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Determining the Clinical Depth of Anaesthesia Using a Pulse Oximeter and Investigating the Utility of the Perfusion Index in Pediatric Patients Undergoing Elective Surgery

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ABSTRACT

The perfusion index (PI) is a reliable, non-invasive measurement obtained through pulse oximetry, effectively evaluating the depth of anaesthesia. Accurate assessment of anaesthesia depth in pediatric patients is crucial to mitigate complications such as intraoperative awareness or over-sedation. This study aimed to elucidate the correlation between the perfusion index (PI) and the clinical depth of anaesthesia in children undergoing elective surgical procedures. Additionally, the secondary objectives included evaluating the viability of the perfusion index as a monitoring tool and identifying factors contributing to its correlation with anaesthesia depth. The prospective observational study included 30 ASA pediatric patients aged 1 to 18 who underwent elective surgery under general anaesthesia. PI, heart rate (HR), and minimum alveolar concentration (MAC) measurements were taken during three critical phases: induction, maintenance, and emergence. Statistical analyses, including ANOVA, Levene's test, and correlation assessments, were conducted to ascertain associations and variability. The perfusion index exhibited statistically significant differences across the phases, demonstrating a peak during intubation (1.49 ± 0.20) and a trough during maintenance (1.07 ± 0.06). Furthermore, the PI displayed significant correlations with traditional measures of anaesthesia depth (HR: $p = 0.002$; MAC: $p = 0.000$). Therefore, the perfusion index strongly correlates with anaesthesia depth and maybe a valuable adjunctive monitoring tool in pediatric anaesthesia. Future studies involving larger sample sizes and comparisons with the bispectral index (BIS) must confirm its clinical applicability and identify potential confounding variables.

Keywords: *Perfusion index, depth of anaesthesia, Pediatric anaesthesia, pulse oximetry, hemodynamic monitoring.*

1. INTRODUCTION

The clinical depth of anaesthesia pertains to the extent of unconsciousness and analgesia achieved during surgical procedures, ensuring that patients are sufficiently sedated and devoid of pain. This depth is influenced by various factors, including the types of anaesthetic agents administered, the physiological responses of the body to these drugs, specific patient characteristics, and the nature of the surgery being performed. Monitoring the depth of anaesthesia is critical to patient safety, as it enables anaesthesiologists to manage medication levels effectively and to counteract any adverse effects that may arise throughout the surgical process [1,2].

In recent decades, technological advancements in clinical monitoring equipment have significantly improved the capacity to assess the depth of anaesthesia. Pulse oximetry has emerged as a universally accepted tool in operating rooms. This non-invasive technique provides real-time tracking of a patient's blood oxygenation levels and feedback on respiratory function. Modern pulse oximeters can supply data on the perfusion index, which reflects the quality of blood flow to peripheral tissues. The relevance of these measurements is particularly pronounced in paediatric patients undergoing elective surgery, where diligent monitoring can profoundly influence clinical outcomes. By evaluating both perfusion index and oxygen saturation, healthcare professionals can better understand the depth of anaesthesia and the patient's physiological status [3]. This serves as a foundation for further comprehensive discussions regarding the application of pulse oximeters in anaesthesia management, especially in optimizing patient care during surgical interventions.

Pulse oximetry measures the oxygen saturation of a patient's blood and heart rate by transmitting light through a pulsating network of capillaries, such as those found in a fingertip or earlobe. The technology assesses light absorption by oxygenated and deoxygenated haemoglobin, enabling clinicians to evaluate the efficiency of oxygen distribution throughout the body, which becomes critically important during anaesthesia.In paediatric surgeries, the advantages of employing pulse oximeters are substantial. They offer immediate feedback regarding a child's oxygenation levels, allowing for prompt corrections should these levels decline [4,5]. This capability is particularly valuable for children more susceptible to respiratory complications under anaesthesia. Furthermore, the non-invasive nature of pulse oximetry minimizes discomfort for the child, as it does not necessitate invasive procedures.

