Acute Renal Failure in the Neonate

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J Pediatr Intensive Care 2016;5:42–49.

Abstract

Acute renal failure (ARF) is a common disorder in high-risk neonates. ARF may be oliguric or nonoliguric, the latter having a better prognosis. Risk factors for ARF include prematurity, respiratory and vascular disorders, heart failure, congenital uropathies, and the use of nephrotoxic drugs. Chemical analysis of urine and ultrasounds help differentiate the nature and the type of ARF: prerenal, intrinsic, or postrenal. Conservative management of prerenal forms of ARF consists in carefully restoring cardiac output and controlling fluid and electrolyte balances. Early relief of obstruction is mandatory in severe postrenal forms of ARF. Renal replacement therapy is often necessary when ARF is secondary to intrinsic renal damage: peritoneal dialysis is the treatment of choice. Hemodialysis and continuous venovenous hemofiltration may be used in specific cases. Overall prognosis of ARF depends on the nature and severity of the renal injury that has led to renal failure.

Keywords

- neonatal nephrology
- neonatal renal failure
- asphyxic renal failure
- nephrotoxic drugs

Introduction

Acute renal failure (ARF) is due to a sudden decrease in glomerular filtration rate (GFR) with consequent retention of nitrogen waste products and disturbances in water, electrolyte, and acid-base balance. Because of its physiologic specifics, the premature fetal and neonatal kidneys are particularly prone to develop ARF. The term *acute kidney injury* (AKI) is now often used instead of ARF. But while kidney injury can lead to renal failure, the latter can occur without kidney injury, as for instance, in conditions of prerenal failure. The causes of ARF (► **Table 1**) can be prerenal (functional), renal (intrinsic), and postrenal (obstructive).

The Developing Kidney

The fetal kidney does not have real homeostatic responsibilities; it starts producing urine around the 12th week of gestation. This urine represents a great part of the amniotic fluid. Nephrogenesis is complete by 35 weeks of gestation. GFR at birth is close to 20 mL/min/1.73 m² in term neonates¹ and reaches 50 mL/min/1.73 m² at 4 weeks of life. It is

somewhat lower in premature neonates.² GFR shows a progressive direct correlation with both gestational and postnatal ages.^{3,4} In healthy premature neonates, nephrogenesis continues after birth, but for only 40 days.⁵ Nephrogenesis stops at birth in growth-retarded neonates. Low-birth-weight infants have consequently a lower number of nephrons as compared with term infants.

Definition

Acute renal failure (ARF) can be oliguric or nonoliguric, so urine flow rate cannot define ARF whose diagnosis is based on the follow-up of the plasma creatinine concentration. ARF is suspected when the plasma creatinine is greater than 130 µmol/L (15 mg/L) for at least 24 to 48 hours while maternal renal function is normal.⁶ In very premature neonates, the elevated plasma creatinine present at birth increases in the first 3 to 4 days of life because of tubular reabsorption of creatinine across the leaky tubules.³ In clinical practice, repeated measurements of plasma creatinine are used to confirm the presence of ARF. *Oliguria* is defined by urine output less than 1.0 mL/kg/h in preterm and less than 0.5 mL/kg/h in term neonates.

received

July 31, 2014

accepted after revision

September 15, 2014

published online

October 19, 2015

Issue Theme Nephrology in Pediatric

Critical Care; Guest Editors: Eunice John,

MD, Dch, FAAP, and Gokhan Olgun, MD

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Verlag KG, Stuttgart · New York

DOI <http://dx.doi.org/>

10.1055/s-0035-1564735.

ISSN 2146-4618.

