Role of Renal Arterial Doppler in Early Detection of Acute Kidney Injury in Critically Ill Late Preterm Infants

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Abstract:

Background: An acute kidney injury (AKI), a potentially fatal illness with a high death rate, high treatment costs, and poor outcomes, is more likely to affect late preterm newborns. Monitoring microcirculation parameters is the most important criteria in anticipating AKI. In order to evaluate renal perfusion at the bedside of critically ill late preterm infants in the intensive care unit, two Doppler-based metrics were proposed: the kidney resistive index (RI) and the pulsitility index (PI).

Objective: The aim was to determine the value of renal arterial Doppler in early recognition of acute kidney injury in critically ill preterm infants.

Methods: Seventy-five late preterm newborns who were admitted to the neonatal critical care unit at AlZahraa Hospital University from January 2023 to January 2024 participated in this observational case control research. This study was done for a period of 1 year. Every case under study went through history taking, physical examination, Laboratory investigations (CBC, ABG, CRP, liver and kidney function) and Radiological investigation (renal Doppler at 3rd and 7th day of life).

Results: The RI and PI levels in the AKI group are increased by a significant amount at the 3rd day and at 7th days compared to the non-AKI group. The ideal cut-off value for RI to anticipate AKI is > 0.82 with sensitivity of 61.54%, specificity of 96.0% and AUC of 0.782 Also, The Receiver operating characteristic curve (ROC) shows that the PI can detect AKI at the cutoff point > 1.2 with sensitivity of 92.31%, specificity of 64.0% and AUC of 0.874.

Conclusion: Renal Doppler assessment is feasible, noninvasive, bedside and promising tool in early identification of acute kidney impairment in extremely ill late-preterm infants.

Keyword: Late preterm, AKI, Renal Doppler.

Introduction:

One of the most common illnesses among NICU patients is acute kidney injury, which has a death rate of 20–50% and a prevalence of 8–24% in hospitalized premature babies.[17]

Congenital renal malformations, renal artery thrombosis, acute tubular necrosis, drugs (gentamicin, indometacin, or ACE inhibitor)[8], and the use of NSAIDs during pregnancy are common causes of AKI in neonates. Other known risk factors for AKI include perinatal asphyxia, neonatal sepsis, patent ductus arteriosus, and necrotizing enterocolitis.[1]

Acute kidney injury is highly related with bad consequences, such as extended NICU stay, higher mortality, and more demand of mechanical ventilation.[18]

In the first few days of life, assuming a mother's kidney function is normal, a progressive rise in plasma creatinine of over 1.5 mg/dl for a minimum of two days is considered acute kidney injury in neonates.[19]

Since creatinine rises during the first three days to four days of life, reflecting the mother's and then declines over the first two weeks, the serum creatinine in preterm newborns throughout the first few days of life might not representing the glomerular filtration rate.[13]

The Kidney Disease Improving Global Outcomes criteria (KDIGO) is dependent on significant changes in renal function tests and urine output. KDIGO is the most accepted criteria for defining AKI until now.[11]

KDIGO have some limits in newborns, considering considerable serum creatinine spikes may occur one to two days after a kidney insult and are usually noticed after greater than a half renal function has been lost. Ultrasonography offers a dependable and safe tool to diagnose and monitor the incidence of AKI in NICU in order to get beyond previously mentioned limits.[15]

Early AKI detection can be achieved with renal arteries Doppler parameters like renal resistive index (RI) and renal pulsatility index (PI), which are quick, noninvasive, and repeatable.[7]

High RRI value indicates development of acute tubular necrosis (ATN), whereas lower value is linked to improved renal perfusion because it represents a resistance to flow of blood.[6]

Ethical consideration:

- An informed consent was obtained from all parents before getting involved in the study.
- Confidentiality of all data was ensured.
- No conflict of interest regarding study or publication.
- The authors declared no fund regarding study or publication.
- Participation was voluntary and the parents had the right to withdraw from the study at any time without giving any reasons and without consequences.

The protocol of the thesis approved by the ethical committee of both pediatric department and the faculty of medicine for girls Al-Azhar University, No. IRB00012239

Sample size calculation:

Through using Z score table with 1 confidence interval (95%) with consideration of estimated incidence ratio of the condition with a 5% drop-out percentage, 75 participants from late preterm infants will be included in study.

