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Original Research Article

ROLE OF PERFUSION INDEX AS A PROGNOSTIC INDICATOR IN PEDIATRIC CRITICAL CARE.

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ABSTRACT

Background: The pulse oximetry-derived peripheral perfusion index (PPI) is a true measure of microhemodynamics that can be used as a valid prognostic indicator in children hospitalized in a PICU. The objective is to determine the usefulness of the peripheral perfusion index as a mortality indicator and morbidity indicator.

Materials and Methods: The Prospective observational study included 377 children over the age of one who were all admitted to the PICU. The mean perfusion index was recorded for 72 hours. The mean perfusion index and its variations were correlated with morbidity and mortality outcomes.

Results: All the parameters that were evaluated in the study were statistically significant with the perfusion index. The majority of the children who had poor outcomes found to have lower mean PI and moderate diurnal and Day 1-Day 3 variations of mean PI.

Conclusion: PPI is a good prognostic indicator that can be used as a parameter in a PICU.

Keywords: Pulse oximetry, Perfusion index, prognostic indicator

INTRODUCTION

Prognosis and clinical outcome are very essential part of Paediatric intensive care unit. Prognostication is central to developing treatment plan and relaying information to family member. Though there are many scores, namely PRISM, PIM, PELOD, SOFA, etc., currently available to predict morbidity and mortality, these scores need repeated clinical evaluation and invasive biochemical procedures as part of risk assessment.

The pulse oximeter-derived Peripheral Perfusion Index (PPI) measures the ratio between pulsatile and non-pulsatile blood flow in peripheral tissues. It directly represents the state of micro-hemodynamic circulation, and its values depend on the perfusion and vascular tone in peripheral tissues. Thus, it reflects two determinants: cardiac output and the balance in the autonomic nervous system. It decreases in patients with sympathetic overactivity and circulatory failure which is predominant in critical illness. Being a representative of these two micro-hemodynamic parameters, the PPI could provide valuable information during the initial evaluation and prognostic assessment.[1]

Poor prognosis was indicated by low PPI in a number of critically ill patient including patient developing shock, sepsis and post-cardiac arrest patients.[2-4]

PPI as guide for fluid therapy

Given that PPI is influenced by both cardiac output and vasomotor tone, in the event that sympathetic activity remains unchanged, PPI may serve as a proxy for cardiac output. Moreover, PPI demonstrated a strong capacity to identify alterations in cardiac output in septic shock patients.[3]

As a result, PPI was substituted for cardiac output in a variety of manoeuvres during fluid responsiveness testing. A five percent increase in PPI after a 200 ml fluid bolus can be used to predict fluid receptivity in patients with septic shock.[5]

The increase in PPI with preload challenge can identify responders, but the failure of the PPI to increase does not definitively rule out fluid responsiveness. It should be noted that the value of PPI in various tests of fluid responsiveness is more prominent in the positive predictive value than the negative predictive value.[5]

PPI as an objective measure for pain

Subjective scores are typically used to assess pain, and patient cooperation is necessary. Therefore, it is typically difficult and necessitates the use of a laborious scoring system to evaluate pain in uncooperative individuals, such as critically ill patients. Lastly, there are no instruments available to measure pain in real time. Numerous research employed the relationship between sympathetic activity and PPI as a roundabout way to assess pain. In patients who are not intubated, a 3-point shift in the behavioural pain scale may be reliably identified by a 0.7 drop in the PPI score.[6]

Other uses of PPI in critically ill patients

Moreover, patient mortality can be predicted by a PPI < 0.2. Within the first half-hour following an out-of-hospital arrest, the mean PPI was found to be independently correlated with poor neurologic prognosis or 30-day mortality in individuals experiencing post-return of spontaneous circulation (ROSC)(1). Hypotension during dialysis can be predicted with a positive predictive value of 80% and a negative predictive value of 100% using a pre-dialysis PPI ≤ 1.8.[7] There is typically an increase in cardiac output when a patient is weaned off of artificial breathing because their thoracic pressure is changing from positive to negative. This rise in cardiac output is thought to be one indicator of a successful weaning process.[8]

