screened for eligibility. This sample size was chosen to ensure adequate representation of common pediatric surgical conditions and to enable meaningful analysis of biochemical markers and postoperative outcomes. The study population included neonates, infants, toddlers, and older children who presented with a range of surgical conditions requiring operative management.

Eligibility Criteria: Children were considered eligible if they were within the defined age range and underwent a surgical procedure requiring postoperative monitoring. Only those patients for whom preoperative and postoperative biochemical investigations could be obtained were included. Written informed consent was obtained from the parents or guardians of all participants. Patients with known immunodeficiency disorders, metabolic abnormalities that could influence inflammatory responses, preoperative sepsis, or systemic infection were excluded. Additionally, children who did not complete the required postoperative follow-up period were not considered in the final analysis.

Ethical Considerations: Ethical approval for the study was granted by the institutional ethics committees of both participating hospitals. The study adhered to international ethical standards, including the Declaration of Helsinki. Confidentiality of all patient information was maintained. Parents or guardians were informed about the study objectives, procedures, and voluntary nature of participation, and written consent was obtained prior to inclusion.

Data Collection Procedures: Data collection began at admission and continued through the postoperative period. Baseline demographic characteristics, including age, sex, weight, nutritional status, type of surgery, comorbidities, and vaccination history, were recorded in a standardized proforma. Preoperative biochemical investigations were conducted within 24 hours before surgery. Postoperative assessments were performed on Days 1, 3, and 5 after surgery. All data were collected by trained pediatric surgical residents under the supervision of senior consultants at both centers. Consistency in data collection procedures was maintained across both hospitals to ensure the reliability of the findings.

Assessment of Biochemical Markers: Four key biochemical markers C-reactive protein (CRP), procalcitonin (PCT), interleukin-6 (IL-6), and serum lactate were evaluated to identify early postoperative complications. Venous blood samples were drawn using aseptic technique and immediately transported to the central laboratory. CRP and lactate levels were measured using automated chemistry analyzers, allowing for rapid assessment of inflammatory burden and tissue perfusion status. Procalcitonin and IL-6 levels were quantified using standardized ELISA assays to ensure high sensitivity in detecting bacterial infection and systemic inflammatory response. Biochemical marker sampling was performed at preoperative baseline and subsequently on postoperative Days 1, 3, and 5 to observe dynamic changes associated with postoperative recovery or complication onset.

Implementation of Public Health Measures: A structured set of public health measures was implemented across both study centers to evaluate their combined effect on postoperative outcomes. These measures included strengthened infection-control practices, strict enforcement of hand hygiene protocols among healthcare staff and parents, regular audits of environmental sanitation, and verification of vaccination status for tetanus, pneumococcal, and Haemophilus influenzae type b vaccines. Preoperative nutritional screening was performed to identify malnutrition or micronutrient deficiencies, and nutritional counselling was provided when required. Parents received education regarding postoperative wound care, danger signs, and the importance of follow-up visits. An antibiotic-stewardship program was applied to regulate prophylactic and therapeutic antibiotic administration based on institutional guidelines. All patients were followed postoperatively according to a standardized schedule that included evaluations on Days 3, 7, and 14.

Outcome Measures: Postoperative outcomes were assessed throughout hospital stay and follow-up visits. The primary outcomes included surgical site infection, postoperative sepsis, delayed wound healing beyond seven days, requirement for reoperation, and need for ICU admission. Secondary outcomes included overall length of hospital stay, readmission within 30 days, and adherence of parents to postoperative instructions. All postoperative complications were diagnosed and classified according to established pediatric surgical definitions and institutional protocols.

Statistical Analysis: Data analysis was conducted using SPSS version 26. Continuous variables such as biochemical marker levels were expressed as mean ± standard deviation, while categorical variables such as postoperative complications were presented as frequencies and percentages. Comparisons of biochemical marker trends across different postoperative time points were performed using analysis of variance. Differences between groups with and without complications were evaluated using independent t-tests. Chi-square tests were used to analyze categorical outcomes, and Pearson correlation analysis was applied to determine the association between biochemical markers and postoperative complications. A p-value of less than 0.05 was considered statistically significant.

RESULTS

The study included a total of 100 pediatric patients, and their baseline demographic characteristics are summarized in Table 1. The mean age of the children was 4.1 ± 3.0 years, ranging from 1 month to 12 years. Males constituted 56% of the sample, while females accounted for 44%. Elective surgeries represented the majority of cases at 63%, whereas 37% underwent emergency surgical procedures. Nutritional screening indicated that 28% of the children were undernourished, and 71% were fully vaccinated according to the Expanded Programme on Immunization. This distribution demonstrates a diverse surgical population and highlights important preoperative variables that may influence postoperative recovery (Table 1).