Study design & population:

This observational case control research was conducted on 75 late preterm infants who were hospitalized to the newborn critical care unit at Al-Zahraa University Hospital, which is part of Faculty of Medicine, Al-Azhar University for girls in Cairo. This study was done for a period of 1 year from January 2023 to January 2024 following approval by the medical faculty's ethical committee at AL-Azhar University. This study population included 38 critically ill late preterm newborn infants and 37 healthy control normal late preterm infants of the same age group.

Inclusion criteria:

Late preterm newborn infants between 34 weeks to 36 weeks of gestation of both sexes, who are critically ill (A critical illness is one that has progressed to the point where the body's physiology is significantly disrupted, as sepsis, respiratory problems, cardiovascular impairment, neurological, gastrointestinal or other problems that require urgent appropriate care).

Normal control late preterm neonates whom are clinically stable and have maternal risk factors admitted in NICU just for follow-up.

Exclusion criteria:

We excluded neonates with developmental malformations of the kidney and urinary system, congenital anomalies of the heart and neonates with any genetic disease, metabolic disease, or any other anomalies.

Study procedure:

Every case under study underwent through following:

I. Thorough maternal history taking including: mode of delivery, maternal risk factors, maternal illness and maternal medications and neonatal history including: gestational age, Apgar score, complication at birth and congenital anomalies.

II. Clinical examination:

• Thorough neonatal complete general including (posture, tone, color, activity, and head to toe examination) and systemic examination including (chest, heart, abdomen, genitourinary, musculoskeletal and neurological examination).

• Vital data (heart rate, respirator rate, blood pressure, oxygen saturation and temperature).

• Anthropometric measurement and demographic data including, weight in kg, length in cm, head circumference in cm, gender and gestational age assessment.

Neonates were monitored clinically for AKI by measuring urine output daily in all infants. After admission the baseline serum creatinine is assessed before 24 hours, then follow-up of serum creatinine until meeting criteria of AKI depending on the modified nKDIGO classification, which is dependent on a rise in serum creatinine levels from reference or baseline creatinine and/or decrease of urine output.

III. Laboratory investigations:

- A complete blood count (CBC) was done using automated counter Cell Dyn Ruby-Germany.
- Arterial blood gases (ABG) were done using the RAPIDLab® 348EX Blood Gas System.
- C-reactive protein (CRP), liver function (ALT and AST) and kidney function (urea and creatinine) tests were done by using the auto analyzer Synchron CX5 (Becckman, USA).

IV. Radiological investigation:

Renal blood flow was evaluated on the 3rd day of life with Doppler, then follow up of renal Doppler on the 7th day by using 9-11 MHz linear probe to scan the kidney in neonates.

Statistical analysis

Data were gathered, edited, coded, and loaded into version 26 of the Statistical Package for Social Science (IBM SPSS). For parametric data, the mean, standard deviations, and ranges were provided; for non-parametric data, the median and interquartile range (IQR) were provided. Additionally, qualitative details were displayed as percentages and numbers.

In order to compare groups with qualitative data, the Chi-square test was used. The Independent t-test was used to compare two groups with quantitative values and a parametric distribution, and the Mann-Whitney test was used to compare two groups with quantitative material and a non-parametric distribution.

The correlation among two quantitative factors in the same group was evaluated using Spearman correlation coefficients.

To predict the incidence of AKI at follow-up, the ROC curve was utilized quantitatively to identify the optimal cut-off point based on its sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the curve (AUC) of RI and PI.

The allowable margin of error was set at 5%, while the confidence

interval was set at 95%. As follows, the p-value was deemed significant:

Non-significant P > 0.05; significant P < 0.05 P less than 0.01: Highly significant.

RESULTS:

Table 1: Demographic and Anthropometric data of the studied neonates:

		Control group No. = 37	Patients group No. = 38	Test value	P-value	Sig.
Sex	Female	17 (45.9%)	14 (36.8%)	0.641*	0.423	NS
	Male	20 (54.1%)	24 (63.2%)			
Gestational age (week)	Mean ± SD	35.62 ± 0.49	35.05 ± 0.84	3.579•	0.001	HS
	Range	35 – 36	34 – 36			
Body weight	Mean ± SD	2.46 ± 0.37	2.34 ± 0.34	1.480•	0.143	NS
	Range	1.8 – 3.4	1.8 – 3.2			
Length	Mean ± SD	44.78 ± 1.67	44.68 ± 1.96	0.237•	0.814	NS
	Range	41 – 47	40 – 49			
Head circumference	Mean ± SD	34.08 ± 1.06	33.87 ± 1.17	0.824•	0.412	NS
	Range	31 – 36	32 – 36			
Mode of delivery	C.S	32 (86.5%)	35 (92.1%)	0.621*	0.431	NS
	NVD	5 (13.5%)	3 (7.9%)			