Nonetheless, it is essential to acknowledge certain limitations. Peripheral blood flow in children may be unpredictable or diminished, potentially leading to inaccurate readings, especially in cases involving hypothermia or reduced perfusion. Therefore, clinicians must interpret this data judiciously [6].When pulse oximetry data is supplemented with additional variables like the perfusion index, it contributes to a more comprehensive understanding of a patient's vascular status and depth of anaesthesia, which is particularly critical in paediatric anaesthesia, where close monitoring is paramount. The perfusion index indicates peripheral tissue blood flow and circulatory efficiency derived from pulse oximeter readings. During elective surgeries involving paediatric patients, monitoring the perfusion index is a straightforward method to assess anaesthesia depth. Research indicates a correlation between perfusion index values and anaesthetic depth; higher values usually indicate sufficient circulation and sedation, whereas lower values may signal inadequate anaesthesia or circulation [7,8].

For paediatric patients, whose physiological responses can be erratic, vigilant monitoring of the perfusion index becomes even more vital. This enables anaesthesiologists to make informed decisions regarding drug dosages, ensuring that children remain comfortable and safe throughout the surgical experience. Furthermore, the capability to detect sudden changes in perfusion index can aid in identifying potential complications, thereby enhancing overall patient outcomes [9,10].In summary, the integration of perfusion index monitoring alongside conventional assessment methods offers greater insights into children's anaesthetic responses. By emphasizing pulse oximetry and perfusion index evaluation, medical professionals can deliver improved intraoperative care for paediatric patients, ensuring they are appropriately sedated while adhering to established safety parameters. This application enhances the precision of anaesthetic depth assessment, ultimately facilitating more effective and safer surgical procedures for younger patients.

Materials and methods

The prospective observational study was conducted in the Department of Anaesthesiology at SRM Medical College Hospital and Research Center in Potheri, Kattankulathur, after receiving approval from the Institutional Ethics Committee (Ethical Clearance No: 8257/IEC/2022). Written informed consent was obtained from the parents or guardians of all participating patients. The study included 30 pediatric patients aged 1 to 18, scheduled for elective surgical procedures under general anaesthesia. Inclusion criteria encompassed those with an American Society of Anesthesiologists (ASA) physical status of I or II. In contrast, exclusion criteria included ASA status III or IV, as well as patients with systemic illnesses or congenital dysfunctions. Standard general anaesthesia was administered according to institutional protocols, and a multiparameter monitor was utilized to track heart rate (HR), non-invasive blood pressure (NIBP), oxygen saturation (SpO2), and minimum alveolar concentration (MAC). The perfusion index (PI) was continuously monitored using a pulse oximeter equipped with an inbuilt PI sensor. Data collection involved measuring PI and other parameters at specific time points during the induction phase (baseline, 1 minute, 5 minutes, 6 minutes, 8 minutes, and 10 minutes), the maintenance phase (25 minutes, 40 minutes, 55 minutes, 1 hour 10 minutes, 1 hour 25 minutes, and 1 hour 30 minutes), and the emergence and postoperative phase (1–5 minutes, 8 minutes, 10 minutes, and 15 minutes). The data collected were analyzed to ascertain the relationship between the perfusion index (PI) and clinical indicators of anaesthesia depth (e.g., MAC and hemodynamic values) using appropriate statistical software (SPSS/R). Equipment utilized in the study included a multiparameter monitor (HR, ECG, NIBP, SpO2) and a pulse oximeter capable of measuring PI.

2. RESULTS

The study investigated the clinical depth of anaesthesia through the utilization of a pulse oximeter and evaluated the efficacy of the perfusion index (PI) in pediatric patients undergoing elective surgical procedures. Thirty patients participated in this research, with the majority (53%) aged between one to five years, 77% female, and most (53%) weighing between 10 to 20 kilograms. According to the ASA classification, 53% of the patients were classified as Class I, while the remaining 47% were categorized as Class II **(TABLE 1).**

Variables		Percentage %
AGE	1-5	53
	5-10	33
	10-15	7
	15-18	7
GENDER	Male	23
	Female	77
WEIGHT	0-10	7
	10-20	53
	20-30	27
	30-40	10
	40-50	3
HIGHT	65-85	20
	85-105	20
	105-125	33
	125-145	23
	145-165	3
ASA Classification	Class I	53
	Class II	47

Table 1: Baseline demographics

Heart rate (HR) was monitored across three phases: intubation, maintenance, and emergence/post-operative periods. The average HR peaked during the intubation phase at 122.38 ± 3.64 bpm, while it declined to a minimum of 112.42 ± 3.45 bpm during maintenance, yielding an overall average HR of 118.87 bpm. Additionally, the perfusion index (PI) was recorded, exhibiting maximum values during intubation (1.49 ± 0.20) and minimum values during the maintenance phase (1.07 ± 0.06). The minimum alveolar concentration (MAC) demonstrated significant variation across the phases, with a mean of 2.46 ± 0.79 during intubation, 1.34 ± 0.19 during maintenance, and 0.00 throughout the emergence and post-operative periods **(TABLE 2)**.