Table 1: Baseline Demographic and Clinical Characteristics of Pediatric Patients (n=100)

Variable	Value
Age (years), mean ± SD	4.1 ± 3.0
Age Range	1 month – 12 years
Male	56 (56%)
Female	44 (44%)
Elective Surgeries	63 (63%)
Emergency Surgeries	37 (37%)
Undernutrition	28 (28%)
Fully Vaccinated	71 (71%)

Biochemical markers showed distinct and consistent trends throughout the postoperative period. Children who developed complications had markedly elevated levels of C-reactive protein, procalcitonin, interleukin-6, and serum lactate compared to those without complications. Table 2 presents the comparison of biochemical markers on postoperative Days 1 and 3. CRP levels were significantly higher in the complication group, rising to 31 ± 8 mg/L on Day 1 and peaking at 54 ± 12 mg/L on Day 3. In contrast, children without complications exhibited far lower CRP values at

similar time points. Procalcitonin followed a similar pattern, with the complication group displaying early elevations on postoperative Day 1 (mean 2.6 ± 1.0 ng/mL), which persisted on Day 3. Interleukin-6 demonstrated early postoperative surges, with levels exceeding 200 pg/mL in the complication group on Day 1. Serum lactate was the earliest biomarker to rise, reaching 3.7 ± 0.6 mmol/L among children who later showed clinical deterioration. These differences between groups were statistically significant, confirming the diagnostic utility of biochemical markers in predicting postoperative complications (Table 2).

Table 2: Comparison of Biochemical Marker Levels Between Children With and Without Complications

Marker (Mean ± SD)	No Complications (n=72)	Complications (n=28)	p-value
CRP Day 1 (mg/L)	12 ± 5	31 ± 8	<0.001
CRP Day 3 (mg/L)	18 ± 7	54 ± 12	<0.001
PCT Day 1 (ng/mL)	0.42 ± 0.19	2.6 ± 1.0	<0.001
PCT Day 3 (ng/mL)	0.31 ± 0.14	1.9 ± 0.8	<0.001
IL-6 Day 1 (pg/mL)	68 ± 22	205 ± 70	<0.001
IL-6 Day 3 (pg/mL)	43 ± 15	146 ± 50	<0.001
Lactate Day 1 (mmol/L)	1.4 ± 0.3	3.7 ± 0.6	<0.001

A total of 28% of children developed postoperative complications, with surgical site infections being the most frequently observed adverse outcome. Detailed frequencies of complications are shown in Table 3. Surgical site infections occurred in 14% of patients, followed by delayed wound healing in 10%, sepsis in 7%, and unplanned ICU admissions in 5%. Readmission within 30 days occurred in 6% of cases. The majority of complications were observed in patients who underwent emergency procedures or who demonstrated elevated biochemical markers in the early postoperative period. The distribution of complications highlights the clinical significance of early biomarker monitoring in identifying children at high risk (Table 3).

Table 3: Frequency of Postoperative Complications in Pediatric Surgical Patients

Complication	Frequency	Percentage
Surgical Site Infection	14	14%
Sepsis	7	7%
Delayed Wound Healing (>7 days)	10	10%
Unplanned ICU Admission	5	5%
Readmission within 30 Days	6	6%
No Complications	72	72%

The implementation of structured public health measures across the two surgical centers resulted in a noticeable reduction in postoperative morbidity. A comparison of institutional complication rates before and after the application of these interventions is shown in Table 4. Surgical site infections decreased from 22% to 14%, representing a relative reduction of 36%. Rates of sepsis declined from 10% to 7%, while delayed wound healing fell from 17% to 10%. Readmission rates dropped from 11% to 6%. These improvements reflect the effectiveness of enhanced infection control practices, vaccination verification, parental education, improved sanitation protocols, and antibiotic stewardship. The notable decline in postoperative complications demonstrates the synergistic benefit of integrating public health strategies with clinical care (Table 4).

Table 4: Effect of Public Health Measures on Postoperative Complication Rates

Outcome	Before Intervention (%)	After Intervention (%)	Relative Reduction
Surgical Site Infection	22%	14%	36%
Sepsis	10%	7%	30%
Delayed Wound Healing	17%	10%	41%
Readmission within 30 Days	11%	6%	45%

Overall, the combined analysis of biochemical markers and public health interventions revealed a strong association between elevated postoperative biomarker levels and the development of complications. The intervention-linked reductions in sepsis, surgical site infections, and delayed wound healing underscore the importance of preventive strategies. Children demonstrating persistent elevations of CRP, PCT, IL-6, or lactate were more likely to experience adverse outcomes, including ICU admission and prolonged hospitalization. The findings emphasize the value of integrating biochemical surveillance with coordinated public health measures to achieve optimal postoperative outcomes in pediatric surgical populations.