Table 1 Causes of acute renal failure in neonates

Prerenal
Hypovolemia or renal hypoperfusion
Asphyxia
Respiratory distress syndrome (RDS)
Dehydration
Hemorrhage (maternal antepartum, twin-to-twin transfusion, intraventricular bleeding, hemolytic disease)
Sepsis
Cardiac disease (patent ductus arteriosus, aortic coarctation)
Polycythemia (hyperviscosity)
Renal
Acute tubular necrosis (ATN)
Persistent prerenal disturbances
Nephrotoxins (nephrotoxic antibiotics, e.g., aminoglycosides, contrast agents angiotensin-converting enzyme [ACE] inhibitors)
Myoglobinuria, hemoglobinuria, hyperuricemia
Vascular disorders (renal vein thrombosis, renal artery thrombosis, aortic thrombosis, disseminated intravascular coagulation)
Congenital renal anomaly (dysplasia, hypoplasia, polycystic kidney, agenesis)
Pyelonephritis
Transient acute renal failure of the neonate Maternal etiology (gentamicin, indomethacin, ACE inhibitors, paraproteinemia)
Postrenal
Congenital anomaly (ureteral or urethral obstruction, neurogenic bladder, megacystis-megaureter)
Obstruction secondary to circumcision
Renal candidiasis
Calculi
Neurogenic bladder

Etiology and Pathogenesis

Etiology

Factors responsible for the occurrence of ARF are listed in ► **Table 1**. Intrinsic renal failure accounts for less than 10% of the cases and may occur due to drug-induced nephrotoxicity or when the hypoxic-ischemic insults are prolonged or severe.^{4,7–9}

Prerenal Causes

More than 75% of cases of neonatal renal failure are prerenal in nature. All factors that decrease cardiac output can lead to renal insufficiency. Hypotension, hypoxemia, disturbances in acid-base balance, and administration of vasoconstrictive agents are common stresses that increase the renal vascular resistance.⁷ Cardiac diseases, the persistence of patent ductus arteriosus, and hyperviscosity states can also impair cardiac output.

Intrinsic Causes

When persisting, prerenal disturbances can lead to acute renal necrosis and severely impair renal function.⁹ The renal

parenchyma can also be injured by vascular disorders, renal thrombosis, nephrotoxins, acute pyelonephritis, myoglobinuria, and hemoglobinuria. Cortical necrosis may result from severe ischemia and microthrombi formation. Congenital renal anomalies, including hypoplasia, dysplasia, and cystic diseases, can favor the occurrence of ARF.

Postrenal Causes

Obstruction on the urinary tract, whatever the cause, can lead to ARF. The obstruction can occur at the level of the ureters, the bladder, or the urethra. When not relieved rapidly, the obstruction can induce permanent damage to the kidney.

Nephrotoxic Drugs

Nephrotoxic drugs can affect the fetus when administered to the pregnant mother, or the neonate when administered postnatally.⁸ Aminoglycosides may cause renal injury even with normal blood levels due to the high tissue concentrations of the drugs that can be achieved. All cephalosporins are potentially nephrotoxic though clinically the third generation appears to be reasonably safe. Vancomycin needs to be used in

appropriate dosages and monitored closely. The use of two simultaneous nephrotoxic drugs should preferably be avoided. Vasoactive drugs interfering with the synthesis of prostaglandins as well as with the renin-angiotensin system are particularly deleterious to the immature kidney.^{10,11}

Nonsteroidal Anti-inflammatory Drugs

The maintenance of prenatal and postnatal GFR is highly dependent on prostaglandin-mediated afferent arteriolar dilation.⁷ Inhibition of prostaglandins can lead to severe fetal or neonatal failure that can even be irreversible.¹⁰ Administration of nonsteroidal anti-inflammatory drugs (NSAIDs) early in pregnancy carries a high risk of inducing renal tubular dysgenesis in the fetus, with fetal oliguria and oligohydramnios. All cyclo-oxygenase (COX) inhibitors, including the COX-2 selective, can harm the developing kidney.¹⁰ When really needed, all NSAIDs must be used with great caution, be it before or after birth.