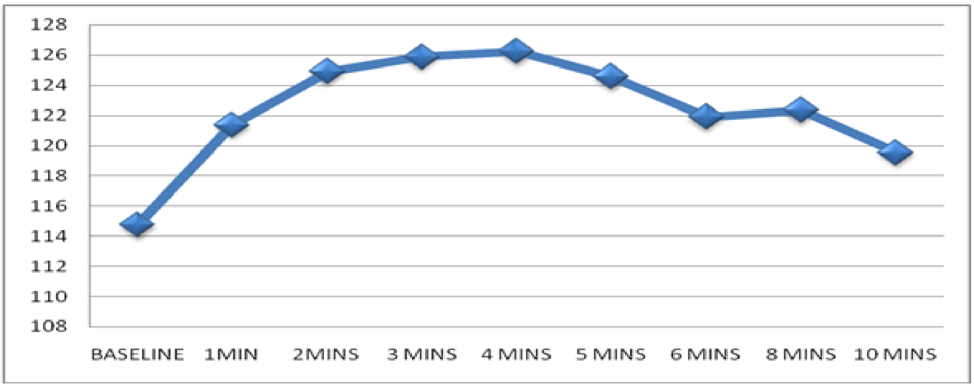
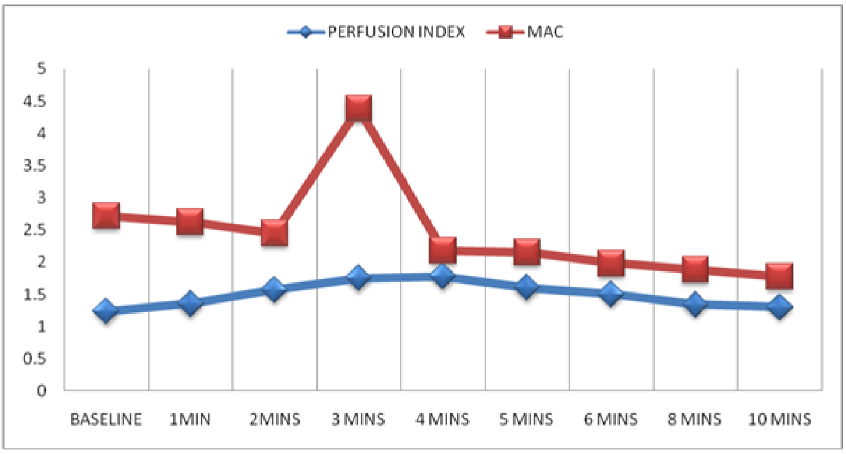