DISCUSSION

The findings of this study demonstrate that biochemical markers and coordinated public health interventions play a critical and complementary role in predicting, preventing, and managing postoperative complications in pediatric surgical patients[11]. Elevated postoperative levels of CRP, procalcitonin, IL-6, and serum lactate were significantly associated with adverse outcomes, indicating that these biomarkers serve as sensitive indicators of early postoperative inflammation, infection, and hemodynamic stress[12]. The progressive rise in CRP and PCT among children who developed surgical site infections and sepsis supports their well-established utility in identifying bacterial infections and systemic inflammatory responses. IL-6 exhibited a rapid early postoperative surge, reflecting its role as one of the earliest cytokines released in response to surgical stress or infection. This makes IL-6 particularly valuable for identifying children who are beginning to deteriorate even before clinical signs fully appear. Serum lactate demonstrated the strongest early predictive capability, particularly for children requiring ICU admission, as elevated lactate levels indicate tissue hypoperfusion and metabolic compromise. The strong statistical association between biochemical markers and complications reinforces the importance of integrating laboratory monitoring into routine postoperative care for pediatric surgical patients[13,14].

In parallel with biochemical trends, the structured implementation of public health measures resulted in a substantial reduction in postoperative complications, demonstrating the necessity of preventive strategies within hospital systems[15]. Improvements in hand hygiene, environmental sanitation, and antibiotic stewardship contributed directly to the decline in surgical site infections and sepsis. Vaccination verification significantly reduced infectious vulnerability among children undergoing surgery, particularly against pneumococcal and Haemophilus influenzae–related infections. Parental education emerged as a crucial intervention, as many complications particularly wound-related issues were associated with inadequate home-based postoperative care in the pre-intervention period[16]. By enhancing caregiver understanding of wound care, hygiene, danger signs, and follow-up requirements, the study observed improved adherence and fewer postoperative complications. The combined reduction of 30–45% across key indicators such as SSI, delayed wound healing, and readmission underscores the effectiveness of public health strategies in pediatric surgical outcomes, especially in resource-limited settings[17].

The integrated interpretation of findings reveals that biochemical surveillance and public health interventions do not work in isolation but collectively form a robust system for reducing postoperative morbidity. Biochemical markers allow clinicians to identify at-risk children early, while public health measures reduce the baseline risk of complications[18]. Children who exhibited elevated postoperative biomarkers were far more likely to fall within the complication group, and these patterns aligned strongly with emergency surgery, malnutrition, and incomplete vaccination status. This underscores the importance of preoperative optimization, early detection of threats, and preventive interventions that extend beyond the operating room[19,20]. The results align with global pediatric surgical literature emphasizing

that the combination of timely biomarker monitoring and strengthened health-system practices improves survival, shortens recovery, and enhances quality of care. These findings have implications for practice in similar resource-constrained healthcare settings across Pakistan and other LMICs, where implementation of coordinated public health systems can significantly improve surgical outcomes[21-25].

CONCLUSION

This study concludes that biochemical markers such as CRP, procalcitonin, IL-6, and serum lactate are highly effective tools for early identification of postoperative complications in pediatric surgical patients. Their consistent elevation among children who developed surgical site infections, sepsis, delayed wound healing, or ICU-level deterioration highlights their value as essential components of postoperative monitoring. When combined with structured public health interventions including infection-control strengthening, vaccination verification, environmental sanitation, parental education, and antibiotic stewardship the incidence of postoperative complications was significantly reduced. The integration of these two approaches creates a comprehensive model that enhances early detection, promotes preventive practices, and improves overall pediatric surgical outcomes. Implementing this dual clinical–public health framework in tertiary-care hospitals can play a transformative role in reducing morbidity, improving surgical safety, and elevating standards of child health care in Pakistan and similar healthcare environments.

Authors' Contributions: A.K. conceived the study, supervised data collection, and contributed to manuscript writing. N.J. participated in study design, data interpretation, and critical revision of the manuscript. R. assisted in data acquisition, laboratory coordination, and drafting of the results. A.A.B. contributed to statistical analysis, data validation, and editing of the final article. S.K. assisted in literature review, methodology development, and manuscript refinement. M.S.Z.K.S. contributed to overall supervision, quality assurance, and final approval of the manuscript. All authors reviewed and approved the final version.

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Availability of Data: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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