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Advances in the Critical Care of Poisoned Paediatric Patients

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Summary Recent improvements in paediatric intensive care may potentially improve outcome for severely poisoned children. The application of advanced techniques of critical care to the poisoned paediatric patient encompasses a wide variety of therapeutic and technical innovations that are primarily directed towards support of the cardiopulmonary system and removal of toxins. New extracorporeal removal techniques such as continuous arterio-venous haemofiltration have not substantively increased our ability to remove toxins except in rare instances. Exotic techniques such as extracorporeal membrane oxygenation remain in the background for use in rare instances only, with little clear data on the relative risks and benefits of applying them.

1. Supportive Care and Monitoring

In general, characterisation of poisoning as severe means that there has been either deterioration in the level of consciousness or in haemodynamic status, due either to the intoxicating agent primarily or resulting from some complication. Poisoning-related alterations in haemodynamic status may present formidable management problems, requiring both sophisticated supportive care and knowledge of the effects of the specific poison.

Monitoring of the haemodynamic status of poisoned patients has few unique aspects, requiring basic information such as vital signs, cardiac rhythm, and the adequacy of peripheral perfusion as assessed by capillary refill time, warmth of ex-

tremities and quality of peripheral pulses. Patients should be re-evaluated at short intervals, however, as medical contact with the patient often begins soon after the poisoning event, when signs and symptoms of poisoning may be evolving rapidly. Also, early management is often focused on decontamination (induced emesis, gastric intubation and lavage, and giving of activated charcoal), although vigilance for untoward haemodynamic events should be maintained.

Since many toxins eventually become depressants at sufficiently great exposure, haemodynamic deterioration due to poisoning most commonly takes the form of decreased blood pressure, vascular tone, cardiac performance and perfusion, although a few poisonings may result in elevated blood pressure (cocaine, phencyclidine).

Adverse cardiovascular effects are no surprise when the poisoning agent is well-known to cause shock, as with the tricyclic antidepressants (TCAs). However, substances thought to be haemodynamically benign may cause shock when the exposure is sufficiently massive. For instance, severe cardiovascular depression was reported in a child poisoned with paracetamol (acetaminophen), a drug usually thought to be devoid of such effects (Lieh-Lai et al. 1984). Thus, in caring for the severely poisoned patient, efforts must be directed not only at the specific poison but also toward support of deranged organ system function.

1.1 Central Venous Access

Patient case study: a 19-month-old native American boy ingested an iron-containing vitamin preparation (estimated 85 mg/kg elemental iron). He had copious diarrhoea and appeared to be in shock, with low-normal blood pressure, cold extremities, poor peripheral pulses and prolonged capillary refill time; the serum iron level was 590 μg/dl (1 μg/dl = 0.18 μmol/L). He was given deferoxamine (desferrioxamine) and Ringer's lactate 40 ml/kg, but there was little improvement in the clinical haemodynamic status, with persistent metabolic acidosis, lethargy and oliguria.

A subclavian vein catheter was then inserted for measurement of central venous pressure. The initial central venous pressure was zero despite the previous fluid administration. An additional 50 ml/kg of Ringer's lactate was infused rapidly, with improvement in the quality of the peripheral pulses, warmer extremities and increase in urine output, with a partial resolution of the metabolic acidosis.

Thus, in this case the patient required large volumes of intravenous fluid to maintain circulation because of fluid loss into the gut, but the physician, aware of the risks of iatrogenic fluid overload, was hesitant to administer further large volumes of fluid based on clinical assessment alone. The insertion of a central venous catheter provided information about intravascular volume; the low central venous pressure indicated that intravascular volume was still low despite the initial volume resuscitation, and that further fluid administration was both indicated and safe.