FIGURE-1: MEAN HEART RATE-INDUCTION



FIGUR-2: MEAN PERFUSION INDEX AND MAC-INDUCTION

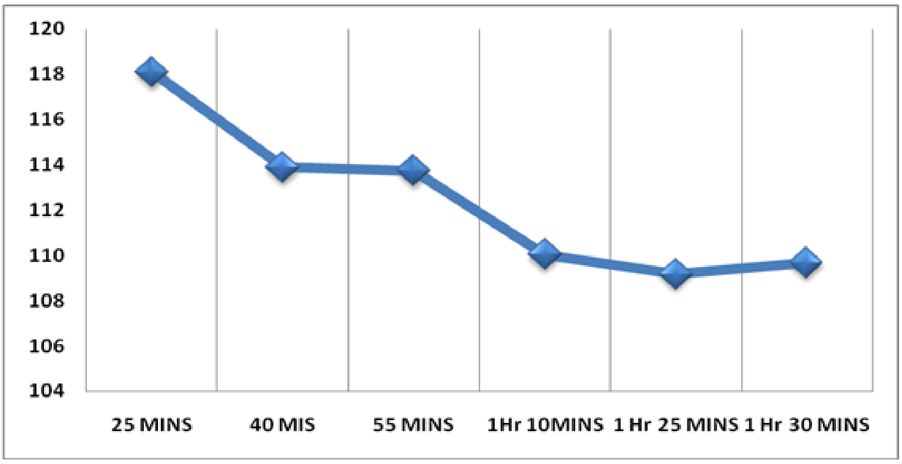
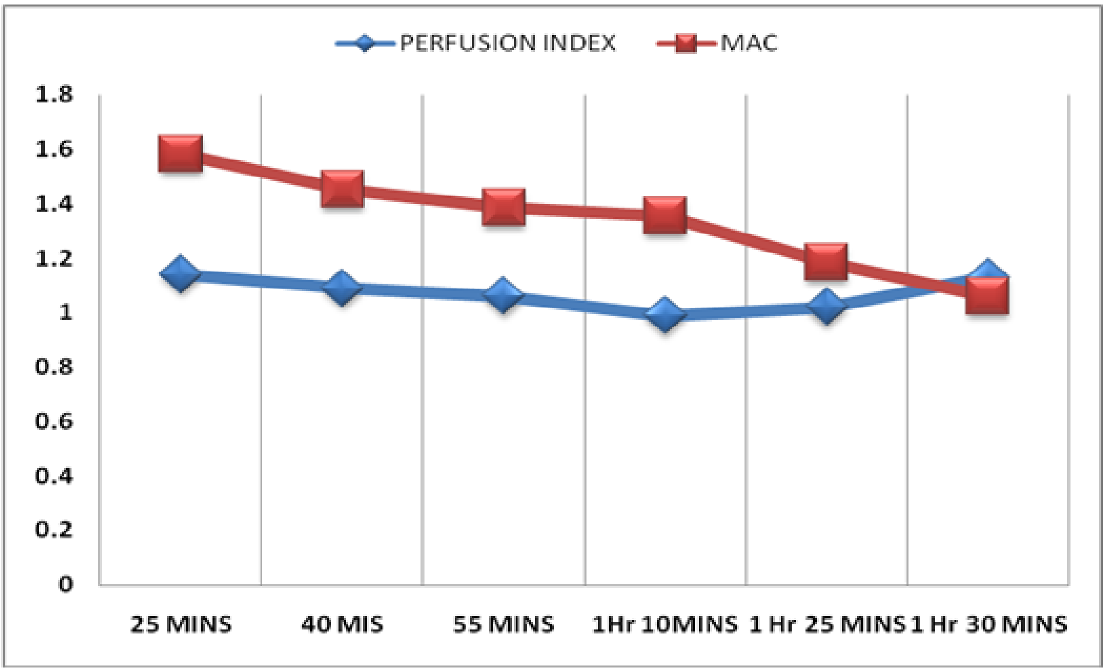
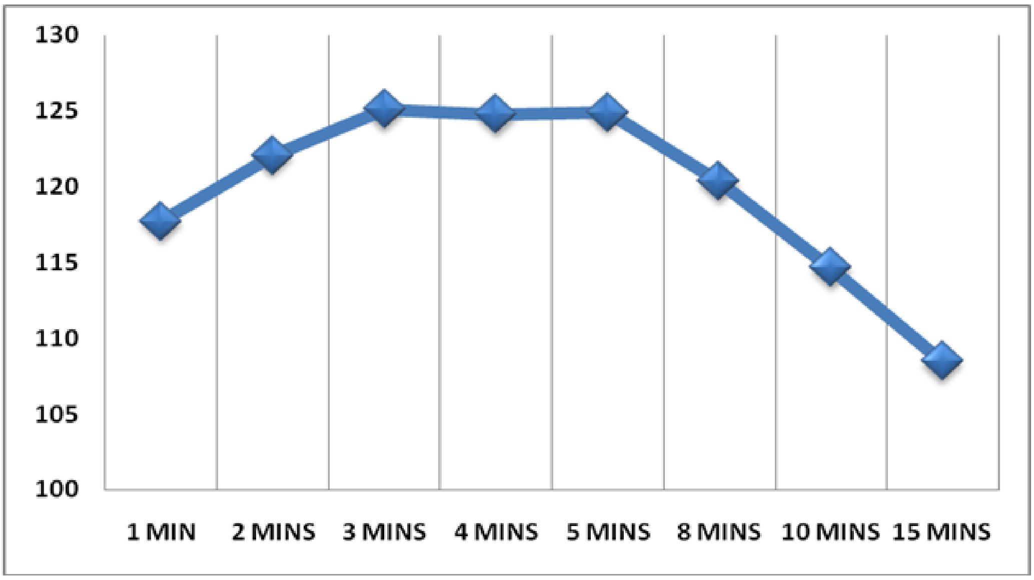