Moreover, stress and sympathetic hyperactivity may be linked to weaning failure, which may have influenced the relationship between the PPI and weaning outcome. 95% of the time, reintubation can be predicted if the PPI does not increase by 40% by the conclusion of the spontaneous breathing trial.[9]

Limitations of PPI

There are certain restrictions on the use of PPI in clinical practice. (1) Because PPI exhibits skewness and a broad measurement range in healthy individuals, it is preferable to compare changes in PPI to baseline values obtained from the same individual. (2) The risk of weak signals should always be considered, particularly in cold extremities, low temperatures, and large vasopressor dosages. (3) Because the PPI measures the ratio of pulsatile to non-pulsatile peripheral blood flow, it is impractical to utilise it in patients undergoing extracorporeal membrane oxygenation. (4) Because the PPI is influenced by two variables—cardiac output and autonomic activity—it is best to evaluate its change over brief intervals during which one of these two variables is comparatively stable. This allows the PPI to be closely linked with a single variable. Nevertheless, because both variables have the same effect on the PPI, even if it was influenced by them, the PPI might still offer a useful indication of the prognosis for the patient(1).

No data on the mean value of the perfusion index (PI) and its variation reflecting the general outcomes of critically ill paediatric patients has been reported, and the studies that have been conducted have mainly focused only on circulatory changes. Hence, this study aimed to evaluate the usefulness of the pulse oximetry-derived perfusion index as a prognostic marker in children admitted to the paediatric intensive care unit, and to determine the correlation between the mean perfusion index value and its variation with morbidity and mortality outcomes.

MATERIALS AND METHODS

This prospective observational study conducted in the paediatric intensive care unit at Kamala Raja Hospital, Gajra Raja Medical College, Gwalior, Madhya Pradesh, through the period from August 2022 to August 2023. This study comprises 377 PICU-admitted children who are aged over 1 year using a simple random sampling method.

Inclusion Criteria

All children aged > 1 year admitted to the paediatric intensive care unit at a tertiary care hospital .

Exclusion Criteria

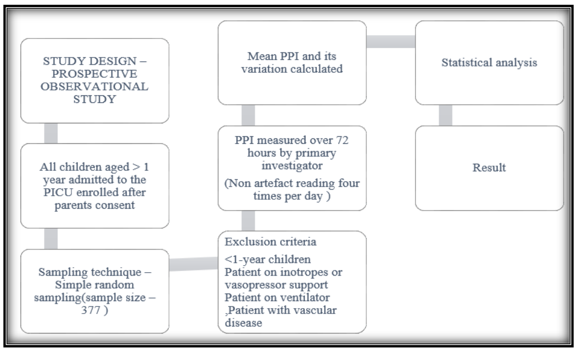
1) < 1-year children
2) Patient on inotropes or vasopressor support;
3) Patient on ventilator;
4) Patient with vascular disease.

Methodology: This study had been started after getting ethical approval of institutional ethical committee of institution. After obtaining informed consent from parents, patients were enrolled as per inclusion criteria. Data collection variable were Patient demographic profile and pulse oximeter parameters (Perfusion Index, PI variation, SpO2, and pulse rate), along with other vital signs, are recorded daily for the first 72 hours of admission or until shifting to ward or death.

For pulse oximetry-derived Perfusion Index measurements (pulsatile infrared signal/non-pulsatile infrared signal× 100), the patient's hand was placed at the heart level, and the pulse oximeter sensor (portable) was placed on the fourth digit of the non-dominant hand (if possible) for at least thirty seconds until a non-artefact reading came up five times and an average of five readings was recorded. The same method and same time interval were used four times in a day for the initial 72-hour recording, which was done till the patient got shifted or died.

Outcome variable were 1)Duration of PICU stay 2) Development of shock; 3) Oxygen required > 72 hours; 4) Require ventilator support; 5) Death.

Study Design – Prospective Observational Study



Statistical Analysis: Descriptive statistics are presented as frequency (percentage) for categorical variables and median with interquartile range (IQR) for non-normally distributed data. SPSS 15.0 was used for statistical analyses. The mean value of daily PI values for 72 hours or until either shifting or death was evaluated. For the prognostic scores, mean PI, diurnal variation & Day 1 – day 3 scores were analyzed.