P-value < 0.05 indicates significance; P-value < 0.01 indicates high significance; P-value > 0.05 indicates non-significant.
*: Chi-square test; •: Independent t-test

According to the table, there was no discernible difference between the two groups in terms of demographic data and characteristics of the patients under study, with the exception of the patient group's significant drop in gestational age (weeks) (p-value <0.001).

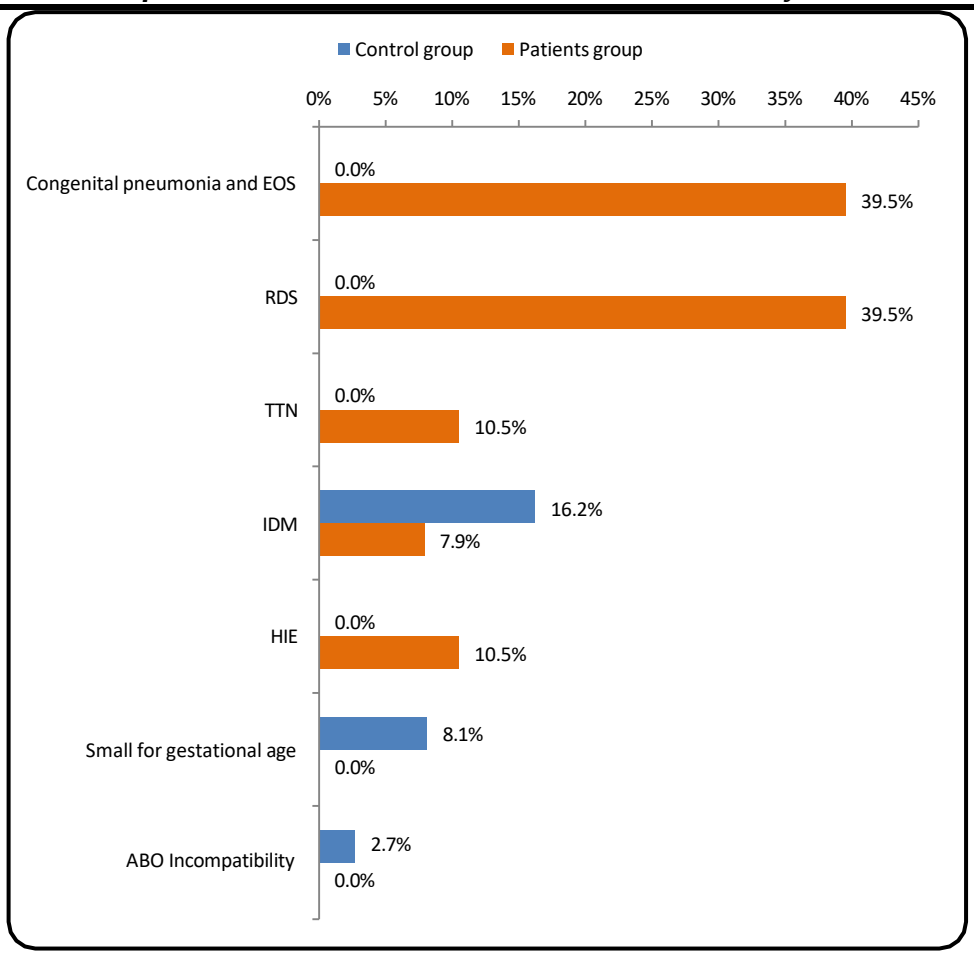

Figure (1): Causes of acute kidney injury in critically ill late preterm infants.