Angiotensin Inhibitors, Angiotensin-Converting Enzyme Inhibitors, and Angiotensin II AT1 Receptor Blockers

Maternal ingestion of angiotensin-converting enzyme inhibitors (ACEIs) and angiotensin II AT1 receptor blockers (ARBs) produces a classic fetopathy with renal tubular dysgenesis.¹¹ It can also result in a dramatic fall in GFR leading to fetal oliguria, oligohydramnios, and postnatal oliguric renal failure that can be irreversible. Postnatal administration of drugs interfering with the action of angiotensin II can also depress GFR and lead to renal failure. Drugs interfering with angiotensin II must definitively be avoided during pregnancy and used with caution after birth.¹¹

Specific Pathogenesis

Hypoxemic-hypoxic insults and sepsis are the major stresses that can induce renal failure by the activation of vasoactive factors and inflammatory agents.⁹

Clinical Events

Bilateral renal agenesis, multicystic dysplastic kidneys, autosomal recessive polycystic kidneys, and obstructive uropathies can all lead to oligohydramnios. Late-onset oligohydramnios is a characteristic finding in renal tubular dysgenesis and warrants a thorough evaluation for exposure to drugs such as NSAIDs, ACEIs, and ARBs.

Mechanical ventilation reduces the preload by increasing the intrathoracic pressure and results in decreased cardiac output and renal perfusion.¹² Umbilical artery and vein catheterization can lead to renal artery or renal vein thrombosis. Indwelling urinary catheters favor the occurrence of urinary tract infections (UTIs), and the use of broad-spectrum antibiotics may result in the development of fungal UTIs and fungal bezoars.

Physical Features

The presence of external features such as Potter's facies, preauricular tags, polydactyly, single umbilical artery, or sacral abnormalities may indicate the presence of an underlying developmental renal anomaly. Enlarged kidneys may

indicate autosomal polycystic renal disease or obstructive uropathy. Palpable bladder and a poor stream of urine in a male child suggest the presence of posterior urethral valves. All these congenital uropathies can damage the developing kidney and lead to severe long-term consequences.¹³

Edema due to fluid overload, hypoproteinemia, or capillary leak may complicate the clinical course. Hypotension due to hypovolemia, sepsis, or cardiac dysfunction may coexist. Hypertension due to renal failure may be encountered during the course of illness as a result of volume overload or a high renin state. Recognition of hypertension requires reference to appropriate charts as the normal range of blood pressure in neonates will vary depending on gestational age, weight, and postnatal age.¹⁴

Oliguric Acute Renal Failure

Approximately 30% of normal newborns void soon after birth; 92% will void within the first 24 hours and 99% by 48 hour. Oliguria is observed in most neonates presenting with ARF. It can also result from poor fluid intake or be due to inappropriate antidiuretic hormone (ADH) secretion in sick neonates.

Nonoliguric Acute Renal Failure

Up to one-third of neonates with ARF may have nonoliguric renal failure that can only be detected by the finding of elevated serum creatinine or cystatin C levels. Birth asphyxia, aminoglycoside therapy, and methoxyflurane anesthesia are some of the conditions leading to nonoliguric renal failure.¹⁵

Laboratory Evaluation

Urinalysis

Urinalysis in prerenal failure may show normal urine, epithelial cells and coarse granular casts, mild proteinuria, and microscopic hematuria. Gross or microscopic hematuria is usually seen in renal vein thrombosis and sometimes in UTIs. Pus cells or pus cell casts reflect severe UTIs.

Blood Count

Anemia is present in neonates with ARF, in whom it may also reflect bleeding or dilution by fluid retention. Eosinophilia suggests an allergic reaction to drugs.

Urea

Plasma urea is a poor marker of renal function as it is influenced by multiple factors such as protein intake, urine output, gastrointestinal bleeding, and a hypercatabolic state. It may be deceptively low in sick neonates as a result of poor protein intake.