RESULTS

This study aimed to determine the pulse oximetry-derived perfusion index as a prognostic indicator among 377 children aged over one year who are admitted to the PICU with a correlation between morbidity and mortality outcome.

Table 1: Demographic variables of study population

Demographic Variables		Number	Percentage
Gender distribution	FEMALE	172	45.62
	MALE	205	54.38
Age distribution	1-5 YEARS	152	40.32
	5-10 YEARS	142	37.67
	> 10 YEARS	83	22.02
Socio economic status	Upper class	32	8.49
	Upper middle	76	20.16
	Lower middle	85	22.55
	Upper lower	142	37.67
	Lower	42	11.14
Body mass index	Underweight	84	22.28
	Healthy weight	210	55.70
	Overweight	51	13.53
	Obesity	28	7.43
	Severe Obesity	4	1.06

Children who were admitted to the PICU were enrolled as per inclusion and exclusion criteria (377); of them, 172 (45.6%) were females and 205 (54.3%) were males. Most of them belong to the age group of 1–5 years, and the majority belong to the upper lower class of modified kuppuswamy classification. Most of them have a healthy weight range.

Table 2: Blood pressure and perfusion index of study population

Parameters		Number	Percentage
Blood pressure	HYPOTENSION	137	36.3
	NORMAL	217	57.6
	HYPERTENSION	23	6.1
Perfusion index	0.1 - 1.5	92	24.40
	1.6 – 3.0	189	50.13
	3.1 – 4.5	83	22. 02
	4.5 – 6.0	10	2.65
	> 6 .0	3	0.80

This data depicts that a majority of individuals in the sample had normal blood pressure levels, while a smaller percentage showed signs of either low or high blood pressure.
Regarding perfusion index, the values were categorized into several ranges: 0.1 - 1.5 (24.40%), 1.6 – 3.0 (50.13%), 3.1 – 4.5 (22.02%), 4.5 – 6.0 (2.65%), and greater than 6.0 (0.80%). This distribution suggests that most individuals had mean PPI Value less than 3.0.

Table 3: Variation of perfusion index in study population

Grades	DIURNAL VAR OF PI	DAY 1-3 VAR OF PI	% DIURNAL VAR OF PI	% DAY 1-3 VAR OF PI
Not Applicable	39	141	10.34	37.40
<10%	127	89	33.69	23.61
10-49%	166	86	44.03	22.81
50-75%	43	52	11.41	13.79
>75%	2	9	0.53	2.39

The data which were obtained, categorized PI (Perfusion Index) variability into different grades based on observations over diurnal periods and across days 1-3. It included several grades of mean PI value variation over the time period: "NOT APPLICABLE," "<10%," "10-49%," "50-75%," and ">75%." In the dataset, the "NOT APPLICABLE" category showed 39 cases of diurnal variability, accounting for 10.34% of the total, and 141 cases across days 1-3, which constituted 37.40%. Grades indicating lower variability, such as "<10%" with 127 cases (33.69% diurnal, 23.61% across days 1-3) and "10-49%" with 166 cases (44.03% diurnal, 22.81% across days 1-3), were predominant. The "50-75%" grade exhibited 43 cases (11.41% diurnal, 13.79% across days 1-3), while the highest variability grade, ">75%," had only 2 cases (0.53% diurnal, 2.39% across days 1-3). This distribution provided a comprehensive overview of the variability patterns observed within the dataset, highlighting the prevalence of different grades of PI variability over both short-term (diurnal) and longer-term (days 1-3) periods.