Table (2): Comparison of the patient group's type of oxygen support with that of the control group:

O2 support	Control group	Patients group	Test value	P-value	Sig.
	No. = 37	No. = 38			
Room air	37 (100.0%)	0 (0.0%)	75.000*	0.000	HS
Head box	0 (0.0%)	4 (10.5%)	4.114*	0.043	S
CPAP	0 (0.0%)	16 (42.1%)	19.804*	0.000	HS
Mech. Ventilation	0 (0.0%)	18 (47.4%)	23.061*	0.000	HS

Non-significant is defined as P-value > 0.05, significant as P-value < 0.05, and highly significant as P-value < 0.01.
*: Chi-square test

According to the previous table, there was an interesting difference between the two groups. The control group had a larger proportion of patients on room air (100.0%) in comparison to the patient group (0.0%). Also, the patient group also had a significantly higher percentage of patients on head boxes, CPAP, and mechanical ventilation (p-values = 0.043, <0.001, and <0.001, in given order) .

Table (3): Comparison between control and patients' groups regarding laboratory data at 3rd day of life:

		Control group No. = 37	Patients group No. = 38	Test value	P-value	Sig.
CBC						
WBCS	Mean ± SD	9.25 ± 1.83	11.36 ± 4.40	-2.701•	0.009	HS
	Range	5.7 – 13	3.4 – 20			
HGB	Mean ± SD	13.74 ± 1.51	12.22 ± 1.52	4.348•	0.000	HS
	Range	8.2 – 16.3	9.3 – 16			
HTC	Mean ± SD	40.08 ± 5.95	34.43 ± 5.81	4.162•	0.000	HS
	Range	22 – 49	25 – 50			
PLT	Mean ± SD	310.11 ± 54.68	237.63 ± 92.08	4.131•	0.000	HS
	Range	199 – 412	110 – 412			
CRP	Median(IQR)	3 (1.1 – 4)	11.5 (3.5 – 49)	-4.309≠	0.000	HS
	Range	0.1 – 8	0.2 – 122			
Liver function						
ALT	Median(IQR)	15 (12 – 22)	18.5 (14 – 25)	-1.853≠	0.064	NS
	Range	8 – 34	7 – 57			
AST	Median(IQR)	20.5 (15 – 24.5)	27 (21 – 45)	-3.154≠	0.002	HS

Non-significant is defined as P-value > 0.05, significant as P-value < 0.05, and highly significant as P-value < 0.01.
*: Chi-square test

The table reveals that there was a notable rise in WBCs, CRP, and AST in the patient group compared to the control group (p-value = 0.009, <0.001, and 0.002, in that order), but no valuable difference in ALT between the patient and control groups and also notable decrease in hemoglobin level, HTC, and platelets count in patients' group than control group with p-value <0.001, <0.001 and <0.001; in given order.

Table (4): Comparison of renal function test and Doppler finding in both studied groups in the 3rd day of life:

		Control group	Patients group	Test value	P-value	Sig.
		No. = 37	No. = 38			
Creatinine	Median(IQR) Range	0.5(0.3 – 0.8) 1.1 -2.2	0.55 (0.4 – 0.8) 0.2 -1.1	-1.205≠	0.228	**NS**
Urine output	Mean ± SD Range	2.21 ± 0.65 1.1 -3.4	2.2±0.58 1.1 -3.2	1.380•	0.123	**NS**
Urea	Mean±SD Range	19.9±3.9 15 □ 32	28.21±11.9 20 □ 25	2.49	0.18	**N.S**
AKI	No	37 (100%)	38(100%)	–	–	–
	Yes	0 (0.0%)	0 (0.0%)			
RI	Mean ± SD	0.62 ± 0.05	0.73 ± 0.13	-5.257•	0.000	HS
	Range	0.4 – 0.8	0.56 – 1			
PI	Mean ± SD	1.14 ± 0.14	1.27 ± 0.20	-3.240•	0.002	HS
	Range	0.9 – 1.4	0.9 – 1.6			

P-value > 0.05: Non significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant
•: Independent t-test

The table demonstrates that, during the third day of life, the patient group's levels of RI and PI were significantly higher than those of the control group, with p-values <0.001 and 0.002, in that order. The table also demonstrates that, with p-values of 0.22, 0.18, and 0.12 for creatinine, urea, and urine output, in that order, no much differences were observed comparing the patients' group with control group.