In general, intravenous fluid administration is the most powerful way in which to manipulate the circulation, and this is as true for shock due to poisoning as it is for other causes. In many cases, the beneficial effects of fluid challenge (10 to 30 ml/kg) may easily be seen as improvement in blood pressure, peripheral pulses and capillary refill. However, invasive monitoring of central venous pressure as a guide to fluid administration is often useful and necessary as indicated in the previous case. Furthermore, central venous catheters provide very stable, reliable vascular access, essential in the management of severe poisoning.

1.2 Thermodilution Pulmonary Artery Catheter

Patient case study: a child was admitted to the paediatric intensive care unit for treatment of TCA poisoning complicated by aspiration pneumonia and hypoxaemic respiratory failure. There was arterial hypotension associated with poor peripheral perfusion, and cardiac dysrhythmias which responded to alkalinisation using sodium bicarbonate and mechanical hyperventilation. Hypotension did not improve with this therapy, and arterial sys-

tolic pressure remained roughly 60mm Hg despite intravenous fluid administration sufficient to increase the central venous pressure to between 12 and 15mm Hg. Dopamine was infused in stepwise increases in dosage, up to 30 μg/kg/min, but there was minimal improvement in blood pressure and peripheral perfusion. Norepinephrine (noradrenaline) infusion was begun, and increased stepwise to 0.2 μg/kg/min with resultant improvement in arterial blood pressure. A pulmonary artery catheter was rapidly inserted.

Initial haemodynamic data included cardiac index 4.82 L/min • m^2, and systemic vascular resistance index 1028 dyn • sec/cm^5 • m^2. Dopamine and norepinephrine dosages were not changed. Over the next hour, there was progressive increase in blood pressure. Repeat haemodynamic measurements were done, revealing a decrease in the cardiac index to 2.68 L/min • m^2, and an increase in systemic vascular resistance index to 2388 dyn • sec/cm^5 • m^2. The norepinephrine and dopamine dosages were then decreased.

In this case, the patient had hypotension despite high dose dopamine and appropriate fluid resuscitation, but whether this resulted from low cardiac output or low systemic vascular resistance could not be known from routine clinical assessment. Insertion of a pulmonary artery catheter provided sophisticated assessment of the circulation, revealing that systemic vascular resistance was low despite high dosages of the two inotropic/pressor agents.

Had the haemodynamic data shown that the problem was primarily one of low cardiac output, high dose norepinephrine would not have been indicated, and a pure inotrope such as dobutamine would have been a more rational choice. As the situation evolved over time, rising systemic vascular resistance suggested that the pressor dose was now excessive. In this way, information obtained with the pulmonary artery catheter enabled the physician to titrate precisely the dosage of potent inotropic/pressor drugs for restoration of the patient's haemodynamic status.

1.3 Haemodynamic Manipulations

Clearly, only a small minority of poisoned patients will benefit from sophisticated haemodynamic monitoring, which carries with it some risk. However, adequate haemodynamic status is occasionally not restored with basic approaches including proper fluid administration and modest doses of inotropic drugs. When this happens, more invasive, sophisticated monitoring of the circulation is possible, even in small babies. Information thus obtained enables physicians to determine more precisely how best to manipulate the circulation via fluid and drug administration.

The overall goal of therapy for severe poisoning is survival of the individual. It may not be obvious, however, how haemodynamic status should be best manipulated to achieve this goal. The purpose of the heart and lungs is not to generate a solid radial pulse or a comforting (to the physician) blood pressure, but to perfuse the peripheral tissues so that they are adequately supplied with substrate, primarily oxygen. Clinical assessment of tissue perfusion, based on skin colour and warmth, capillary refill, hourly urine output and mentation, is unfortunately crude and inaccurate. Blood pressure would appear a good measure of cardiovascular function, but use of blood pressure as the therapeutic endpoint does not appear to improve survival in critically ill patients.

Tissue perfusion can be assessed directly by calculation of oxygen consumption using the thermodilution pulmonary artery catheter, and restoration of oxygen transport parameters does appear to improve survival from various forms of critical illness. For severely poisoned patients with multiorgan dysfunction, manipulation of the circulation to achieve adequate haemodynamic status, and oxygen transport status in particular, may be helpful in assuring survival. Unfortunately, published therapeutic goals are not available for poisoned patients, but restoration of normal haemodynamics and oxygen transport seems a reasonable goal.