Table 4: Correlation between mean perfusion index and morbidity outcome in study children

Parameters		Perfusion index 0.1 – 1.5 (n=92)	1.6 – 3.0 (n=189)	3.1 – 4.5 (n=83)	4.6 – 6 (n=10)	> 6 (n=3)	Total (n=377)	p value
Development of shock	No	20	151	61	9	3	244	< 0.05
	< 24 hours	48	17	8	1	0	74	
	24 – 48 hours	19	13	12	0	0	44	
	48 – 72 hours	5	8	2	0	0	15	
Oxygen support	< 24 hours	22	33	10	1	0	66	0.008
	24 – 48 hours	22	84	31	5	3	145	
	48 – 72 hours	23	48	24	4	0	99	
	> 72 hours	25	24	18	0	0	67	
Ventilatory support	No	56	155	71	10	3	295	0.003
	< 24 hours	14	9	1	0	0	24	
	24 – 48 hours	5	5	1	0	0	11	
	48 – 72 hours	7	6	0	0	0	13	
	> 72 hours	10	14	10	0	0	34	
Picu stay	< 24 hours	12	20	7	0	0	39	< 0.05
	24 – 48 hours	8	71	21	3	3	106	
	48 – 72 hours	32	54	35	7	0	128	
	> 72 hours	40	44	20	0	0	104	

The table 4 presents data on correlation of mean PI with different parameters (Perfusion Index, Development of Shock, Oxygen Support, Ventilatory Support, and PICU Stay) of children who are admitted in PICU. Notably, the majority of patients without shock fell within the 1.6 - 3.0 PI range (151 patients, 78.09%), whereas shock was more prevalent in patients with PI ≤ 1.5 (20 patients, 21.74%). Thus suggesting a correlation between lower PI values and increased likely hood of developing shock. Further, most of the children who required prolonged oxygen support (> 72 hours), undergone prolonged ventilatory and lengthier hospital stay shown to have mean PI value less than < 3.0. This association was statistically significant ($p < 0.05$), indicating that lower mean PI values may influence the poor morbidity outcome.

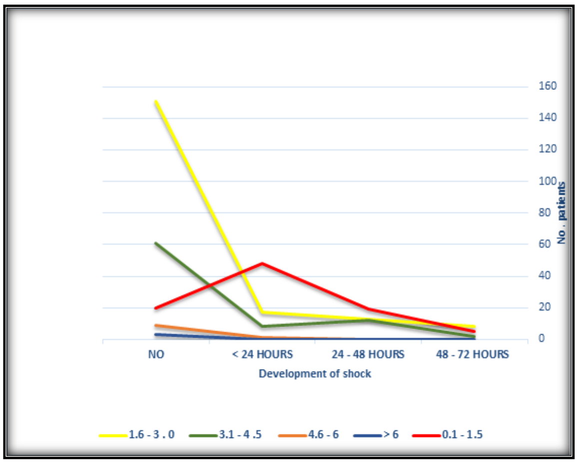


Figure 1: correlation of mean perfusion index with development of shock

Table 4: Correlation between diurnal variation of perfusion index and its morbidity outcome in study children.

Parameters		Diurnal variation of perfusion index NA (n=39)	<10% (n=127)	10-49% (n=166)	50-75% (n=43)	>75% (n=2)	Total (n=377)	p value
DEVELOPMENT OF SHOCK	NO	27	113	103	1	0	244	< 0.05
	< 24 HRS	12	4	19	39	0	74	
	24 – 48 HRS	0	7	32	3	2	44	
	48 – 72 HRS	0	3	12	0	0	15	
OXYGEN SUPPORT	< 24 HRS	39	13	9	5	0	66	< 0.05
	24 – 48 HRS	0	74	59	12	0	145	
	48 – 72 HRS	0	29	58	10	2	99	
	> 72 HRS	0	11	40	16	0	67	
VENTILATORY SUPPORT	NO	28	113	129	25	0	295	< 0.05
	< 24 HRS	11	2	6	5	0	24	
	24 – 48 HRS	0	4	6	1	0	11	
	48 – 72 HRS	0	2	7	2	2	13	
	> 72 HRS	0	6	18	10	0	34	
PICU STAY	< 24 HRS	39	0	0	0	0	39	< 0.05
	24 – 48 HRS	0	65	35	6	0	106	
	48 – 72 HRS	0	47	62	19	0	128	
	> 72 HRS	0	15	69	18	2	104	