Table (5): Comparison of renal function test and Doppler finding in both studied groups at the 7th day of life:

7th day for prediction of AKI						
		Control group	Patients group	Test value	P-value	Sig.
		No. = 37	No. = 38			
Urea	Median(IQR) Range	15 (12 – 20) 8 – 31	23 (16 – 38) 6 – 58	-3.778≠	0.000	HS
Creatinine	Median(IQR)	0.2 (0.2 – 0.3)	0.4 (0.3 – 1.6)	-4.268	0.000	HS
	Range	0.1 – 0.5	0.1 – 2.7			
AKI	No	0 (0.0%)	25 (65.8%)	–	–	–
	Yes	0 (0.0%)	13 (34.2%)			
Urine output	Mean ± SD Range	2.4±0.44 1.8 -3.1	1.5±0.88 0.4 -3.1	5.220•	0.000	HS
Fluid balance	Median(IQR) Range	10 (-13 – 20) -30 – 30	35 (17-55) -25 -67	-4.926≠	0.000	HS
RI	Mean ± SD Range	0.57 ± 0.05 0.56 - 0.68	0.65 ± 0.13 0.49 – 0.93	-5.011	0.000	HS
PI	Mean ± SD Range	1± 1.1 0.9 - 1.3	1.2 ± 0.81 0.9 – 1.6	-3142	0.002	HS

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant
*: Chi-square test; •: Independent t-test; ≠: Mann-Whitney test

The table illustrates a considerable increase in the level of creatinine, urea, fluid balance, RI and PI in the patient group than the control group with p-value 0.000, < 0.001, <0.001, 0.000 and 0.002; in that order. While there was a notable decrease in urine output in the patients' group than the control group with p- value <0.001; in given order. The table also shows that from the 38 patients; 13 patients had AKI at the 7th day of life (34.2%).

Table (5): Relation of the presence of AKI with renal Doppler parameters at baseline and at follow-up among the studied patients.

Renal Doppler		No AKI	AKI	Test value	P-value	Sig.
		No. = 25	No. = 13			
Baseline						
RI	Mean ± SD	0.69 ± 0.09	0.82 ± 0.14	-3.570•	0.001	HS
	Range	0.58 – 0.83	0.56 – 1			
PI	Mean ± SD	1.18 ± 0.17	1.44 ± 0.13	-4.658•	0.000	HS
	Range	0.9 – 1.5	1.2 – 1.6			
Follow-up						
RI	Me an ± SD	0.61 ± 0.06	0.85 ± 0.06	-8.469•	0.000	HS
	Range	0.5 – 0.68	0.8 – 0.93			
PI	Mean ± SD	1.20 ± 0.15	1.47 ± 0.10	-4.444•	0.000	HS
	Range	1 – 1.46	1.3 – 1.6			

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant
•: Independent t-test

The table illustrates that there was a considerable increase in the level of RI and PI at the 3rd day with P value 0.001 and 0.000; in that order and a notable rise in the level of RI and PI at the 7th day of life with P value 0.000 and < 0.001; in given order in patients with AKI than patients without AKI.

Table (6): Relation of the presence of AKI with the duration of NICU stay and outcome.

		No AKI	AKI	Test value	P-value	Sig.
		No. = 25	No. = 13			
Duration in NICU (days)	Median (IQR)	5 (4 – 8)	11 (5 – 13)	-2.179≠	0.029	S
	Range	2 – 16	3 – 16			
Outcome	Died	3 (12.0%)	7 (53.8%)	26.099*	0.000	HS
	Discharged	22 (88.0%)	6 (46.1%)			

P-value > 0.05: Non-significant; P-value < 0.05: Significant; P-value < 0.01: Highly significant
*: Chi-square test; ≠: Mann-Whitney test

The table demonstrates a notable increase in the duration of NICU stay in AKI patients than non AKI patients with p-value 0.029.

Also, the percentage of died patients was found higher in AKI patients (53.8%) than non AKI patients (12.0%) with p- value <0.001.