Inspection of haemodynamic profiles will generally suggest a therapeutic response. For instance, the patient with low oxygen consumption associ-

ated with low cardiac output but normal blood pressure, should benefit from fluid administration (guided by central venous and pulmonary artery wedge pressures), a 'pure' inotrope such as dobutamine, or both. The hypotensive patient with low vascular resistance should benefit from a drug to improve vascular tone, such as norepinephrine or possibly high dose dopamine. A hypertensive patient with normal cardiac output and hence elevated systemic vascular resistance should benefit from a vasodilator drug such as nitroprusside. Following each such manipulation, the haemodynamic measurements should be repeated to evaluate the effects of therapy, until the desired endpoint has been reached.

1.3.1 Selected Intoxications

There are a number of agents available to manipulate the circulation of poisoned patients. As noted in the above section, knowledge of the patient's circulatory status obtained via invasive monitoring can be used to make therapeutic decisions. However, knowledge of the effects of the specific poisoning agent is also necessary.

Tricyclic Antidepressants

The pharmacology of TCA poisoning is complex and interesting, and important because overdose with this class of drugs is both common in children and characterised by severe, potentially life-threatening cardiovascular effects (Crome 1986; Lacroix et al. 1989; Litovitz et al. 1992). Shock in TCA poisoning is due largely to a decrement in myocardial performance, with a variable component of vasodilatation (Brown 1976; Jandhyala et al. 1977; Vernon et al. 1991).

Alkalinisation via bicarbonate administration is a mainstay of treatment for TCA poisoning. However, inotropes are necessary and even life-saving in severe cases. At the cellular level, TCAs are known to inhibit reuptake of neurotransmitters by the presynaptic neuron, potentially leading to depletion of body stores of norepinephrine (Pentel & Benowitz 1986; Richelson & Pfenning 1984). Since the inotropic effect of dopamine is to some degree indirect, resulting from release of endogenous norepinephrine, it seemed logical that its effectiveness would be blunted in TCA-induced shock; indeed, norepinephrine was found to be superior in a small experimental study (Jackson & Banner 1981), and became the inotropic drug of choice for TCA poisoning.

Subsequently, however, a recent, larger study of experimental amitriptyline poisoning demonstrated that both dopamine and norepinephrine were effective in reversing the shock of TCA poisoning (Vernon et al. 1991).

Theophylline

Despite current controversy about the role of theophylline in the treatment of asthma, it remains widely prescribed, and both suicidal and accidental overdose occur quite often (Sessler 1990). Theophylline possesses a narrow margin of safety, and is severely toxic in overdose (39 US fatalities reported in 1991 in adults and children) [Gaudreault & Guay 1986; Litovitz et al. 1992; Sessler 1990].

The pharmacological effects of theophylline are complex and include inhibition of phosphodiesterase, inhibition of calcium uptake, blockade of adenosine receptors, and increased blood levels of catecholamines from release of endogenous stores. However, the contributions of these properties to theophylline toxicity is not clear (Dawson & Whyte 1989; Gaudreault & Guay 1986; Heath & Knudsen 1987; Rall 1990).

In overdose, cardiovascular effects are prominent and generally resemble a state of sympathetic overactivity, including tachycardia, a variety of supraventricular and ventricular dysrhythmias (especially in older adults), an increase in cardiac output, and in severe intoxication, hypotension from vasodilatation (Biberstein et al. 1984; Dawson & Whyte 1989; Gaudreault & Guay 1986).