Creatinine

Plasma creatinine is the most widely used marker of GFR. The serum creatinine in the first few days of life reflects maternal creatinine levels and gradually comes down to normal neonatal levels close to 4 mg/L (35 μ mol/L) by 1 week of age in term infants. In preterm babies the creatinine may actually rise further before falling slowly to normal neonatal levels over 2 to 3 weeks.¹

Failure of plasma creatinine to decrease below the maternal level after the first few days of life or a rise in serum creatinine greater than 25 to 30 $\mu\text{mol/L}$ (3 mg/L) per day is indicative of ARF.⁶ Creatinine levels may also be artifactually elevated, depending on the associated comorbid conditions as well as the methodology used for its estimation. In the commonly used Jaffe's method that also measures noncreatinine chromogens, creatinine levels may be spuriously high in the presence of hyperbilirubinemia or treatment with cephalosporins. However, the use of newer techniques such as the kinetic or enzymatic assays does not measure these chromogens and give truer values of creatinine. Further improvement in measuring creatinine has recently been achieved by the use of newer techniques such as the high-performance liquid chromatography and the gas chromatography-isotope dilution mass spectrometry.¹

Cystatin C

Plasma cystatin C has been used to estimate GFR. It is freely filtered, almost completely reabsorbed, and catabolized by proximal tubular cells. Its clearance can consequently not be calculated. The clinical use of this marker suffers important drawbacks: (a) the handling of this product by the immature tubular cells, in particular when their injury is not known; (b) its production and concentration are influenced by factors independent of GFR, such rises in serum protein C-reactive levels, thyroid dysfunction, or corticosteroid administration; and (c) its measurement is considerably more expensive than that of creatinine, by a factor of at least 12.¹ That plasma cystatin C is a better marker of GFR (or an earlier marker of AKI) than creatinine is questionable and has not yet been clearly demonstrated.

Urinary Indices

Chemical analysis of urine may help distinguish prerenal from intrinsic ARF. Previously healthy kidneys respond to acute hypoperfusion by maximally conserving water and electrolytes, thus excreting concentrated urine with low sodium concentration (U_{Na}). Therefore a urinary osmolality (U_{osm}) greater than 400 mOsm/kg H_2O , a U_{Na} less than 40 mmol/L, and a fractional excretion of sodium (FE_{Na}) less than 2% suggest the presence of prerenal functional insufficiency. By contrast, an intrinsically damaged kidney is not able to concentrate urine and retain sodium. It should be noted that these urinary indices are only valid when measured before the administration of volume expanders or diuretics, and that they cannot be used in very premature salt-wasting neonates who may "normally" present with FE_{Na} greater than 5%.^{1,7}

Biomarkers of Acute Kidney Injury

The most promising novel biomarkers of early injury include *plasma* neutrophil gelatinase-associated lipocalin (NGAL) and *urine* interleukin 18, NGAL, and kidney injury molecule 1 (KIM-1). These markers are presently under investigation in neonates.^{16,17}

Imaging

Ultrasound examination of the genitourinary tract is useful for assessing the size, the shape, and the echogenicity of the

kidneys; for diagnosing pelvic-calyceal dilation; and for examining the ureters and the bladder. Imaging gives highly valuable diagnostic information. Evaluation of the renal vessels by color Doppler gives important information regarding the presence of renal vein or renal arterial thrombosis. Radionuclear scan utilizing various isotopes may help differentiate the causes of ARF. Voiding cystourethrography is useful to identify lower urinary tract obstruction (posterior urethral valves).

Conservative Management of Acute Renal Failure

Management of Suspected Prerenal Oliguric Acute Renal Failure

Regular monitoring of urine output and serial measurements of serum creatinine allow the early detection of renal insufficiency. Analysis of the urinary indices is mandatory to define the type of ARF (Fig. 1).