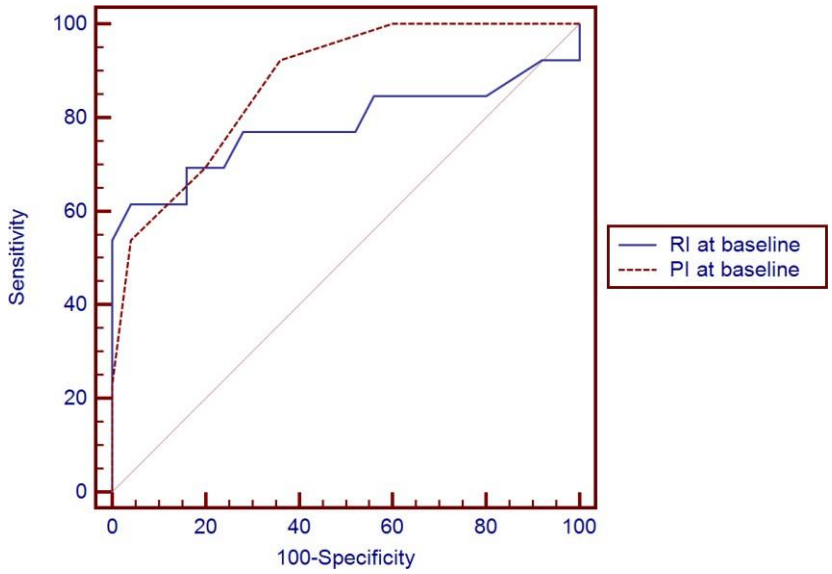

Figure (2): Receiver operating characteristic curve for renal Doppler to detect AKI cases

Parameters	Cut off point	AUC	Sensitivity	Specificity	+PV	-PV
RI at baseline	>0.82	0.782	61.54	96.00	88.9	82.8
PI at baseline	>1.2	0.874	92.31	64.00	57.1	94.1

The previous table shows that the RI can predict AKI at the cutoff point > 0.82 with sensitivity= 61.54%, specificity= 96.0% and AUC= 0.782. Also, the ROC curve shows that the PI can detect AKI at the cutoff point > 1.2 with sensitivity= 92.31%, specificity= 64.0% and AUC= 0.874.

DISCUSSION

Renal artery Doppler parameters, as the renal resistive index (RI) and renal pulsatility index (PI), are simple, safe and reliable. The renal resistive index represents a

resistance to the flow of blood, so lower RI values are associated with improved renal perfusion, whereas higher RI values indicate the development of acute tubular necrosis.[3]

No statically significant differences were observed between the patient and control groups in our study with respect to (gender, length, weight, head circumference, and mode of delivery) except for a considerable decrease in gestational age (by weeks) in the patients' group as illustrated in Table (1).

Our findings may be explained by the fact that late preterm infants' prognosis and death rates are influenced by lower gestational age at delivery and presence of maternal risk factors in the patient group leading to early termination of pregnancy with outcomes of moderate and late preterm infants.[9]

The current study results showed that the patient group presented with one or more of the following: congenital pneumonia and EOS (39.5%), RDS (39.5%), TTN (10.5%) and HIE (4%) that were markedly greater in the patient group compared to the control group with (p-value <0.005) as shown in figure (1). Another study reported by Mekic et al. (2023) [12]conducted on late preterm neonates admitted in NICU showed that RDS (74%), congenital pneumonia (19.5%), TTN (2.6%) and when combined with maternal health issues, newborn morbidity is much higher. Late preterm birth has an independent impact on early neonatal deaths that is almost seven times larger than the independent impact of maternal risk factors.[12]

Regarding respiratory support, comparing the two groups under study, there was a clinically considerable difference. In the control group all studied infants were admitted on incubator air, while in the patient group, 47.4% were admitted on M.V, 42.1% on CPAP and 10.5% on head box, p-values of 0.043, <0.001, and <0.001 indicated that this was considerably greater in the patient group than in the control group, accordingly as shown in Table (2). This results in the same line with Elgendy et al., (2023) [4], who reported that none of the controls had required respiratory support. While Ramaswamy et al. (2019) [16], reported that the controls had required respiratory support. Also this results are inconsistent with Natile et al. (2014) [14], who reported that patients on M.V were 12.4%, 64.8% on CPAP, and 3% on nasal oxygen.