Most clinicians, when managing patients with hypotension, will tend to first use a vasopressor agent such as dopamine or norepinephrine; however, vasopressors are not reliably effective in reversing theophylline-induced hypotension (Biberstein et al. 1984). Since excessive β_2-adrenergic stimulation is thought to be responsible, use of β-blockers is an obvious potential therapeutic

option. Indeed, brief clinical reports have supported the effectiveness of propranolol in reversing tachycardia, cardiac rhythm disturbances and profound hypotension in severe theophylline poisoning, although propranolol administration would not appear to obviate the need for haemoperfusion (Biberstein et al. 1984). The ultra–short-acting cardioselective β-blocker, esmolol, was effective in a canine model of theophylline toxicity (Garr et al. 1987), and is attractive because of its safety, ease of administration and titratability, and short duration of action.

2. Extracorporeal Removal Techniques

In general, the same indications exist for the use of extracorporeal removal techniques in the paediatric population as in the adult. One change over the last 20 years is the availability of smaller catheters and their more frequent placement by intensive care physicians. This allows for the application of dialysis techniques in smaller infants, with lower risks. It is thus no longer acceptable to consider a modality such as peritoneal dialysis as a standard of care for the removal of toxins in acute severe intoxication. Similarly, exchange transfusion, while common in the neonate for removing bilirubin, is no substitute for charcoal haemoperfusion or haemodialysis in the acute setting.

2.1 Chelation and Extracorporeal Removal

One purported application for this therapy is the treatment of inorganic mercury intoxication using dimercaptosuccinic acid in conjunction with conventional haemodialysis (Kostyniak et al. 1990). The patient described in this case report did not survive and thus we as yet have no indication of the potential long term improvement in outcome from such an approach. In contrast to the experience with inorganic mercury, methyl-mercury was found to be poorly removed by the combination of haemodialysis and acetylcysteine in a single patient (Lund et al. 1984). In contrast, the experimental removal of iron by charcoal haemoperfusion has been described with and without the chelator, deferoxamine (Ross et al. 1991). Chelation had no influence on the effectiveness of removal by charcoal haemoperfusion, but surprisingly, iron was fairly readily removed by charcoal.

2.2 Continuous Arterio-Venous Haemofiltration

Continuous arterio-venous haemofiltration (CAVH) is a new technique in the intensive care unit that uses either veno-venous pump-assisted flow or arterio-venous passive flow to pass blood through a membrane gradient capable of filtering molecules up to about a molecular weight of 50 000 (Bishof et al. 1990; Paret et al. 1992; Zobel et al. 1991). Overall, the clearance of drugs using this process is a relatively small fraction of the body burden, and is limited by the blood flow attainable through the peripheral cartridge.

It is possible that this procedure may be useful for substances with a larger volume of distribution, or where a chelating agent needs to be given by slow infusion. In a study using an animal model of iron intoxication, only the deferoxamine-bound iron could be removed using a CAVH filter despite iron concentrations greatly exceeding normal iron binding saturation (Banner et al. 1989). Given the propensity for patients to go into renal failure in association with iron intoxication, this may be a rare but reasonable approach. Similarly, Bellomo and coworkers (1991) described a case of lithium intoxication where CAVH was felt to be useful in achieving clearances of about half that of conventional haemodialysis. The same authors argue that in a setting where conventional haemodialysis may not be available, this chronic approach will still achieve acceptable improvements in outcome and is superior to saline diuresis or peritoneal dialysis.

Some substances, such as thallium and formaldehyde, cannot be removed by CAVH despite their relatively low molecular weight (Koppel et al. 1990; Wainwright et al. 1988). In contrast, evidence has been presented for the removal of paraquat, *N*-acetyl-procainamide and vancomycin using CAVH, although improvement in outcome is less readily demonstrable (Bellomo et al. 1990; Domoto et al. 1987; Dupuis et al. 1989; Lau & John 1988; Pond et al. 1987; Walczyk et al. 1988).

It is probably reasonable to conclude that toxins that have a relatively large volume of distribution requiring redistribution for removal during acute dialysis, or those substances that are not rapidly toxic (such as lithium), are possible candidates for the use of CAVH filtration.