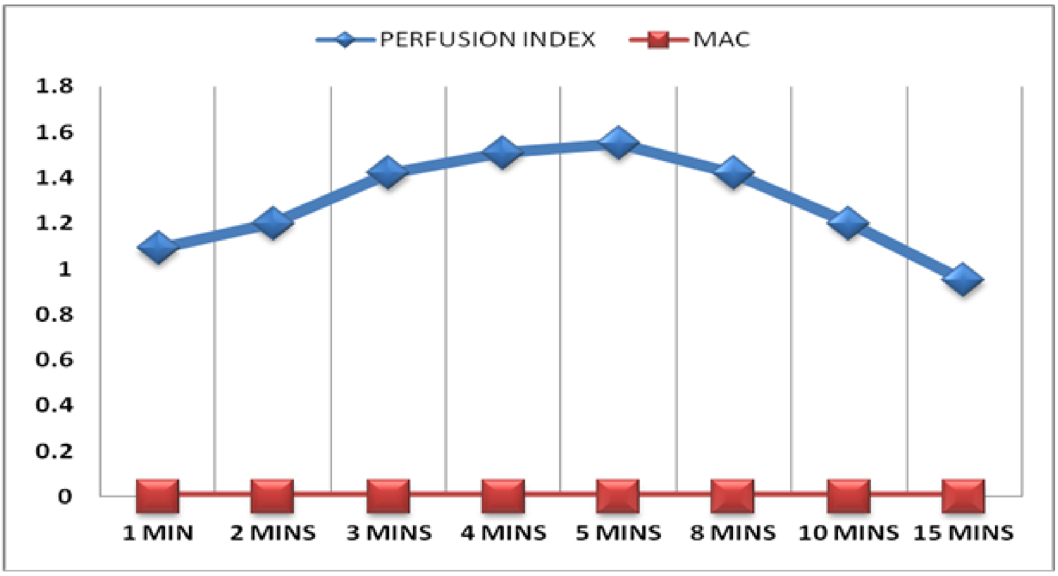
FIGURE-3: MEAN HEARTRATE–MAINTANANCE

FIGUR-4: MEAN PERFUSTION INDEX AND MAC-MAINTANANCE



FIGUR-5: MEAN HEARTRATE–EMERGENCE





FIGUR-6: MEAN PERFUSION INDEX AND MAC–EMERGENCE

TABLE 2: Heart Rate, Perfusion Index, and MAC Across Anaesthesia Phases

Descriptives									
		N	Mean	SD	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
HR	INTUBATION	9	122.38	3.64	1.21	119.58	125.18	114.73	126.23
	MAINTANANCE	6	112.42	3.45	1.41	108.80	116.05	109.17	118.07
	EMERGENCE AND POST OP	8	119.76	5.89	2.08	114.84	124.68	108.50	125.10
	Total	23	118.87	5.93	1.24	116.31	121.44	108.50	126.23

PI	INTUBATION	9	1.49	0.2	.07	1.34	1.64	1.23	1.78
	MAINTANANCE	6	1.07	.06	.02	1.01	1.13	.99	1.14
	EMERGENCE AND POST OP	8	1.29	.21	.08	1.11	1.47	.95	1.55
	Total	23	1.31	.24	.05	1.21	1.42	.95	1.78
MAC	INTUBATION	9	2.46	.79	.26	1.85	3.07	1.77	4.39
	MAINTANANCE	6	1.34	.19	.08	1.14	1.53	1.06	1.58
	EMERGENCE AND POST OP	8	.00	.00	.00	.00	.00	.00	.00
	Total	23	1.31	1.18	.25	.80	1.82	.00	4.39

Statistical analyses employing Levene's test **(TABLE 3)** and ANOVA **(TABLE 4)** indicated significant differences in HR ($p = 0.002$), PI ($p = 0.001$), and MAC ($p = 0.000$) among the various phases of anaesthesia, highlighting distinct physiological responses during the administration of anaesthesia. This research established a robust correlation between the perfusion index and the clinical depth of anaesthesia. Furthermore, the findings support the notion that the perfusion index serves as a reliable indicator for assessing the depth of anaesthesia and advocate for its integration into standard anaesthetic practice to improve the management of pediatric patients.