Regarding laboratory investigation at the time of renal Doppler assessment there was no notable changes were detected in ALT, urea and creatinine in the patient group when compared to the control group as shown in Table (3). because the blood creatinine during the first three days of birth indicates the maternal kidney's function; renal injury is not harmful enough to impact both kidneys' excretory function since creatinine increases after 50% of kidney function is lost.[2]

In our study, renal Doppler parameters between the patient and the control group at the third and seventh days of life, we noticed a valuable elevation in the patient group's RI and PI values compared to the control group. with (<0.001 and 0.002) at the 3rd day and p-value (<0.000 and<0.001) at the

7th day; in that order, also urine output and kidney function test on the third day weren't quite different between the two groups, while on the seventh day, the patient group's creatinine level in the blood elevated and their urine output declined significantly compared to the control group with p-value 0.001 and 0.000;in that order, as shown in Table(4&5). This explained by neonatal illness as congenital pneumonia, EOS, RDS, and asphyxia affect renal blood flow and predispose to AKI despite absence of clinical and laboratory indices abnormalities.[10]

Comparing renal Doppler parameters in AKI and non-AKI patients, there was a noticeable rise in the level of RI and PI at the 3rd day and at 7th day in the AKI group than the non-AKI group. This agrees with El- Sadek et al. (2020)[5], who observed that neonates with AKI had more RI on days three and five compared to those without AKI.

In our study, Renal RI's ideal cut-off value for predicting AKI point is > 0.82 with sensitivity of 61.54%, specificity of 96.0% and AUC of 0.782 Also, the ROC curve shows that the PI can detect AKI at the cutoff point > 1.2 with sensitivity of 92.31%, specificity of 64.0% and AUC of 0.874. This consistence with **de Carvalho et al. (2023)** [3] who reported that AKI was anticipated by both RRI and RPI on D3, presenting an area under curve of 0.93 (95% CI 0.85 – 0.97; $p < 0.001$) and 0.87 (95% CI 0.77 – 0.93; $p < 0.001$), in that order. The area under curve of the inter-rater reliability (IRR) was noticeably higher than the renal PI's result ($p = 0.023$). For RI, the ideal cut-off was 0.85, where the sensitivity was 91.6% (95%CI 61.4 – 99.7%), specificity was 84.8% (95%CI 74.4 – 92.2%), PPV was 50.0% (95%CI 28.2 – 71.8%), and NPV was 98.3% (95%CI 91.2 – 99.9%). This study was applied on critically ill children.

CONCLUSION:

The current study demonstrated that AKI development is statistically significantly associated with oxygen requirement as reflected by renal Doppler, Renal Doppler parameters (RI, PI) have a statistically negative association with hemoglobin and platelets, but they have a favorable correlate with CRP, the AKI group's levels of RI and PI increased statistically on the third and seventh days compared to the non-AKI group and renal RI's ideal value for anticipating AKI point > 0.82 with sensitivity of 61.54%, specificity of 96.0% and AUC of 0.782.Also, the ROC curve shows that the PI can detect AKI at the cutoff point > 1.2 with sensitivity of 92.31%, specificity of 64.0% and AUC of 0.874.

Recommendation:

- All high-risk late-preterm infants admitted to the NICU should be screened for acute kidney injury.
- Early recognition, monitoring and careful management of AKI in high-risk neonates are required to limit worth outcome.
- The RRI and RPI have been used as bedside tool for critically ill neonates. It is a non-invasive, rapid and repeatable technique that allows renal hemodynamics assessment by pulsed Doppler ultrasonography.

LIMITATION:

- Some of patients were died before the period need to diagnose AKI.
- Renal Doppler is highly operator dependent.
- Lack of standardized reference values of renal Doppler parameters in neonates.
- Further researches are needed to study the role of renal Doppler in early prediction of acute kidney injury in late preterm infant.

REFERENCES:

Agrawal G, Wazir S, Sethi SK, et al. Incidence, Risk Factors, and Outcomes of Neonatal Acute Kidney Injury: Protocol of a Multicentric Prospective Cohort Study [The Indian Iconic Neonatal Kidney Educational Registry]. Front Pediatr. 2021;9:690559. Published 2021 Jul 9. doi:10.3389/fped.2021.690559.

Branagan A, Costigan CS, Stack M, Slagle C, Molloy EJ. Management of Acute Kidney Injury in Extremely Low Birth Weight Infants. Front Pediatr. 2022;10:867715. Published 2022 Mar 30. doi:10.3389/fped.2022.867715.

de Carvalho AV, Ferraz IS, de Souza FM, et al. Acute kidney injury in critically ill children: predictive value of renal arterial Doppler assessment. Pediatr Res. 2023;93(6):1694-1700. doi:10.1038/s41390-022-02296-1.

Elgendy MM, Cortez J, Saker F, et al. Acute kidney injury in infants with hypoxic-ischemic encephalopathy. Pediatr Nephrol. 2024;39(4):1271-1277. doi:10.1007/s00467-023-06214-3.