Another intriguing possibility is that administration of a binding antibody may be useful as an adjunct to renal removal of a toxin. One of the principle limitations of the use of dialysis techniques is the large molecular weight of some toxins or toxin-antidote complexes. As a possible alternative, plasmapheresis is capable of removing the digoxin-Fab fragment complex (Rabetoy et al. 1990). With the advent of monoclonal technology, binding antibody fragments may be used in the future with plasmapheresis as an adjunct.

3. Advanced Techniques to Support Paediatric Poisoning Patients

An unusual occurrence in paediatric toxicological emergencies is inadequate response to detoxification, antidotes and conventional medical support. When conventional measures fail and death appears imminent, unconventional support may be attempted. Present modes of unconventional support of the poisoned patient have the disadvantages of high expense, technical complications and a general lack of efficacy data. Choosing a population with a suitably high mortality will balance these disadvantages with the potential these modalities may have to save lives.

Unconventional support presently available for use in poisoned children includes extracorporeal membrane oxygenation (ECMO), the intra-aortic balloon pump (IABP), and artificial surfactant replacement. All are limited to relatively short term application and entail great expense. They all treat the cardiac or respiratory systems only, and improvement in the function of other organs derives solely from improved perfusion and gas exchange. These treatments are best applied to poisoned patients in whom the toxic effect is expected to wane within days and in whom heart failure, respiratory failure, or a combination of the two is the major organ dysfunction.

3.1 Extracorporeal Membrane Oxygenation

ECMO is the most invasive, most expensive and possibly most effective of the unconventional modes of cardiopulmonary support. Currently, no organisation tracks both poisoning and ECMO applications. Therefore, data are limited to case reports and basic investigations. ECMO, in which nearly the entire cardiac output, blood oxygenation and ventilation can be provided artificially, is suitable when intrinsic cardiac output is extremely low or when lung function is very deranged. Technical descriptions of ECMO are amply available in the literature (Anderson et al. 1990).

Two general types of ECMO are commonly used. The most flexible is veno-arterial ECMO. Large cannulae drain the central veins or right atrium of deoxygenated blood. Blood flows through a pump, membrane lung, heat exchanger and blood filter. Oxygenated blood then flows into the aorta through a cannula placed in the internal carotid, subclavian or femoral artery (Anderson et al. 1990). Veno-arterial ECMO supports cardiac output and blood pressure (pump function), and oxygenation and ventilation (lung function).

Veno-venous ECMO supports gas exchange but not cardiac function. The circuit is similar to veno-arterial ECMO with the exception that blood is returned to the central veins instead of to the major arteries. The heart remains the principal source of blood flow. The lungs, though they conduct the entire cardiac output, need not ventilate or oxygenate as efficiently as they would without the membrane lung. The high partial oxygen pressure and pH of the mixed venous blood may dilate a constricted pulmonary vascular bed. If cardiac function deteriorates in a patient on veno-venous ECMO, conversion to veno-arterial ECMO may be performed (Andrews et al. 1983).

Both forms of ECMO allow lung rest because of the action of the membrane lung. Lung rest entails lowering minute ventilation, distending pressure and fraction of inhaled oxygen in an effort to

reduce barotrauma, impaired thoracic venous return and pulmonary oxygen toxicity. Lung rest to the point of complete apnoea is often performed while reintubation, bronchoscopy and thorough suctioning are carried out. Complete atelectasis is generally avoided due to difficult re-expansion of injured lungs: moderate distending pressure and a low mandatory ventilator rate are usually sufficient. ECMO can also rewarm hypothermic patients. The circuit adapts to include a haemoperfusion or haemofiltration cartridge (Anderson et al. 1990), and patients on ECMO can be haemodialysed (Sell et al. 1987).