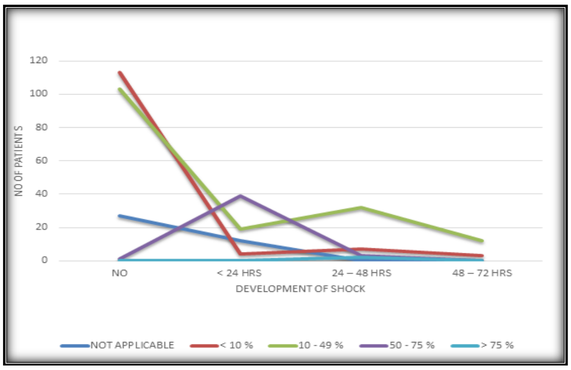


Figure 2: correlation between diurnal variation of perfusion index with development of shock

Data [Table 5] shows that children with a diurnal variation in mean perfusion index (PI) between 50–75% were more likely to develop shock within 24 hours of PICU admission. Children who required prolonged oxygen and ventilatory support were noted to have a diurnal variation in mean PI between 10–75%. Furthermore, children with longer hospital stays (>72 hours) generally had a diurnal variation in mean PI between 10–49%. This suggests that moderate variability in perfusion index may correlate with extended hospitalization. Although all the parameters were statistically significant, the diurnal variation in mean PI correlated most strongly with the development of shock—indicating that greater variability within a narrower range may be more predictive.

[Table 6] indicates that the overall variation in mean perfusion index (PI) from day 1 to day 3 was statistically significant. Most children who developed shock early, required prolonged oxygen or ventilator support, and had longer hospital stays exhibited a moderate (10-49%) D1–D3 variation in mean PI.

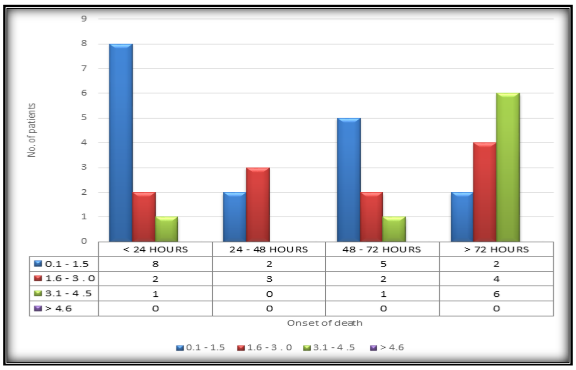


Figure 3: Correlation of mean perfusion index and its variation with mortality outcome

Table 6: Correlation between Day 1 and Day 3 variation of mean perfusion index and its morbidity outcome in study children.

Parameters		Day 1 to Day 3 variation of perfusion index					Total (n=377)	p value
		NA (n=145)	<10% (n=89)	10-49% (n=84)	50-75% (n=50)	>75% (n=9)		
Development of shock	NO	121	80	31	9	3	244	< 0.05
	< 24 HRS	21	8	28	15	2	74	
	24 – 48 HRS	3	0	18	19	4	44	
	48 – 72 HRS	0	1	7	7	0	15	
Oxygen support	< 24 HRS	50	5	4	6	1	66	< 0.05
	24 – 48 HRS	95	21	16	11	2	145	
	48 – 72 HRS	0	52	28	17	2	99	
	> 72 HRS	0	11	36	16	4	67	
Ventilatory support	NO	129	80	50	31	5	295	< 0.05
	< 24 HRS	13	1	3	6	1	24	
	24 – 48 HRS	3	0	1	5	2	11	
	48 – 72 HRS	0	2	8	3	0	13	
	> 72 HRS	0	6	22	5	1	34	
PICU stay	< 24 HRS	39	0	0	0	0	39	< 0.05
	24 – 48 HRS	106	0	0	0	0	106	
	48 – 72 HRS	0	70	35	23	0	128	
	> 72 HRS	0	19	49	27	9	104	

Table 7: Correlation of mean diurnal variation of perfusion index and its variation with mortality outcome