Fluid Challenge and Rehydration

In the prerenal types of ARF, volume expansion by the administration of 20 mL/kg of normal saline over 1 to 2 hours usually improves urine output. Such an administration should not be given when there is clinical evidence of fluid overload. In neonates with fluid refractory hypotension, dopamine infusion should be started to improve blood pressure and renal perfusion. Low-dose hydrocortisone may be useful in fluid and dopamine refractory hypotension.¹⁸

Low-Dose Dopamine

The use of low-dose dopamine (2.5–5.0 $\mu\text{g/kg/min}$) in preterm babies with hyaline membrane disease has been claimed to improve renal blood flow, natriuresis, and diuresis, and produce a modest improvement in renal function.¹⁹ Dopamine can have several adverse effects such as tachycardia, cardiac arrhythmia, and increased pulmonary vascular resistance. The modest benefits that may be obtained in some babies with low-dose dopamine have to be weighed against the possible adverse effects of the drug. All neonatal studies in favor of the "renal" doses of dopamine were uncontrolled, and a placebo-controlled randomized study in adult patients failed to demonstrate that low-dose dopamine could protect the stressed kidney.²⁰

Furosemide

When urine output fails to improve after fluid repletion, a trial of loop diuretics can be given. Intravenous furosemide at 1 to 3 mg/kg may improve the diuresis. The natriuretic and diuretic responses to furosemide are highly variable and depend on the level of GFR. When a diuretic response is present, it carries the risk of inducing hypovolemia. Clearly, loop diuretics basically should not be used to treat oliguric neonates, but primarily those presenting with edematous states and congestive heart failure.²¹ When given in association with dopamine, furosemide has been claimed to have a synergetic effect in increasing urine output.

Fig. 1 Management of oliguric acute renal failure.

Whether this would also improve renal function remains questionable.

Low-Dose Theophylline

Adenosine-mediated vasoconstriction appears to play a crucial role in the pathogenesis of asphyxial neonatal renal failure. Experimental studies²² and clinical trials have suggested a potential renoprotective effect of low-dose theophylline (5 mg/kg) in perinatal asphyxia and in idiopathic respiratory distress syndrome (1 mg/kg).^{23–25} This beneficial effect has been ascribed to the adenosine antagonistic properties of theophylline.²²

Fluid Management in Neonates with Intrinsic Acute Renal Failure

Oliguric neonates who fail to respond to these maneuvers (→ Fig. 1) should be considered to have intrinsic renal failure and will require additional measures to prevent major homeostatic disturbances. In those neonates responding to the aforementioned measures by an increase in urine output, a progressive fall in the serum creatinine is observed. Persistence of elevated creatinine or increase in creatinine levels in the face of a good urine output suggests the presence of nonoliguric renal failure.

In oliguric neonates, fluid administration should be restricted to insensible water losses plus the ongoing renal and extrarenal losses. The insensible water losses in full-term neonates amount to 35 mL/kg/day whereas in preterms this may vary from 60 to 70 mL/kg/day. The fluid administered should be electrolyte-free and the concentration of glucose adjusted to deliver the adequate amount of glucose. Daily weight of the neonate is mandatory. In oligoanuric neonates a daily weight loss of 0.5% is expected and reflects appropriate fluid balance.

Electrolyte Disorders

Hyponatremia

When present in ARF, hyponatremia is dilutional in nature and should not be treated by giving sodium chloride. Free-water administration should be restricted instead to produce

a gradual increase in the serum sodium concentration. However, when serum sodium level is less than 120 mmol/L, it can give rise to cerebral edema that may manifest as lethargy, seizures, and apnea. In such situations, 3% NaCl may be given intravenously at a slow rate of 5 to 6 mL/kg over 2 to 4 hours. The amount of sodium required to correct the hyponatremia can be estimated as follows: $\text{Na needed} = (\text{desired } P_{\text{Na}} - \text{actual } P_{\text{Na}}) \times 0.8 \times \text{BW (kg)}$, where Na is expressed in mmol and P_{Na} in mmol/L; BW represents body weight and $0.8 \times \text{BW}$ represents total body water.