El-Sadek AE, El-Gamasy MA, Behiry EG, Torky AA, Fathy MA. Plasma cystatin C versus renal resistive index as early predictors of acute kidney injury in critically ill neonates. J Pediatr Urol. 2020;16(2):206.e1-206.e8. doi:10.1016/j.jpurol.2019.12.001.

Gameraddin M. Ultrasound of the Kidneys: Application of Doppler and Elastography [Internet]. Essentials of Abdominal Ultrasound. IntechOpen; 2019. Available from: http://dx.doi.org/10.5772/intechopen.85196.

Haitsma Mulier JLG, Rozemeijer S, Röttgering JG, et al. Renal resistive index as an early predictor and discriminator of acute kidney injury in critically ill patients; A prospective observational cohort study. PLoS One. 2018;13(6):e0197967. Published 2018 Jun 11. doi:10.1371/journal.pone.0197967.

Hanif MO, Bali A, Ramphul K. Acute Renal Tubular Necrosis. In: StatPearls. Treasure Island (FL): StatPearls Publishing; July 4, 2023.

Hu Q, Li SJ, Chen QL, Chen H, Li Q, Wang M. Risk Factors for Acute Kidney Injury in Critically Ill Neonates: A Systematic Review and Meta-Analysis. Front Pediatr. 2021;9:666507. Published 2021 Jul 14. doi:10.3389/fped.2021.666507.

Jetton, J.G., Vidal, E. Evaluation and Management of Acute Kidney Injury in Neonates. In: Emma, F., Goldstein, S., Bagga, A., Bates, C.M., Shroff, R. (eds) Pediatric Nephrology. Springer, 2021: Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-27843-3_125-1

Li PK, Bavanandan S, Mohamed R, et al. Kidney Disease Improving Global Outcomes (KDIGO) Hepatitis C in Chronic Kidney Disease Guideline Implementation: Asia Summit Conference Report. Kidney Int Rep. 2020;5(8):1129-1138. Published 2020 May 21. doi:10.1016/j.ekir.2020.05.001.

Mekic, N., Selimovic, A., Cosickic, A. et al. Predictors of adverse short-term outcomes in late preterm infants. BMC Pediatr 23, 298 (2023). https://doi.org/10.1186/s12887-023-04112-z.

Monzani A, Crespi I, Genoni G, et al. Kidney-Detrimental Factors and Estimated Glomerular Filtration Rate in Preterm Newborns: The Role of Nutrition. Nutrients. 2020;12(3):651. Published 2020 Feb 28. doi:10.3390/nu12030651.

Natile M, Ventura ML, Colombo M, et al. Short-term respiratory outcomes in late preterm infants. Ital J Pediatr. 2014;40:52. Published 2014 Jun 3. doi:10.1186/1824-7288-40-52.

Perazzo S, Revenis M, Massaro A, Short BL, Ray PE. A New Approach to Recognize Neonatal Impaired Kidney Function. Kidney Int Rep. 2020;5(12):2301-2312. Published 2020 Oct 3. doi:10.1016/j.ekir.2020.09.043.

Ramaswamy, V. V.; Saili, A.; Anand, R.; Nangia, S. Doppler Evaluation of Renal Blood Flow As a Predictive Index of Acute Renal Failure in Perinatal Asphyxia. J Pediatr Neonat Individual Med 2019, 8, e080210**.**

Stoops C, Stone S, Evans E, et al. Baby NINJA (Nephrotoxic Injury Negated by Just-in-Time Action): Reduction of Nephrotoxic Medication-Associated Acute Kidney Injury in the Neonatal Intensive Care Unit. J Pediatr. 2019;215:223-228.e6. doi:10.1016/j.jpeds.2019.08.046.

Vemuri SV, Rolfsen ML, Sykes AV, et al. Association Between Acute Kidney Injury During Invasive Mechanical Ventilation and ICU Outcomes and Respiratory System Mechanics. Crit Care Explor. 2022;4(7):e0720. Published 2022 Jun 29. doi:10.1097/CCE.0000000000000720.

Vidal, E., Ray, P.E. Acute kidney injury during the first week of life: time for an update?. Pediatr Nephrol 39, 2543–2547 (2024). https://doi.org/10.1007/s00467-024-06310-y.