Parameters		Diurnal variation of perfusion index					Total (n=377)	P value
		NA (n=39)	<10% (n=127)	10-49% (n=166)	50-75% (n=43)	>75% (n=2)		
Death	NO	28	121	156	35	1	341	< 0.05
	< 24 HRS	11	0	0	0	0	11	
	24 – 48 HRS	0	2	1	1	1	5	
	48 – 72 HRS	0	3	3	2	0	8	
	> 72 HRS	0	1	6	5	0	12	

Table 8: Correlation of mean day 1 to day 3 variation of perfusion index and its variation with mortality outcome

Parameters		Day 1 to day 3 variation of perfusion index					Total (n=377)	p value
		NA (n=145)	<10% (n=89)	10-49% (n=84)	50-75% (n=50)	>75% (n=9)		
Death	NO	130	87	68	47	9	341	
	< 24 HRS	11	0	0	0	0	11	
	24 – 48 HRS	4	0	1	0	0	5	<0.05

	48 – 72 HRS	0	2	5	1	0	8	
	> 72 HRS	0	0	10	2	0	12	

Mean Perfusion Index and Mortality:

- The mean perfusion index (PI) was found to be statistically significant in relation to overall mortality. Specifically, most children who died during their PICU stay had a mean PI ranging between 0.1 and 1.5.None of the children who died had a mean PI greater than 4.5. This suggests that extremely high perfusion index values (>4.5) may not be associated with mortality in this cohort.

Variation in Perfusion Index and Mortality:

- Both diurnal variation and day 1 to day 3 variation of the mean perfusion index were statistically strongly significant in relation to mortality outcomes.
- But, Most children who died during their PICU stay had moderate diurnal and day 1 to day 3 variations in their mean perfusion index (10 - 49%).

DISCUSSION

Correlation of PPI and shock: A prospective observational study conducted by Siva Prasath P. et al. found that clinical shock could be reasonably detected when the perfusion index (PI) value was less than 1.15 in children under 3 years of age, less than 1.25 in children aged 3–10 years, and less than 1.55 in children aged 10–12 years. Additionally, a 57% reduction in the PI value from the baseline was indicative of impending shock in children.[2] Also, Yuanfeng Shi, Ruihong Yin et al. reported that the sensitivity of PPI < 1.4 for detecting septic shock was 94.3%, while the specificity was 28.2%.[10] Similarly, Hanan Mostafa et al. conducted a prospective observational study to evaluate peripheral perfusion index and heart rate variability (HRV) as early predictors of intradialytic hypotension in critically ill adult patients. Both baseline HRV and baseline PPI showed good predictive value for intradialytic hypotension.[7] In our study, after 72 hours of monitoring, 133 children developed shock. Most of those who had a perfusion index (PI) range of 0.1–1.5, a 50–75% diurnal variation, and a 10–49% D1–D3 variation developed shock within 24 hours. Notably, Only one child who developed shock had a mean PI value greater than 4.5. This finding signifies that children with a lower mean PPI are more likely to develop clinical shock earlier than those with higher mean PPI values.

Correlation of PPI with Oxygen Support: Yuankai Zhou et al. found that a lower PI might be associated with prolonged oxygen support in adult patients.[11] In contrast, Katrina T. Ionia et al. and Gec Baslangich et al. reported that PPI values did not correlate with hypoxemia or oxygen requirements in the neonatal age group.[12,13] In our study, it was observed that all children admitted to the PICU required oxygen support, and most had a mean PI value between 1.6 and 3. Children who required prolonged oxygen support and hospital stays (>72 hours) had a mean perfusion index (PI) value of less than 4.5, a wider range of diurnal variation (10–75%), and moderate variability (10–49%) in D1–D3 changes of the mean PI. These findings were statistically significant. As our study focused on children over one year of age, more research is needed to support this observed negative correlation.