ECMO is used when expected mortality is 75% or greater. The need for this strict criterion follows from the frequent morbidity associated with ECMO. ECMO requires systemic heparinisation to prevent thrombosis within the circuit and embolism to the arterial tree of the body, as haemorrhage is a frequent and major complication (Hirschl & Bartlett 1987). Cannulation of the right internal carotid artery in veno-arterial ECMO may predispose the right brain to vascular compromise, which is compounded by the ischaemia or asphyxia that often precede ECMO initiation (Hirschl & Bartlett 1987). Mechanical failure of the ECMO circuit may cause exsanguination, hypotension, low blood flow and failure of gas exchange.

Intoxications for which ECMO has been applied in humans include propranolol (McVey & Corke 1991), quinidine (Thomas et al. 1993), desipramine (Goodwin et al. 1993), chlorine gas (Morton et al. 1991), paraquat (Klaff et al. 1977) and hydrocarbon aspiration (Scalzo et al. 1990). Full cardiovascular, pulmonary and neurological recoveries are the rule, but deaths have been reported after paraquat ingestion (Klaff et al. 1977) and hydrocarbon aspiration in children (National ECMO Registry 1992).

One trial of ECMO for experimental drug intoxication in animals has been published (Freedman et al. 1982). After receiving lidocaine (lignocaine) 30 mg/kg as an intravenous bolus, dogs received either standard treatment (cardiopulmonary resuscitation and advanced cardiac life support) or veno-arterial ECMO. Dogs in both groups experienced similar types and frequencies of dysrhythmias, cardiovascular collapse and respiratory arrest. At 120 minutes, 2 of 8 conventionally-treated dogs and 8 of 8 ECMO-treated dogs survived. Analysis of lidocaine concentrations showed that ECMO redistributed lidocaine from the central circulation to its full volume of distribution, whereas conventional treatment was associated with persistently high blood lidocaine concentrations. ECMO may also have restored hepatic drug clearance by improving liver perfusion.

There is speculation that ECMO may be effective in poisonings with antiarrhythmics, digoxin, calcium channel blockers, α- and β-adrenoceptor blockers, TCAs, anaesthetics, antihypertensives, cocaine and all classes of pulmonary irritants. Prerequisites for its use are ability of the patient to survive until ECMO is applied (typically 2 hours), high expected mortality from cardiac or respiratory failure if ECMO is not applied, and lack of long term debilitating effects from the toxin.

3.2 Intra-Aortic Balloon Pump

The IABP is a less invasive alternative to ECMO for support of poisoned patients with isolated cardiac dysfunction. The features of IABP in children are likewise well described (Webster & Veasy 1985). IABP involves placing a distensible balloon catheter in the superior descending aorta. The balloon is inflated during diastole, and diastolic blood pressure augmentation to suprasystolic levels has been described (Webster & Veasy 1985). The major effect of the technique, however, is improvement in diastolic function of the left ventricle. The balloon isolates the proximal aorta from back pressure generated in the distal aorta, effectively reducing aortic impedance in end-diastole (Bush & Farmer 1988). In doing so, it reduces diastolic pressure in the left ventricle. This pressure unloading of the left ventricle results in improved cardiac output and reduction in myocardial oxygen consumption.

Balloon pumping in infants and children has been reported by several clinical groups (Park et

al. 1993; Webster & Veasy 1985). The technique usually involves a femoral artery incision for balloon catheter placement. The catheter is inserted into a fabric sidearm graft to preserve femoral artery patency after removal of the catheter. Balloon inflations are timed with the patient's electrocardiogram, so a stable or reliably paced cardiac rhythm is a prerequisite for use. Timing of inflations is adjusted such that inflation begins near the dicrotic notch; optimal timing is confirmed by measurable haemodynamic changes. Such timing adjustment usually provides the maximal diastolic blood pressure augmentation, the greatest decrease in peak systolic pressure and the lowest left heart filling pressure. The ratio of inflations to heart beats is initially 1 : 1, and the ratio is decreased to 1 : 2 then 1 : 3 as cardiac function improves.