Hyperkalemia

Elevated potassium levels are fairly common in ARF. Mild hyperkalemia of 6 to 6.5 mmol/L without electrocardiographic (ECG) changes may require nothing more than the correction of coexisting metabolic acidosis. Higher levels of potassium or the presence of ECG changes require active cardioprotective measures that include intravenous calcium administration (0.5–1.0 mL/kg of 10% calcium gluconate, over 5 minutes under ECG surveillance), inhaled or parenteral salbutamol (4 µg/kg in 5 mL water or saline over 5 minutes), and glucose-insulin infusions. When the neonate is still passing urine, diuretics such as furosemide (1 mg/kg) can be tried. The use of potassium binding resins is not without risk in infants. It may cause gastric erosions when given orally and colonic ulcerations and fecal impaction when given rectally.²⁶ They are thus best avoided in a sick neonate. Severe hyperkalemia (> 7.5 mmol/L) and/or major ECG changes represent an indication for immediate dialysis.

Hypocalcemia

Hypocalcemia is common, but the ionic fraction may not be very low because of concomitant hypoalbuminemia and metabolic acidosis. When the hypocalcemia is symptomatic, intravenous calcium gluconate (10% calcium gluconate at a dose of 0.5–1.0 mL/kg in 5 minutes under cardiac monitoring) needs to be given and repeated every 6 to 8 hours. Caution is required in the administration of IV calcium in the presence of hyperphosphatemia, as it may lead to soft tissue calcification and nephrocalcinosis.

Hyperphosphatemia

Hyperphosphatemia is common in neonates with renal failure. Calcium-containing phosphate binders such as calcium carbonate may be used although severe hyperphosphatemia is best treated with dialysis. Aluminum-containing phosphate binders are best avoided.

Acidosis

Mild metabolic acidosis is common in renal failure. When the plasma bicarbonate concentration falls less than 12 mmol/L and/or the plasma pH less than 7.20, correction of the acidosis is best achieved by adding sodium bicarbonate to the maintenance fluid.

Convulsions

Convulsions are the consequence of electrolyte imbalance or arterial hypertension. Symptomatic therapy is achieved by

Table 2 Hypotensive agents in the neonate

Agent	Starting dosage	Intervals	Maximum recommended	Route of administration
Furosemide	1 mg/kg	q4–6h	5 mg/kg/dose	O/IV
Hydrochlorothiazide	1 mg/kg	q8h	3 mg/kg/dose	O
Propranolol	0.25 mg/kg/dose	q6–8h	5 mg/kg/dose	O/IV
Atenolol	0.5 mg/kg/dose	q12–24h	4 mg/kg/dose	O
Labetalol	0.5 mg/kg/dose	q1–4h	2 mg/kg/dose	IV
Sodium nitroprusside	0.5 µg/kg/min	–	6 µg/kg/min	IV
Captopril	0.1 mg/kg/dose	q8–12h	0.5 mg/kg/dose	O
Enalapril	5 µg/kg/dose	q8–24h	20 µg/kg/dose	IV
Nifedipine	0.5 mg/kg/dose	q4–6h	2 mg/kg/dose	O

Abbreviations: IV, intravenous; O, oral.

giving diazepam (0.5 mg/kg IV or rectally), IV clonazepam (0.1 mg/kg), or IV phenobarbital (15–20 mg/kg).

Hypertension

Hypertension may occur as a result of volume overload as well as hyperreninemia. Severe or symptomatic hypertension is best treated with continuous intravenous infusion of nicardipine. Esmolol, enalaprilat, or sodium nitroprusside can be used with caution (► **Table 2**).¹⁴ The optimal oral therapy for newborns is not clearly known. ACEIs, notably captopril, have been used in neonatal hypertension. However, their use in the context of neonatal renal failure is risky as they may worsen the condition. If necessary, they should be used cautiously in small doses. Calcium channel blockers can be used as first-line drugs. β-Adrenergic blockers should be used with caution and are best avoided in babies with coexisting respiratory problems. In these babies diuretics may form a good adjunct.

Sepsis

Severe infection is a common cause of death in neonates with ARF. Adequate intravenous antibiotherapy is essential. The dosage of drugs excreted mainly by the kidney (aminoglycosides, vancomycin) must be adapted to the severity of renal failure (► **Table 3**). When possible, monitoring of plasma concentrations is recommended.