PPI as prognostic indicator: In this study, it was observed that the mean perfusion index (PI) value and its variation were statistically significant predictors of morbidity outcomes. Several research studies have analyzed the role of PPI as an overall prognostic indicator. Patrick S. Rasmussen et al. reported that the highest frequency of serious adverse events and mortality was seen among patients with a low median PPI.[14] Xinge Shi et al. also found that a lower mean PPI value was a better predictor of prolonged ICU stays in adult surgical patients than elevated lactate levels.[15] Interestingly Claudio De Felice et al. noted that a maternal perfusion index ≤1.9 during the perianesthesia phase of elective cesarean section was an independent predictor of early adverse neonatal respiratory outcomes.[16] A prospective cross-sectional study conducted by Murat Das et al. stated that a decrease in PPI increased the likelihood of hospitalization and 30-day mortality.[17] Furthermore, Pyoyoon Kang et al. reported that the risk of postoperative acute kidney injury (AKI) increased when PPI remained below 0.5 for more than 10% of the surgery time in his retrospective cohort study.[18]

Correlation of PPI and requirement of mechanical ventilation: It was observed that Children who required ventilatory support, most of them had mean PI value less than 3.0. Similiarly children who required prolonged ventilation most of them had mean PI value less than < 3.0 , diurnal variation between 10-75 % and D1 – D3 variation between 10-49 %. Ahmed Lotfy et al. noted that failure to augment the PPI by 41% at the end of spontaneous breathing trial could predict re-intubation with a negative predictive value of 95%.[19] Longxiang Us et al. also reported that higher mean airway pressure and a lower perfusion index provide a worse prognosis in mechanically ventilated patients, and it appears that these two variables have a causal interaction.[20] Soumya C. et al. found an association between peripheral perfusion status and the prognosis of patients on mechanical ventilators. In that study, it was found that prognosis had a significant association with the level of peripheral perfusion among mechanically ventilated patients ($p<0.001$).[21]

PPI as mortality indicator: In this study, the mean perfusion index was shown to be statistically significant with respect to overall mortality. Most of the children who died in the PICU had a mean PI of 0.1 to 1.5. None of the children who died in the PICU had a mean PI of more than 4.5. Overall, the diurnal and day 1–day 3 changes in mean perfusion index have a statistically significant effect on mortality. Most of the children who died in the PICU showed diurnal and D1-D3 variations in their mean PPI, ranging from 10 to 49%. Similarly, Huai-wu He et al. evaluated that PI < 0.2 is related to poor outcomes, and PI is highly predictive of mortality for septic patients after resuscitation.[22] Hiroshi Okada et al. conducted an observational study and found that PI (per 1% decrease) was associated with the development of cardiovascular death (hazard ratio, 1.49; 95% CI, 1.30 to 1.70) among patients without ABI≤0.9.[23] Also Mehmet Alakaya et al. reported that the specificity and sensitivity values for mortality were 90.1% and 75.9% at a perfusion index cutoff of </= 0.63, respectively.[24] An observational study conducted by Yahaya Ayhan Acar et al. conducted a cohort study to determine the ability of the perfusion index to predict mortality in critically ill patients. In that study, it was known that with a set cut-off value of 2.35, the sensitivity and specificity were 88% and 94%, respectively.[25]

A review of the literature on the aforementioned studies revealed that a lower mean Perfusion Index (PPI) was associated with poor morbidity and mortality outcomes. However, the cutoff value for low PPI varied among different studies, ranging from 0.2 to 2.5. Notably, none of these studies examined diurnal variation or day 1 to day 3 (D1–D3) changes in mean PPI to assess the effect of therapy and outcomes following PICU admission. Our study, with a large sample size, compares mean PPI values and their variations with cardiorespiratory parameters, aiming to establish a cutoff value for low mean PPI and its predictive value for morbidity and mortality outcomes.

CONCLUSION

Prognostic assessment in pediatric intensive care is crucial for planning therapeutic interventions and communicating possible outcomes to parents at the time of triage. This study, by correlating various parameters with ranges of mean PPI and its variations, found that PPI could be a useful tool for prognostication during initial assessment and follow-up care.

Recommendations

- Measurement of pulse oximeter-derived perfusion index is a simple, less time-consuming, feasible, and cost-effective technique.
- The measurement of mean pulse oximeter-derived perfusion index should be included as an integral part of emergency triage and routine pediatric critical care monitoring for early detection of shock and prognosis assessment.

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