IABP has been used in patients poisoned with specific cardiotoxins. It is not expected to improve pulmonary function unless congestive failure with pulmonary oedema is the prominent pulmonary pathophysiology. Toxicity treated with IABP in humans includes that of verapamil and atenolol (Frierson et al. 1991), mepyramine (pyrilamine) [Freedburg et al. 1987], propranolol (Lane et al. 1987) and mushrooms (Margulis & Mordashev 1984). It has also been used to treat anaphylactic shock due to thiopental (thiopentone) and bee venom (Raper & Fisher 1988).

IABP has a significant complication rate. Complications include aortic dissection, thrombocytopenia, leg ischaemia, infection (Webster & Veasy 1985) and balloon rupture (Rutten & Meijne 1991).

3.3 Surfactant Replacement

An extension of the treatment of respiratory distress syndrome in premature neonates is the availability of surfactant replacement therapy for use in other populations. Initially intended to supplement surfactant levels in neonates too immature to make adequate surfactant, it has become a research topic in adults and children. The inward pressure produced by surface forces at the air/fluid interface of the alveolus ordinarily promotes deflation. Unchecked, these forces would produce atelectasis that would require inordinate transpulmonary inflation pressures to overcome. Respiratory failure would then ensue.

Endogenous surfactant reduces surface forces and allows alveolar inflation at transpulmonary pressures that are easily generated in normal persons. Reduction of surface forces by surfactant prevents atelectasis even during expiration, when transpulmonary pressures are quite low. Supplemental surfactant has actions similar to endogenous surfactant. It is clearly beneficial in lung disease of premature neonates (Avery & Merritt 1991; Morley 1991).

Depletion or inactivation of surfactant during hydrocarbon aspiration (Giammona 1967) and the acute respiratory distress syndrome (Petty et al. 1979; Seeger et al. 1990) has led clinicians and investigators to consider surfactant replacement in children and adults (Morton 1990; Richman et al. 1987).

Artificial surfactant is commercially available in several forms. One ('Exosurf') is an artificial mixture of dipalmitoylphosphatidylcholine, cetyl alcohol and tyloxapol. Two others ('Survanta' and 'Infasurf') are bovine lung extracts containing surfactant proteins. These proteins appear to aid adsorption of surfactant by the alveolar surface (Soll & Lucey 1991), though the benefit may be only theoretical. A bolus of liquid surfactant suspension is given via the endotracheal tube and is ventilated into the lungs. An acute increase in lung compliance follows, and rapid weaning of mechanical ventilation may be possible. Pulmonary improvement is often transient, and retreatment over several days has become common.

Available surfactants are very expensive; adult doses cost several thousand US dollars.

Giammona (1967) demonstrated that the surface tension of lung extracts is increased following mineral seal oil aspiration. Preliminary data from a trial of surfactant in sheep given intratracheal kerosene (Widner et al. 1993) show that treatment eliminated mortality at 6 hours and improved pH, arterial oxygen partial pressure, cardiac output,

and oxygen transport. Ambroxol, a surfactant synthesis inducer, has reduced the toxic effects of paraquat poisoning in rats and cultured cells; the number of survivors and survival time of paraquat-poisoned rats pretreated with ambroxol were both increased significantly versus sham-pretreated animals (Salmona et al. 1992).

Human data on the use of surfactant and ambroxol in poisonings and inhalation injuries are not available, but controlled trials seem warranted.

4. Conclusion

The ability of paediatric intensive care techniques to provide support of the cardiorespiratory systems of children is the most obvious benefit of the new technology in the management of paediatric poisonings. Advanced monitoring of the central nervous and cardiovascular systems should allow more appropriate targeting of this supportive care. The techniques of haemofiltration and plasmaphoresis may provide useful ways of removing toxins in rare cases, but probably will not be widely applicable to many poisoning situations.

Extracorporeal support for cardiac and respiratory failure holds some promise for the support of intractable yet reversible poisonings, but as yet the indications for this therapy remain unclear. Surfactant replacement therapy may be useful for hydrocarbon aspiration syndrome, but should be considered experimental at this time.

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