Test of Homogeneity of Variances				
	Levene Statistic	df1	df2	Sig.
HR	1.429	2	20	.263
PI	5.489	2	20	.013
MAC2	4.680	2	20	.022

TABLE 3: Parameters during various phase of anaesthesia.

ANOVA						
		Sum of Squares	Df	Mean Square	F	Sig.
HR	Between Groups	366.627	2	183.314	8.983	.002
	Within Groups	408.138	20	20.407		
	Total	774.765	22			
PI	Between Groups	.638	2	.319	9.738	.001
	Within Groups	.656	20	.033		
	Total	1.294	22			
MAC2	Between Groups	25.635	2	12.818	49.172	.000
	Within Groups	5.213	20	.261		
	Total	30.849	22			

TABLE 4: Parameters during various phase of anaesthesia using anova.

3. DISCUSSION

The findings of this study indicate a robust correlation between the Perfusion Index (PI) and clinical depth of anaesthesia in pediatric patients undergoing elective surgical procedures. The observed trends in Perfusion Index (PI) during different stages of anaesthesia—highest at intubation (1.49 ± 0.20), lowest at maintenance (1.07 ± 0.06), and intermediate at emergence (1.29 ± 0.21)—are in alignment with existing literature, thereby validating the use of PI as a non-invasive indicator of anaesthesia depth. These results are substantiated by Krishnamohan et al. (2016) and Enekvist and Johansson (2015), who reported similar fluctuations in PI corresponding to changes in sedation levels. The responsiveness of PI across various phases of anaesthesia, as demonstrated by ANOVA findings (p = 0.001), further underscores its potential as a complementary tool alongside standard measures, including heart rate (HR) and minimum alveolar concentration (MAC) [11,12].

Moreover, the negative correlation identified between PI and MAC during the maintenance phase suggests that PI may also reflect reduced peripheral perfusion under more profound anaesthesia, a finding consistent with the expectations outlined by Coutrot et al. (2021). Nonetheless, the observed heterogeneity in the variance of PI (Levene's p = 0.013) indicates individual differences, potentially attributable to variations in vascular reactivity or hemodynamic stability, as previously noted by Skowno (2013) [13,14,15]. This variability emphasizes the need for individualized interpretation, particularly in pediatric populations with inconsistent physiological responses. The noted increase in PI during the emergence phase corresponds with a restoration of peripheral perfusion, corroborating findings by Liu et al. (2018) in patients awakened from sevoflurane anaesthesia. The significant correlations between PI and HR/MAC ($p < 0.05$) advocate for the integration of PI into multimodal monitoring systems, as recommended by Ricci et al. (2023), to enhance the detection of inadequate anaesthesia or excessive sedation, thereby improving patient safety [16,17].

Limitations and Future Directions:

The limited sample size (n = 30) restricts the generalizability of the findings, necessitating more extensive studies to ascertain PI's reliability across diverse pediatric populations. Additionally, the absence of comparisons with the Bispectral Index (BIS) represents a notable omission, and future research should explore the relationship between PI and BIS to evaluate their equivalence. Technical challenges, including motion artefacts and insufficient peripheral perfusion frequently observed in pediatric patients, may adversely affect the accuracy of perfusion index measurements. This situation highlights the need for standardized measurement techniques to ensure reliable results.

4. CONCLUSION

A strong correlation exists between the Pulse Index (PI) and traditional indicators of anaesthesia depth, such as heart rate and minimum alveolar concentration. These findings suggest that continuous monitoring of PI using a pulse oximeter can enhance anaesthesia management by providing a noninvasive and effective method for assessing anaesthesia depth. This approach can improve patient safety, optimise anaesthesia delivery, and improve surgical outcomes for children. Integrating PI into standard anaesthesia practices can significantly improve paediatric anaesthesia care quality.

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