Nutrition

Nutritional inadequacy is an important contributor to neonatal mortality. When feasible, enteral nutrition should consist of appropriate formulas that are calorically dense with a low electrolyte content. Neonates require 120 kcal/kg/day. Protein restriction should be avoided in neonates. When enteral nutrition is not feasible, parenteral nutrition may have been used. High concentrations of glucose need to be given to provide the required nonprotein calories.

Acute Renal Replacement Therapy

Renal replacement therapy (RRT) is indicated when the renal failure produces serious derangements such as fluid overload,

severe hyperkalemia, uncontrolled metabolic acidosis, hyperphosphatemia, or hyponatremia unresponsive to fluid restriction.²⁷ RRT with ultrafiltration may also be required to create enough fluid space to allow the administration of the necessary medications, blood products, and nutrition that the child may need.

Peritoneal Dialysis

Peritoneal dialysis is the most common and widely used option for RRT in this age group.^{4,27} It is easily instituted even in the very tiny infant with either percutaneous bedside placement of a stiff catheter or surgical placement of a soft Tenckhoff catheter. Acutely ill babies on ventilator may not tolerate large intraperitoneal volumes. Small volumes with short dwelling times may suffice to tackle the acute life-threatening problems. Bicarbonate dialysis is needed in children with liver dysfunction or advanced sepsis as use of lactate-based dialysis fluid may lead to worsening of acidosis in these babies. The presence of intra-abdominal pathology may preclude the use of the peritoneum for dialysis.

Table 3 Drugs requiring dose adjustment when GFR is compromised

Antibiotics
Aminoglycosides (amikacin, gentamicin, tobramycin)
Amoxicillin, amoxicillin-clavulanic acid
Cephalosporin (cefixime, cefotaxime, ceftazidime)
Cotrimoxazole
Ticarcillin
Vancomycin
Antifungal agents
Fluconazole
Cardiac drugs
Digoxin

Abbreviation: GFR, glomerular filtration rate.

Hemodialysis

Hemodialysis is infrequently used in this age group and can be considered only in hemodynamically stable babies. In neonates, it requires the availability of suitably small dialyzers and tubings. Blood or albumin priming of the lines and filter is usually needed. It can be done only in units where sufficient technical expertise is available.

Continuous Venovenous Hemofiltration

Continuous venovenous hemofiltration is a modality that can be used in sick neonates requiring renal replacement. It allows greater fluid removal, better hemodynamic stability, and better nutrition. Its use in critically ill children with renal failure is increasing steadily with improving results.

Outcome

Despite major advances, the mortality in neonates with ARF is fairly high and ranges from 45 to 60%.^{28–31} Neonates with prerenal failure have a better outcome than those with intrinsic renal failure. The worst outcome is seen in babies with intrinsic renal failure in the context of multiple organ dysfunction. As the development of renal failure is a reflection of the severity of illness, it is not surprising that the mortality is so high. Babies with nonoliguric renal failure have a much better outcome than those with oligoanuric renal failure.²⁸

Following recovery from the ARF, residual renal dysfunction may be seen in more than half the babies without an underlying congenital uropathy.¹³ Incomplete recovery is present in the neonates who have suffered cortical necrosis. Babies with in utero exposure to NSAIDs, ACEIs, or ARBs have a poor renal outcome, and are likely to have persistent irreversible renal failure. Long-term follow-up of extremely low-birth-weight infants with neonatal renal failure has shown that nearly 45% of the children show a decrease in GFR over time. Urine proteins/creatinine ratio of greater than 70 g/mol creatinine (0.6 mg/mg creatinine), and serum creatinine greater than 55 μ mol/L (6 mg/L) at 1 year of age were predictors of a poor prognosis for long-term renal function.³²

Conclusion

When recovery from ARF is incomplete, the occurrence of chronic renal failure is associated with significant morbidity, such as growth retardation and renal osteodystrophy. When renal replacement therapy is considered, decisions must be discussed with the family and an expert ethical committee, keeping in mind the difficult global management of renal failure in the first years of life.

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